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Strokovno društvo za mikroelektroniko elektronske sestavne dele in materiale

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Časopis za mikroelektroniku, elektronske sastavne dijelove i materijale
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VSEBINA CONTENT

Več kot le čestitka za novo leto

Ponavadi se ob koncu leta ozremo nazaj in naredimo kratek obračun opravljenega dela ter ga primerjamo s cilji in nalogami, ki smo si jih zastavili na začetku leta.

MIDEM, Strokovno društvo za mikroelektroniko, elektronske sestavne dele in materiale je kljub stalni finančni stiski v letu 1994 uspelo uresničiti dva pomembna cilja :

- ☐ *organizacijo Mednarodne konference o mikroelektroniki, elektronskih sestavnih delih in materialih, MIEL-SD'94*
- ☐ *redno izdajanje strokovne revije " Informacije MIDEM "*

Pričujoča številka Informacij MIDEM je posvečena prav konferenci MIEL-SD'94. Poleg vseh vabljenih in pozno prispelih referatov objavljamo še tekste predstavitev laboratorijev v okviru konference, kakor tudi poročilo o sami konferenci. Splošna ocena je, da je letošnja konferenca uspela , čeprav smo pogrešali referente in poslušalce iz industrije.

Revija " Informacije MIDEM " si je v letu 1994 še utrdila sloves mednarodne revije. Poleg znanih domačih strokovnjakov drugo polovico časopisnega sveta sestavljajo priznani tuji strokovnjaki s področja , ki ga obravnava revija. V vsaki letošnji številki Informacij MIDEM smo objavili vsaj en vabljeni strokovni prispevek iz tujine. Prav tako smo začeli s proceduro kvalifikacije revije za pridobitev SCI indeksa.

Člane društva in bralce revije vabiva k sodelovanju v delu društva in vsem želiva zdravo, srečno in uspešno novo leto 1995.

More than Greetings for the Newcoming Year

At the end of each year we usually look back and try to summarize our work or to compare it with the goals and activities planned at the beginning of the year.

MIDEM, Professional society for microelectronics, electronic components and materials, despite constant financial trouble did succeed to realize two important planned activities in the year 1994 :

- ☐ *organization of the international professional conference on microelectronics, electronic components and materials, MIEL-SD'94*
- ☐ *regular publishing of the professional journal " Informacije MIDEM "*

The present issue of the journal is actually devoted to the Conference MIEL-SD'94 itself. Besides invited and late papers we are bringing also texts of laboratory presentations which were held in a special session, as well as full conference report. It is generally accepted that MIEL-SD'94 Conference was a success despite few participants from the electronic industry.

Our professional journal " Informacije MIDEM " kept its fame of an international journal. Besides known domestic experts, second half of the international advisory board consists of foreign experts from the fields covered by the journal. This year we also succeeded in publishing at least one professional paper from abroad in each issue. As well, we started the preparatory procedure to obtain SCI index.

We invite Society members and readers of the journal to participate in the Society activities. As well we wish all of You a healthy, happy and successful new 1995 year.

MIDEM Society President
Dr. Rudolf Ročak

Editor in Chief
Iztok Šorli

Iztok Šorli

TRENDS IN MIXED SIGNAL ASIC DESIGN

Janez Trontelj
University of Ljubljana, Slovenia

INVITED PAPER
22nd International Conference on Microelectronics, MIEL'94
30th Symposium on Devices and Materials, SD'94
September 28. - September 30., 1994, Rogla, Slovenia

Key words: integrated circuits, ASIC, circuit design, technology progress, future development, design methodology, new applications, new requirements

Summary: The paper presents an overview of some future trends in mixed signal ASIC design due to the progress of technology, new applications requirements and new design approaches. Some examples demonstrating such trends are presented.

Smernice razvoja načrtovanja analogno/digitalnih vezij ASIC

Ključne besede: IC vezja integrirana, ASIC vezja, projektiranje vezij, napredek tehnologije, razvoj bodoči, metodologije projektiranja, aplikacije nove, zahteve nove

Povzetek: Članek obravnava pregled nekaterih smernic razvoja v načrtovanju vezij ASIC, ki so pogojena z napredkom tehnologije, z novimi zahtevami za integracijo in z novimi načrtovalskimi prijemi. Podani so nekateri zgledi, ki prikazujejo nakazane smernice.

INTRODUCTION

ASIC designers are challenged to cope with three major directions of future development: progress in technology, new application requirements and design methodology improvements.

Progress in technology. Although presently the volume IC production (except for memories) is still in CMOS technology with typical one micrometer minimal dimension we see a fast trend towards submicron (typically 0.6 μm to 0.8μm) processes. The consequences of this trend and associated problems and benefits are discussed. Higher cost of BiCMOS processes compared to CMOS processes is being compensated by the advantages of having unipolar and bipolar active devices available. Wider availability of BiCMOS processes requires upgrading of the designers skills and knowledge to be able to optimize the circuitry and to use all the benefits available in such process.

New application requirements. Battery operation at the user's end is very difficult requirement which emerges from the need of portable electronic devices, presently portable telephones and in future personal inteligent terminal and a number of medical electronic aids.

The other extreme addressed is very high frequency ASIC design which is used mainly for information distribution on coaxial and fiber optic cables.

Complex electronic systems including various sensors and other transducers incorporated to the ASIC is another trend requiring new design approaches.

Design methodology improvements. It is clear that the mentioned design tasks demand more powerful design methodologies and design tools. CAD hardware being more and more capable to support very demanding algorithms contributes to the development of new design tools. Mixed signal ASIC design expertise has become the most desirable and on the other hand the most difficult.

PROGRESS IN TECHNOLOGY

Trends in processing technology are towards process modularisation. This means that specific process steps will be developed independent and controlled by the set of target features. Such process module can be used in a variety of standard and non standard ASIC production simply by verifying the process module parameters. Specific process module parameters will be translated to manufacturing tools setting. Wafer fab will therefore become universal wafer fab consisting of so called cluster tools where the complete manufacturing process will be completely robotized. Such wafer fab will be suited to manufacture according to application specific process enabling the designer not only to optimize the

IC to the application function but also to select the optimal process.

Such trend is shown in the present status of BiCMOS processes. The designer can select from at least three different varieties of BiCMOS process for ASICs:

- CMOS based BiCMOS for improved speed
- Digital BiCMOS for high frequency and static RAM
- Mixed mode BiCMOS for having the selection of full range of active and passive devices for analog design

BiCMOS based processes seem to be the basis for future ASIC designs due to various advantages offered by both types of active devices.

Some of advantages of bipolar transistors are:

- Transconductance of the bipolar transistor is larger by an order of magnitude compared to the unipolar transistor.
- The high frequency behaviour of bipolar transistors is much better than unipolar transistors.
- Noise of bipolar transistors is lower especially at low frequency since the 1/f noise phenomena is almost negligible.
- Matching characteristics of bipolar transistor are superior due to the low variation of V_{BE} on the same chip.

The most important advantages of unipolar transistors are:

- No input bias current is needed, so very high input impedance is achievable.
- Zero power supply quiescent current in fully complementary structures at dc conditions.
- Full power supply swing available for both analog and digital signals with simple electrical topology allowing high functional density at high noise immunity.
- Unipolarity allows more circuit design freedom, e.g. circuits with bi-directional switches, circuits operating in weak inversion region etc.

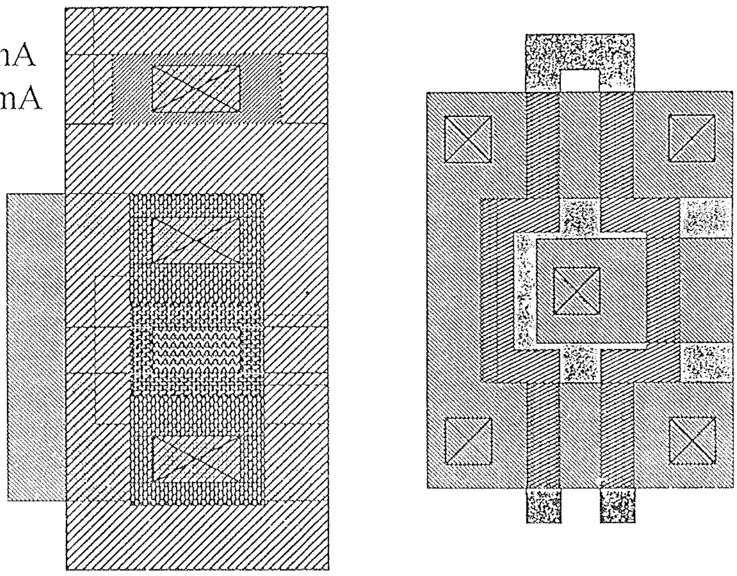
Fig.1 shows the layout of equal area unipolar and bipolar transistors to demonstrate the fact that minimum size bipolar transistors is compared to unipolar transistors with W/L ratio much larger than minimum size. Nevertheless at the same operating current g_m of bipolar transistors is still 18 times higher.

Minimum geometry scaling down is one other trend in process technology development. Effects of geometry scaling down are the following:

- Packing density increase
- Circuit complexity increase
- Parasitic capacitance decrease
- Switching speed increase
- Contact resistance increase
- Interconnection resistance increase

To demonstrate the drastic increase of packing density of a standard digital cell, D flip-flop with asynchronous reset with the schematic shown in fig. 2 was used. Fig. 3 shows the layout of the same cell when using 5µm, 3µm, 2µm, 1.2µm and 0.6µm CMOS processes.

g_m bipolar $\approx$ 18mA/V at $I_C \approx 0.5$mA
g_m unipolar $\approx$ 1mA/V at $I_D \approx 0.5$mA



a b

Fig. 1: Bipolar and unipolar transistor comparison example: a) layout of minimum emitter area of bipolar transistor, b) layout of equal size MOS transistor

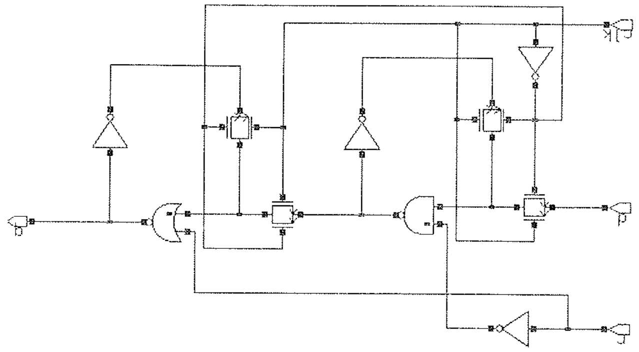


Fig. 2: Schematic diagram for D flip-flop with reset used for packing density comparison

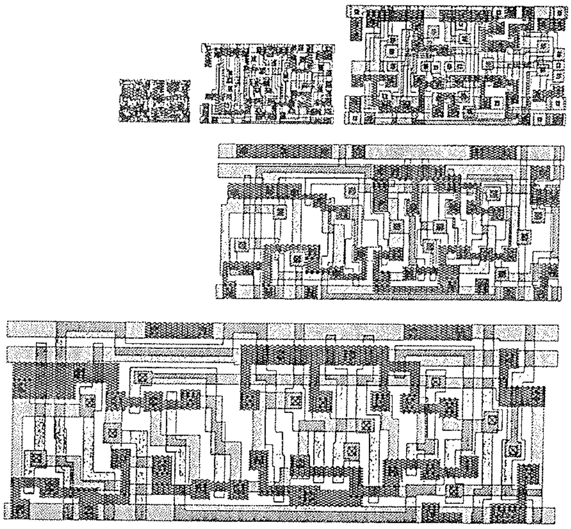


Fig. 3: Packing density comparison for 5μm, 3μm, 2μm, 1.2μm and 0.6μm CMOS processes

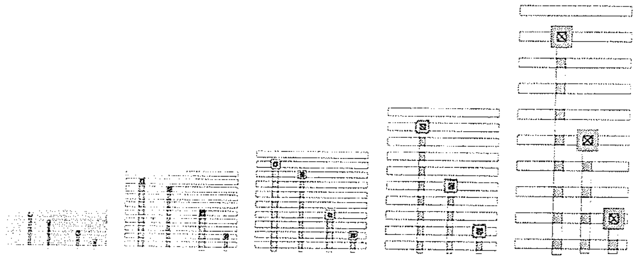


Fig. 4: Packing density comparison for 5μm, 3μm, 2μm, 1.2μm and 0.6μm CMOS processes

Fig. 4 shows typical interconnection channel for the same technologies.

Table 1 shows area and speed comparisons for the listed technologies.

Table 1: Packing density and switching speed comparison for 5μm, 3μm, 2μm, 1.2μm and 0.6μm CMOS processes

CMOS Process	5μm	3μm	2μm	1.2μm	0.6μm
Cell area (μm^2)	28000	14000	6720	2680	756
Cell area factor	37	18.5	8.8	3.5	1
Channel width (μm)	131	76	51.6	40.2	19.8
Channel width factor	6.6	3.8	2.6	2	1
Propagation delay (ns)	17.6	4.3	2.8	1.5	1.15

The effect of scaling down in analog design is most important in the following areas:

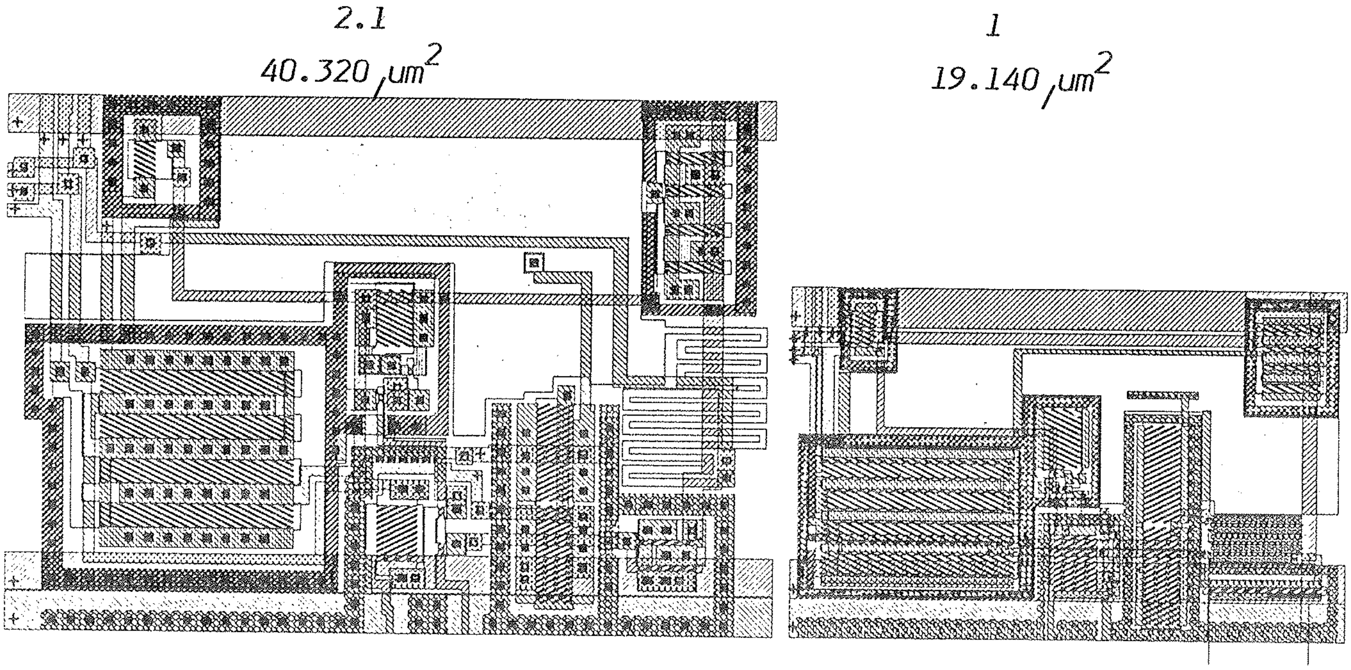


Fig. 5: Design example of operational amplifier with equal performance and topology using 2μm CMOS and 0.8μm CMOS

- Matching characteristics scaling coefficient proportional to lithography
- 1/f noise scaling coefficient proportional to t_{ox}
- Interconnection parasitics

To achieve approximately the same performances and using the same electrical topology two operational amplifiers were designed using 2µm and 0.8µm technology. The outcome is presented in fig. 5 showing packaging density improvement factor 2.1 which is much less that it would be for digital cell.

NEW APPLICATION REQUIREMENTS

We are facing a rapid demand of new ASICs designs in the area of:

- Low voltage low power battery operation ASICs
- High frequency operation
- Integrated electronic systems

For the low voltage design the following design specific should be observed:

- Decrease the noise floor to maintain input signal dynamic range or digital noise immunity levels
- Decrease the input offset voltage
- Avoid any stacking techniques (cascoding)
- Improve slew rate or switching speed
- Improve fan-out and output voltage range
- Use charge pumping and other boosting techniques

Table 2 shows design example of low noise low power realizations of battery operated microphone amplifier using both CMOS and BiCMOS technology.

Table 2: Comparison of CMOS and BiCMOS realization of the microphone differential amplifier

Feature	CMOS realization	BiCMOS realization
Min power supply voltage/current	± 1.2V / 1mA	± 1.2V / 1mA
Silicon area	1.672 mm x 0.567 mm 0.948 mm^2	0.416 mm x 1.304 mm 0.542 mm^2
Total harmonic distortion at 2 Vpp output voltage	0.25%	0.3%
Input referred psophometric noise voltage	0.406µV	0.502µV
Input current	< 10^{-9}A	3µA

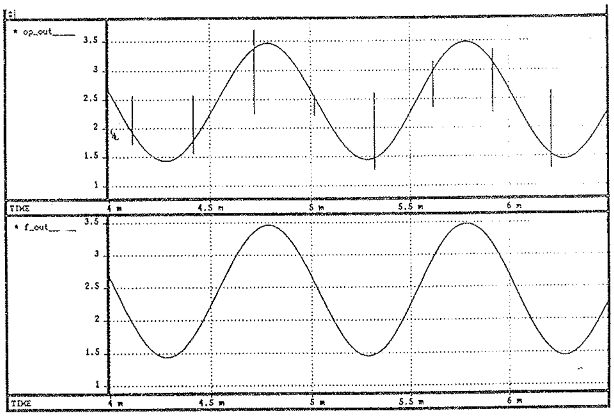


Fig. 7: Result of "out of signal frequency band" offset cancellation

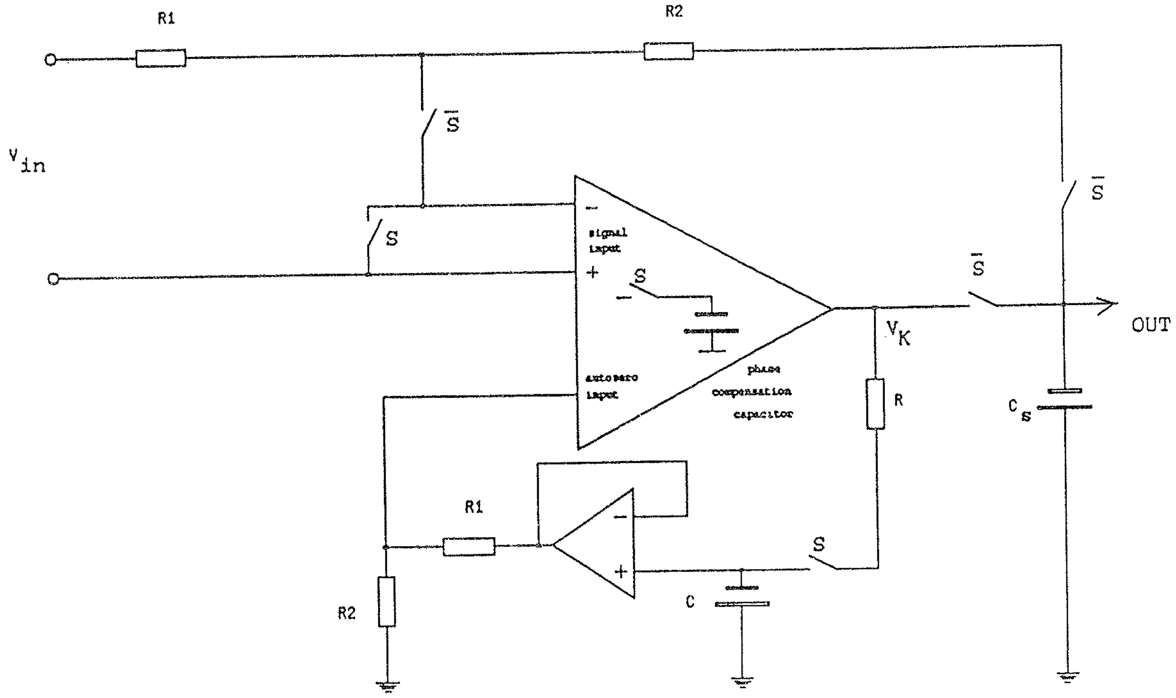


Fig. 6: Principal schematic of "out of signal frequency band" offset cancellation

An example of novel approach to input offset voltage cancellation technique is shown in fig. 6. This approach provides automatic offset voltage cancellation without any disturbances of the signal. This is achieved by shortening the offset measurement time to shift the disturbance out of signal frequency band. This can only be achieved by switching the operational amplifier into a "fast" ie comparator mode. The resulting signal of such cancellation is shown in fig. 7.

DESIGN METHODOLOGY IMPROVEMENTS

In mixed signal design simulation will remain a major design tools specially for the analog part of the design.

The simulation phase of the design will not be used only for functional and parametric verification but to perform design centering and specially to predict and improve yield loss caused by process variations and operation conditions variations.

Efficiency of simulation depends on

- Simulation models
- Simulation method
- Simulation coverage
- Interpretation of simulation result

Conservative approach to design centering used to be as follows:

- Design according to specification fabrication according to matrix of technology parameters
- Characterize to find the correlation of ASIC parameters to process parameters
- Redesign if necessary
- Determine the best process parameters and fabricate as close as possible to given process parameters

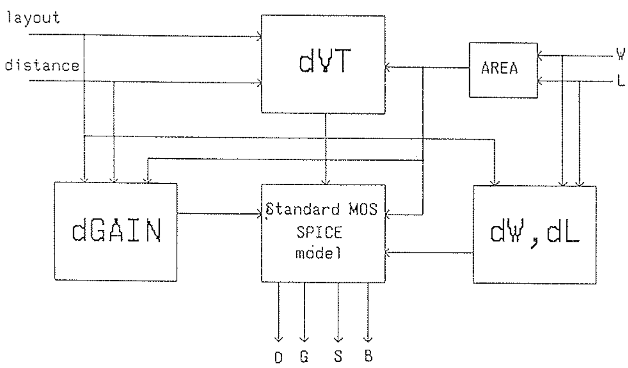


Fig. 8: Block diagram of the MOS transistor matching model

Much more effective approach is to shift the design centering and yield prediction in the design phase, without doing costly and time consuming fabrication.

To do this the following activities are necessary:

- Simulation with typical parameters
- Simulations using Monte-Carlo approach
- Simulation using four (all corners)
- Post-layout simulation with layout parasitic extracted
- Post-layout simulation with extended parasitics and with extended models

For real high volume production this approach can be extended to the following procedures:

- Design according to specifications using described approach
- Fabrication
- Characterization of the ASIC
- Resimulation with actual parameters and comparison to measured results

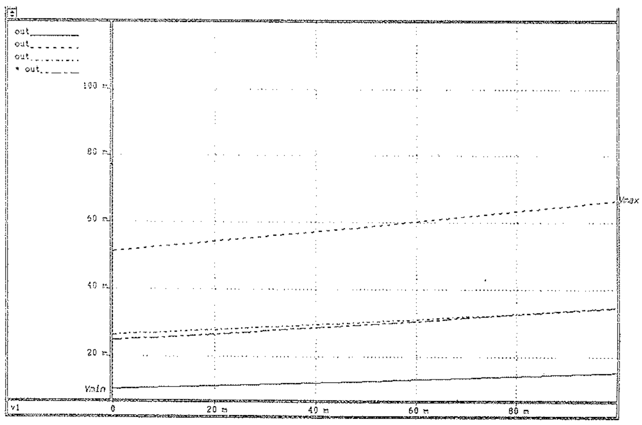


Fig. 9: Simulation result of four corner active device Vin analysis. Vout max / Vout min ≈5. No. of simulations = 4

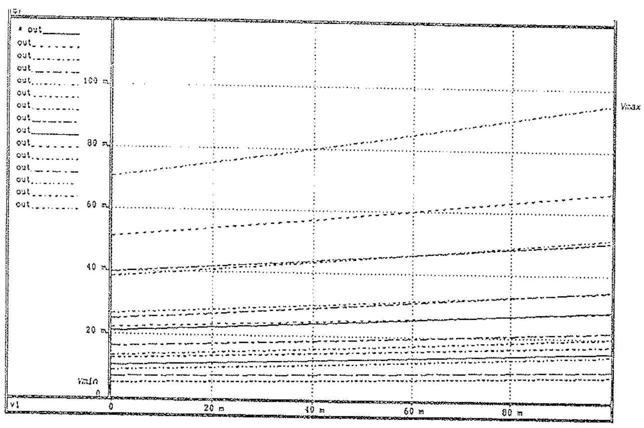


Fig. 10: Results of full corner analysis with four transistor corners, two resistor corners, two temperature corners and two power supply corners. Vout max / Vout min ≈22. No. of simulations = 32

- Optimization of the simulation models
- Optimization of the design

The simulation procedure should take into account the following effects:

- Process parameters variations influence on active devices
- Process parameters variations influence on passive devices
- Power supply voltage variations
- Temperature variation
- Other external conditions (load variation, input common mode and differential mode voltages etc.)

The importance of verifying all possible conditions is shown in figs. 9 and 10. Fig. 9 shows simulation result of only four corner process variations giving $V_{out\ max}$ to $V_{out\ min}$ ratio approximately 5. Fig. 10 shows full corner analysis where this ratio has increased to 22. It is important to mention that simulation models should be enhanced in the following areas:

- Models of interconnections
- Models of integrated resistors
- Models of integrated capacitors
- Models of active devices

Interconnection models take into account: ground interconnections, power supply interconnections, sensitive interconnections and interconnections carrying high speed signals.

Parameters of enhanced model of integrated resistor are: contact resistance, distributed resistor capacitance, resistor matching factor (worst case corners).

The parameters of extended model for integrated capacitor depend on:

☐ Matching factor as a function of
- capacitor size
- capacitor shape
- capacitor position
- capacitor border conditions

☐ Capacitor quality as a function of
- capacitor layout
- capacitor connection network

Fig. 8 shows block diagram of matching model of MOS transistor.

CONCLUSION

Future mixed signal ASIC designers will be challenged to design in much richer variety of processes, possibly in application specific processes. To do that the designer should have better knowledge of the available technologies. This requires:

☐ Deep understanding of all passive and active devices offered by modern "universal" ASIC technology

☐ Know-how to select the most effective subprocess for the selected application. The designer should have also the ability to adapt to novel application requirements, i.e. his electronic and mechanical systems knowledge has to widen.

☐ In the area of design methodology he has to concentrate to effective simulation for verification of each design step, to use extended device modeling and to become familiar with new and efficient simulation tools.

prof. dr. Janez Trontelj
University of Ljubljana
Faculty for Electrical and Computer Engineering
tel.:+386-61-121 121, fax: +86 61 27 578
61000 Ljubljana, Tržaška 25, Slovenia

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SURFACE, INTERFACE AND THIN FILM ANALYSIS IN MATERIAL SCIENCE

Helmut Viefhaus
Max-Planck-Institut für Eisenforschung GmbH
40237 Düsseldorf, Germany

INVITED PAPER
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Keywords: material science, surface phenomena, interface layers, industrial applications, thin films, surface analysis, electron diffraction, Low Energy Electron Diffraction, Scanning Tunnelling Microscopy, Auger Electron Spectroscopy, Secondary Ion Mass Spectroscopy, X-ray Photoelectron Spectroscopy, Secondary Neutrals Mass Spectrometry, material interaction

Abstract: Surface phenomena and processes occurring at interfaces play an important role in a variety of industrial applications and an ever growing need for surface characterization allowing better understanding of the processes can be observed.
After giving a short definition of a surface of a solid, some of the main surface analytical methods like LEED Low energy electron diffraction, STM Scanning tunneling microscopy, AES Auger electron spectroscopy, XPS X-Ray photo electron spectroscopy, and SIMS Secondary ion mass spectroscopy are briefly discussed.
The main surface phenomena which can change the chemical composition of surfaces are adsorption from the surrounding gas phase and segregation of atoms from the bulk at elevated temperatures. Some theoretical considerations and illustrating examples of experimental studies on those phenomena will be presented.

Analiza površin, meja in tankih plasti v materialoznanstvu

Ključne besede: znanost o materialih, pojavi površinski, sloji vmesni, aplikacije industrijske, plasti tanke, analiza površine, difrakcija elektronska, LEED difrakcija elektronov energije nizke, STM mikroskopija skenirna tunelna, AES Auger spektroskopija Elektronska, SIMS spektroskopija masna z ioni sekundarnimi, XPS spektroskopija fotoelektronska z X-žarki, SNMS spektrometrija masna z nevtrali sekundarnimi, vplivanje med materiali

Povzetek: Pojavi, ki se dogajajo na površini in na meji med površinama, postajajo vse bolj in bolj pomembni v različnih industrijskih vejah, saj lahko opazimo stalen porast zanimanja za karakterizacijo površine, ki omogoča boljše razumevanje procesov na površini.
Kratki definiciji površine trdne snovi sledi opis nekaterih glavnih analitičnih metod za karakterizacijo površine, kot so: LEED-Low Energy Electron Diffraction, STM - Scanning Tunnellling Microscopy, AES-Auger Electron Spectroscopy, XPS-X-ray Photo Electron Spectroscopy in SIMS-Secondary Ion Mass Spectroscopy.
Pomembna površinska pojava, ki lahko spremenita kemično sestavo površin, sta adsorpcija iz okolišnega plina in segregacija atomov iz notranjosti snovi pri povišani temperaturi. V referatu predstavljam nekaj teoretičnih izhodišč, kakor tudi ilustrativne eksperimentalne rezulate teh fenomenov.

Introduction

As every material interacts by its surface with the environment, the surface will be different from the material beneath it. But even if a clean surface of a solid would be created within an extremely good vacuum bonding imbalances for the atoms exist for the outermost atomic layers and they induce very special surface properties. By those surface properties on the other hand, many phenomena in material science are affected, some of those phenomena are listed in table 1.

The surface of a solid metal may be defined by the termination of the bulk state, where the symmetry of the bulk is disturbed to give altered interaction forces in this region. As a consequence of the bonding imbalances at the surface the structure of the outermost atomic layers may change in comparison to the bulk structure, this is schematically illustrated in fig. 1. The first example, shown in fig. 1a, may be an acceptable model for so-called "sheet" structures like graphite for example which exhibits only weak dispersion forces between the individual atomic layers. For a strong bonding between the atomic layers the breakdown of balanced bonding

- corrosion
- catalysis
- adhesion
- wear
- joining
- inhibition
- passivation
- sintering
- a.s.o.

TABLE - 1

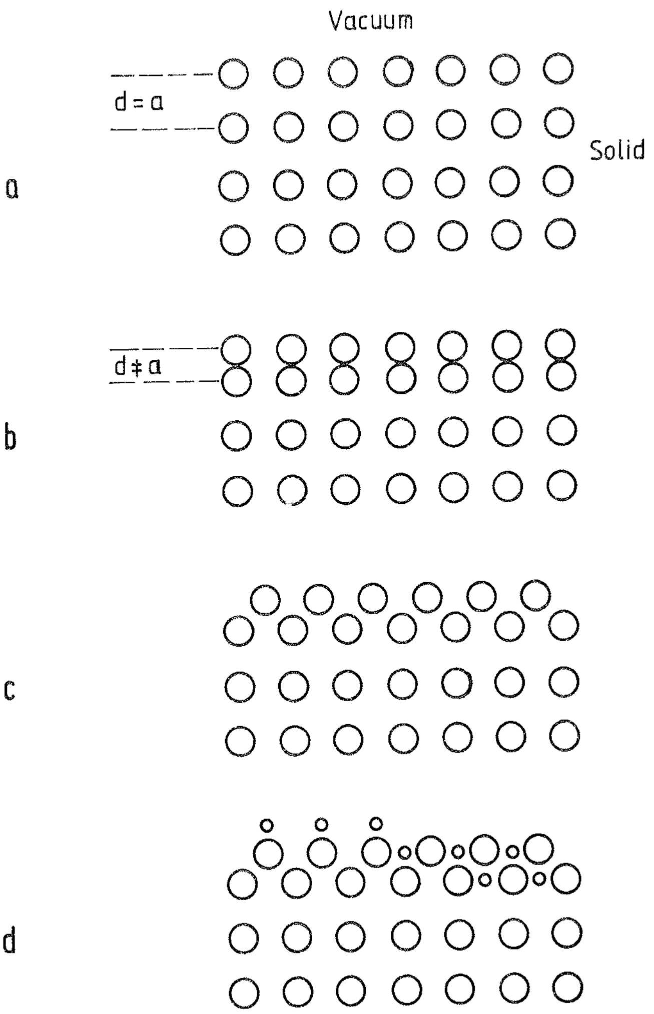


Fig. 1: Schematic of
a) a solid surface created by terminating the bulk of a crystalline solid
b) bonding imbalances cause the outer layer to move
c) reconstruction of the surface
d) when exposed to a reactive medium, foreign atom adsorption can occur, possibly leading to surface compound formation

forces at the surface leads to a rearrangement of the outermost atomic layers, fig. 1b, which may result in a relaxation or contraction up to 25% of the normal interlayer spacing, as was shown by detailed structure analysis for several crystal planes of metals /1/. Surface reconstruction, fig. 1c, to minimize the surface energy, can occur and is observed for some crystal faces of covalently bonded semiconductor materials /2/. For surfaces which are exposed to reactive gas environment atomic adsorption followed by incorporation into the near surface region and surface compound formation can appear, fig. 1d.

For most real surfaces of polycrystalline materials the situation will be much more complex than for the ideal case of individual crystals as was discussed up to now. For polycrystalline materials not only the outer surface is of great importance, but also the structure and composition of inner interfaces like grain boundaries can drastically influence material properties, this is illustrated schematically in fig. 2. From all considerations up to now it can be concluded that the most important interface properties which have to be characterized by surface analytical methods are:

a) the interface structure

b) the chemical composition of the interface

c) the chemical bonding state at the interface

d) the electronic structure of the interface

To instrumentally probe a solid surface one of six basic probes may be applied to the surface: electrons, ions, neutrals, photons, heat or a field. The analysis consists of measuring the surface's response, also evident in one of these six ways, fig. 3. Combining all the probes and responses in principle a large number of experimental techniques results by which a surface may be analyzed.

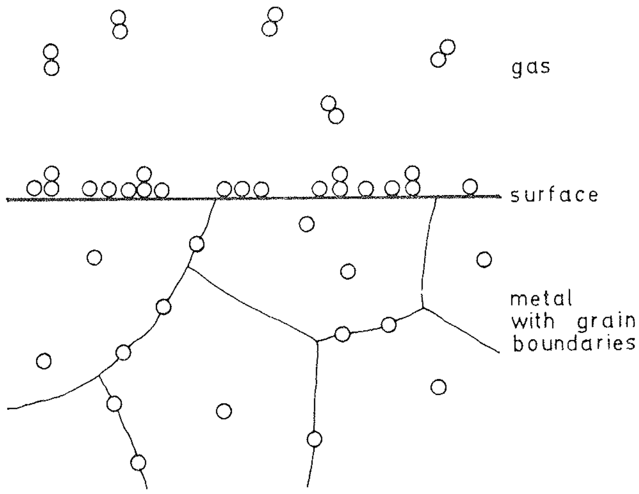


Fig. 2: Schematic of the equilibrium of species and nonmetal atoms (dissolved) in the metal matrix and segregated at the grain boundaries

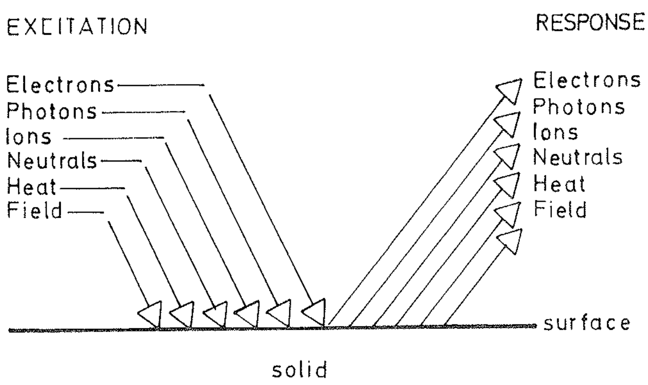


Fig. 3: Basic probes for surface analysis

Most of the standard surface analytical methods are based on unperturbated particle impact and detection and thus require vacuum conditions, where the mean free path of the gas molecules is larger than the dimensions of the reactor. Moreover, since it is demanded to analyze or characterize well-defined systems it is necessary to establish ultra high vacuum conditions. From kinetic gas theory it follows that the number of gas particles N_S striking a surface area of 1 cm^2 per second is given by

$$N_S = N \sqrt{\frac{RT}{2\pi M}} = 2.634 \cdot 10^{22} \frac{p}{\sqrt{MT}}$$

where N equals the number of gas molecules per cm^3 and p is the gas pressure in mbar. Assuming an average molecule is built of M = 28 (which could be N_2 or CO) we can see that at 10^{-6} mbar ambient pressure the number of particles colliding with 1 cm^2 surface area is about 10^{15} and corresponds to the average number of surface atoms being present in 1 cm^2 surface area. So for a sticking coefficient of 1 within 1s a complete monolayer of gas molecules would cover the surface. Even at 10^{-10} mbar still about 10^{10} to 10^{11} particles hit a 1 cm^2 surface area in 1s, which means contamination problems could arise during long-term surface analysis.

The achievement of those necessary ultra high vacuum conditions nowadays is possible with commercial stainless steel vacuum chambers and for more detailed information relevant textbooks on vacuum technology exist /3-7/.

Experimental methods to characterize surfaces

During the last three decades a lot of different surface analytical methods (about 130) have been developed, but only a few of them have gained widespread use and will briefly be discussed here. These are:

- for structural analysis
  LEED Low Energy Electron Diffraction
  STM Scanning Tunneling Microscopy
- for the elemental composition and chemical bonding states
  AES Auger Electron Spectroscopy
  XPS X-ray Induced Photoelectron Spectroscopy
- for the elemental composition and/or for depth profiling
  SIMS Secondary-Ion-Mass-Spectroscopy
  SNMS Secondary-Neutrals-Mass-Spectroscopy

LEED Low Energy Electron Diffraction

About 70 years ago the theroretically predicted wave nature of electrons /8/ had been experimentally demonstrated by the LEED method /9/. According to the de Broglie relationship

$$\lambda = \frac{h}{p} \approx \frac{\sqrt{150}}{V} \text{Å}$$

an electron wave length λ may be derived from the momentum p and is related to the accelerating voltage V (≤ 1 keV) of an electron gun. Thus for electrons having a kinetic energy of 150 eV the wave length λ ≈ 1 Å which is similar to the spacing between rows of atoms in a crystal. If on a well-ordered crystal surface mono-energetic electrons are impinging constructive interference occurs for elastically backscattered electrons depending on the crystal structure.

A schematic set-up of a LEED experiment is displayed in fig. 4. Low energy electrons are produced by a cathode and are focused on the sample. The backscattered electrons pass a grid system which cuts off the inelastically reflected electrons before the elastically diffracted electrons are post-accelerated on to a fluorescent screen. The diffraction and imaging process is illustrated by fig. 5. The sample crystal, characterized by the magnified two-dimensional grating, is mounted in the center of the screen curvature on a mechanical manipulator within a UHV chamber.

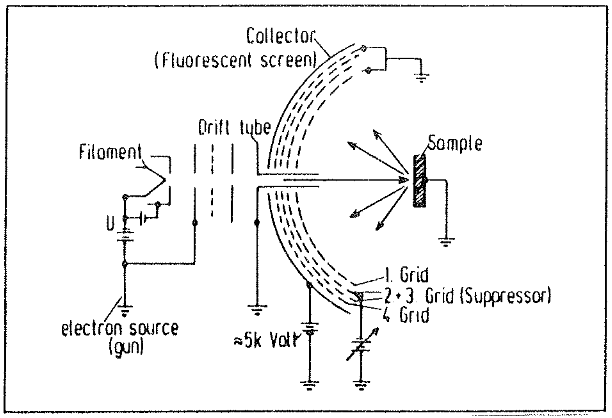


Fig. 4: Schematic set-up of a LEED experiment

The electron wave originating from the gun hits the surface and is diffracted at its atomic grating. The elastically backscattered electrons interfere with each other thus leading to diffraction maxima and minima. The maxima become visible on the fluorescent screen and characterize the surface ordering.

Fig. 6 gives a typical example, the diffraction pattern for a clean (100) oriented iron surface is shown.

If by an ordered surface reaction new positions on the clean surface will be occupied, additional reflexes on the fluorescent screen should appear if the ordering of the additional atoms is not related by a (1x1) symmetry to the ordering of the surface atoms. The ordered enrichment of dissolved phosphorus atoms at higher temperature on (100) surface results at its saturation level in a so-called c(2x2) surface structure, which is schematically demonstrated by fig. 7a. The corresponding LEED pattern registrated for half a monolayer P atoms on the clean iron (100) surface is given in fig. 7b.

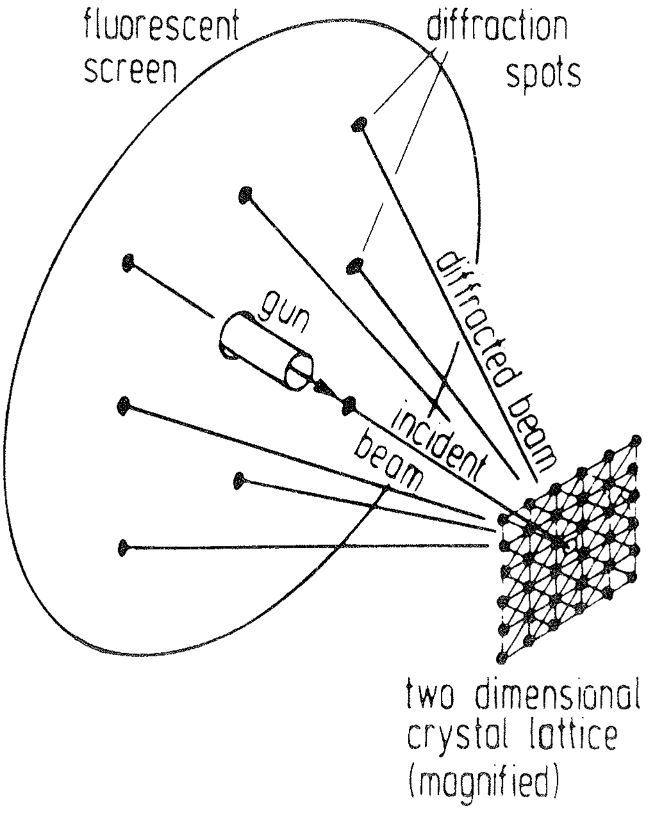


Fig. 5: Illustration of the diffraction and imaging process occurring on a surface with a two-dimensional grating

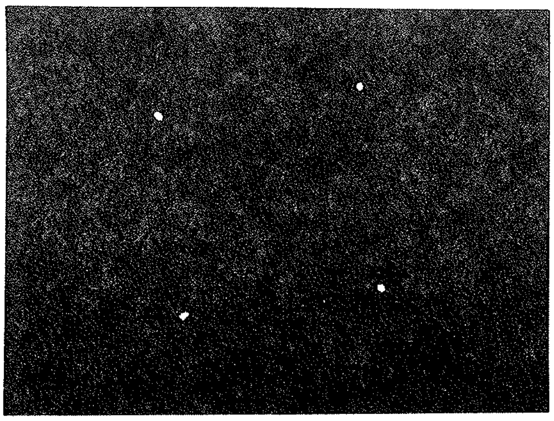
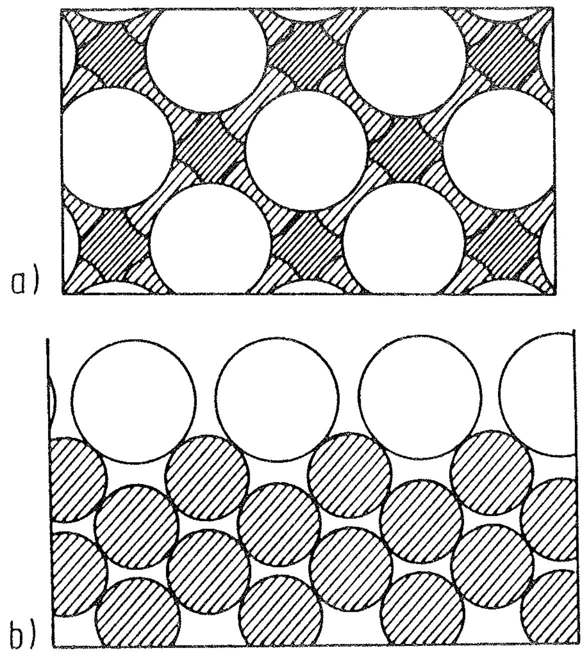


Fig. 6: First order LEED reflexes of a clean iron (100) surface



Model of c(2 × 2) adsorption (segregation)

Fig. 7a: Schematic of a phosphorus c(2x2) structure on an iron (100) surface

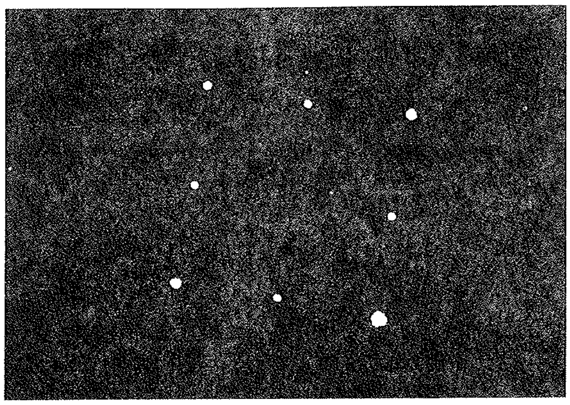


Fig. 7b: LEED pattern of a phosphorus c(2x2) structure on Fe(100) (compare with fig. 6)

The electron spectroscopic methods

Because of several principal and experimental similarities between the electron spectroscopic methods Auger Electron Spectroscopy (AES) and X-Ray Induced Photoelectron Spectroscopy (XPS), both methods will be discussed together. In both cases an electron energy analysis is performed with respect to electrons which are emitted from the sample under study after primary excitation with primary electrons in the case of AES and with X-Rays for XPS. For electrons which are emitted and traveling within a solid with a definite energy, the inelastic mean free path λ_M governs the surface sensitivity. λ_M is defined as the mean distance an electron travels before undergoing an inelastic event, i.e. some interaction whereby it loses energy. A compilation of experimentally determined electron mean free path values for solid elements was given by Seah and Dench /10/ and is displayed in fig. 8. For electrons within the range of 10-2000 eV, which is the typical energy range for the electron spectroscopic methods AES and XPS, λ_M is within the range of 0.5 to 2 nm or within about 2 to 10 atomic layers.

The actual escape depth λ of electrons depends on the direction in which they travel on their way to the analyzer:

$$\lambda = \lambda_M \cos \Theta$$

with Θ being the emission angle with respect to the surface normal. Thus electrons emitted perpendicular to the surface will arise from maximum escape depth whereas electrons which are emitted nearly parallel to the surface come from the outermost region of the surface.

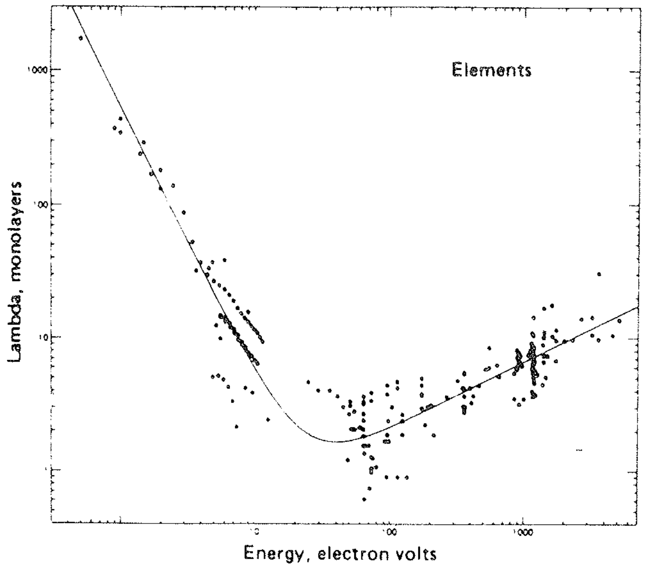


Fig. 8: Variation of the elastic mean free path for electrons in solids with energy after Seah and Dench /10/

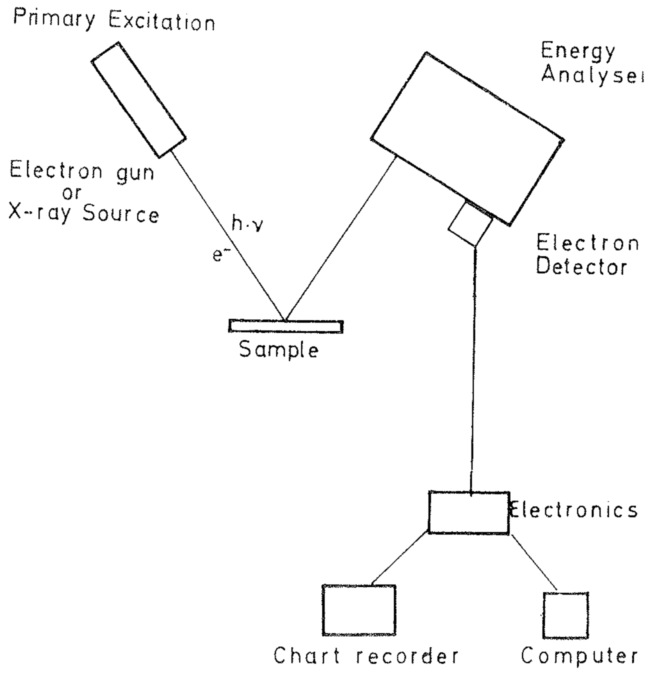


Fig. 9: Schematic representation of the components necessary for performing AES or XPS

By varying the angle of detection during an experiment the surface sensitivity may be enhanced for the electron spectroscopic methods.

The main components necessary to perform either Auger Electron Spectroscopy or Photo-electron Spectroscopy are very similar and fig. 9 gives a schematic representation of them. These consist of an excitation source (X-Ray source or electron gun), a sample/ support system, an electron energy analyzer and an electron detector (Multiplier), all maintained under ultra high vacuum. A further component outside the vacuum system are suitable electronics to convert the detected current into a readable spectrum. Two types of energy analyzers are currently most frequently in use, the cylindrical mirror analyzer (CMA), mainly for AES and the concentric hemispherical analyzer (CHA) mainly for XPS. Fig. 10 gives a schematic representation of both types of energy analyzers. More detailed information on the properties, advantages and disadvantages of the different analyzers may be found in literature /11/.

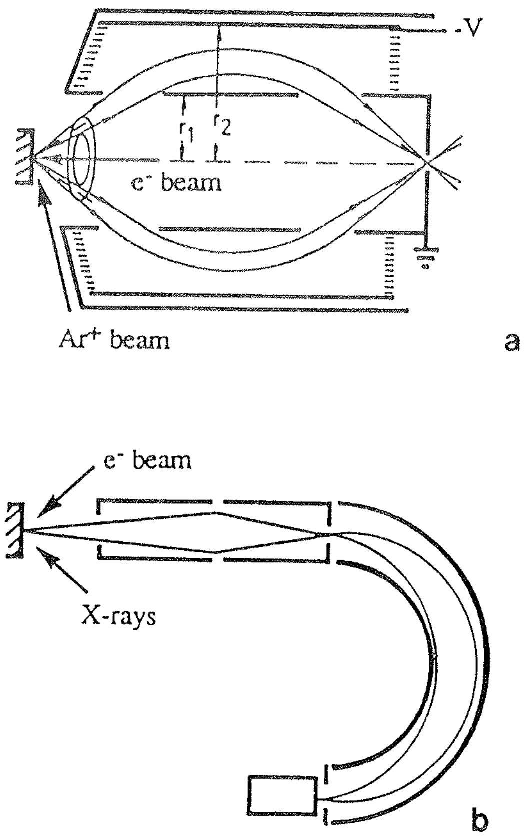


Fig. 10: Electron spectrometers used mainly for
a) AES CMA Cylindrical mirror analyzer
b) XPS CHA Concentric hemispherical analyzer

Auger Electron Spectroscopy

The origin and nature of the Auger process /12/ can be understood from the schematic diagram of electron energy levels given in fig. 11. Ionizing radiation (electrons or X-Rays) ejects an electron from an atom in the solid, leaving a hole in one of the atomic core levels. This core level hole is quickly filled by an electron from a higher level and energy is released. This energy can be emitted in form of X-Rays or by a competing process where another electron gains energy and is ejected from the atom. This ejected electron is called an Auger electron and its energy depends on the energy of the atomic levels involved in its production and is independent of the energy of the ionizing radiation. Because of the element specifity of the atomic energy levels, the emitted Auger electrons are element specific and the energy distribution of the emitted Auger electrons may therefore be used for an elemental analysis.

All elements besides H and He give rise to Auger electrons. For routine analysis of materials it is usually not necessary to understand the origin of the Auger transition in detail and as a first approximation the kinetic energy of an Auger electron may be given by (according to fig. 12)

$E_{kin} = E_{L_1} - E_{L_{23}}$

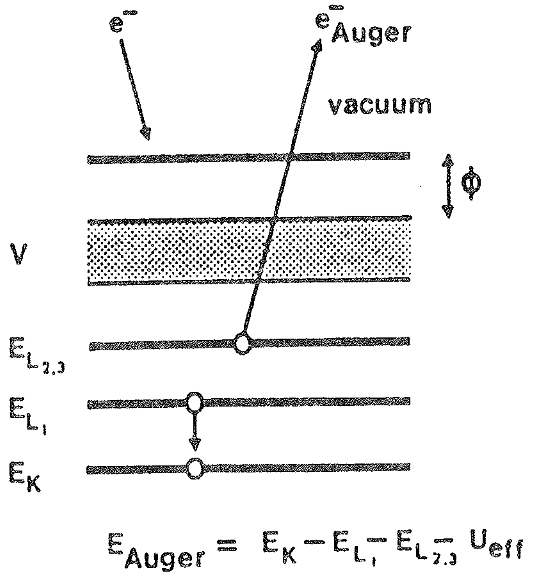


Fig. 11: *Schematic of the Auger process*

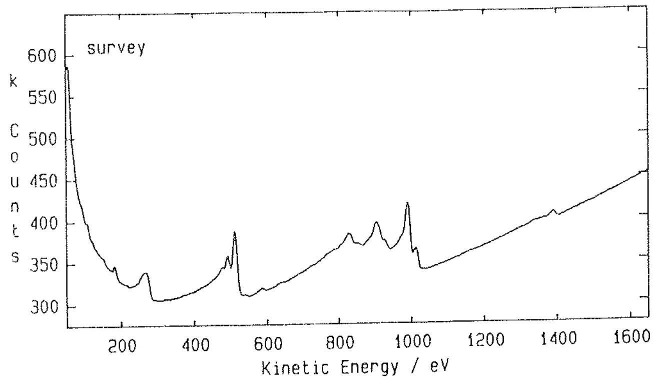


Fig. 12a: *AES spectrum energy distribution N(E)/dE vs E*

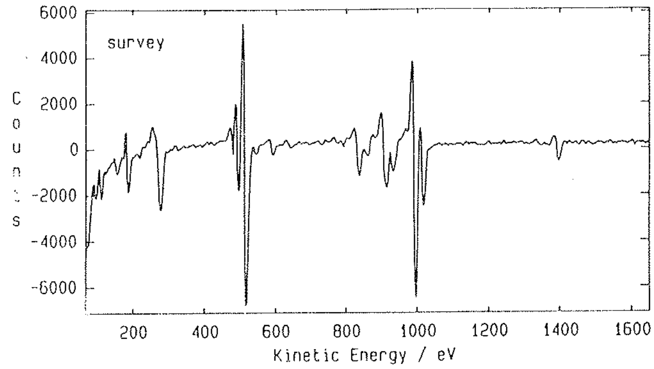


Fig. 12b: *AES spectrum dN(E)/d(E) vs E*

Auger spectra are normally displayed in one of two ways. The direct spectra, fig. 12a, which shows the energy distribution N•N(E) in dependence on E. Historically however, the derivate spectra E•(dN(E))/dE have been preferred, fig. 12b, which has the advantage that the large slowly varying, inelastic background under the Auger peaks is suppressed, as may be recognized by a comparison of fig. 12a and 12b.

Auger spectra may be quantified with quite different levels of sophistication. The level of accuracy depends very much on the materials system and the instrument. Up to now there is no general method of quantifying Auger spectra. Several reviews on this subject are given in literature /13,14/.

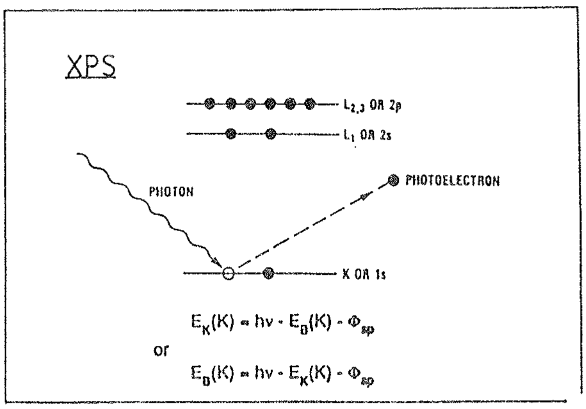


Fig. 13: *Schematic respresentation of the XPS process*

X-Ray Photoelectron Spectroscopy

Fig. 14 schematically presents the related process which is involved in the ejection of a photoelectron. The photoemission process is shown on an energy level diagram. The sample is irradiated with X-Rays of known energy h.υ and a sample electron is emitted from the K (or 1s) level. Due to the photoeffect the kinetic energy E_K of the emitted electron is given by

$E_K = h \cdot \upsilon - E_B$

where E_B is the binding energy of electrons in the K-level. As the energy h.υ of the X-Rays is known, a measurement of the kinetic energy of the photoelectron can be used to determine the binding energy of the electrons. A typical XP-spectrum is generated by plotting the measured photoelectron intensity as a function of binding energy, fig. 14. The binding energies of the observed lines are characteristic for each element and are a direct representation of the atomic orbital energies. Handbook data of these lines for all elements (besides H and He) exist /15/.

By XPS it is possible to distinguish between a particular element in different environments. This is due to the fact that placing the same atom into different chemical environment gives rise to a change in the binding energies of the core-level electrons. This change in binding energy is called "chemical shift" and appears as a definite movement of the binding energy of the involved elemental peak in the XP-spectrum. One of the major advantages of XPS is the ease with which quantitative data can routinely be obtained. This is usually performed by determining the area under the peaks in question and applying previously determined sensitivity factors. A more detailed discussion of quantification of XPS results is given by several authors, for example by /16/.

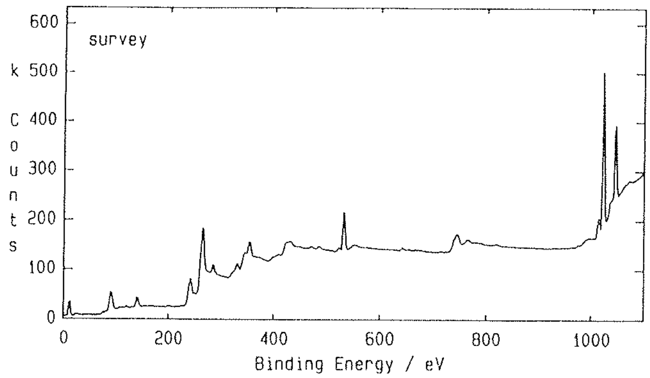


Fig. 14: XPS survey spectrum

As was pointed out already the depth from which photoelectrons are measured depends on the angle Θ of detection, i.e. the angle of emission direction to surface normal, schematically shown in fig. 15. From this figure we can see that detection close the surface normal enhances signals from the bulk relative to the surface while detection close to the surface place enhances the signal from the surface to the bulk. Thus by varying the angle of detection non-destructive depth information, as presented in fig. 16, can be achieved. This figure shows XPS data for a thin film of SiO_2 on Si. For small values of Θ the main contribution to the spectrum is from the bulk Si, while at larger values of the Θ contribution from SiO_2 becomes more important. For very thin layers on a substrate this approach is obviously preferable to the destructive ion etching methods for thin film analysis, which will be discussed in the following section.

Secondary Ion Mass Spectrometry (SIMS)

The basic principle of the SIMS method is illustrated schematically in fig. 17. Primary ions of high enough energy (0.1 to 10.0 keV) bombard the surface of a solid and generate a collision cascade within the surface near region of the sample. During this impact ionized atomar or molecular species are emitted from the surface into the vacuum. The ejected secondary ions are detected by a mass spectrometer. The distribution of the emitted positive and negative ions is characteristic for the chemical composition of the sample surface. There are two

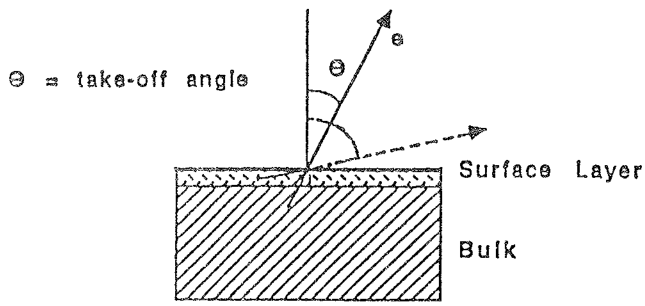


Fig. 15: Schematic showing surface sensitivity as a function of emission angle. Small Θ enhances the signal from the bulk, while large Θ enhances the signal from the surface

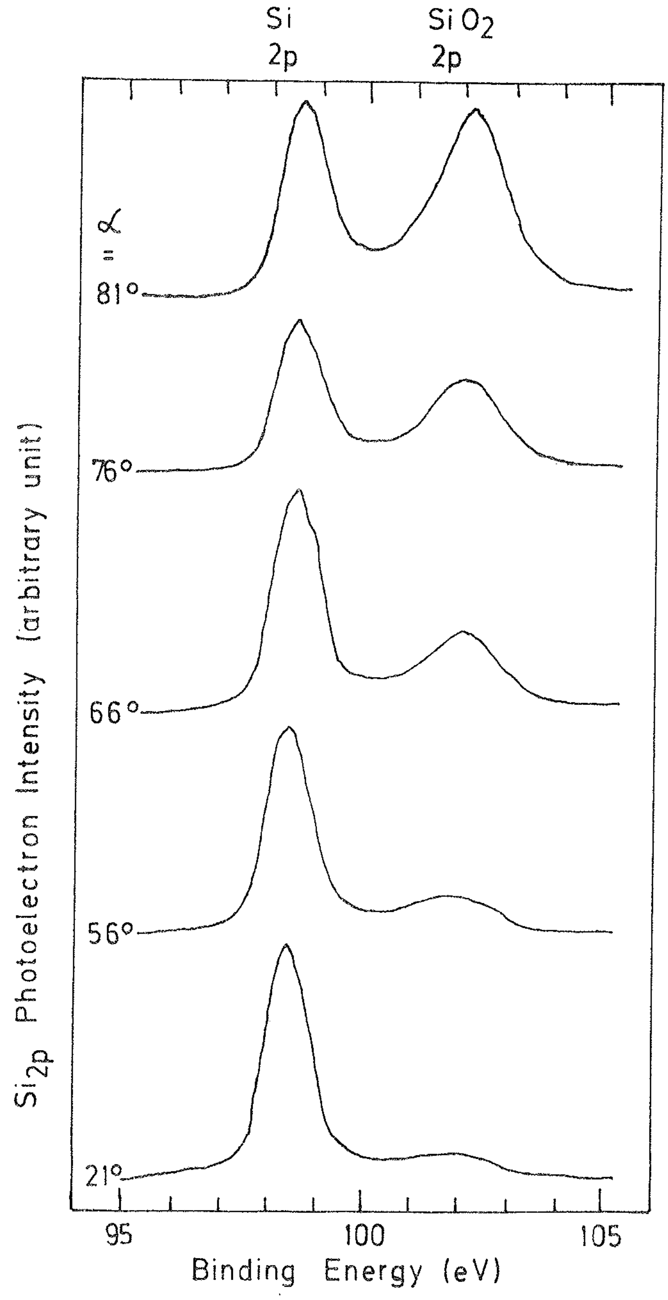


Fig. 16: Study by XPS of the interface between Si and a thin film of SiO_2 on the Si substrate. α– angle between surface and normal

different modes of application of the SIMS method. For the static SIMS method very low primary ion current densities are used so that the analysis is restricted to the outermost atomic layer of the solid sample. If fine focused ion sources are used and the primary ion beam is scanned across some sample area, the secondary electrons emitted by the impact cascade may be used to get a topographic image of the sample. By recording selected emitted secondary ions, an elemental mapping of the sample surface is possible. Each elemental mapping of the sample surface is possible. Each elemental corresponds to one removed atomic layer.

For the dynamic SIMS method high ion beam current densities are used in order to sputter with a relatively high rate succeeding surface layers. By this a high detection sensitivity of 10^{13} atoms per cm^3 can be reached. This high sensitivity combined with the possibility to measure concentration profiles means that this kind of application of SIMS is ideal to determine doping and impurity levels in solids. By SIMS not only all elements but also isotopes can be detected mass spectrometrically.

A schematic drawing of a SIMS system is given in fig. 18. The main components are the ion source, the mass spectrometer and the sample holder and manipulator. Additionally, an electron gun may be used for charge compensation during analysis of poor conducting samples or insulators. The oxygen ion source enables reactive sputtering in order to increase the secondary ion yield for metallic samples and to minimize so-called matrix effects.

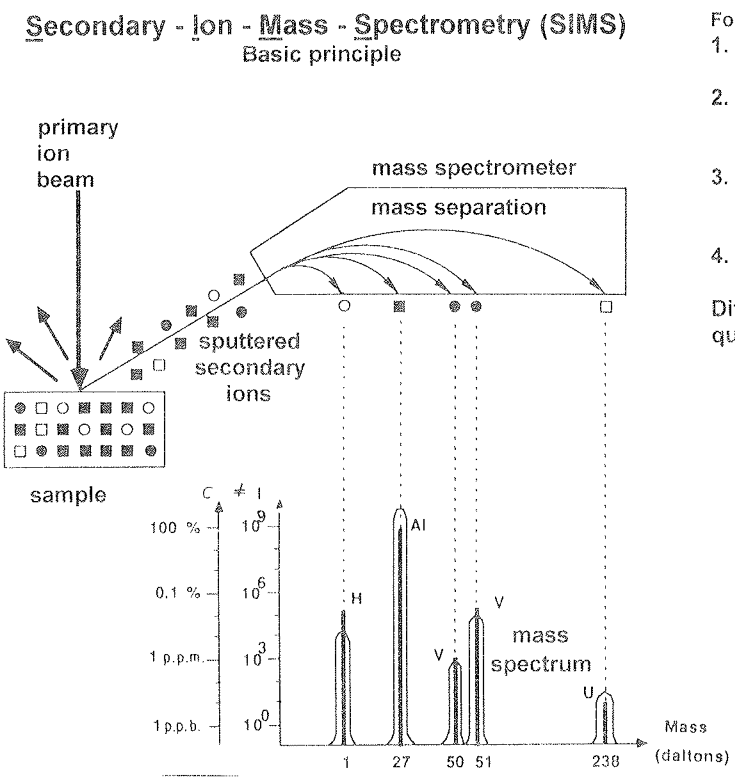
The static method of SIMS was very frequently used to study the adsorption of gases particulary oxygen on metal surfaces. To illustrate the possibilities of the static SIMS method an example will be given for carbon monoxide adsorption on an iron surface. Depending on the kind of metal the adsorption of carbon monoxide on metal surfaces may be molecular or dissociative. Examples are

Cu, Pd, Ni molecular
and W dissociative

In the case of iron both types of carbon monoxide adsorption can occur. By static SIMS studies the individual type of adsorption may be characterized by the type of secondary ions which appear during sputtering as was shown by /17/ for example for CO adsorption on iron, fig. 19. For dissociative adsorption MC^+, MO^+, MO^+_2 and M_2C (M for metal) secondary ions should be observed and on the other hand molecular adsorption. Fig. 19 demonstrates that for CO adsorption on iron all types of secondary ions were registrated.

Secondary Neutrals Mass Spectrometry (SNMS)

The SNMS method shows many similarities with the SIMS method discussed before. Again primary ions of



Four steps are involved in SIMS characterisation:
1. The bombardment of the sample (under uhv-conditions) by primary ions of sufficient energy in the keV range
2. Sputtering of the outermost atomic layers, the sputtered material consists of about 99% secondary neutrals and a small fraction of positive or negative secondary ions
3. The extraction of the emitted ions prior to their injection into a mass spectrometer which separates (or filters) the different species according to their mass/charge ratio
4. The detection of the secondary ions with a large dynamic range (10^{10}) in intensity I (c.p.s.)

Different types of mass spectrometers can be used: quadrupoles, ToF, magnetic.

Fig. 17: Schematic of the SIMS process

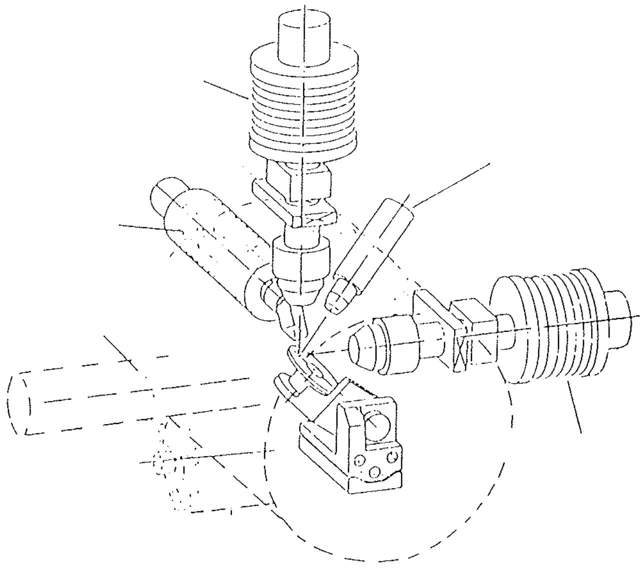


Fig. 18: SIMS system (main components)

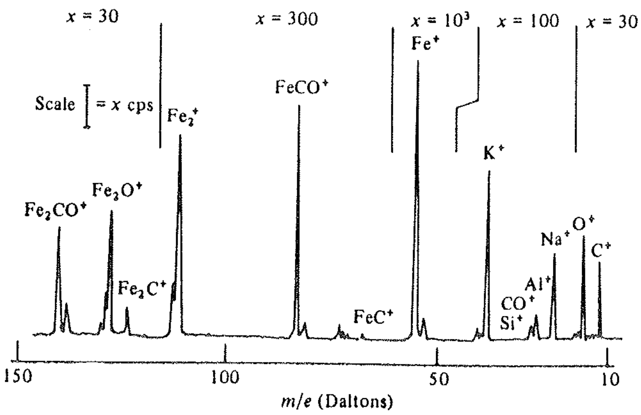


Fig. 19: SIMS spectrum recorded at equilibrium when iron is exposed to 10^{-8} Torr of carbon monoxide

high enough energy (0.1 to 10 keV) generate a collision cascade in the surface near region of a solid sample. As a consequence molecular and atomar fragments are emitted from the surface into the vacuum. The emitted secondary ions used for SIMS analysis are separated and the emitted neutrals are post ionized by electron impact and detected by a mass spectrometer. Also in this case the emitted neutrals are characteristic for the chemical composition of the sample surface. Post ionization may also be performed by a low pressure plasma above the sample or by laser bombardment. Decoupling the sputter and ionization process the ionization probabilities are predictable and independent on matrix effects. For this reason, the SNMS method is much better suited for quantitative measurements than the SIMS method.

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H. Viefhaus
Max-Planck-Institut für Eisenforschung GmbH
Max-Planck-Str. 1
D-40237 Düsseldorf, Germany
tel. + 49 211 6792 290
fax + 49 211 6792 268

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FERROELECTRIC THIN FILMS FOR APPLICATIONS IN MICROELECTRONICS AND IN MICROMECHANICS

Nava Setter
Laboratoire de céramique, EPFL
Ecublens, Lausanne, Switzerland

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Keywords: microelectronics, micromechanics, thin films, ferroelectric films, practical applications, new applications, recent developments, new products, FRAM, PZT ferroelectric materials, DRAM memories, high dielectric constants, piezoelectric micro actuators, pyoelectric sensors, IR image sensors, IR imaging

Abstract: Because of their unique properties, ferroelectic thin films are of interest for non-volatile memories, for DRAM's, for applications as integrated sensors (e.g. IR sensors) and for a variety of micro mechanical devices such as micro motors and micro pumps. An overview of recent developments is presented here, with emphasis on fabrication related issues and on properties relevant to the above applications.

Feroelektrične tanke plasti in njihova uporaba v mikroelektroniki in mikromehaniki

Ključne besede: mikroelektronika, mikromehanika, plasti tanke, plasti feroelektrične, aplikacije praktične, aplikacije nove, razvoj nedavni, proizvodi novi, FRAM feroelektrični RAM, PZT materiali feroelektrični, DRAM pomnilniki, konstante dielektrične visoke, mikroaktuatorji piezoelektrični, senzorji piroelektrični, IR senzorji slik, IR upodabljanje

Povzetek: Zaradi svojih edinstvenih lastnosti lahko feroelektrične tanke plasti uporabimo pri izdelavi nebrisnih pomnilnikov, DRAM pomnilnikov, integriranih senzorjev (npr. IR senzorjev) in za izdelavo raznovrstnih mikromehaničnih naprav, kot so to mikro motorji in mikro črpalke.
V prispevku podajam pregled rezultatov najnovejših raziskav in dosežkov s poudarkom na izdelavi in lastnostih izdelanih struktur z zgoraj naštetih področij uporabe.

INTRODUCTION

Whereas bulk ferroelectrics are in use since long time, high quality ferroelectric thin films have been fabricated only recently. This new development allows for the first time the integration of ferroelectrics with silicon and opens the way to the realisation of a variety of new products, the first of which (a pyroelectric detector) has just appeared on the market /1/. Among the potential applications are ferroelectric non-volatile memories, DRAM storage capacitors and various micro-electromechanical devices. It is the large microelectronics companies who are interested in the memory applications of ferroelectrics, and the development is accelerating in particular in Japan. As for the applications in micromechanics, the interest is growing in medium size industries and is strong in particular in Germany and in Switzerland. In the latter field, the applications are just beginning to be discovered.

FERROELECTRIC RANDOM ACCESS MEMORY (FRAM)

Ferroelectric materials, such as $Pb(Zr,Ti)O_3$ (PZT), possess a permanent dipole that can be reversed with electric field (Fig. 1). Being such, they make a non-volatile memory. When thin ferroelectric films are integrated with CMOS circuits, they can form a solid-state non volatile memory. The properties of the ferroelectric films are ideal for memories: Read and write is very fast (nano seconds) /2/, the needed voltage for operation is small (3-5 V) and the stored information is maintained for long duration (high retention, no refresh needed). Other advantages are its potentially very high storage density and its insensitivity to radiation. The films show potential

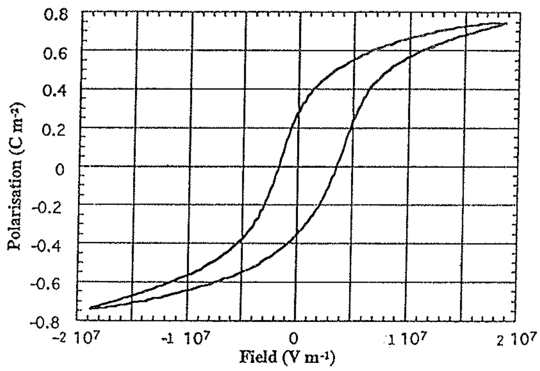


Fig. 1: The ferroelectric hysteresis loop.

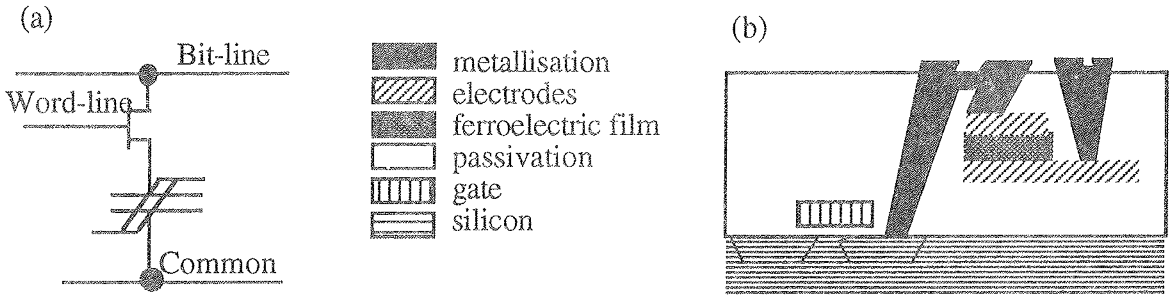


Fig. 2: Description of a ferroelectric non-volatile memory. a) schema, b) cross section.

to be compatible with VLSI processes and therefore the memory could have the same performance as that of DRAM with the advantage of being non volatile. Fig. 2a and 2b show one of the current proposed structure of the ferroelectric memory.

One of the important characteristics of a memory is the difference between the switched and the non switched signal after a pulse is given. Fig. 3 shows a typical behaviour of a "well prepared" PZT film on platinum metal electrode. The decrease in the signal, referred to as "fatigue", constituted a major problem of the films. Two solutions have been proposed: a) the use of a ceramic conductor such as RuO_2 instead of platinum which is reported to eliminate the fatigue problem at least up to 10^{13} cycles /3/, b) the use of an undisclosed material which is claimed to be fatigue free and has been patented /4/ and is used by Matshushita and Sony for the memory development.

The fabrication of the ferroelectric layers is still in development. The material mostly studied until now is PZT, showing a high spontaneous polarisation, a low coercive field and a high resistivity. The three methods suitable for a large scale fabrication are sol-gel technique, sputtering and MOCVD. Presently MOCVD, with its high growth rate and good step coverage is gaining importance /5/. The electrodes have a strong influence on the performance of the memory cell. The bottom electrode has to withstand the high processing temperature of the film (600 -700 °C) and the corrosive atmosphere (oxygen and lead vapours). Problems of lead migration into the silicon, through the electrodes, and problems of diffusion of Si or Ti (Ti is used as adhesion layer between the SiO_2 and the platinum) have been detected. The upper electrode is as important. Its deposition is done after the ferroelectric layer is processed, but problems are encountered related to adhesion and to the possible existence of a passive layer or a gap between the upper electrode and the PZT film (Fig. 4). The processing and the integration problems are being studied presently at numerous industries. Recently, researchers at Philips have shown reliable operation of memory cells (25 μm^2 area) of PZT with Pt electrodes, at 3V supply voltage and 20 n s pulse-width, up to 10^{13} cycles /6/.

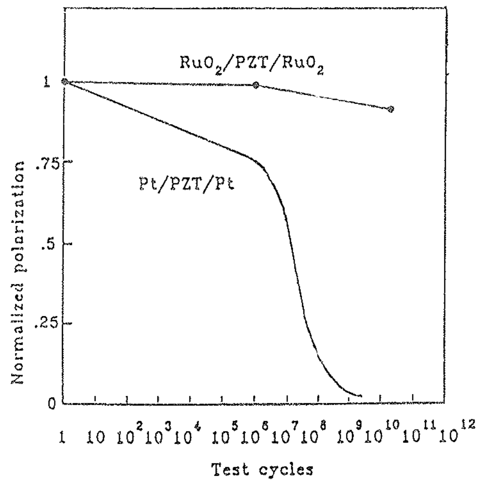


Fig. 3: Schematic curve comparing fatigue of films with Pt electrodes and with RuO_2 electrodes.

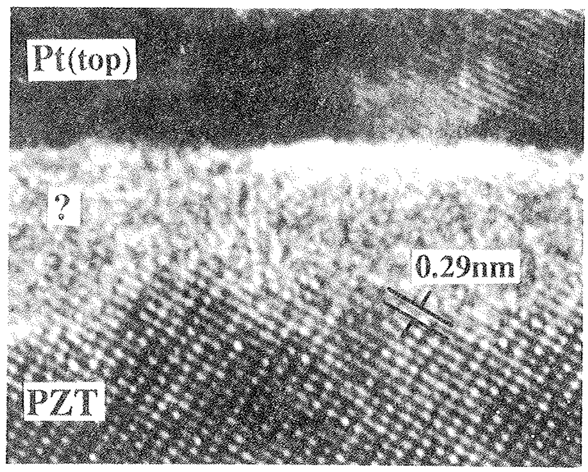


Fig. 4: TEM micrograph of PZT film with Pt upper electrode showing a gap between the film and the electrode (courtesy of I.Reaney, Laboratoire de céramique, EPFL)

HIGH DIELECTRIC CONSTANT MATERIALS FOR DRAMS

In parallel to the development of ferroelectric non-volatile memories, there is a current effort to replace SiO_2 capacitors of dynamic random access memories with very high dielectric constant films. The reason for this is the need to increase DRAM density beyond that achievable by low permittivity dielectrics. Until now the increase in density has been obtained by a reduction in the capacitor area and a subsequent reduction in the capacitor thickness, but low thickness limitations have been attained and an increase in density beyond 1Gbit is hardly foreseeable even with Ta_2O_5 whose dielectric constant is higher than that of silica (ε_r = 17 and 4 respectively). Ferroelectrics with high permittivity would seem advantageous, since they allow reduction in the capacitor area while maintaining a reasonable thickness. However, the paraelectric (Ba,Sr)TiO_3 (BST) seems more appropriate for this application, since it possesses high permittivity up to the high frequencies envisioned for ULSI DRAMs (GHz regime) and its losses at these frequencies are much lower than those of the high permittivity ferroelectrics. Low leakage current (<1.5fA at Vcap (3V)) and null time dependent dielectric breakdown (TDDB) at Vcap for long duration (10 years) /7/ are the most important impositions on the new capacitor material. Recently Koyama et al. /8/ and others have shown large charge storage capabilities of BST and Taguchi /9/ has shown that this material performed better than thin Si_3N_4 with regards to leakage current. Activity in this area is pursued in most DRAM producing industries, in particular in Japan /10/.

PIEZOELECTRIC MICRO ACTUATORS

The application of piezoelectric films in micromechanics is presently at the demonstration level. Piezoelectric micromotors based on ZnO thin films have been fabricated /11/, and more recently a PZT micromotor has been demonstrated with rotational velocities 100-200 rpm and torques in the pN-m/V^2 range /12/. ZnO has the advantage of ease of deposition and low permittivity while ferroelectric ceramics, like PZT, have much larger piezoelectric coefficients. Until now, the piezoelectric properties of the ferroelectric films have hardly been investigated and the question whether the piezoelectric properties of the films are similar to those of bulk ceramics is still open. The answer to this question is needed before commercialisation can take place. Direct piezoelectric measurements (measurements of the induced piezoelectric charge under alternating force) on poled Pb($Zr_{0.53}Ti_{0.47}$)O_3 films of $\approx$ 1 μm thickness showed piezoelectric coefficient $d_{33} \approx$ 130 pC/N/13/. This result is not sensitive to the ac pressure excerted (Fig. 5a) but is less than half of the bulk value. The converse piezoelectric effect is studied using optical interferometry and the results are consistent with those obtained by the direct method. Fig. 5b shows a typical piezoelectric hysteresis loop of PZT obtained by laser interferometry. The piezoelectric coefficient is dependent on the applied DC bias and, unlike the case of bulk ceramics, is significantly reduced upon removal of the bias. The origin of the effect may be due to clamping of domain walls either at the electrode-film interface or in the bulk. A clear answer is still missing. The piezoelectric response of a micromachined cantilever beam has been measured as well /14/. In this configuration, precise determination of the coupling coefficient k_{13} (the efficiency of conversion from electrical to mechanical energy) can be done. 0.4 μm thick films have shown k_{13} = 0.15, or about half of the value reported for bulk PZT ceramics. DC bias was necessary in order to obtain this coupling coefficient.

Few demonstrations have been presented by now concerning potential applications. A new configuration of a micromotor has been presented, with enhanced coupling between the piezoelectric (ZnO) stator and the metallic rotor. This motor includes standard micromechanical components with components similar to those used by the watch industry /15/. The same configuration has also been used recently with PZT /16/. Another

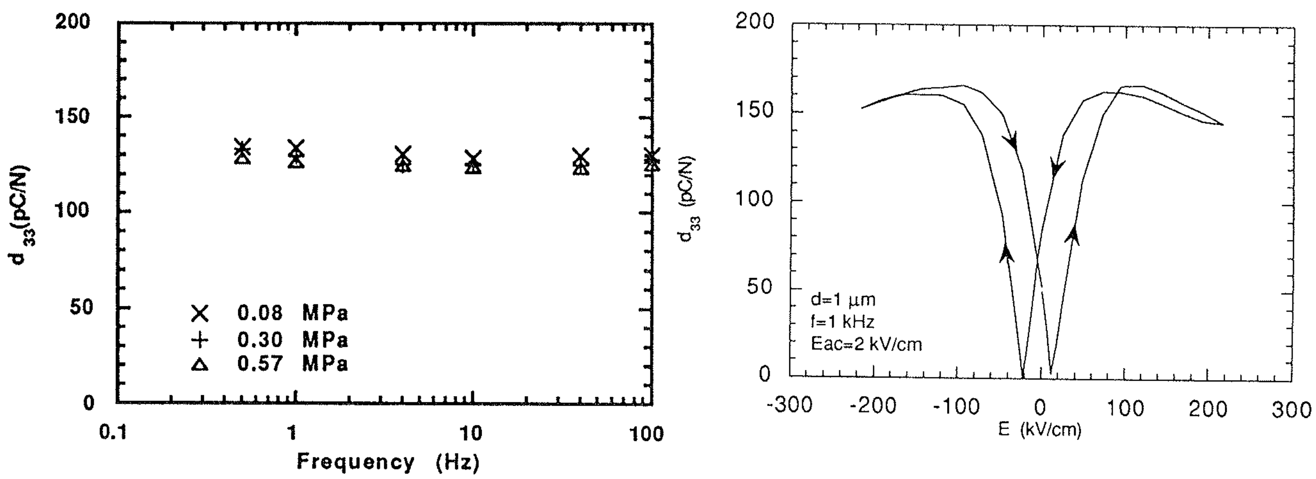


Fig. 5: Piezoelectric properties of PZT films. a) d_{33} as a function of ac force frequency measured in the direct method, b) Piezoelectric hysteresis loop of a 1.0μm thick film, measured by interferometry (courtesy of A. Kholkine and D. Damjanovic, Laboratoire de céramique, EPFL).

direction which has been pursued first with ZnO and then with PZT /14/ is the development of a piezoelectric micropump where travelling waves carry the liquid forward. One of the potential application of such pumps is in continuous drug delivery. Another possibility is the use of a tubular micropump in a structure similar to that shown in Fig. 6a. In this case, a microtube with outer diameter 30 μm and wall thickness 5 μm has been fabricated from ZnO and coated with Pt electrodes /17/. A longitudinal wave could then generate the pumping action. Piezoelectric micro-beams on micro-machined silicon have been proposed for sensors and actuators. Fig. 6b shows such a structure.

Piezoelectric coatings on optical fibers have been used to create an optical phase modulator. The piezoelectric coating would deform under the applied field, stressing the fiber and modulating the optical signal. A family of interferometric sensors is expected to result from this work /18/.

For piezoelectric applications, thin films thicker than 1 micron are needed. Processing studies are being carried out presently in order to develop high quality "thick" thin films. The problem is the control of stoichiometry during the long period of heat treatment necessary for the growth process. Fig. 7 shows PZT films of thickness 1μm. In the films prepared by the sol-gel methods (Fig. 7a) a lead deficient layer is seen at periodicity of 0.3 μm, resulting from the thermal history of the film. The sputtered films (Fig. 7b) are highly crystalline, but demand a higher thermal budget for the preparation.

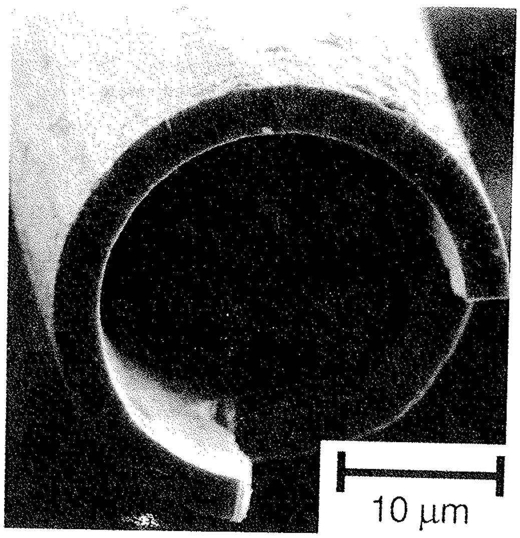
PYROELECTRIC SENSORS

Generating charge under temperature variations, pyroelectrics crystals and bulk ceramics are often used as infra-red sensors. When the pyroelectric elements are fabricated in a matrix array form, they allow the extraction of spatial temperature distribution and its temporal variation and make efficient IR imaging systems.

The fabrication of pyroelectric thin films adds the two following advantages: The pyroelectric signal, being inversely proportional to the element thickness, is enhanced by the thickness reduction (up to a certain thickness the level of which is dependant on the configuration of the component), and therefore thin films have potential for better performance than the bulk pyroelectrics. Secondly, the possibility to deposit the pyroelectric film on silicon has the potential to allow the integration of the device with the needed electronics.

A suitable material for pyroelectric applications is lead titanate, $PbTiO_3$, doped with lanthanum. Lead titanate is useful due to its high pyroelectric coefficient (p = 180 $\mu cm^{-2}K^{-1}$) and low dielectric constant (ε_r = 180). The lantanum is known to further enhance the pyroelectric coefficient. The preparation of bulk lead titanate ceramic is difficult because of cracking that occurs due to the large distortion at the phase transition. Lead titanate thin films do not suffer from this problem. In addition it is possible to prepare these films on MgO substrates with their c-axis perpendicular to the surface so that the figure of merit is optimised /19/.

In order to optimise the pyroelectric sensor performance, low thermal conductivity between the film and the substrate is needed. In this case, micromachining technology is of great use. Ye et al. /20/ have deposited the active element on a sacrificial layer which was later removed, leaving the active element above a cavity and supported by a polysilicon membrane (Fig. 8a). In this way, the high thermal conductivity of Si does not degrade the device performance. Another possibility to avoid the heat conductivity by the silicon is to etch the silicon below the active element, leaving only a thin supporting membrane /21/ (Fig. 8b). Weda et al. /22/ have shown



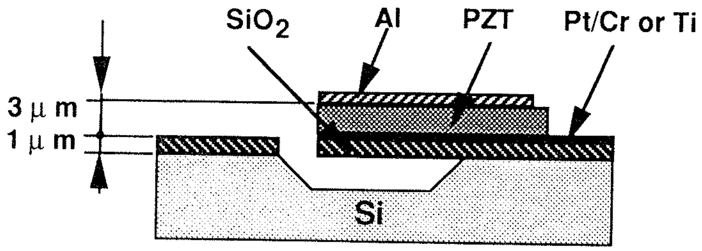


Fig. 6: Various piezoelectric microcomponents. a) piezoelectric microtube and b) schematic view of a piezoelectric micro beam (courtesy of G. Fox and K. Brooks, Laboratoire de céramique, EPFL).

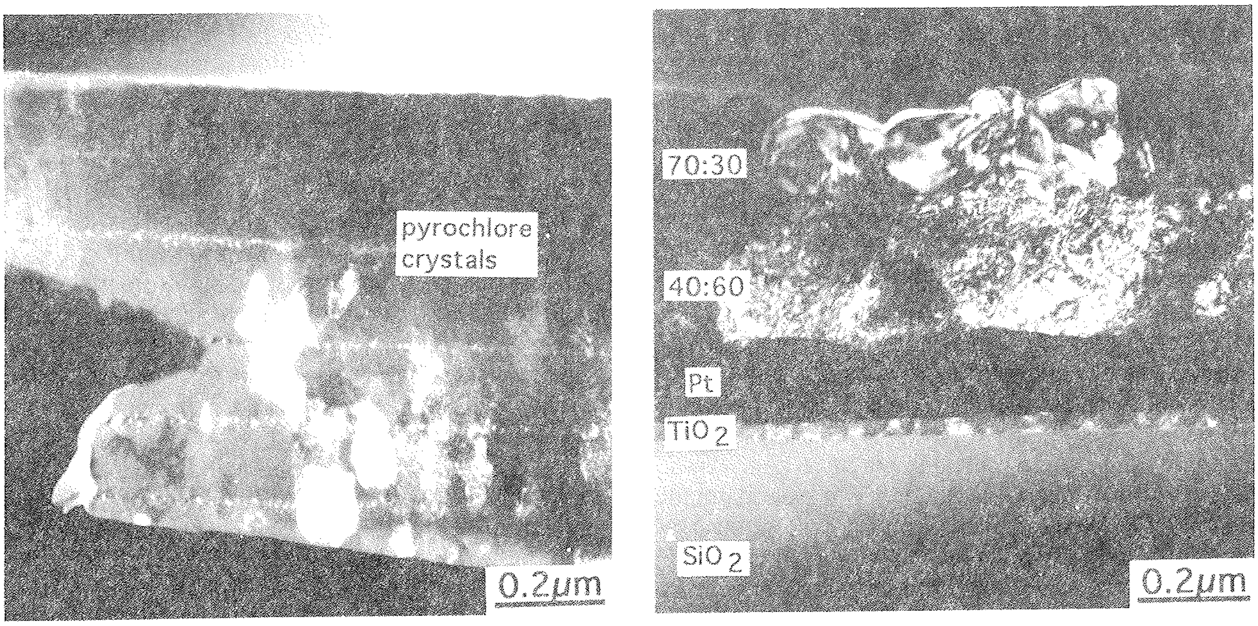


Fig. 7: Microstructure of 1 micron PZT film: a) sol gel film , b) sputtered film.

another efficient configuration. Lead titanate film was grown on MgO to provide preferred orientation growth with optimised properties. Then a support, thermal insulating layer, has been grown on the active element and the MgO has been etched away. The structure was then bonded to a supporting ceramic substrate (Fig. 8c).

FINAL REMARKS

The current experiments related to the performance of FE films indicate numerous advantages for their use in many applications. At the same time it is clear that the addition of the ferroelectric layer on standard Si devices, whether in microelectronics or for micro sensors and actuators, means additional fabrication costs. It is not clear yet whether the additional advantages will be attractive enough to allow for the extra cost. In the meantime, development is proceeding in both industry and academic laboratories throughout the world.

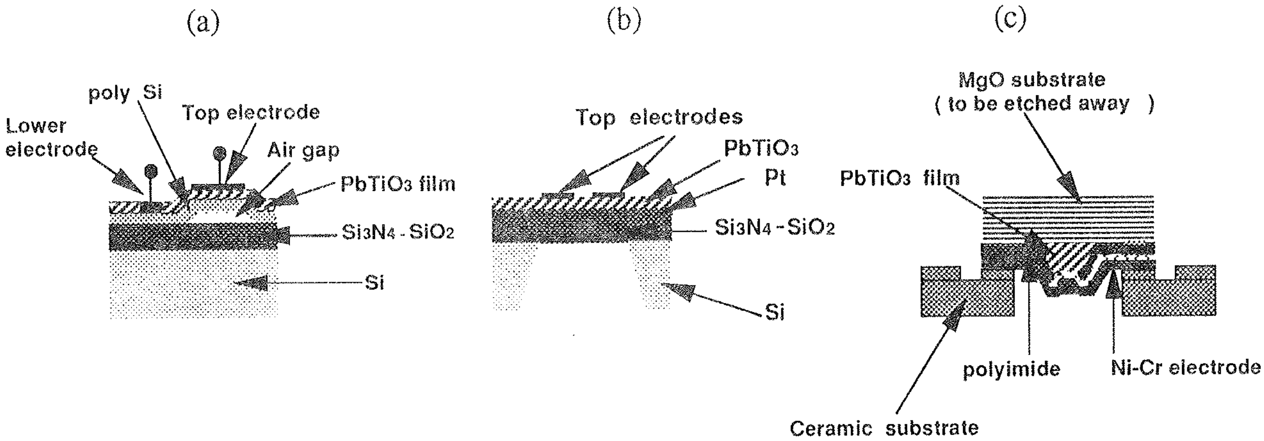


Fig. 8: Proposed configuration for pyroelectric micro-sensors. a) sacrificial layer method /20/, b) micromachined silicon method /21/, c) inverted MgO method /22/.

ACKNOWLEDGEMENT

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prof.dr. Nava Setter
Ecole Polytechnique Fédérale de Lausanne
Laboratoire de céramique, EPFL
Ecublens, Lausanne, CH-1015 Switzerland
tel.: 021-693 29 61, fax.: 021-693 29 35

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MOLECULAR BEAM EPITAXY FOR THE GROWTH OF FERROELECTRIC THIN FILMS

Z. Sitar, F. Gitmans, and P. Günther
Institute of Quantum Electronics, ETH Zürich, Switzerland

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Keywords: microelectronics, thin films, ferroelectric films, MBE growth, material deposition, two-dimensional structures, Ultra High Vacuum

Abstract: Recent developments in the field of thin film ferroelectrics include also deposition by a molecular beam epitaxy process. It is anticipated that this will yield high quality epitaxial films and two-dimensional ferroelectric structures. Present paper discusses the requirements which have to be fulfilled for a successful and controlled deposition of ferroelectric thin films in an UHV environment and gives a comparison with the classical MBE. It describes the feasible methods to obtain stable low pressure molecular beams of different metals and briefly discussed the in-situ low temperature oxidation issue.

Rast tankih feroelektričnih plasti z molekularno epitaksijo

Ključne besede: mikroelektronika, plasti tanke, plasti feroelektrične, MBE rast molekularna žarkovna epitaksialna, nanašanje materialov, strukture 2 D dvodimenzionalne, UHV vakuum ultravisoki

Povzetek: Med dosežke najnovejšega razvoja feroelektričnih tankih plati štejemo tudi rast le-teh s tehniko molekularne epitaksije. Predvidoma bomo s pomočjo te tehnike uspeli nanesti feroelektrične tanke plasti visoke kvalitete in izdelati dvodimenzionalne feroelektrične strukture.
V pričujočem delu obravnavamo zahteve, ki morajo biti izpolnjene, če hočemo uspešno in kontrolirano nanesti feroelektrične tanke plasti v UHV okolju in hkrati jih primerjamo s klasično MBE metodo. Nadalje opisujemo ustrezne pristope, s katerimi dobimo stabilne molekularne tokove različnih kovin pri nizkih tlakih, kakor tudi na kratko obravnavamo nizkotemperaturno oksidacijo na licu mesta.

1. Introduction

1.1. Ferroelectric Thin Films

Ferroelectrics are a very complex class of materials which combine a large variety of useful properties in a single material; i.e., mechanical, optical, electrical, ferroelectric, piezoelectric, pyroelectric, electro-optic, nonlinear-optic, acusto-optic... The sensitivity of these properties to external stimuli makes ferroelectrics interesting for a wide variety of applications in electronics, sensoric, micromachines and transducers, and in integrated and acusto-optics. Their main attribute is spontaneous electrical polarization (arising from the relative displacement of the ions within the unit cell) which has more than one possible equilibrium orientation and can be thus switched by the application of an adequate external electric field. In many ferroelectrics the polarization decreases with temperature and vanishes at the ferroelectric phase transition or Curie point T_C. Ferroelectrics crystallize in many crystal structures, however, the cubic perovskite structure, which is the high temperature form of many ABO_3 oxides, is probably the most important ferroelectric prototype. To this family belong technologically important ferroelectrics like $BaTiO_3$, $PbTiO_3$, $SrTiO_3$, $PbZrO_3$, $NaNbO_3$, $KNbO_3$, or solid solutions of these materials. The other two technologically interesting ABO_3 compounds are $LiNbO_3$ and $LiTaO_3$ which have a similar coordination but a hexagonal structure. The ion displacements in the ferroelectric phase are for the latter two materials exceedingly large. Ferroelectrics have been most commonly used in a ceramic or crystalline bulk form. Their advantages in a thin film form have been recognized in the 80's and since then a variety of deposition techniques have been applied for their production. We can divide them into two large groups; with and without particle bombardment. While at the beginning of the ferroelectric thin film work the techniques with bombardment, like different kinds of sputtering, were very popular, today they seem to be fading out to give room to less expensive techniques, like sol-gel, or to advanced growth techniques like metallorganic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE), where a high control over the growth process is available. Figure 1 shows a chart of the most commonly used deposition techniques. PZT and related ferroelectrics were probably the most popular materials grown in thin film form. Nevertheless, development of ferroelectric thin films with controlled properties at relatively low growth temperatures still

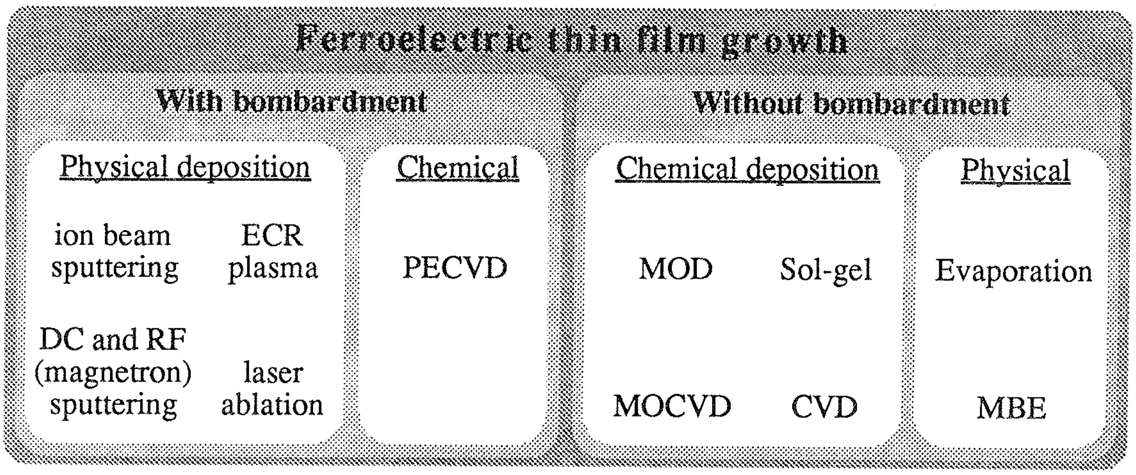

Fig. 1: Thin film deposition methods used for the growth and deposition of ferroelectic thin films

remains a major research task and among all deposition techniques being used today no single method seems to be a clear winner. While sol-gel method is widely used for the deposition of thicker films where the grain structure and high cycling temperatures do not matter, the growth of high quality epitaxial two dimensional structures will have to be performed by MOCVD or MBE.

1.2. Molecular Beam Epitaxy in Science and Technology

MBE has been developed over the last two decades as a response to the need for a thin film growth technique capable of depositing nearly perfect and contamination free semiconducting materials with very well defined thicknesses in the range of a single monolayer to several hundreds of monolayers. Since the pioneering work of J. R. Arthur and A. Y. Cho /1,2/ the technique has matured into a sophisticated thin film growth tool which has been applied mainly to the growth of different compound semiconductors but is currently evolving also in the field of high T_C superconductors and dielectrics. It is not an exaggeration to say that MBE has not only made possible the fabrication of classical quantum mechanical structures but has extended the imagination of researchers and device physicist to design a whole new generation of devices based on new artificially structured materials. In general terms, MBE is a refined form of vacuum evaporation. The hardware system usually consists of two to three interconnected stainless steel chambers; a growth chamber, a load lock, and an optional surface analysis chamber. A load lock is essential for maintaining UHV conditions over many growth runs. In the MBE process molecular beams, directed beams of neutral molecules or atoms of a relatively low density produced by heating solid substances in effusion cells, impinge under the ultra high vacuum (UHV) conditions

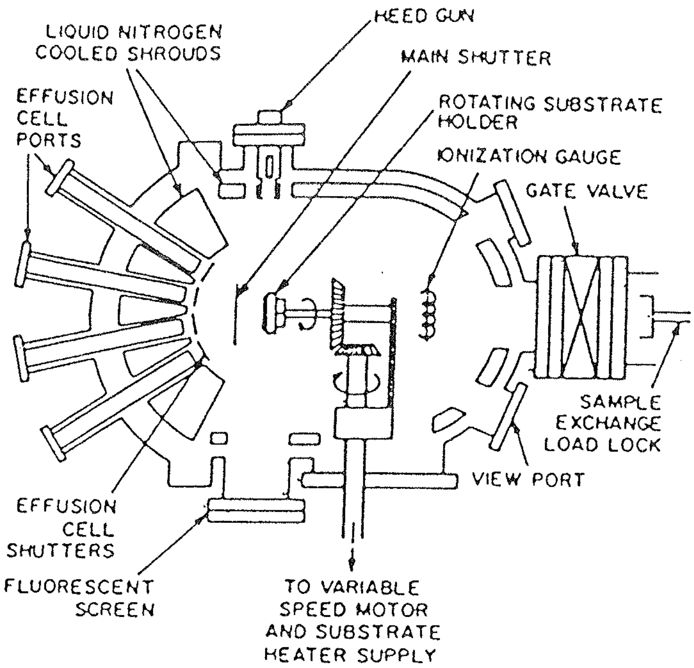

Fig. 2: Schematic of a solid source MBE chamber showing the arrangement of effusion cells, shutters, substrate manipulator, RHEED system, and cryo-panels.

on a heated substrate where they react and contribute to the formation of a thin film. Low background and beam pressures allow a line of sight process where the probability for collisions in the vapor phase is practically negligible. The beam fluxes are interrupted by mechanical shutters. A reflection high energy electron diffraction (RHEED) system is an invaluable tool for the in-situ quality and thickness control of the growing thin films. It allows observation of individual monolayers and through its help the growth of single quantum wells and superlattices has become possible. The growth chamber incorporates large area cryo-panels providing additional pumping and a trap surface for the molecules which did not successfully contribute to the growth. Figure 2 shows a typical layout of an MBE chamber used for the growth of III-V compounds, i.e., GaAs, AlAs, AlGaAs...

2. Issues to be Considered for MBE of Ferroelectrics

2.1. Materials

The beams of each individual specie to be deposited play in MBE a central role. It depends on the nature of material how easy or difficult it is to create these beams and maintain them stable over the whole deposition period which can take several hours to complete. Most materials used in MBE of semiconductors have to be heated to around 1300 K. This is a very comfortable temperature to work with; the radiation losses are high enough to allow a quick response to the control parameters and the temperature is still to low to cause any problems with containers (crucibles) or contamination. For the comparison let's consider now a few interesting ABO_3 ferroelectric materials and their components. An important parameter for the selection of the right source for the creation of molecular beams is materials vapor pressure. Figure 3 shows the vapor pressure curves of selected materials found in ferroelectric compounds mentioned at the beginning of the introduction. For comparison, the curves for Ga and Al, the most commonly used materials in MBE, are also given. Data has been obtained from the work by R. E. Honig/3/. A perusal of Figure 3 shows that most of the materials found in ferroelectric compounds differ considerably in their properties from the respective III-V components; the "A"-site elements are very volatile and exhibit several orders of magnitude higher vapor pressures while the vapor pressures of the "B"-site components are normally several orders of magnitude lower than those of Al and Ga. Considering the extremes: potassium has a suitable vapor pressure slightly above the room temperature while Ta has to be heated to almost 3000 K. This shows clearly that A and B component molecular beams can not be obtained with the same kind of sources.

2.2. Material Sources - Suitability, Stability, and Control Issues

2.2.1. "A" component sources

Fluxes of different components normally have to be stable within a few percent over the whole range of operation and over longer periods of time. In standard III-V MBE systems this means that the effusion cells have to be stabilized to better than 0.5 K. This is quite routinely achieved at the operating temperatures of 1300 K and over. For materials like lead, barium, and lithium the same flux stability requires a temperature stability better than 0.2 K at operating temperatures around 700 K. Normal effusion cells are designed with extensive Ta shielding in order to minimize heat loses and can be therefore poorly stabilized at low temperatures. For this purpose specially designed low temperature effusion cells have to be used which allow radiative cooling and still maintain temperature uniformity over the whole volume. Potassium and sodium are two materials which are not suitable for the evaporation from effusion cells. There are many reasons for that: (1) The required temperature stability and uniformity would have

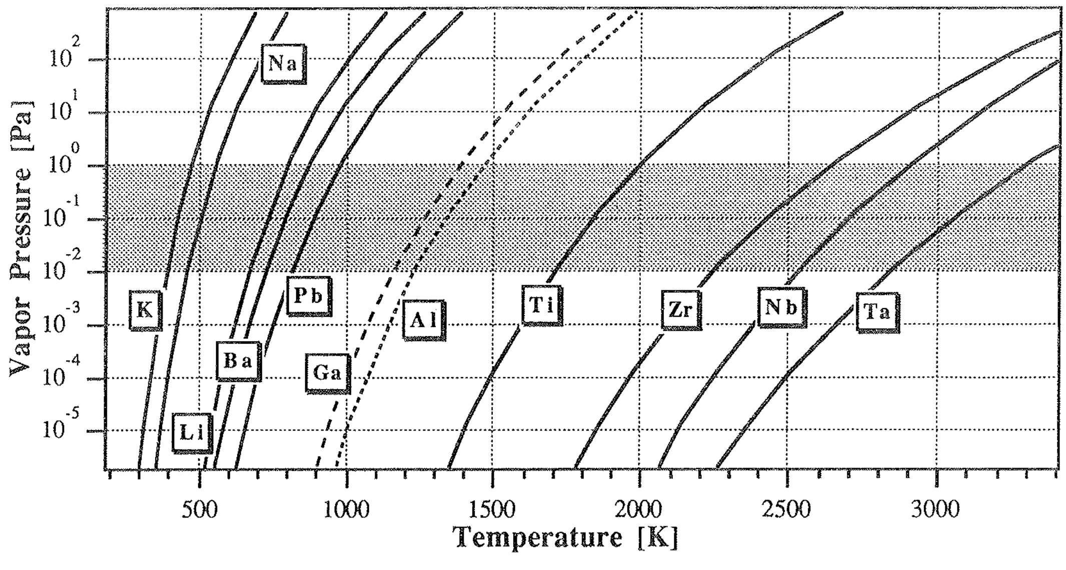

Fig. 3: Vapor pressure data of selected components of ABO_3 ferroelectric materials and Ga and Al. The shaded area shows the desired range of beam pressures which facilitate a growth rate in the range of 0.1 nm/s.

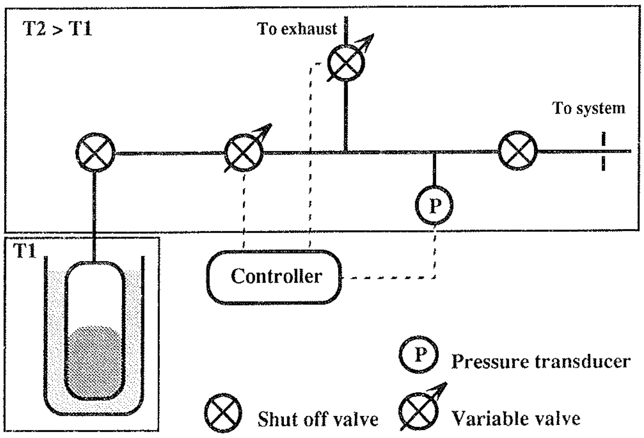

Fig. 4: External source useful for the high vapor pressure materials with active pressure control in front of the system orifice.

to be better than 0.1 K. (2) The operating temperature would be too low to achieve the required control parameters. (3) Due to the high vapor pressure already at the room temperature the materials would evaporate steadily until the depletion of the source, causing a high potassium background pressure (cooling of the source when not in use is not an option because this would condense also unwanted impurities on the source walls and on the material itself which would volatilize upon the warm up). (4) The conditioning of the chamber at high temperatures (normally around 500 K) in order to achieve UHV conditions would be impossible for it would result in total exhaustion of the material from the source. Figure 4 shows a feasible way of obtaining controlled and stable fluxes of materials like potassium and sodium. It consists of an ampoule containing the desired material which is placed externally in a thermally stabilized bath. The material is guided to the system through a thermalized tube which ends with an orifice. The ampoule is isolated from the vacuum system by a valve. System can be either temperature controlled or combine temperature and pressure control. Two pressure controlled valves control pressure in front of the orifice by admitting more material from the ampoule when the pressure has dropped or by removing excess material through an exhaust line when the pressure has exceeded the desired value. Without this valve the excess pressure would have to be relieved through the front orifice which would result in a slowly reacting control system. The latter, more sophisticated approach, has a potential of achieving very stable fluxes even at the non equilibrium evaporation of the material.

2.2.2 "B" component sources

The transition metals have a low vapor pressure and are, with the exemption of maybe titanium, not suitable for the evaporation from classical effusion cells. These materials can be evaporated from e-beam evaporators which heat a small amount of material with a high current electron beam. E-beam evaporators have been successfully used for the production of optical metallic coatings where flux stability and thickness control on the monolayer scale are not important. For these applications sources run normally at a constant power level and are shuttered off once a desired film thickness has been achieved. The evaporation times are short so that long term stability is not a problem. Application of such a source to an MBE process with three to four orders of magnitude lower beam densities and hours, instead of minutes or seconds, long evaporation times is therefore not straightforward. The constant power approach proves to be useless due to long term drifting problems. In order to be used in MBE these sources require an active control loop which regulates the supplied heating power according to the changes in flux. In order to maintain controlled and stable deposition conditions the fluctuations of the flux in MBE should be on an average maintained within one to a few percent of the controlled value. Achieving this at the deposition rates of 0.01 nm/s is a real technological challenge. Three different control

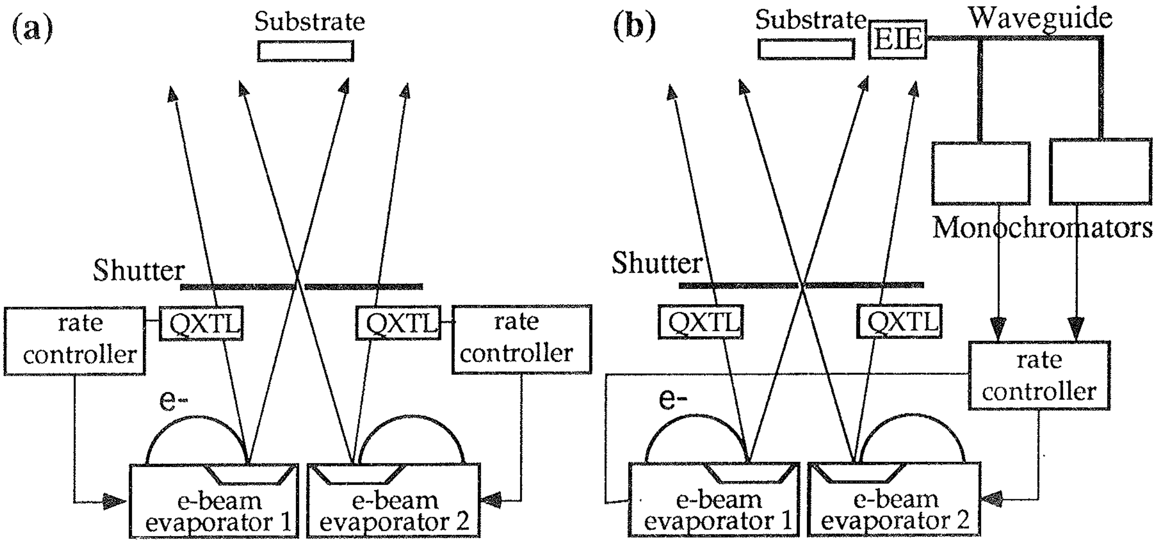

Fig. 5: Configuration of an active flux control system; (a) with quartz crystal oscillator, (b) with EIES.

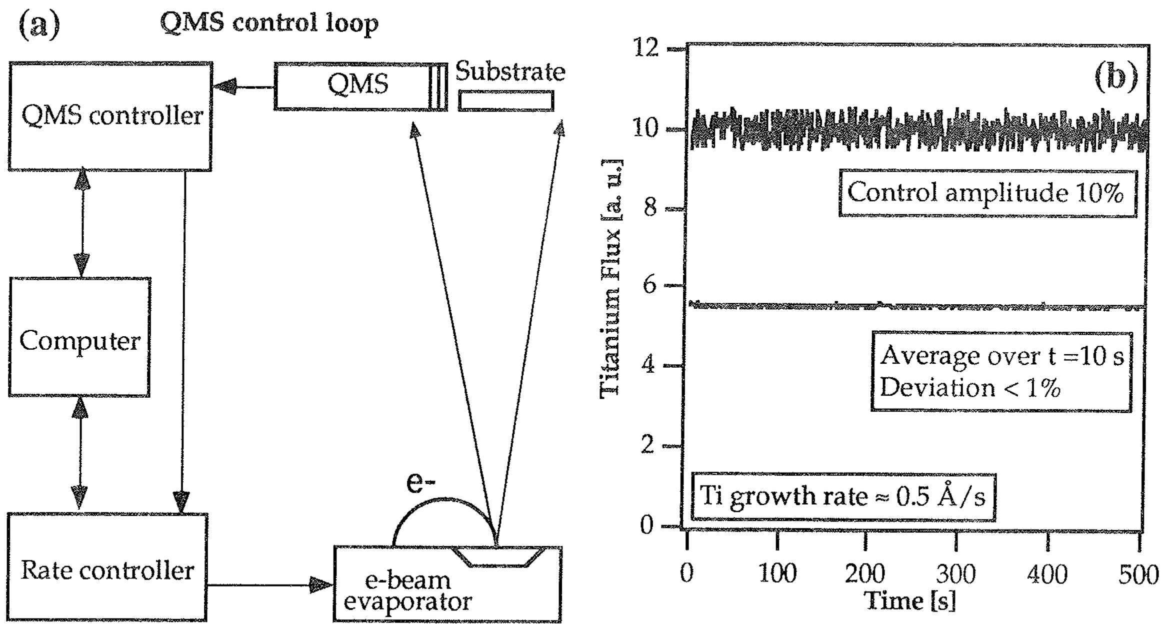

Fig. 6: Schematic of the principle of the flux control by QMS (a) , and the measured Ti flux stability after the optimization of control parameters (b).

systems have been developed whose main difference is in the flux sensing device. The simplest and the least expensive variant is based on quartz crystal (QXTL) deposition rate monitors which sense the mass deposited on the crystal through the oscillation frequency change. In order to be able to control and stabilize the flux already before the shutter is opened they have to be positioned so that they see unperturbed flux of material all the time. The accuracy of such a system can be increased if the crystals are placed closer to the material sources where the flux density is higher. Such systems have been used relatively successfully but they have a few major shortcomings; they are heat sensitive (the problem increases with the proximity to evaporators), they have a relatively short lifetime (for the replacement of the quartz crystals the whole deposition system has to be exposed to the atmosphere), they are deposition rather than flux monitors, each e-beam evaporator requires its own quartz crystal monitor. Figure 5(a) shows a typical setup with two quartz monitors. A typical rate control resolution achieved by such a system is 0.02 nm/s.

The second control system uses an electron impact emission spectrometer (EIES) as the flux sensing device. It measures the characteristic light which atoms emit when being struck by electrons. In contrast to a quartz deposition monitor this is a real flux measuring device. The measuring head is placed close to the substrate and is not heat sensitive or of a deposit dependent lifetime. Commercial systems can control up to two e-beam evaporators with a rate control resolution of 0.01 nm/s (Leybold's specification). A schematic of a setup employing EIES is shown in Figure 5(b).

Both previous approaches have been developed for the alloy deposition control for a standard evaporation process and have been transferred to the UHV technology. The control system based on a quadrupole mass spectrometer (QMS) has been developed specifically for the UHV processes with low evaporation rates in mind. In order to prevent contamination by the direct flux the QMS has to be shielded and equipped with a cross-beam ionizer, which efficiently ionizes species flying orthogonal to the axis of the spectrometer. The operation principle is quite simple; a QMS scans over a desired number of masses and sends respective mass intensity signals to a computer or directly to a controller which controls the evaporator's power supply. A schematic of an experimental setup is shown in Figure 6(a). The control frequency is typically 100 Hz for a single mass and decreases with the number of controlled sources. A typical control amplitude at a deposition rate of 0.01 nm/s lays around 10% but the average over a few seconds shows a deviation of under one percent. Such a setup controls well even the flux of tantalum, as shown in Figure 6(b), that is a difficult material to evaporate.

Table I. Comparison of the three flux control systems at a glance. Data and specifications have been taken from respective manufacturer's catalogues.

Control system	QXTL	EIES	QMS
Manufacturer	Leybold	Leybold	Balzers
Lowest controllable rate [nm/s]	0.01	0.01	0.005
Control deviation at 0.01nm/s [%]	10	10	1
Control frequency [Hz]	4	8	100
Lowest measurable rate [nm/s]	0.02	0.0003 (Cu)	0.0000005

2.2.3. Oxygen sources

The limiting factor for the growth rate of the oxidic materials in an MBE environment is the oxidation process. Molecular oxygen is normally not sufficiently reactive and does not lead to a complete oxidation even at very low growth rates. Thin films grown under a flux of molecular oxygen have to be post growth annealed. This action cancels the benefit of the low temperature processing offered by MBE. However, the amount of active oxidizing species can not be increased as easily as the flux of metals. A higher reactivity under UHV conditions can be achieved by the use of ozone or atomic oxygen.

Ozone has been successfully used for the growth of thin film high temperature superconductors. It is produced by passing O_2 through an electrical discharge followed by the separation of O_3 from O_2 in an LN_2 cooled container. Since ozone is toxic and liquid ozone explosive only a small amount of liquid (a few ml) is produced just prior to growth/4/. The hazard can be reduced significantly by adsorbing ozone into silica gel /5/ and then slowly releasing it. In this manner it can be stored over a week without significant deterioration. As found by many researchers, ozone offers significant improvements in oxidation capability over molecular oxygen, however, due to its hazard many people have been reluctant to use it.

For the use of plasma sources in an MBE environment the main challenge is to produce a sustained and stable plasma at low pressures (< 10^{-2} Pa) governed by the line of sight process. In the past few years two different plasma sources have been developed for the application in MBE, a radio frequency (rf) radical source and a microwave electron cyclotron resonance (ECR) source. The former produces an rf discharge in a small volume which is maintained at a higher pressure than the rest of the deposition system. The active species are allowed to exit through several capillary holes. The upper limit for the cracking efficiency of this source has been estimated to be about 30%, /6/.

The ECR source creates a plasma through magnetic confinement of electrons. In this manner a stable plasma can be achieved at pressures even as low as 10^{-3} Pa, /7/. Because of this the source does not require an aperture which would impede the exit of active species. This type of source has been successfully used for the growth of nitrides and oxides, / 8/.

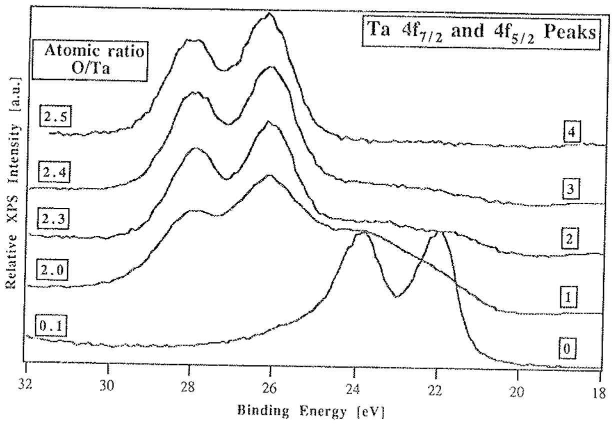

Fig. 7: XPS spectra taken from different samples exhibiting various degrees of oxidation of tantalum. Spectrum "0" - Ta, spectrum "4" -

To better understand the difference in the oxidation capability in different experimental conditions let us examine Figure 7 which shows the XPS results obtained during the evaporation of tantalum oxide. Pure tantalum exhibits a characteristic XPS 4f doublet peak located at the electron binding energy of 22 eV, as shown in the spectrum "0". In an oxidized state this peak shifts for over 4 eV toward the higher binding energies. As such, one observes four different peaks in a partially oxidized state, two shifted and two unshifted, and only two shifted peaks in fully oxidized samples. In order to determine the degree of oxidation one can simply compare the area under shifted and unshifted peaks. The calculated oxygen/tantalum ratio is given for each case on the left side of Figure 7. The results shown in spectrum "1" were obtained from a film deposited with a flux of molecular oxygen while other spectra represent different degrees of plasma excitation. From these results it is clear that the ECR plasma source plays an important role in the in situ oxidation process.

3. Summary

Molecular beam epitaxy of ferroelectrics can potentially create new thin film materials and enable the research of ferroelectric two dimensional structures. For this purpose it is important to achieve stable growth conditions by the application of suitable sources for different metals. The achievement of complete in-situ oxidation at low growth temperatures is of great importance and can be conveniently achieved by active species produced by a plasma source.

Acknowledgment. Our MBE activity in the field of ferroelectrics is supported by the Swiss Priority Program LESIT.

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Dr.. Z. Sitar,
Dr. F. Gitmans,
Dr. P. Günther
ETH Zürich,
Institute of Quantum Electronics
8093 Zürich, Switzerland, HPT E4
tel. +41 1 633 21 43; fax. + 41 1 633 10 56

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SENSORS: A GREAT CHANCE FOR MICROELECTRONIC TECHNOLOGIES

Roberto Dell'Acqua
MiTeCo, Pavia, Italy

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Keywords: microelectronics, silicon sensors, pressure sensors, position sensors, temperature sensors, acceleration sensors, flow sensors, silicon wafers, sensors on ceramics, thick film technology, thin film technology, micromachining, functional raliability, low cost production, high accuracy

Abstract: During the past few decades, the price of microprocessors has dropped below the cost of sensors that tie the processor to the analog world of pressure, position, temperature, acceleration, flow, and other physical and chemical variables. As result, real time control applications, were hampered by the lack of reliable, accurate , inexpensive, and digitally-compatible sensors. However, in the last years a growing trend in fabricating either micromachined sensors on silicon wafers and thick film sensors on ceramics is appeared. IC production techniques allow manufacturing of inexpensive silicon sensors chips that integrate moving structures with resistive Wheatstone bridges (or sometimes with variable capacitors), laser trimmable resistor networks for calibrations, and even signal processing circuitry. Thick (and sometimes thin) film technology, taking advantage of special materials developed on pourpose, provides extremely rugged physical and chemical sensors at very reasonable prices. In this paper the basic principles of these two technologies, when used for sensors, are recalled and some of the most interesting existing and future devices described. In particular , pressure, acceleration, and gas sensors will be discussed. Even if silicon and thick film sensors seem to be in competition each other, the two technologies should be considered as complementary. Having their own advantages and drawbacks, their choice must be well evaluated taking into account the type of application, the size, the environmental conditions, the performances, and so on. The future need for great amounts of high performance, low cost sensors will be fulfilled only by a perfect understanding and by a clever use of the new sensor-related developments which take place inside these already "old" technologies.

Senzorji: velika priložnost za mikroelektronske tehnologije

Ključne besede: mikroelektronika, senzorji silicijevi, senzorji tlaka, senzorji položaja, senzorji temperature, senzorji pospeška, senzorji pretoka, rezine silicijeve, senzorji na keramiki, tehnologije debeloplastne, tehnologije tankoplastne, obdelava najfinejša, zanesljivost delovanja, proizvodnja cenena, natančnost visoka

Povzetek: Tekom zadnjih nekaj desetletij je cena mikroprocesorjev padla pod ceno senzorjev, ki povezujejo procesor z zunanjim analognim svetom pritiska, položaja, temperature, pospeška, pretoka in drugih fizikalnih in kemičnih spremenljivk. Tako je pomanjkanje zanesljivih, točnih, poceni in digitalno kompatibilnih senzorjev povzročilo zastoj v razvoju elektronskih kontrolnih sistemov v realnem času.
Zadnja leta opažamo naraščajočo potrebo po proizvodnji bodisi mikromehanskih senzorjev na silicijevi rezini, oz. debeloplastnih senzorjev na keramičnih substratih. Tehnologija izdelave integriranih vezij omogoča tudi izdelavo poceni čipov, na katerih so gibljive senzorske mikrostrukture integrirane z Wheatstone-ovimi mostički, oz. včasih s spremenljivimi kondenzatorji, uporovnimi verigami, ki jih lahko lasersko doravnavamo ali z vezji za procesiranje signalov. Debeloplastna in včasih tudi tankoplastna tehnologija, ki izkorišča lastnosti prav za ta namen razvitih materialov, pa nam daje izredno robate fizikalne in kemične senzorje po sprejemljivih cenah.
V tem prispevku opisujemo izdelavo senzorjev z obema tehnologijama, kakor tudi nekaj najbolj zanimivih današnjih in potencialnih bodočih izdelkov. Konkretno pa obravnavamo senzorje pritiska, pospeška in plinske senzorje. Čeprav se na prvi pogled zdi, da so si silicijevi in debeloplastni senzorji konkurenčni, pa je potrebno obe tehnologiji obravnavati kot komplementarni druga drugi. Ob poznavanju njunih dobrih in slabih strani, pa moramo pri izbiri ustreznega senzorja upoštevati namen, fizično velikost, pogoje okolja, njegove delovne lastnosti ipd. Bodoče potrebe po velikih količinah kvalitetnih in cenenih senzorjev bomo lahko zadovoljili le ob ustreznem dobrem razumevanju in uporabi novih tehnoloških dognanj, ki so orientirana k senzorjem znotraj že "starega" področja obstoječih mikroelektronskih in debeloplastnih tehnologij.

INTRODUCTION

Sensor worldwide market is expected to grow, according to a recent survey, from 18.8 B$ in 1991 up to 39.9 B$ in 2001 (see table 1). This represents in terms of turnover a growth around 7 % per year. But taking into account the expected price reductions (at least 50 % in the same period), it means that the number of sensors will increase by a factor 4 in 10 years.

To support either the cost reduction and the production increasing, suitable manufacturing technologies are

Table 1: Worldwide Sensor Market

Year 1991:	B $ 18.8	Year 2001:	B $ 39.9
U.S.A.	34.3 %		34.1 %
Japan	23.6 %		24.3 %
Germany	13.5 %		14.1 %
France	7.1 %		7.0 %
U.K.	5.9 %		5.5 %
Italy	5.7 %		5.5 %
Others	9.9 %		9.5 %

needed. The choice of such technolologies must be well evaluated since sensors are very peculiar components whose electrical, mechanical, and environmental characteristics are probably the most severe of the electronics world. In fact, when talking about sensors, most of the attention is paid to the sensing element itself; this is sometimes misleading since the sensing elements needs also a signal conditioning electronics for the suitable adjustments and a package for the environmental protection. Just to clarify this item, it can be useful to look at the manufacturing cost breakdown of a low-cost micromachined silicon pressure sensor, given in table 2.

Table 2: Micromachined pressure sensor manufacturing cost breakdown

Finished device cost: 6.3 $	
Processed die (sensing element)	5 %
Processing, assembly, and test	30 %
Package	65 %

This cost breakdown indicates that the choice of the silicon die can be debated if a different sensing element, yet more expensive, can be processed and packaged at lower costs. Beyond these considerations, it seems today clear that silicon and thick/thin film technologies can lead, when cleverly used, to very effective solutions in the sensor area.

1. SILICON SENSORS

Silicon has become a synonim for integrated circuits, thanks to its quite spectacular electronic properties that have already lead to the fabrications of several sensors like, for example, speed/position sensors based on Hall Effect. Now its equally amazing mechanical properties, together with a rather recent technique called micromachining, allow to shape silicon into the tiniest electromechanical systems ever built.

Silicon has several advantages for use in sensors; in particular, it has no mechanical hysteresis and is highly sensitive to mechanical stress. Its modulus of elasticity is the same as steel. Silicon is also as hard as quartz, yet less dense than aluminium. Perhaps most important, silicon sensors having tightly controlled submicron geometries can be built and packaged with the same mature process, equipment, and ultrapure materials used for producing high-volumes of integrated circuits.

A number of innovative fabrication techniques have recently been developed specifically for micromechanical structures and they fall into two cathegories: bulk micromachining and surface micromachining.

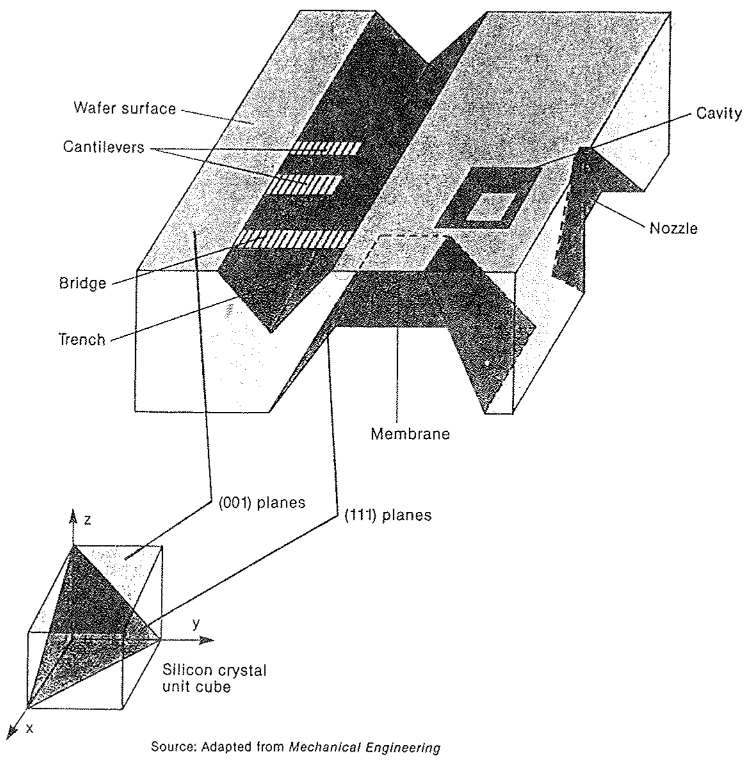
The first involves sculpturing the silicon substrate by means of chemical etchant, and the second etching layers of thin films deposited upon the substrate.

Etching with alkaline solutions, is the key technology for bulk micromachining either isotropic, anisotropic, or a combination of both. In isotropic etching, the etch rate is identical in all the directions, whereas in anisotropic etching (Fig. 1) the etch rate depends on the wafer's crystallographic orientation: an anisotropy ratio of 100/1 is possible in the <100> direction relative to <111> one. Etch process can be made selective by the use of dopants (heavily doped regions etch more slowly), or may even be halted electrochemically (etching stops upon encountering a region of different polarity in a biased p-n junction). The common microelectronic thin film materials as silicon dioxide or silicon nitride can serve to mask the portions of the wafer that are not to be etched.

Bulk micromachining, a proven high-volume production process, is routinely used to fabricate microstructures with crytical dimensions that are precisely determined by the crystal structure of the silicon wafer, by the etch-stop layer thickness, or by the lithographic masking pattern. To obtain complex structures, the ability to bond silicon to glass and silicon to silicon is an important adjunct to bulk micromachining.

In contrast to the bulk technique, surface micromachining does not penetrate the carrier, or handle wafer, as it is called. Instead, the wafer has thin film materials selectively added to and removed from it (Fig. 2). The handle wafer is often used for interface circuitry.

Wet and dry etching techniques and thin film deposition are essential in surface micromachining. Thin films (usually polysilicon, silicon oxide, and nitride) provide sensing elements and electrical interconnections, as well as structural, mask, and sacrificial layers.



Source: Adapted from *Mechanical Engineering*

Fig. 1: Silicon bulk micromachining

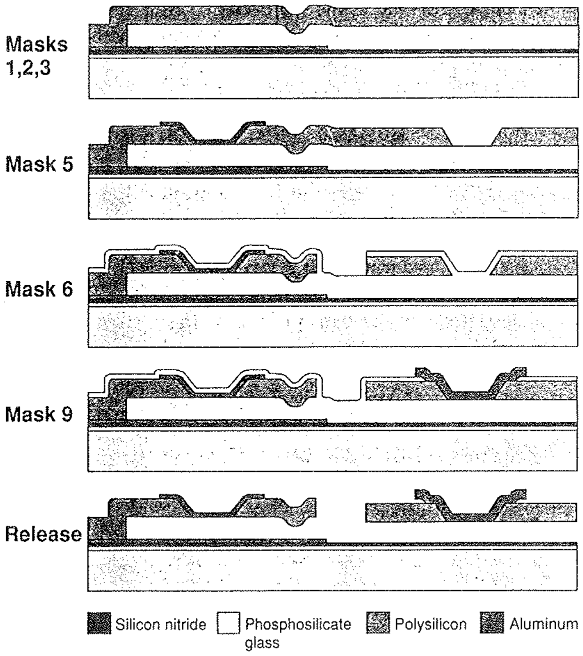


Fig. 2: Silicon surface micromachining: a sacrificial layer is grown or deposited and patterned. Then the mechanical layer is deposited and patterned. Finally the sacrificial layer is etched away to release the mechanical structure.

Sacrificial etching is the basis of surface micromachining. A soluble layer (often silicon dioxide) is grown or deposited for later removal from beneath other patterned materials, usually by wet chemical etching. Since the patterned materials left behind (the released layers) are separated from the substrate or from other surfaces by the thickness of the removed sacrificial layer, they are actually free-standing, thin film mechanical structures. Multiple depositions of structural and sacrificial films, each individually patterned, can build surprisingly complex micromechanical structures. Still there is a limit to the number of layers since each one increases surface roughness, gradually degrading the photolithographic process.

1.1. Silicon Pressure Sensors

Mostly based on bulk micromachining, silicon pressure sensors are produced in very large volumes for several applications. Capacitive and piezoresitive pressure sensors are available, but the piezoresistive device is more popular due to the lower cost.

The process of manufacturing a pressure sensor (Fig.3) begins with a silicon substrate that is polished on both sides. An epitaxial layer is first deposited on the surface of the wafer; the typical thickness of the layer is 15 microns and depends on the required sensitivity of the pressure sensor.

Boron-doped piezoresistors and both p+ and n+ enhancement regions are introduced by means of diffusion and ion implantation. Because their resistances vary with stress, piezoresistors are the sensing elements in pressure and acceleration sensors. A thin layer of deposited alluminium or other conductors creates the ohmic contacts and connects the piezoresistors into a Wheatstone bridge. Finally, the device side of the wafer is protected and the back is patterned to allow formation of an anisotropically etched diaphragm. After stripping and cleaning , the wafer is anodically bonded to Pyrex and finally diced.

The anodic bonding is a process that requires a high voltage of 1500 V between the two parts to be bonded and a temperature of 400 degrees centigrade; an alternative to silicon-Pyrex bonding is given by the silicon-to-silicon fusion, a high temperature process which fuses silicon wafers together at the atomic level without a "glue" layer or an applied electric field.

In most cases, silicon pressure sensor dice are unusable without signal processing circuitry and adequate packaging. The bridge output signal must be amplified and several adjustments and thermal compensations are needed to obtain the proper output characteristics. The

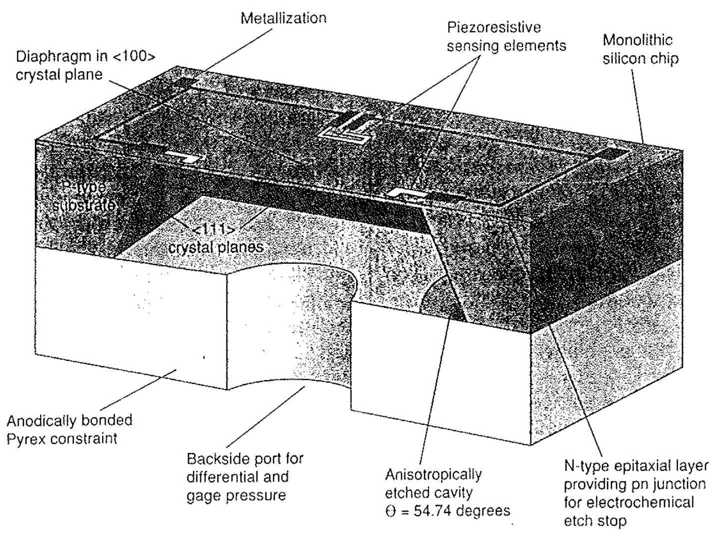


Fig. 3: A bulk micromachined pressure sensors with the thin silicon diaphragm; its deflection depends on the pressure and it is sensed by the piezoresistors.

die attach is a crucial step since mechanical stresses can be induced into the chip; moreover, the chip cannot be directly exposed to the environment since it could be damaged by corrosive media.

Due to the difficulty found in putting together the micromachining and the IC manufacturing processes, most of the today silicon sensors are produced by mounting the silicon sensor die on a ceramic substrate where the signal conditioning electronics is implemented. On the other side, the market shows also a strong demand for entirely monolithic solutions that can lead to:

- remarkable miniaturisation
- reduced cost for high volumes
- better performances due to the fact that the sensor and the relevant circuitry are on the same subtsrate.

However, the monolithic pressure sensor has still several limitations when operating in tough environmental conditions and a rather high cost mainly due to low production yields. Instead, the monolithic sensor is widely used when the small size and the need for an amplified signal are mandatory.

In fig. 4 it is shown, for example, a pressure/temperature integrated sensor produced by Ascom Microelectronics (now Micronas) in Switzerland and used to build a catheter for medical applications. On the die (1 by 5 mm in size) a pressure and temperature sensor are located together with a voltage reference and the amplifier. The thermal compensation is provided via software by the computer to which the output of the sensor is directly connected.

1.2. Silicon Accelerometer

Even if the feasibility of silicon accelerometers have already been demonstrated several years ago, their mass production is starting just now under the push of automotive industry which needs them for active suspension control and air-bag deployment. These applications require only intermediate performances but very high reliability and low cost. Both bulk and surface micromachining seem to be suitable for high volume production of silicon accelerometers.

1.2.1 Bulk-micromachined Accelerometers

A typical design incorporates a bulk-micromachined silicon mass (called proof mass) suspended by silicon beams (Fig. 5).

Ion-implanted piezoresistors on the suspension beams, sense the motion of the proof mass produced by acceleration. Even here, as in the case of pressure sensors, a temperature compensation, mainly due to the implanted piezoresistors, is needed. The compensation is usually performed by mounting the sensor chip on a ceramic board, by connecting it with a proper circuitry, and by actively or passively trim suitable thick film resistors.

For high precision applications, such as inertial navigation, high-quality silicon accelerometers are needed. In this case, the preferred mean for detecting movement of the proof mass is a change in capacitance. In some design, capacitor plates on top and bottom capping wafers (the two wafers that enclose the proof mass) also apply a restoring elettrostatic force to the mass to null

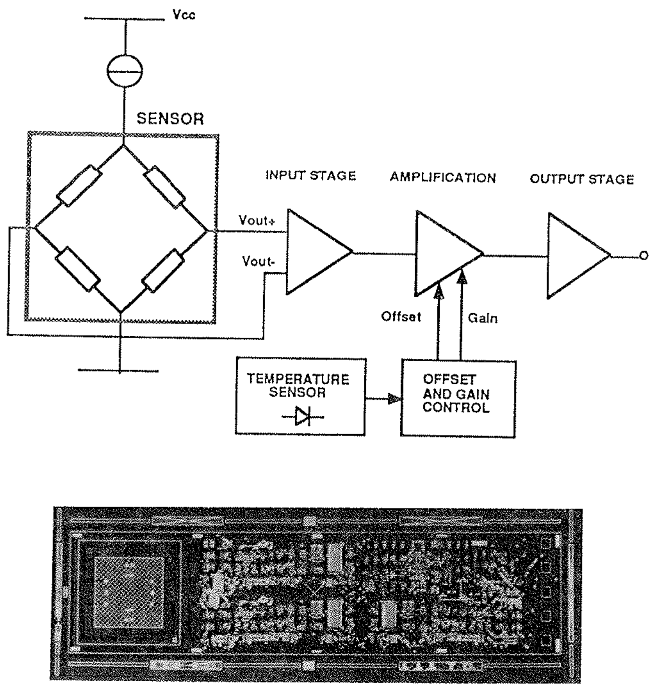


Fig. 4: Block diagram and layout of a monolithic pressure and temperature sensor (Ascom Microelectronics)

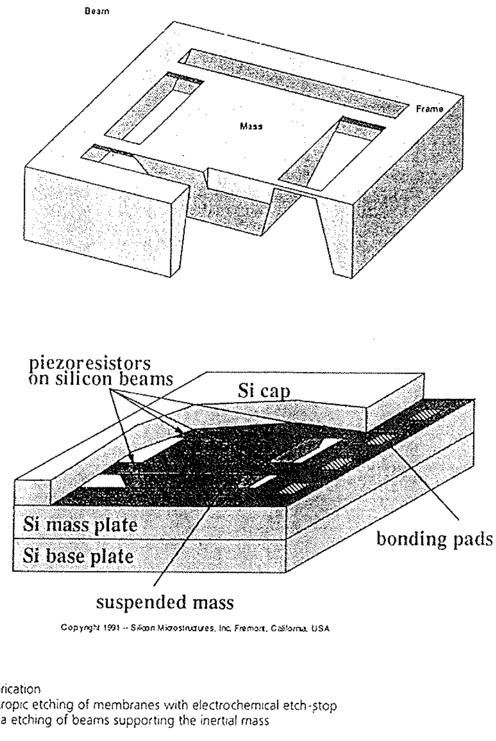
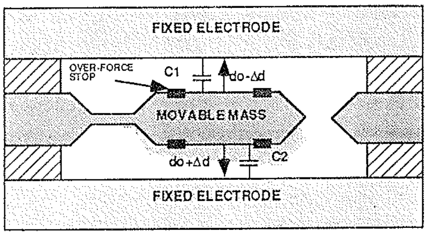


Fig. 5: Structure of a piezoresistive accelerometer.



$$\frac{C_1 - C_2}{C_1 + C_2} = \frac{\Delta d}{d_o}$$

Fig. 6: *Structure of a capacitive accelerometer*

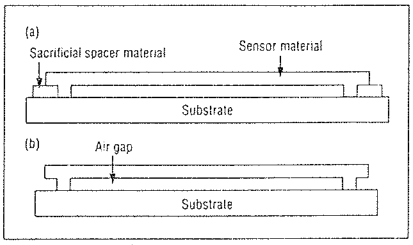
its displacement, offering improved reliability and dynamic range over "open loop" devices (Fig. 6).

1.2.2. Surface-micromachined Accelerometers

A fully integrated surface-micromachined accelerometer developed for air-bag deployment, with a range of 50 g, has been recently presented by Analog Devices (Fig.7).

A 3 by 3 mm, 3-microns minimum feature size BiCMOS chip contains a micromachined polysilicon sensing element and complete circuitry, including a self test function.

Unlike bulk-micromachining, where substrate silicon comprises the sensing element, surface-micromachining utilizes deposited films, such as polysilicon, silicon nitride, and nickel. The simple fixed-beam spring design used in the accelerometer necessitates tight control of



Surface micromachining (a) with sacrificial layer (b) after sacrificial layer removal.

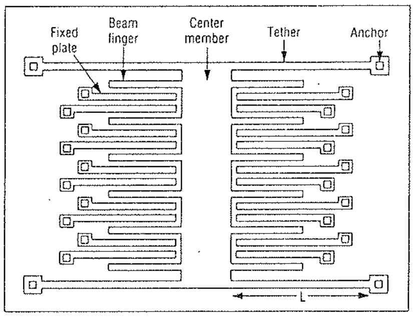


Fig. 8: *Simplified view of sensor geometry*

the intrinsic stress present in the polysilicon film. The center member and movable capacitor plates (or beam fingers) are suspended by four springs or tethers (Fig. 8). Fixed capacitor plates are interspersed between the beam fingers (Fig. 9). When subjected to an acceleration, the proof mass (center member and attached fingers) move while the fixed plates remain stationary. The separation between the plates and beam fingers therefore changes. Each set of fingers and fixed plates comprises a parallel plate capacitor with the air gap as the dielectric: therefore, the capacitance changes as this gap varies.

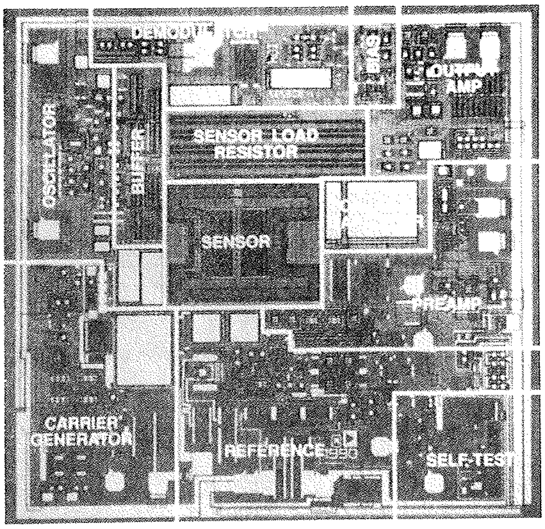


Fig. 7: *The Analog Devices accelerometer*

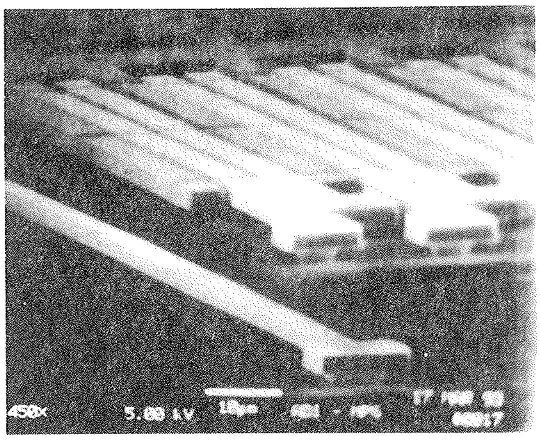


Fig. 9: *Magnified view of tether and fixed plate anchors of polysilicon*

The manufacturing process of the sensor and of the relevant circuitry, that also includes thin film resistors for functional trimming, is rather complex (it needs more than 25 masking steps) but it leads to a device which could represent a turning point in low cost accelerometer manufacturing.

2. THICK FILM SENSORS

Thick film sensors are based on the outsdanding properties of several different materials developed on purpose and deposited on suitable substrates by screen printing techniques. The intrinsic simplicity of manufacturing process, the increasing availability of new sensing materials, the possibility of using many kinds of substrates (including cofired multilayer ceramics) have already lead to the implementation of temperature, pressure, force, acceleration, displacement, oxygen, gas, humudity sensors, and so on. The achievable integration and miniaturisation are those typical of hybrid circuits.

The most important features of thick film sensors are the very high flexibility, the low development cost and time, the easy handling, the low investment cost, and the exceptional environmental behaviour. When needed and possible, the signal conditioning electronics can be implemented on the sensor substrate by adding to the passive thick film sensor network the suitable semiconductor dice to complete the circuitry. This can be done in a very short time by using standard ICs thus greatly reducing the time to market. Of course, incidental design changes can be quickly performed and the functional trimming of the whole circuit can easily taylor the sensor parameters to the customer requirements.

Generally speaking, the cost of a thick film sensing element is higher than that of the equivalent silicon device, at least for very high volumes, but it becomes very competitive for medium and low volumes.

An other interesting feature which gives some bonus to thick film sensors is the environmental behaviour. Usually, they are less affected by temperature and poisoning media thus offering a better global reliability. To emphasize and possibly better explain the above mentioned concepts, a few examples are given below.

2.1. Ceramic Thick Film Pressure Sensors

The classical structures of a thick film capacitive and of a piezoresistive pressure sensor are shown in fig. 10.

In both cases a thin (how thin depends on the pressure to be measured) ceramic diaphragm is bonded by means of a suitable screen printed glass to a robust baseplate. In the case of the capacitive device, two metal layers are previously printed on the diaphragm and on the baseplate to form a capacitor; in the case of piezoresistive sensors, four thick film resistors, connected into a Wheatstone bridge configuration, are deposited in the points of diaphragm maximum deflection, thus maximizing the bridge unbalancing when deformated.

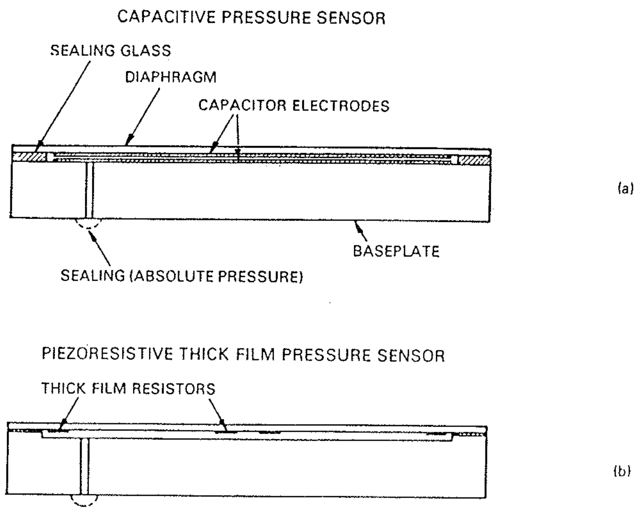


Fig. 10: Structure of thick film pressure sensors: (a) capacitive, (b) piezoresistive

The electrical contacts between the diaphragm and the signal conditioning electronics, usually located on the back of the baseplate, are obtained by means of metallized through holes (Fig. 11).

Either capacitive and piezoresistive thick film pressure sensors have been produced in very large volumes during the last 15 years fulfilling the requirements of a wide variety of applications like automotive, medical, industrial, aerospace.

The overall accuracy, usually better than that of silicon, the linearity, the insensitivity to most of the dirty media have been their strong points.

The size of the ceramic sensing element is larger than that of silicon chips and usually ranges from 15 mm up to 40 mm in diameter (silicon chips are ranging from 1 by 1 mm up to 5 by 5 mm). If this fact makes the ceramic sensors unusable for certain applications, on the other side it allows a much easier handling. It should also be

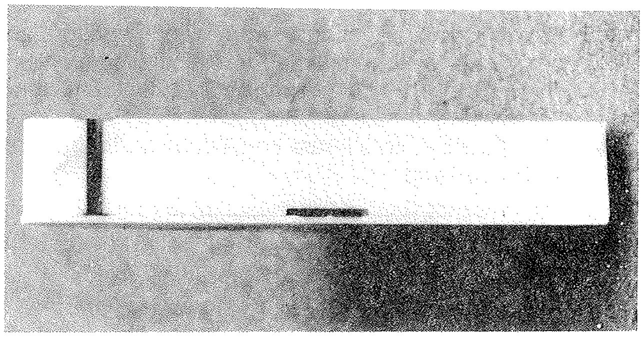


Fig. 11: Cross section of a ceramic piezoresistive pressure sensor

noted that in most cases the dimension of the finished sensor depends mainly on the packaging and on the signal conditioning electronics size.

Unfortunately, the cost of the ceramic structure above described is much higher (five to ten times) than that of the silicon pressure sensor chip. On the other side, processing and assembly of thick film sensors as well as their packaging (when the medium to be measured is air) are slightly less expensive than those of silicon devices.

In fact, even if the gauge factor of thick film resistors is lower (15 versus 50) than that of silicon, thus leading to a lower sensitivity, the better temperature coefficient of resistance (50 versus 1500) and of gauge factor (200 versus 2000) allow a simpler signal conditioning electronics and an easier functional adjustment. When the pressure of dirty or wet media must be measured, the package of the thick film sensor remains inexpensive (Fig. 12), while the silicon sensor needs usually a very expensive protection.

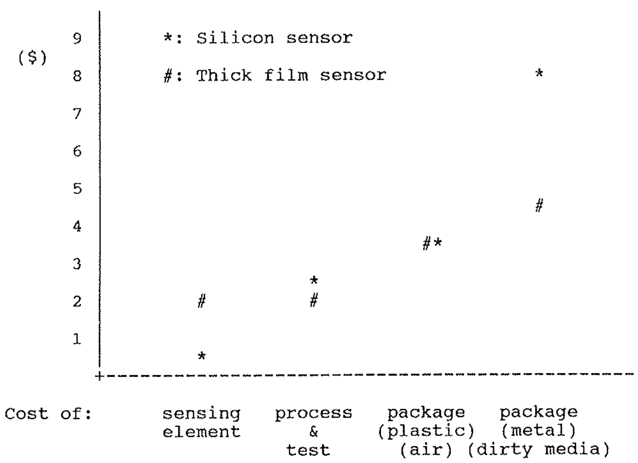


Fig. 12: Manufacturing cost breakdown comparison between silicon and thick film pressure sensors (hig volume production)

2.1.1. Trends in Piezoresistive Pressure Sensors

There are several applications where silicon sensors are not economically and sometimes technically convenient. This is the reason why a lot of space still exists for the thick film piezioresistive sensor technology evolution. This evolution is based either on a better knowledge and reputation of these devices and:

- on the improvement of the thick film resistive compositions in terms of gauge factor, noise, and long term stability
- on the use of different types of substrate.

Partially stabilized zirconia, for example, with a flexural strength three times higher than that of alumina, can broaden the pressure range already covered either towards the low and the high pressures.

High precision hot pressed ceramic parts with a built in cavity/diaphragm will greatly simplify the sensor structure. High and low temperature green tape multilayers can be also used to reduce the costs.

Most likely, the next thick film pressure sensor generation, shown in fig. 13, will considerably reduce the price gap with the silicon sensors, where it exists, still mantaining the today outstanding performances.

2.2 Ceramic Thick Film Accelerometers

The rather low sensitivity of thick film piezoresistors and the fragility of ceramics have restrained the development of such devices. However, the intrinsically high cost of silicon accelerometers can leave a lot of room to intermediate performance thick film accelerometers. For example, a ceramic cantilever type thick film accelerometer has been produced since 1987 by Magneti Marelli, Italy, for suspension control of Lancia cars.

2.3. Ceramic Thick Film Gas Sensors

Thick film technology seems particularly suitable for gas sensing. The very tough environmental conditions, the long term stability requirements, the low production costs can be usually met with ceramic-based thick film devices. A lot of research and development activity has been carried out in the past ten year on the gas sensors since the existing ones were expensive and sometimes unreliable. One of the most interesting works in this area is tied to the exhaust gas sensor used on cars to control the air/fuel ratio in fuel injection systems. The classical structure is, in this case, a thimble-shaped zirconia solid electrolyte cell, obeying the Nerst law. As the requirements became more stringent, planar solutions based either on a multilayer ceramic structure and on full thick film structure have been developed, reproducing and improving the Nerst cell, that will be soon on the market. Since a lot of literature exist on this matter, it is probably most interesting to look at an other very interesting device.

2.3.1. Thick Film Methane Sensor

Gas sensing properties of semiconductor oxides films, like ZnO and SnO_2, are well known since a long time and in fact, SnO_2 sensors have been available for more than 20 years.

The basic mechanism that gives these oxides their sensitivity to reducing gases is well known: the reduction of their surface makes electrons available for electrical conduction and causes the electrical resistance of oxide to decrease.

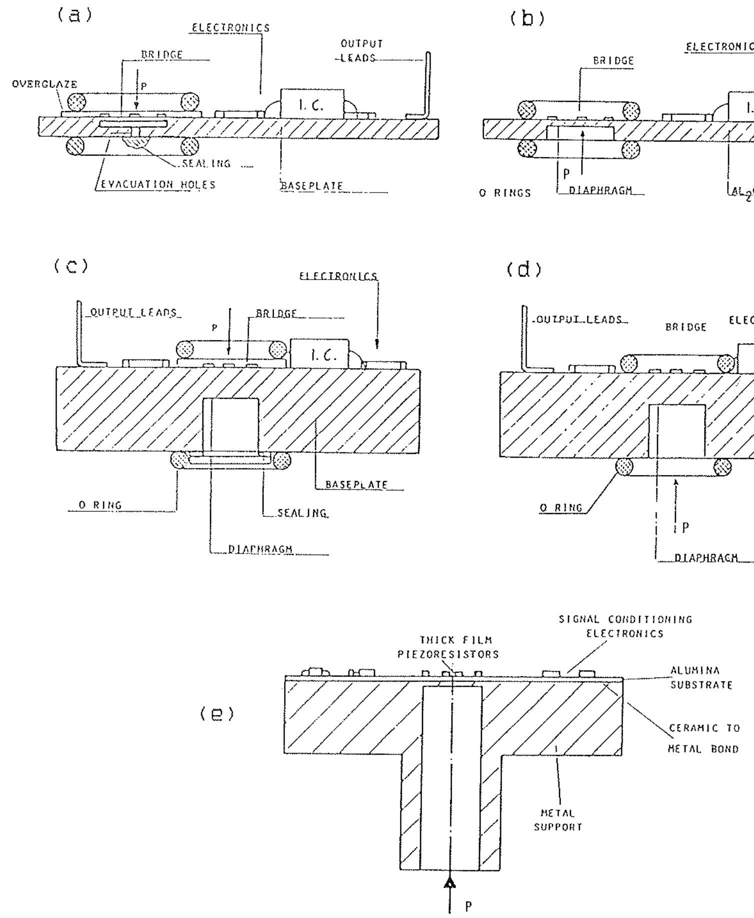


Fig. 13: *Possible configurations of thick film pressure sensors: (a) low pressure, absolute; (b) low pressure, gage; (c) high pressure, absolute; (d) high pressure, gage; (e) very high pressure (metal/ceramic diaphragm).*

Gas sensors generally consist of a mixture of SnO_2 and electrically inert oxides as Al_2O_3 and SiO_2 with some noble metals acting as catalyst. Usually the properties of gas sensors depend very strongly on composition and preparation conditions.

Characteristic features for a sensor to detect fuel gas leakage are:

- reliable detection of the alarm threshold concentration, independence from the history of the sensor and in particular of previous exposures to other gases;
- selectivity versus the main interfering gases possibly present in the same environment (a false alarm produces disregarding the true danger signal);
- high reliability in terms of working life.

To fulfil these requirements, not always fully satisfied by the today available sensors (one of wich produced by Figaro, Japan, is shown in fig. 14), ENIRICERCHE S.p.A., Italy, has chosen as manufacturing technique the thick film on ceramic approach which also provides high reproducibility and low production costs.

Screen printing can be used both for sensing and for heating elements, with possibility of array integration of smart sensors.

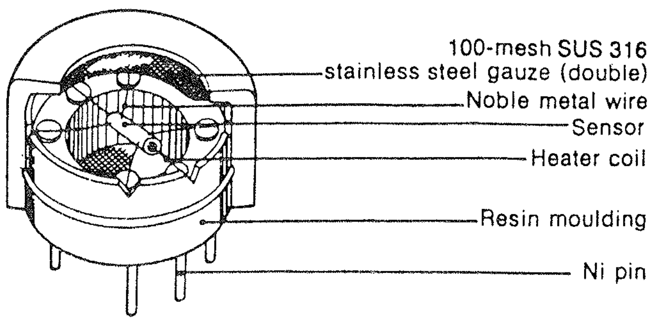


Fig. 14: *Configuration of the Figaro gas sensor: the sensing material is deposited on a ceramic cylinder and heated by a coil.*

The material for the sensing element is a blend of tin and aluminium oxides with dispersed catalyst which is screen printed on a ceramic substrate. The heater is a resistive platinum stripe printed on the other side of the ceramics. The material chosen for the sensing element exhibits high sensitivity to methane at an operating temperature around 500 degrees centigrade (Fig. 15).

Fig. 15 displays sensitivity versus operating temperature curves for the following gases: CH_4, CO, NH_3, C_2H_5OH, and CH_3COCH_3. The concentrations for the interfering gases are the highest expected in a home environment.

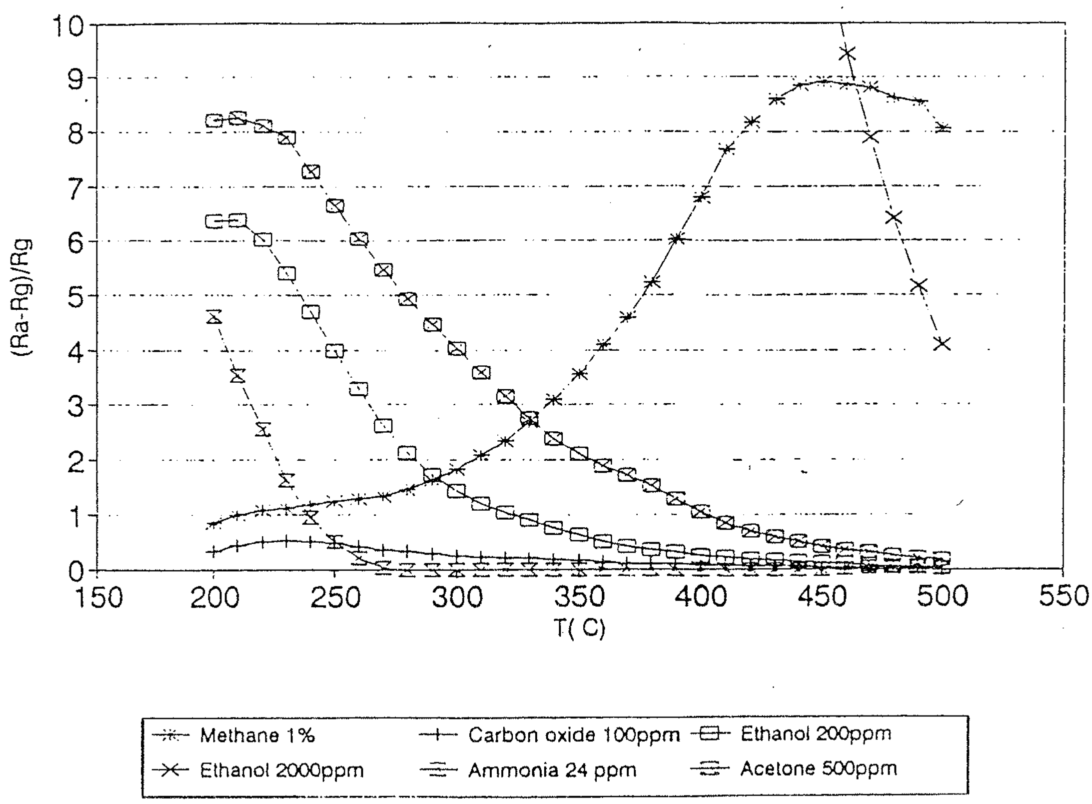


Fig. 15: *Sensitivity vs temperature to methane and interfering gases of the ENIRICERCHE gas sensor. The sensitivity is given as (Ra-Rg)/Rg, where Ra is the resistance of the sensing element in air and Rg its resistance in an atmosphere with the selected methane concentration.*

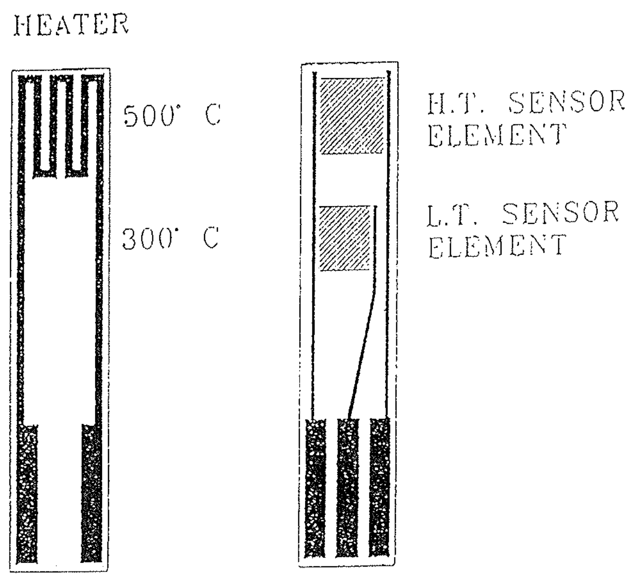


Fig. 16: *Layout of the ENIRICERCHE methane thick film sensor*

As shown, the sensitivity to methane is the highest at high sensor temperature while the highest sensitivity to the interfering gases occurs at low temperatures. An improvement of the selectivity against high concentration of interfering gases is obtained through comparison of measurements taken at different temperatures, e.g. 300 and 500 centigrades.

The comparison is easily done taking advantage of a simple arrangement integrating two sensing elements on the same substrate: the pattern of the heater has been designed so that the two elements are heated at two different temperatures (Fig. 15).

CONCLUSIONS

The increasing demand for real time electronic control systems drives the growth of the sensor market and the improvement of their features.

Very large volumes are already demanded in automotive, industrial, medical, safety, and home appliance field.

Since the volume request already exists, silicon and thick/thin film technologies can show at least their potentiality. The need for higher accuracy, reliability, and lower cost can be fulfilled by their proper and clever use. The few examples given in the paper, show that these two technologies have their own advantages and drawbacks; they should be very well understood and evaluated by sensor designers.

Silicon micromachining and the integration of signal conditioning electronics on the same chip offer incredible chances for several applications and when very high volumes are involved.

Silicon micromachined devices mounted on ceramic hybrids can represent the fastet approach to the market with still reasonable cost for several types of sensors.

Thick film technology seems particularly suitable and economical for very hard working conditions sensors.

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R. Dell'Acqua
MiTeCo
Corso Cairoli 96,
27100 Pavia, Italy
tel. /fax+ 39 382 27376

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DISTANCE MEASUREMENTS USING OPTICAL FIBER SENSORS

Alojz Suhadolnik
University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

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Keywords: distance measurements, resolution < 1 μm, optical fiber sensors, displacement sensors, distance changes, intensity modulation, phase modulation, light beams, optical sensors, fiber optic reflection sensors, interferometric sensors, PMMA = Polymethil methacrylat, multimode optical fibers, monomode opticals fibers, Mach-Zehnder interferometers, Michelson interferometers, Fabry Perot interferometers

Abstract: Optical fiber sensors are widely used as displacement and distance probes. The intensity and phase modulation of the light beam is used in this technique to measure small distance changes. Several types of the fiber optic reflection and interferometric sensors were developed for those purposes. The fiber optic reflection sensors are simple in construction and are capable to measure the distances in submicrometer range. In this contribution the fiber optic reflection sensors and interferometer are described.

Meritev razdalje z uporabo senzorjev z optičnimi vlakni

Ključne besede: merjenje razdalje, ločljivost < 1μm, senzorji z vlakni optičnimi. senzorji premikov, sprememba razdalje, modulacija intenzivnostna, modulacija fazna, žarki svetlobni, senzorji optični, senzorji refleksije z vlakni optičnimi, senzorji interferometrični, PMMA polimetil metakrilat, vlakna optična večrodovna, vlakna optična enorodovna, Mach-Zehnder interferometri, Michelson interferometri, Fabry-Perot interferometri

Povzetek: Senzorji z optičnimi vlakni se v merilni tehniki uveljavljajo tudi na področju merjenja pomikov in določanja položaja. Pri meritvah majhnih pomikov s pomočjo svetlobe se uporabljajo predvsem intenzitetno in fazno modulirani senzorji. V ta namen je bilo razvitih več senzorjev z optičnimi vlakni na podlagi odboja svetlobe in interference. Odbojnostni senzor z optičnimi vlakni, ki je namenjen določanju razdalj, lahko meri pomike v območju pod mikrometrom. Z interferometrom, sestavljenim iz optičnih vlaken, pa lahko merimo še manjše pomike. V tem članku so prikazani odbojnostni in interferometrski senzorji z optičnimi vlakni za merjenje majhnih pomikov.

1. INTRODUCTION

In recent years, several fiber optic displacement sensor schemes have been suggested /1/. Most fiber optic displacement sensors are based on intensity or phase modulation of light. Those sensors can be used in many other applications as the surface finish sensor /2/, the pressure sensor /3/, and others. We developed the fiber optic refractive index sensor /4/, the fiber optic microphone /5/, and the surface pattern sensor /6/, on the base of the reflective fiber optic displacement sensors. We also developed the vibration and refractive index sensor /7/, which base on the interferometric displacement sensor.

In this paper some of the fiber optic displacement sensors are described. Basic characteristics and principles of operation are shown. This type of sensors has advantages in noncontact and remote measurements, with high resolution. They can be applied inside electromagnetic fields and explosive environments where other sensors are not usable. The optical fiber reflection sensors are simple in construction and are not sensitive to external influences if compensation technique is used /8/. On the other hand the fiber optic interferometers enable high accuracy in measuring the distances, smaller than the light wavelength.

2. INTENSITY MODULATED FIBER OPTIC DISTANCE SENSORS

Several types of the fiber optic intensity based displacement sensors have been developed. Two different configurations are possible with this sensors. In the first configuration, the light beam from LED or LD is launched into the input fiber. The input fiber delivers light through the Y coupler to the sensor tip. The light is coupled out of the fiber and reflected at the moving mirror. Part of the reflected light is captured by the same fiber and returned to the Y coupler. One part of the light travels back to the light source and the second part to the detector. The described sensor is shown on Fig. 1a.

The second configuration includes two fibers, where the first is the input fiber and delivers the light to the mirror. The reflected light is captured by the output fiber and the receiving diode. This configuration is presented on Fig. 1b. The sensor performance can be enhanced by ano-

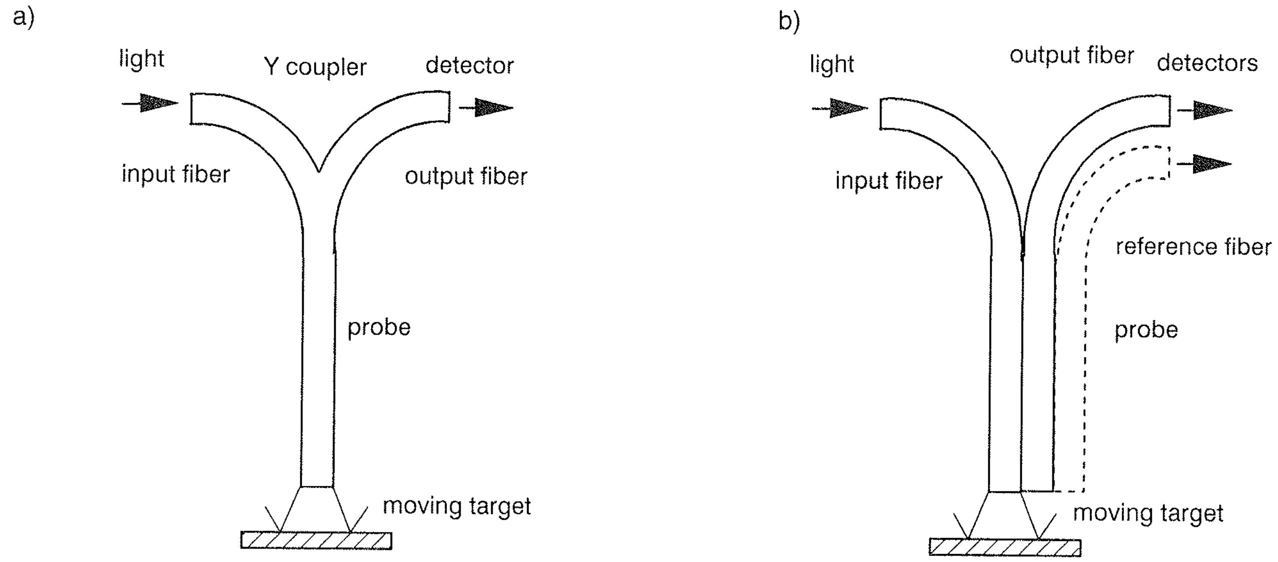

Fig. 1: Reflective fiber optic sensors including a) Y coupler and b) two fibers.

ther output fiber which is added parallel to previous one (dashed lines in Fig. 2b). The output fibers guide the light to separate receivers. By measuring the ratio of both outputs, the light source intensity variations, reflectivity of the mirror, opacity of the transmitting medium as well as light bending losses can be eliminated /8/. The bending losses can be neglected if both output fibers are in close contact and have equal curvature radius.

Different types of optical fibers were used. The standard monomode and multimode telecommunication silica fibers, and multimode fibers made of polymethyl methacrylate (PMMA) were used. The core diameter was 9 μm for the monomode silica fiber, 50 μm for the multimode silica fiber and 1 mm in case of PMMA fiber. The output characteristics for monomode and multimode silica fibers are shown on Fig. 2a. Both sensors employ Y coupler. The monomode optical fiber probe has better sensitivity than the multimode and enables the measurement of the displacement with resolution below 1 μm and dynamic range of 50 μm. The multimode probe has wider dynamic range (100 μm).

The multimode PMMA fibers were used in a two fiber probe. The sensor characteristic is shown on the Fig. 2b and is linear before reaching the maximum. The signal from the second output fiber was measured also. The compensated signal is derived by dividing both output signals. The compensated sensor has good time stability and wider dynamic range.

The theoretical descriptions and additional comments on the multimode fiber optic reflection probe consisting of Y coupler and two fibers were explained in Ref. 6 and Ref. 4.

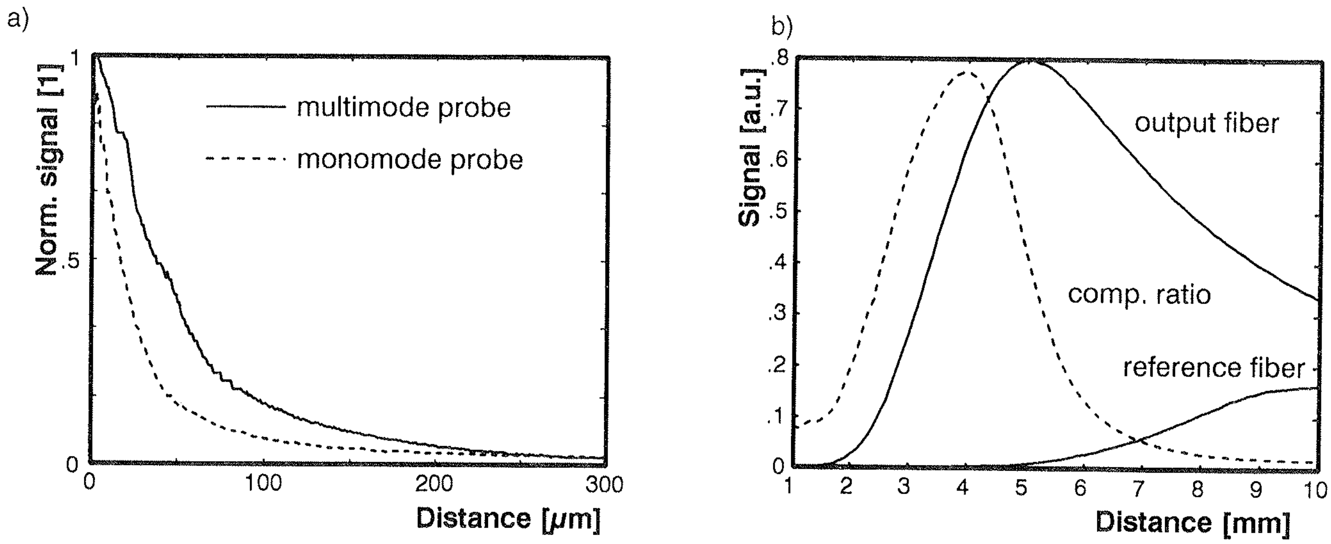

Fig. 2: Sensor characteristic for a) monomode and multimode silica probes and b) multimode PMMA probe with double output and compensated signals.

3. PHASE MODULATED FIBER OPTIC DISTANCE SENSOR

The fiber optic interferometers allow measurements of differential phase shifts in the optical fiber generated by the external physical or chemical parameters. The optical phase change ϕ in the interferometer is equal /8/

$$\phi = nkL, \qquad (1)$$

where n is refractive index of the medium, k is the optical wavenumber defined by the light wavelength λ as $k=2\pi/\lambda$, and L is the path length of the light. If the phase variations are small the equation 1 must be differentiated and the phase change $d\phi$ can be expressed by the changes of n, k, or L

$$d\phi/\phi=dn/n+dk/k+dL/L. \qquad (2)$$

Three basic fiber optic interferometer configurations which used for the distance measurements are Michelson, Mach-Zehnder and Fabry-Perot interferometer. The Mach-Zehnder configuration is shown in Fig. 3.

In the Michelson and Mach-Zehnder interferometers the signal and the reference arm are separated, while in Fabry-Perot configuration the signal and reference light beam travels through the same fiber. In experiments the hybrid Mach-Zehnder configuration was used (Fig. 4a). Monomode fibers and X coupler were incorporated in this arrangement.

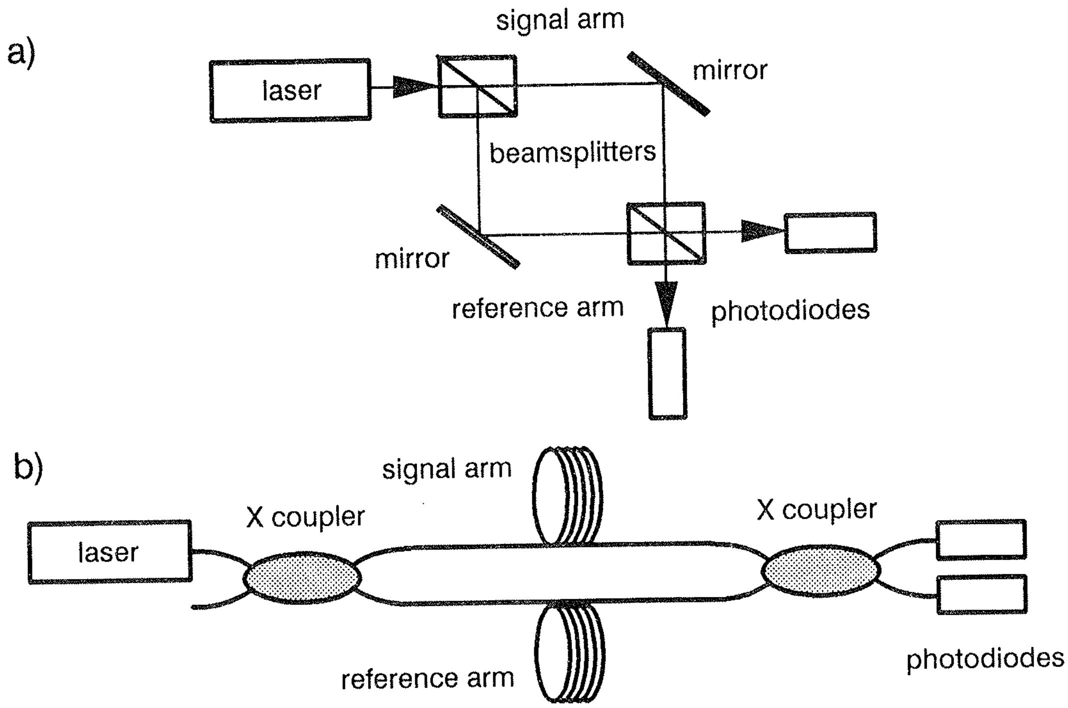

Fig. 3: Mach-Zehnder interferometer a) conventional b) fiber optic

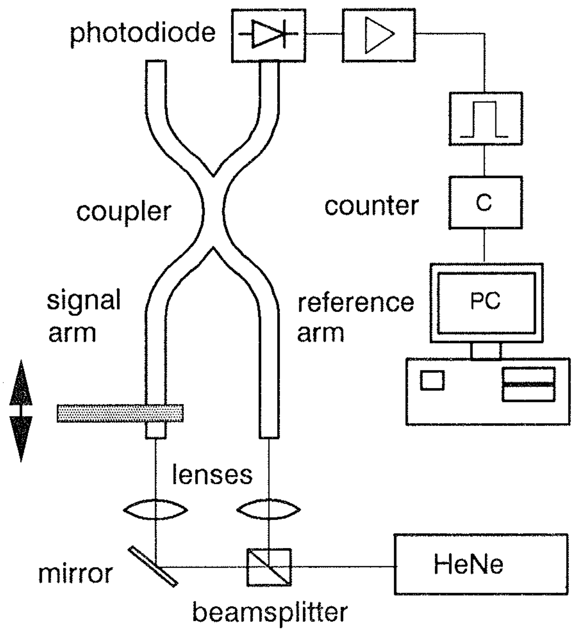

Fig. 4a: Experimental interferometer

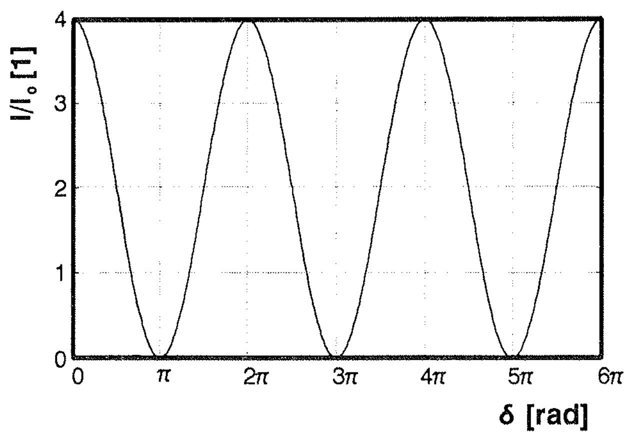

Fig. 4b: Interferometer signal

In the hybrid Mach-Zehnder interferometer only the second beamsplitter is the fiber optic X coupler. The proposed configuration enables distance measurements in wide range. The distance range is limited only by the coherence length of the light source. In this configuration a HeNe laser (λ=633 nm) was used with coherence length approximately 1 cm. The signal fiber was attached to the moving stage and the phase change was achieved by moving the stage. The receiving electronics is capable to count multiples of π of the phase change. The path difference L can be determined from the equation 1 and is equal to $\lambda/2$ for one count. The output intensity on photodiode I can be determined from the following equation

$$I = I_s + I_r + 2\sqrt{I_s I_r} \cos \delta \qquad (3)$$

where I_s is intensity in the signal fiber, I_r the intensity in the reference arm and δ is the phase difference between both arms. In Fig. 4b the ideal interferometer response is shown where the $I_s=I_r=I_0$ ($I=4I_0 \cos^2(\delta/2)$). In real interferometer the response is between the maximum and minimum of the ideal response. The light coupling in the beamsplitter and fiber coupler is not perfect and the light losses in both arms are not equal. Small displacements can be measured with a similar interferometric setup where the compensator is added in the reference arm. The compensator shifts the phase and holds the interferometer at the point of maximal sensitivity (interferometer quadrature).

4. CONCLUSIONS

Several fiber optic displacement measurement techniques are discussed in present paper. The reflection type sensors are simple in construction and provide resolution of less than 1 μm. The dynamic range and sensitivity are determined by the geometrical arrangement of the sensor. The compensated technique increases the sensor stability.

The interferometric sensors have wider dynamic range and higher resolution but are complex in construction. The Mach-Zehnder interferometer enables resolution of $\lambda/2$ by using the fringe counting technique.

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Dr. Alojz Suhadolnik
University of Ljubljana,
Faculty of Mechanical Engineering,
Aškerčeva 6, 61000 Ljubljana, Slovenia
tel. + 386 61 126 13 10,
fax. + 386 61 218 567

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MAGNETIC PROPERTIES, SPINODAL DECOMPOSITION AND COLD DEFORMATION IN FeCrCo ALLOYS

Franc Vodopivec,
Institute of Metals and Technology, Ljubljana, Slovenia

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Key words: permanent magnets, FeCrCo alloys, FeCrCo magnets, magnetic properties, spinodal decomposition, cold deformation, material ductivity, heat treatment, material microstructure, magnetic remanence, coercitivity field strenght

Summary: In technical iron-chromium cobalt alloys the microstructure of ferromagnetic phase α is obtained with addition of suitable alloying elements preventing the formation of phases γ and σ. Alloys have pour ductility by ambient temperature. Magnetic properties depend upon the proper combination of spinodal decomposition, deformation and aging. All magnetic properties are improved by cold deformation. The greatest remanence is obtained by appr. 60% of deformation. The coercivity grows proportionally to the deformation and to the decrease of the distance between particles of phase α_1, while the remanence grows proportionally to the allongement of particles of this phase.

Magnetne lastnosti, spinodalno razmešanje in hladna deformacija v zlitinah FeCrCo

Ključne besede: magneti trajni, FeCrCo zlitine, FeCrCo magneti, lastnosti magnetne, razmešanje spinodalno, deformacija hladna, raztegljivost materiala, obdelava toplotna, mikrostruktura materiala, remanenca magnetna, poljska jakost koercitivna

Povzetek: V tehničnih zlitinah železa, kroma in kobalta je potrebno z dodatkom sekundarnih legirnih elementov preprečiti nastanek faz γ in σ in doseči mikrostrukturo iz feromagnetne faze α. Zlitine imajo zelo majhno duktilnost pri temperaturi ambienta. Magnetne lastnosti so pri pravi sestavi odvisne od kombinacije temperature spinodalnega razmešanja, stopnje deformacije in procesa staranja. Vse magnetne lastnosti se izboljšujejo z naraščanjem stopnje deformacije. Največja remanenca je dosežena pri ca. 60% deformaciji. Koercitivna sila raste proporcionalno z zmanjšanjem razdalje med delci faze α_1, remanenca pa proporcionalno s podaljškom zrnate faze.

1. Introduction

The property of permanent magnetism is obtained in iron-chromium-cobalt alloys through the spinodal decomposition of the solid solution of both alloying elements in the ferromagnetic phase α Fe in two spinodal components. During this decomposition the matrix α_2 is enriched in chromium and particles α_1 are enriched in cobalt. Both components have the same α ferromagnetic lattice, however a different lattice parameter because of the difference in composition. Both phases accommodate with elastic stresses which increase the hardness and stabilise the externally imposed uniform orientation of Weiss domains the more, the greater is the difference in composition, which is increased through a proper aging. Better magnetic properties are obtained by a combination of heat treatment and cold deformation by wire drawing, which produces a spinodal structure aligned and allonged in the deformation axis /1-18/. On principle, good magnetic properties are obtained also by a very slow cooling in magnetic field. By the technically acceptable cooling in magnetic field, which gives the required properties to AlNiCo alloys, several times smaller coercivity is obtained in a $Fe_{28}Cr_{16}Co$ alloy than combining heat treatment and cold deformation. The initial microstructure consists of coarse grains of phase α (fig. 1) obtained by annealing the alloy at 1200°C and quenching. The microstructure should be free of phase σ, which makes the alloys unductile and of the non ferromagnetic phase γ. Already the thin grain boundary layer of phase γ in fig. 2, decreases the magnetic properties by appr. 20%. The proper microstructure is obtained in technical alloys, containing elements stabilisers of the phase σ , f.i. carbon, nitrogen and manganese through a proper addition of aluminium or titanium, which prevent also the formation of phase σ. Twinning makes the monophase coarse grained microstructure virtually undeformable at room temperature, therefore the wire drawing deformation is performed by increased temperature, when deformation by sliding occurs.

In this paper a short and simplified presentation of the relationship between the spinodal decomposition, the deformation and the magnetic properties will be given. The microstructure and the ductility were presented earlier /26/. Unpublished findings will be discussed as well as already published data /19-25/. In the paper the denomination phase will be used for the spinodal components although physically both components are not

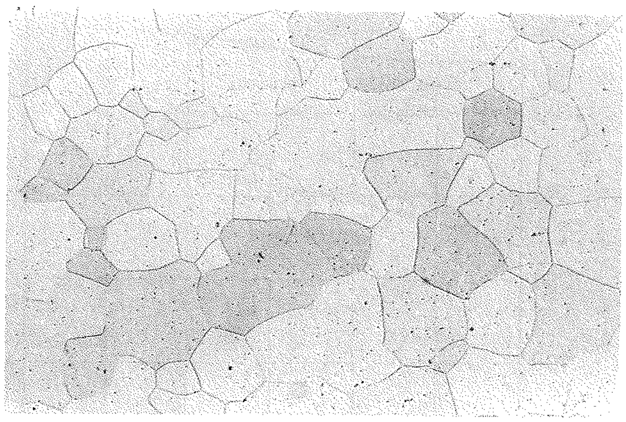


Fig. 1: mag. 50x, $Fe_{28}Cr_{16}Co$ alloy. Microstructure after 30 min. of annealing at 1200°C and quenching.

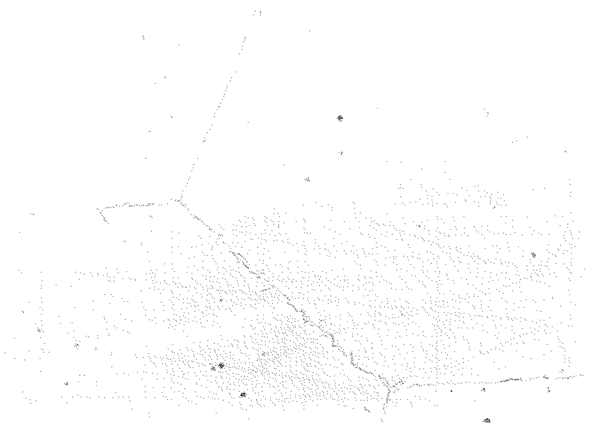


Fig. 2: mag. 500x. A thin layer of phase γ at the boundaries of α grains.

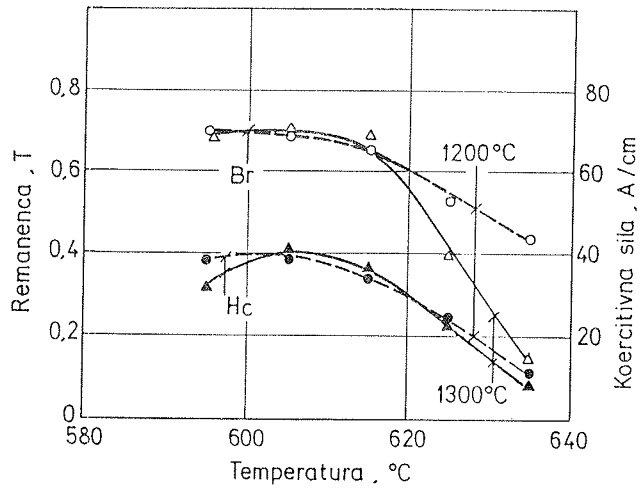


Fig. 3: $Fe_{31}Co_{10}Co$ alloy. Influence of the 30 min. annealing for spinodal decomposition on coercitivity and remanence. Homogenisation temperatures 1200 and 1250°C.

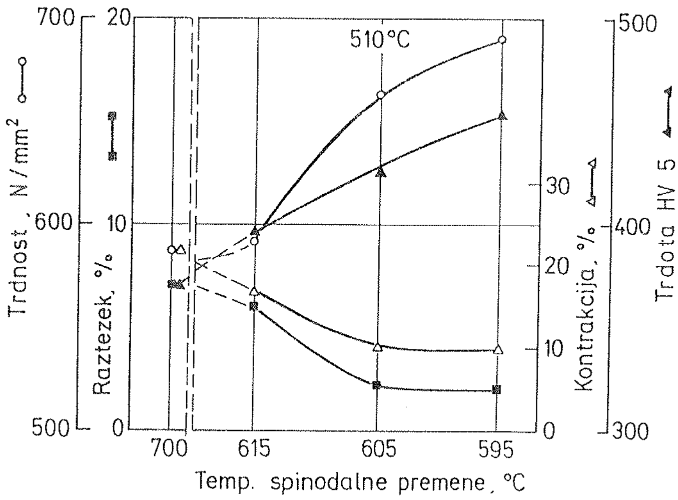


Fig. 4: The same alloy as in fig. 3. Influence of the 30 min. annealing for spinodal decomposition on hardness and ductility.

real phases, since they are separated through a chemical gradient and not by a phase boundary.

2. Spinodal Decomposition and Magnetic Properties

The size and the number of particles of phase α_1 as well as their composition depend upon the spinodal decomposition temperature and time. Fig. 3 shows that very similar coercivity and remanence are obtained by the alloy $Fe_{30}Cr_{15}Co$ by 30 min. of annealing in temperature range from 615 °C to 595°C. By higher temperature the magnetic properties decrease very fast. By low spinodal temperature the hardness is increased and the ductility diminished (fig. 4). Experience shows that a sufficient ductility is obtained if the spinodal temperature is above 620°C. A similar effect of spinodal temperature on the ductility was found also for the alloy $Fe_{28}Cr_{16}Co$. By short annealing time the spinodal structure is stable below appr. 620°C. By the temperature of 630°C, which was found as optimal for ductility and magnetic properties after wire drawing deformation, the best properties are obtained by a 30 min. annealing (fig. 5). After the wire drawing deformation the alloys are submitted to a 12 hr. aging in temperature range from 600 in 500°C. During the aging the difference in chemistry between both phases, the accommodating stresses, coercivity and energy product are increased, while remanence shows a slight decrease at initial aging temperature (fig. 6).

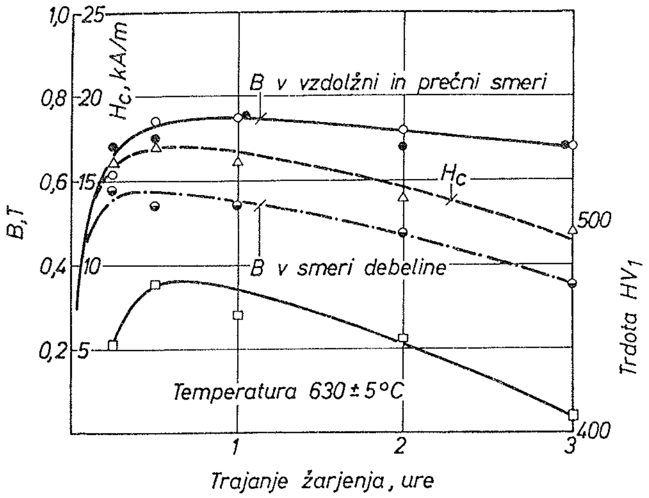


Fig. 5: $Fe_{30}Cr_{10}Co$ alloy. Effect of annealing for spinodal decomposition at 630°C on coercitivity, remanence and hardness. The alloy was homogenised at 1200°C and quenched.

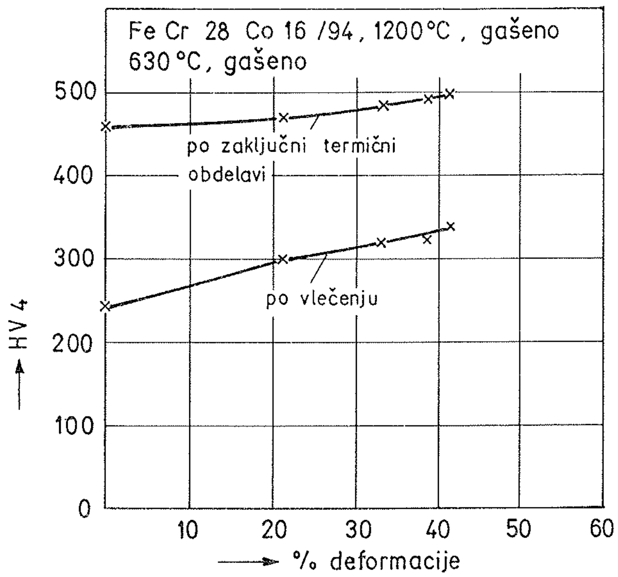


Fig. 7: $Fe_{28}Cr_{16}Co$ alloy. Effect of deformation by wire drawing on hardness before and after aging. The alloy was initially annealed at 1200°C, quenched, reannealed 30 min. at 630°C and quenched.

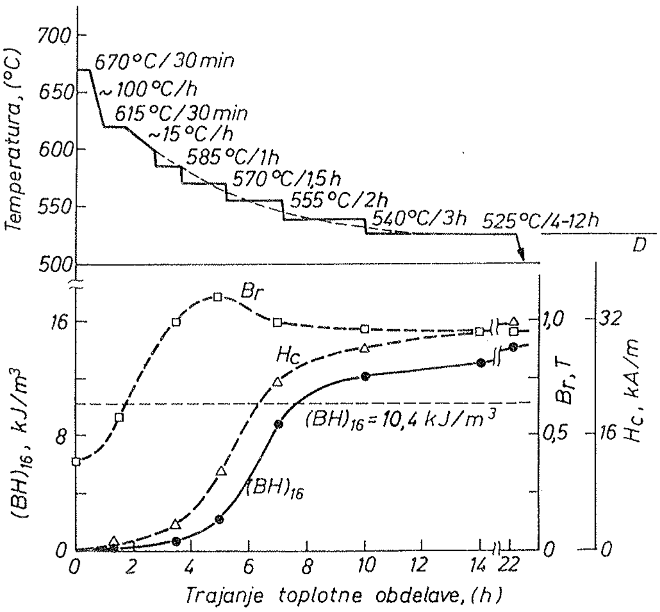


Fig. 6: $Fe_{30}Cr_{10}Co$ alloy. Evolution of magnetic properties and hardness by controlled slow cooling (aging). The alloy was initially annealed at 1200°C, quenched, annealed for 30 min. at 620°C and quenched.

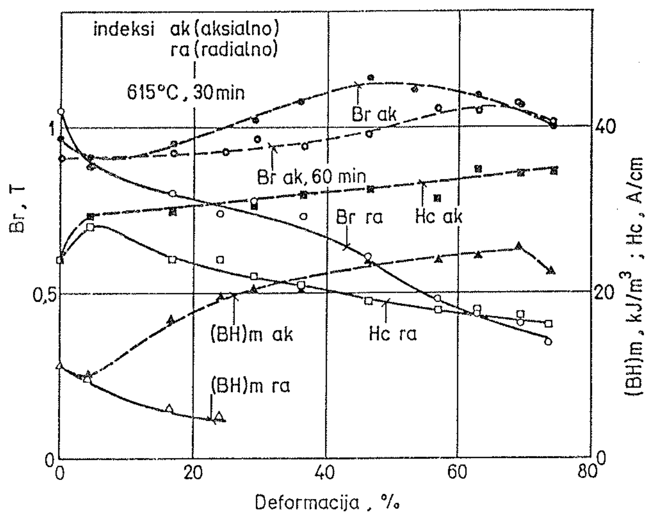


Fig. 8: $Fe_{32}Cr_{10}Co$ alloy. Influence of wire drawing deformation on magnetic properties in axial (ak) and radial (ra) directions. Initially the alloy was annealed at 1200°C, quenched, reannealed 30 min. at 615°C and quenched.

3. Deformation and Magnetic Properties

The wire drawing deformation is carried out at increased temperature. This should be, however, below that which could affect the spinodal decomposition and the dynamic as well as static softening processes. By wire drawing deformation a low strain hardening is obtained (fig. 7), appr. proportional to the degree of deformation. It is interesting that after aging, which is started at a temperature appr. 200°C above the wire drawing temperature, the strain hardening is conserved. The deformation increases the magnetic properties in axial direction and diminishes these properties in radial direction (fig. 8). Correspondingly, the shape of the demagnetisation curve becomes more rectangular (fig. 9). A careful evaluation of experimental findings showed that the remanence grows proportially to the square of the ratio between the initial (di) and the final (da) diameter of the deformed rod (fig. 10), while the coercivity is increased proportionally to this ratio (fig. 11) and it is appr. proportional to the strain hardening. The relationships in fig. 10 and 11 can be explained supposing that the change in magnetic properties in dependence of the deformation is connected to the modification of the shape of the particles of

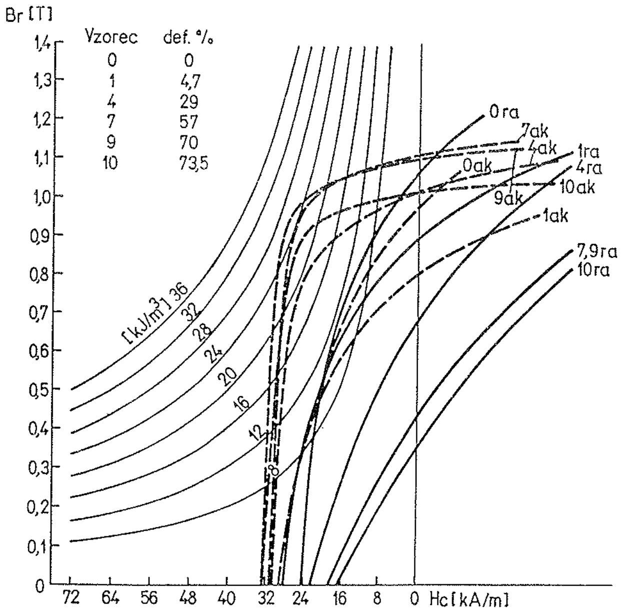


Fig. 9: *Alloy form fig. 8. Influence of the deformation degree on the shape of the demagnetisation curve in axial and radial directions.*

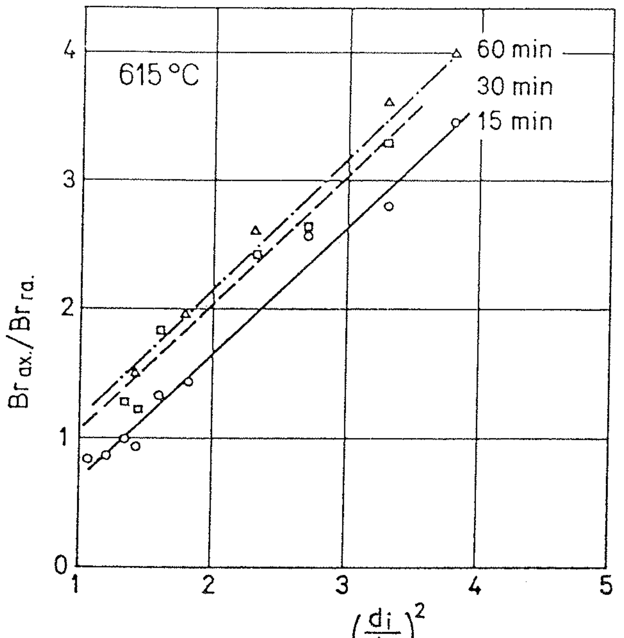


Fig. 10: *Alloy from fig. 8. Relationship allongement-remanence.*

phase α_1. These particles are initially spherical and are deformed in the same way as the matrix of phase α_2, because the change in chemistry has no significant effect on the hardness of both phases through solid solution hardening. Shematically, the effect of the shape change of particles of phase α_1 is shown in fig. 12. The coercivity is the higher the smaller is the distance between particles of phase α_1, it increases thus with the gradient of chemistry between both spinodal phases. The effect of deformation on coercitivity is similar to the effect of the lowering of the spinodal temperature. The

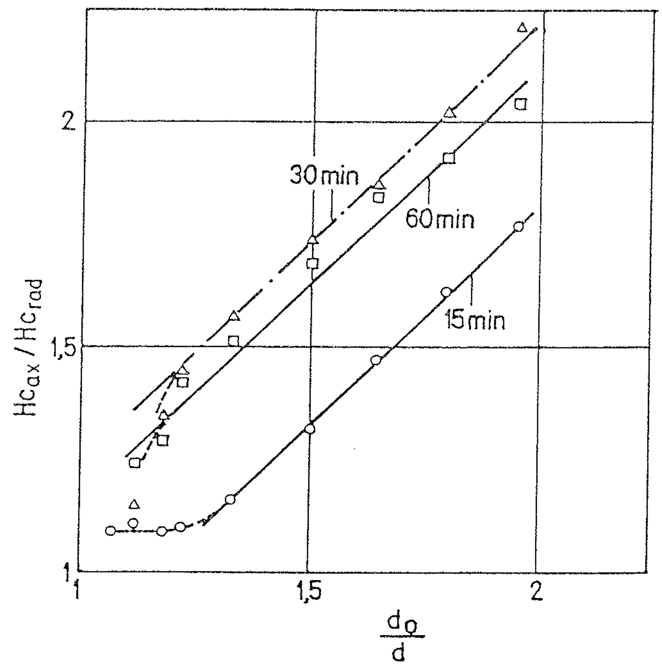
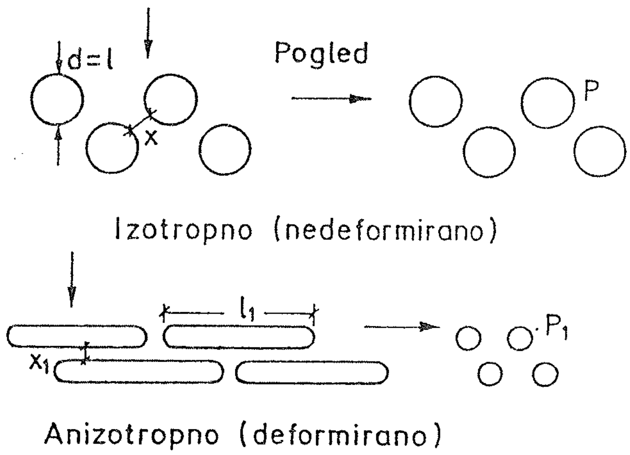


Fig. 11: *Alloy from fig. 8. Relationship decrease of rod thickness-coercitivity.*



$$An \cdot B_r = K\left(\frac{d}{d_1}\right)^2 = K\frac{P}{P_1} = \boxed{K\frac{l_1}{l}}$$

$$An \cdot H_c = K\frac{d_1}{d_2} = K\frac{x}{x_1}$$

Če je $x < x_1 > 0$ B_r in $(BH)_m$ ↗

Če je $x_1 = 0$ B_r in $(BH)_m$ ↘

Fig. 12: *Schematically representation of the dependence of the shape of particles of phase α1 and the remanence and the coercitivity.*

remanence depends upon the ratio length over diameter of particles of phase α_1, which is proportional to the wire drawing allongement and to the ratio of the initial over final diameter of the deformed rod.

Let us suppose that one Weiss domain occupies a volume of one particle of phase α_1 with the corresponding part of the matrix of phase α_2 /15/. If the alloged particles of phase α_1 approach below a critical distance or even a mutual contact is established, the shape and the size of Weiss domains is changed, and the remanence, which depends upon their size, is diminished also. Indirectly this explanation is confirmed by the fact that the greatest remanence is obtained by a 45-50% deformation after 30 min. of spinodal decomposition at 630°C, while after 60 min. of spinodal annealing at the same temperature the highest remanence is obtained by appr. 65% of deformation. By isothermal annealing the number of particles of phase α_1 (N) is diminished accordingly to the parabolic law $N \approx Kt^{0.2}$ (t - annealing time) and parallelly their size is increased also.

4. Conclusion

In the technical iron-chromium-cobalt alloys is necessary through the addition of secondary alloying elements obtain a microstructure of the ferromagnetic phase α. This microstructure gives, however, after homogenisation and quenching a very poor ductility at ambient temperature. By a selected chemistry of the alloy the magnetic properties depend strongly upon the combination of the temperature of spinodal decomposition, the wire drawing deformation and the aging process. All magnetic properties are improved by the deformation. The highest remanence is found by appr. 60% of wire drawing deformation. The coercivity grows proportionally to the decrease of the distance between α_1 particles, while remanence increases proportionally to the allongement of these particles.

The support of the Ministry of Science and Technology of Slovenia is gratefully a knowledged.

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Prof.dr. Franc Vodopivec,
Institute of metals and Technology,
Lepi pot 11, 61000 Ljubljana, Slovenia
tel. + 386 61 125 11 61
fax. + 386 61 21 780

Prispelo (Arrived): 18.11.1994 ***Sprejeto (Accepted): 22.11.1994***

MIEL-SD'94 CONFERENCE PRESENTATION OF LABORATORIES

KONFERENCA MIEL SD - 94 PREDSTAVITVE LABORATORIJEV

LABORATORY FOR MICROELECTRONICS
Faculty of Electrical and Computer Engineering
University of Ljubljana, Slovenia

The Laboratory was founded in 1969. It started with the development and the design of complex thin film integrated circuits and monolithic discrete devices.

In 1976 the 2" wafer p-channel metal gate prototyping line was operational.

Joint development teams were established with American Micro Systems, International Microelectronic Products and with Austria Mikro Systeme Inc.

In some areas the achievements of the Laboratory were at the leading edge of IC design and design methodology.

ACTIVITIES IN RESEARCH, DEVELOPMENT AND TEACHING IN MICROELECTRONIC

- CMOS & BiCMOS submicron process modules development
- Industrial ASIC design
- Design and analysis of complex electronic system
- Development of new design methodologies and CAD tools for mixed analog-digital signals

RESEARCH STAFF: total 37

- 14PhDs with average 15 years of experience
- 11MS senior designers and technologists
- 12 experienced engineers and technicians

RESEARCH FACILITIES

- 400m^2 clean room area for experimental submicron CMOS & BiCMOS process
- 1800m^2 floor space for technology support assembly and design, mask shop and test laboratory

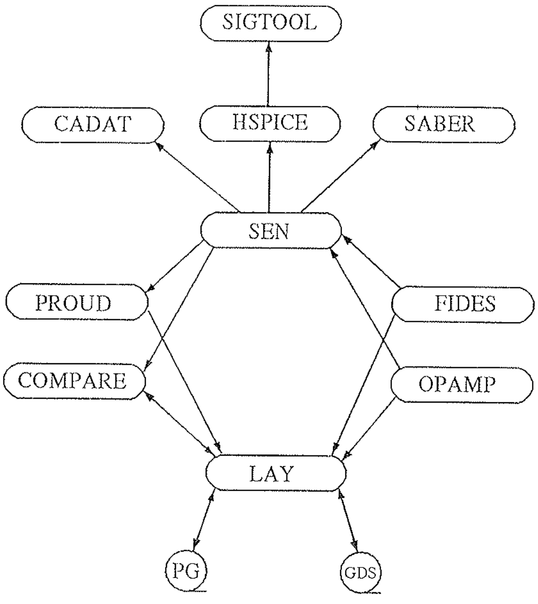
TEACHING

Courses:

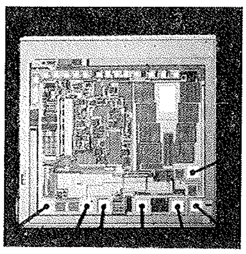
- MOS circuit design
- Integrated circuits
- Semiconductor technologies
- Microcomputer systems
- Testing of integrated circuits
- Digital system technology

MAJOR ACHIEVEMENTS

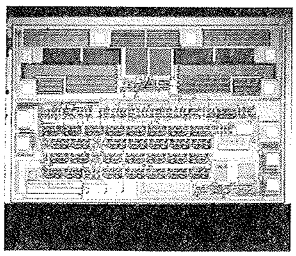
- Joint development (with IMP) of submicron CMOS, BiCMOS process modules



Major tools and data flow:



Regulator for alternator with multiple fault detection & indication
Chip size: 2600μm x 2600μm
Process: 5μm dual poly single metal p-well



25. Electric stimulation IC for active plaster for accelerated wound healing
Chip size: 2835μm x 1861μm
Process: 5μm dual poly single metal p-well

Two design examples

- Design of modern telecom circuits (single chip telephone, SLIC circuit, etc.)
- Design of precise instrumentation ASICs (fully integrated Hall effect Watthour meter, 16 bit absolute encoder for space application, etc.)
- Automotive ASICs (single wire data bus receiver-transmitter, ABS subcircuits, etc.)
- Design methodology and supporting CAD for Automatic synthesis of analog subcircuits

Prof.dr. Janez Trontelj
Laboratory for Microelectronics
Faculty of Electrical and Computer Engineering,
University of Ljubljana, Tržaška 25,
61000 Ljubljana, Slovenia

Activities, Equipment and Program Line of the Laboratories of Chemical Technology Department "NIKOLA TESLA" Telecommunications Systems and Equipment Company Zagreb, Croatia

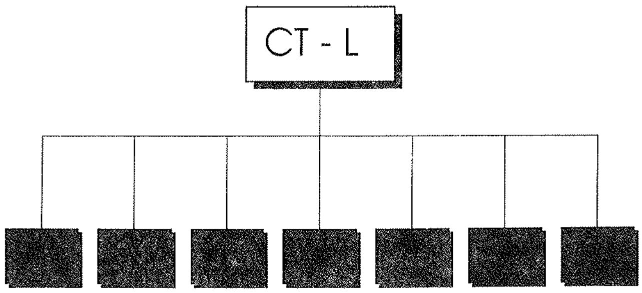
CHEMICAL TECHNOLOGY DEPARTMENT

1. RESPONSIBILITY

- research, development and adoption of materials, production procedures and test methods which are necessary for design and production of electronic equipment, and are in connection with diferent chemical processes and electronic technologies or belong to chemical industry
- certain services and production (prototype and small series production) of the indicated materials, production procedures and testings
- solving ecological problems (ecologically suitable materials) in company for assuring safe handing of materials (regarding personnel and environmental protection as well as product and technological process protection)
- standardization of the indicated materials, production procedures and testing
- assurance of support to organizational units for development, control, production, technology, purchase and sales, which implies tests
- activities of autorized laboratory for control of wastewater from our own technological process
- the introduction of the quality system in accordance with ISO 9XXX in its own organizational unit

2. LABORATORIES

CHEMICAL TECHNOLOGY DEPARTMENT
LABORATORIES



L1 - LABORATORY FOR ANALITICAL CHEMISTRY
L2 - LABORATORY FOR PHYSICAL AND CHEMICAL TESTING
L3 - LABORATORY FOR PRINTED CIRCUIT BOARDS
L4 - LABORATORY FOR SURFACE TREATMENT
L5 - LABORATORY FOR PHOTOGRAPHICS TREATMENTS
L6 - LABORATORY FOR THICK FILM TECHNOLOGY
L7 - LABORATORY FOR SURFACE MOUNT TECHNOLOGY

L1 - LABORATORY FOR ANALITICAL CHEMISTRY

ACTIVITIES

- Research, development and standardization of chemical methods for testing surface treatment baths, wastewater, organic and inorganic materials, metals and alloys, fluxes, metallic coatings, ...
- Routine chemical analysis (materials, electrolites, wastewater, ... determining basic component or an aditive or impurity in various samples)

EQUIPMENT

Standard equipment in analitycal laboratory for:

- volumetric and gravimetric analysis
- qualitative analysis
- sample preparations for instrumental analysis
- other various chemical testings

L2 - LABORATORY FOR PHYSICAL AND CHEMICAL TESTING

ACTIVITIES

Testing of materials, processes media, products, environment...

- chemical analyses (basic components and impurities or additives) of soldering alloys, fluxes and pastes; electrolytes for gold-, cooper-, tin-, electroplating; trace metal analyses of various samples; wastewater control; ...
- determination of cleanliness of printed circuit boards and assemblies (ionic contamination control acc to MIL-P-28809A and other related standards)
- testing of metal and nonmetal coatings: thickness measurements, ductility of metalic coatings acc ISO 8401, porosity, assessing of quality of sealed anodic coatings, hardness, adhesion, corrosion
- testing of solid nonmetals: maesling and bow/twist test for copper clad laminates, flammability of plastic materials (UL94), chemical resistance, identification of plastic, rubber and laminate,

EQUIPMENT

- atom absorption spectrophotometer PYE UNICAM
- UV/VIS spectrophotometer PERKIN ELMER
- polarographic/voltometric analyzer with static and hanging mercury drop electrode and with rotating disk electrode PAR
- equipment for potentiometric titrations, pH/mV and ion-selective electrode measurements RADIOMETER
- conductometer ISKRA
- equipment for determination of ionic contamination of PCB and PCA OMEGAMETER ALPHA
- electrographic porosity tester OWEN
- ductilomat SCHERING
- instrument for measurement of coating thickness ELECTRO PHISIK
- salt chamber for testing corrosion HERAEUS
- flamability test equipment acc to UL 94

L3 - LABORATORY FOR PRINTED CIRCUIT BOARDS

ACTIVITIES

- surface treatment for PCB (testing, Tin strip and Sn/Pb techniques) in class IV - VI

EQUIPMENT

- two lines with control unit
  - copper plating line (surface preparation for metalizing of holes, electroless copper plating, coper electroplating)
  - tin and tin/lead line (tin electroplating; tin/lead electroplating)

L4 - LABORATORY FOR SURFACE TRETMENT

ACTIVITIES

Surface treatment: pretreatmens and cleaning

- chemical treatment
  - Zn immersion (Al)
  - Sn immersion (Cu, brass)
  - black oxidizing (Cu, Fe)
  - cromating (Al, Zn)
- electrochemical deposition -Ni, Au, Ag, Cu, Sn, Pb, Fe

EQUIPMENT

- Three laboratories electroplating lines with 12 units and complete equipment: tanks, rectifiers, barrels, heaters, filter pumps, stiring, cooling
- Pulse plating rectifier
- Ultrasonic cleaners

L5 - LABORATORY FOR PHOTOGRAPHICAL TREATMENTS

ACTIVITIES

- Screenprinting operations including surface preparation
- Stencil production including metal masks for SMT
- Solder mask application
- Image transfer processes
- Research and application of Adhesive Joining Technology in Electroning Manufacturing (SMT; display interconnections; ...)
- Manufacturing PCB (prototype)

EQUIPMENT

- Laminator DU-Pont
- Screen tensiometer
- Exposure lamp
- Vacuum copying frame with vacuum pump
- Screenprinting machine
- Developing machine RESCO
- Etching machine RESCO

L6 - LABORATORY FOR THICK FILM TECHNOLOGY

ACTIVITIES

Research and development in the field of thick film technology

- Prototype and small series production of thick film resistor networks and hybrid circuits

EQUIPMENT

- semiautomatic screen printer DEK
- radian dryer BTU
- laboratory thick film firing furnace BTU
- rotadip unit SOLBRASE
- soldering system IR ARGUS
- wave soldering system
- lasertrim system TERADYNE
- varsatrim trim-test control instrument BIDDLE
- epoxy die bonder DAGE PRECIMA
- hybrid ultrasonic wedge bonder
- stereo zoom microscopes
- ultrasonic cleaning system BRANSONIC
- temperature test chamber HERAEUS
- digital multimeter HP
- surfometer PLANER

L7 - LABORATORY FOR SURFACE MOUNT TECHNOLOGY

ACTIVITIES

- Research, development and adoption of materials and processes in connection with Surface Mount Technology
- SMT Prototype and small series production

EQUIPMENT

- semiautomatic printer DEK
- dispensers I J FISNAR
- pick and place machine COSY
- rework/replace station PLANER
- visual inspection station MEIJII
- zoom microscope BAUSCH/LOMB
- IR/UV oven SURF SYSTEM
- flow soldering machine ELECTROVERT

3. PROGRAM LINE

PROTOTYPE AND SMALL SERIES PRODUCTION

PRINTED CIRCUIT BOARDS

- single sided
- duble sided
- copper tinn, tinn/lead, gold
- solder resist mask
- isolation mask
- notation marks

THICK FILM RESISTOR NETWORKS AND HYBRIDS

SMT ASSEMBLIES - various types

SCREENS STENSILS - for production of PVB and SM

SURFACE TREATMENT

- electrochemical deposition: Ni, Au, Ag, Cu, Sn, Sn/Pb, Pb, Fe
- chemical treatment: Zn immersion (Al)
  Sn immersion (Cu, brass)
  black oxidizing (Cu, Fe)
  chromating (Al, Zn)

TESTING

CHEMICAL ANALYSES

- basic componets and impurities or additives of soldering alloys, fluxes, solder pastes, solder wires, electrolytes for gold, copper, tinn, tinn/lead, silver, nickel, ...electroplating
- trace metal analyses of various

DETERMINATION OF CLEANLINESS acc to MIL-P-28809A
and other related standards of printed circuit boards, clasic electronic assemblies, SMT assemblies

QUALITY OF METAL AND NONMETAL COATINGS

- thickness, ductility of metal coatings acc to ISO 8401, porosity, assessing of quality of seald anodic coatings, hardness, adhesion, corrosion, ...

QUALITY OF SOLID NONMETALS

- measling and bow/twist test for copper clad laminates, flammability of plastic materials (UL94), chemical resistance, identification of plastic, rubber and laminate, ...

M. Sc. Gorana Lipnjak, B. CH. E
Nikola Tesla, Kemijski odjel
Krapinska 45, 41000 Zagreb, Croatia

CERAMICS DEPARTMENT
Jožef Stefan Institute
Ljubljana, Slovenia

The Ceramics Department at the Jožef Stefan Institute, established in 1964, is a multidisciplinary advanced ceramics research group. Its activities encompass:

- basic research,
- postgraduate education and professional training,
- applied research and technical consultancy.

The Department's 50 researchers, including a permanent research staff, graduate students and visiting engineers/scientists, study all aspects of powder synthesis, powder processing, and the shaping and sintering of ceramics. Particular emphasis is given to characterisation of ceramic products - from structures to functional properties. Being up to date with the latest achievements and current trends in science and technology, it is qualified to act as an intermediary between university scientists and partners interested in practical applications.

Basic Research

- Ceramic powder synthesis: solid state reactions, sol-gel and hydrothermal synthesis
- Powder processing: solid liquid interfaces, stability of ceramic suspensions
- Ceramic processing: tape casting, low pressure injection moulding, slip casting, pressing, HIP-ing
- Thin and thick film processing
- Sintering and microstructure design
- Microstructure-property relationships of functional and structural ceramics
- Powder metallurgy for application in intermetallic magnet processing
- Glass research
- Defect chemistry and crystal structure determination
- High temperature phase equilibria determination

Education

Close collaboration exists with the Universities of Ljubljana and Maribor. Two members of the Department are full-time professors at the University while four members of the group are part-time faculty members. An average of 13-15 post graduate students perform research work at the Ceramics Department.

Applied Research

The Ceramics Department is deeply involved in several industrial programmes. Cooperative companies in 1994 include Iskra Feriti Ljubljana (production of ferrites), Iskra Varistor Ljubljana (production of varistors), Iskra Magneti Ljubljana (production of magnetic materials), KEKO Žužemberk (production of ceramic varistors and PTCR), Iskra Hipot Šentjernej (production of hybrid circuits), Iskra AET Tolmin (production of technical ceramics), Fotona Ljubljana (production of electrooptical devices), Krka- Novoterm (glass fibres), Termo Škofja Loka (mineral fibres), and the glass factories Steklarna Rogaška Slatina, Steklarna Hrastnik, Steklo Slovenska Bistrica and Steklarska šola (Glass School) Rogaška Slatina.

International Cooperation

Members of the Department cooperate in several international projects such as COST, PECO and bilateral projects with research institutions in Germany, the United Kingdom and USA.

Some Current Projects:

- The relationship between microstructure and electrical properties in nonlinear ZnO ceramics
- Hydrothermal synthesis and sintering of MnZn ferrites
- Materials for solid oxide fuel cells
- Sol-gel processing of PZT and PLZT thin films
- Solution processing of PZT powder
- TiO_2 humidity sensors from sol-gel monoliths
- The role of powder properties in tape casting - PZT as a case study
- Injection moulding of monolithic and reinforced reaction bonded ceramics
- Water-based injection moulding
- Dielectric ceramics
- Microwave ceramics based on the BaO-TiO_2-Ln_2O_3 system (Ln = La, Nd, Gd); processing - microstructure - properties relationships
- Chemical reactions and microstructures in $BaTiO_3$ based ceramics
- HDDR processing of NdFeB high coercive powders
- Phase equilibria studies in BaO-TiO_2-rare earth oxide systems
- Processing and properties of $Sm_2Fe_{17}N_x$ magnets
- Thick film materials and technology for sensor applications.
- Glass and mineral fibres for thermoisolation.

Main Equipment

- Powder processing equipment for milling, sieving, blending, wet chemical methods.
- Processing equipment for pressing, isostatic pressing, injection moulding, casting,
- Sintering and heat treatment equipment: furnaces: air and controlled atmosphere 1500-2500°C, hot pressing: air, O_2, vacuum, 1200°C, HIP: 2000°C, 20 MPa.
- Ceramic machining: diamond cutting, grinding, drilling, metallographic polishing.
- Mechanical testing: Instron mechanical tester.
- Electrical and magnetic testing: magnetometer, piezo d_{33} meter, impedance analyser, 4129 LF Hewlett Packard.
- Equipment for thick film technology
- BET Surface analyser, Perkin-Elmer
- Particle Sizer, Cilas Alcatel
- Porosimeter, Micromeritics
- Rotary viscosimeter, Haake (to 1500°C)
- Thermal analyser 429 Netzsch (to 1600°C)
- Dilatometer Bähr (to 1500°C)

- XRD, Phillips PN 1710
- SEM, Leitz - AMR 1600 T with EDS PGT 4
- SEM, Jeol JXA-840 with EDS and WDS
- STEM, Jeol JEM 2000 FX with EDS AN 10000 (LINK)
- Several optical microscopes with stereological image analyser (Contron)

Space:

The Department occupies 3 buildings with a total space of 2.000 m^2.

Dr. Marija Kosec
Ceramics Department
Jožef Stefan Institute
Jamova 39, 61000 Ljubljana, Slovenia

LABORATORY FOR ELECTRON DEVICES
Faculty of Electrical and Computer Engineering, University of Ljubljana, Slovenia

GROUP MEMBERS

Prof. dr. Jože Furlan semicond. materials and devices
Prof. dr. Slavko Amon semicond. materials and devices
doc. dr. Franc Smole a-Si:H modelling and processing
mag. Drago Resnik semiconductor processing
mag. Danilo Vrtačnik semiconductor processing
mag. Dejan Križaj device modelling
mag. Ivan Skubic a-Si:H modelling
mag. Elvis Bassanese a-Si:H modelling
mag. Saša Sokolić device modelling
mag. Uroš Aljančič semiconductor processing
mag. Pavle Popović a-Si:H modelling
mag. Marko Topič a-Si:H modelling
Žurga Marijan technician
Matjaž Cvar. ing. technician

GROUP MEMBERS

Jože Furlan, Ph.D.	Professor, Head of the Laboratory
Slavko Amon, Ph.D.	Professor
Franc Smole, Ph.D.	Associate Professor
Drago Resnik, M.Sc.	Research Assistant
Elvis Bassanese, M.Sc.	Research Assistant
Danilo Vrtačnik, B.Sc.	Research Assistant
Dejan Križaj, M.Sc.	Research Assistant
Ivan Skubic, M.Sc.	Research Assistant
Saša Sokolić, M.Sc.	Research Assistant
Pavle Popović, M.Sc.	Research Assistant
Marko Topič, M.Sc.	Research Assistant
Uroš Aljančič, M.Sc.	Research Assistant
Aleš Groznik, B.Sc.	Research Assistant
Marijan Žurga	Technician
Matjaž Cvar	Technician

ACTIVITIES

A. DEVICE MODELLING & SEMICONDUCTOR PHYSICS

- numerical 1D stationary and transient modelling of semiconductor devices (S.Amon)
- process and device modelling (SUPREM, MEDICI) (S.Amon, D.Križaj, S.Sokolić, D. Vrtačnik))
- device modelling (D.Križaj, S.Amon)
- mathematical techniques, multigrid method
- high voltage termination techniques modelling of specific semiconductor phenomena (S.Sokolić, S.Amon)
- heavily doped semiconductor modelling (band gap narrowing, incomplete ionization)
- device modelling at low temperatures I-V, C-V modelling, DOS derivation in low conducting materials with traps (I.Skubic, J.Furlan) transient response of charge-carrier densities in amorphous semiconductors (J.Furlan, E.Bassanese)
- large signal light excitations
- small signal light excitations internal and external properties of a-Si:H p-i-n solar cells (F.Smole, J.Furlan, P.Popović, M.Topič)
- effect of gap states distribution, p-i, i-n interfaces, heterostructures, quality of surface
- numerical and analytical evaluation of internal and external electrical properties of a-Si:H solar cells quasi 3D solar cell modelling (S.Sokolić, D. Križaj)
- code development (SIMCELL)
- analysis of monocrystalline and amorphous solar cells and related devices
- study of lateral effects parallel connected tandem a-Si solar cell (J.Furlan, P.Popović, F.Smole, M.Topič) light generation modelling (J.Furlan, P.Popović)

B. SEMICONDUCTOR TECHNOLOGIES & DEVICES

Bipolar discrete devices processing (D.Vrtačnik, D.Resnik, U.Aljančič, S.Amon)

Silicon sensors processing (D.Vrtačnik, D.Resnik, U. Aljančič, S.Amon)

Developed devices :

- Si solar cells
- planar power bipolar transistor

- Zener diodes with double diffused technology
- pressure sensors
- p-i-n a-Si:H solar cells

Pilot Line:
- Si photosensors

C. MATERIAL AND DEVICE CHARACTERIZATION

C-V measurements (I.Skubic, S.Sokolić)
- Quasi static
- High frequency

C-t measurements (I.Skubic, S.Sokolić)
- Zerbst method for life time determination

DC device parameter measurements (I.Skubic, U.Aljančič)

a-Si:H DOS characterization using SCLC measurements (I.Skubic, J.Furlan)

a-Si:H DOS evaluation using small transient response (J.Furlan, E.Bassanese)

a-Si:H DOS evaluation using turn-off transient response from stady-state (E.Bassanese, J.Furlan)

spectral response measurements, radiometric measurements (I.Skubic, J.Furlan)

EQUIPMENT

A. DEVICE & PROCESS MODELLING

NUMERICAL TOOLS PROCESS MODELLING
- TMA SUPREM III: 1D process simulator, Palo Alto, USA.

DEVICE MODELLING
- TMA MEDICI: 2D device simulator, Palo Alto, USA.
- BAMBI 2.0: Basic analyzer of MOS and bipolar devices, Technische Universität Wien, Austria.
- MG3: 2D program for junction termination simulation, LED.
- ASPINM: Program for a-Si:H p-i-n solar cells modelling, LED.
- SIMCELL 1.3: quasi 3D SIMulator for solar CELLs, LED.
- TRADES: Transient a-Si:H modelling, LED.

COMPUTER EQUIPMENT
- 6x PC/AT personal computer
- 8x PC 486 systems
- 2x HP 720 workstation
- 2x HP 710 workstation
- Novell LAN
- connected to the university VAX 8550
- connected to the faculty HP SUPER MINI 835

B. PROCESS & DEVICE CHARACTERIZATION

Sheet resistivity prober: VEECO 4 point measurement

Diffused profile measurements: anodic oxidation, Philtec sectioner.

Electrical characterization:
- HP 4145 B Semiconductor Parametric Analyzer
- HP 4284A Precision LCR meter
- HP 4140 B pA - meter, DC voltage source
- HP 4280 A 1MHz C - meter, CV plotter + Mercury Probe Hg- 401RL
- HP 3457A Multimeter
- Tektronix Curve Tracer 577
- Wentworth AWP 1050 Automatic Wafer Prober
- IBM PC with IEEE controller interface card

Optical characterization:
- Solar Simulator AM1
- spectral characterization system (200 - 1500nm) Measurements of thickness and refractive index of thin films:
- Gaertner ellipsometer L 116 + HP 9825A

C. SEMICONDUCTOR TECHNOLOGIES

GENERAL

Fabrication facilities are capable of 3" diameter Si wafer processing. Process room of total area 70 m^2 consists of three clean rooms of class 100, class 10 under laminar flowhoods.

MASK FACILITIES

Emulsion masks 3,5"x 3,5"; 4"x 4"; 5"x 5", supported by manual or CAD design, 10 - 20 x reduction on GCA reduction camera, final 10x or 3x reduction on step & repeat GCA camera.

LITHOGRAPHY

Headway photoresist applicator

Cannon 300 PLA proximity mask aligner

DIFFUSION & OXIDATION

2 Tempress Omega Junior Diffusion Furnaces with 6 tubes

Stack No.	Process	Gas
I.	Boron deposition	N_2, H_2, O_2
	Oxidation	N_2, O_2, bubbler, TCA
	B drive-in, B reox.	N_2, O_2, bubbler, TCA
II.	Phosphor deposition	N_2, O_2
	P drive-in, PSG bake	N_2, O_2, bubbler
	LPCVD Si_3N_4	SiH_2Cl_2, NH_3, N_2
III.	Sinter, Alloy	N_2, H_2

Solid diffusion sources:

p - type:

- BN 975 from Carborundum, used with temperature H2 injection
- Boron Plus (GS 126, GS 139, GS 245) from Owens Illinois

n - type:

- Phosplus TP 250, TP 360 from Owens Illinois
- PH 900, PH 950, PH 1025 from Carborundum

METALLIZATION

MRC 603 - 1 Sputtering System

Targets: Al - Si 1%, Ag, Ti, Ni(V)

WET ETCHING & WAFER CLEANING

Millipore Reverse Osmosis /Super Q High Purity Water System

Micro Air Wet Stations

Tempress wafer Rinse & Dry

OPTICAL INSPECTION

Optical microscope OLYMPUS, magnification 1000x

UV inspection lamp

SOME RECENT PUBLICATIONS

J.Furlan: Charge Carrier Dynamic Nonequilibrium in Amorphous Semiconductors, IEEE Trans. on Electron Devices, ED-39, p. 448, 1992.

J.Furlan, E.Bassanese: Charge Carrier Response to Bias Enhanced Step of Light in a-Si, J. Non-Cryst. Solids, 146, pp. 175-189, 1992.

F.Smole, J.Furlan: Effects of abrupt and graded a-Si:C:H/a-Si:H interface on internal properties and external characteristics of p-i-n a-Si:H solar cells, J. of Applied Physics 72 (12), p. 6400, 1992.

S.Sokolić, D.Križaj, S.Amon: Lumped Series Resistance of Solar Cells as a Result of Distributed Sheet Resistance, Solid State Electronics Vol. 36, No. 4, pp.623-630, 1993.

COOPERATION WITH OTHER INSTITUTIONS

EC: project EC/JOULE II: Investigation of parallel connected a-Si solar cells

SIEMENS, München, GERMANY: Design and modelling of tandem a-Si solar cells

Technische Universität München, München, Germany: Transient response of carriers in a-Si

IRST, Trento, ITALY: Investigations in semiconductor technologies (test structures developement, CCD, CMOS process scaling)

UNIVERSITA DI TRENTO, Trento, ITALY: Modelling and design of low temperature (cryo) devices

TMA, Palo Alto, USA: Developement of physical models for semiconductor device simulation

LAAS/CNRS, Toulouse, FRANCE: Modeling of high-voltage termination structures

CERN, Geneva, SWITZERLAND & IJS, Ljubljana, SLOVENIA: Research and developement of high-energetic particles sensors

ISKRA HIPOT, Šenternej, SLOVENIA: Research and developement of silicon pressure sensors

RLS, Ljubljana, SLOVENIA: Research and processing of silicon photosensors

ISKRA Tela, SLOVENIA: Research and processing of silicon photosensors

M.Sc. Dejan Križaj
Laboratory for Electron Devices
Faculty of Electrical and Computer Engineering,
University of Ljubljana,
Tržaška 25, 61000 Ljubljana, Slovenia

MIEL-SD'94 KONFERENCA - POROČILO

22. Mednarodna konferenca o mikroelektroniki, MIEL'94
30. Simpozij o elektronskih sestavnih delih in materialih, SD'94

Dvaindvajseta konferenca o mikroelektroniki, MIEL'94 nadaljuje tradicijo mednarodnih konferenc, ki jih vsako leto prireja MIDEM - Strokovno društvo za mikroelektroniko, elektronske sestavne dele in materiale. Že tretjič zapored je ta konferenca potekala skupaj s tokrat tridesetim Simpozijem o elektronskih sestavnih delih in materialih, SD'94.

Oba dogodka nudita priložnost mnogim strokovnjakom širom Evrope, da predstavijo svoje delo in najnovejše rezultate, kakor tudi da izmenjajo izkušnje s svojimi kolegi. Rdeča nit konference je ostala možnost druženja, povezovanja in graditve prijateljstva med strokovnjaki s tega področja.

Obe konferenci sta znani tudi zaradi udeležbe priznanih povabljenih referentov. Letos smo imeli priliko poslušati J. Trontlja, Univerza v Ljubljani, Fakulteta za elektrotehniko in računalništvo, čigar referat "Smernice razvoja načrtovanja analogno - digitalnih vezij ASIC" je obravnaval izredno zanimivo področje načrtovanja telekomunikacijskih naročniških integriranih vezij. Naslednji povabljeni referent, H. Viefhaus, Max Planck Institute für Eisenforschung GmbH, Düsseldorf, je v referatu "Analiza površin, meja in tankih plasti v materialoznanstvu" obravnaval površinske analizne metode, ki so nujno potrebne pri raziskavah in razvoju mikroelektronskih tehnologij. Gospa N. Setter, École Polytechnique Fédèral de Lausanne, je v referatu "Feroelektrične tanke plasti in njihova uporaba v mikroelektroniki in mikromehaniki" opisala uporabo feroelektričnih plasti za izdelavo spominov, integriranih senzorjev ter mikromehanskih naprav, kot so mikro pumpe in motorji. Z. Sitar, Institute of Quantum Electronics, Zürich, je v referatu "Rast tankih feroelektričnih plasti z molekularno epitaksijo" predstavil stanje in razvoj tehnike nanosa feroelektričnih tankih plasti z molekularno epitaksijo v ultravisokem vakuumu. Zadnji povabljeni referent, R. Dell'Acqua, MiTeCo - Microelectronics Technology Consultants, Pavia, je v referatu "Senzorji: velika priložnost za mikroelektronske tehnologije "opisal zanimivo in pomembno področje silicijevih in debeloplastnih senzorjev.

Zbornik referatov, ki smo ga izdali, je razdeljen v več delov, podobno kot je potekala konferenca, in sicer MIEL sekcije: Integrirana vezja, Tehnologija, Modeliranje in fizika polprevodnikov, Fotovoltaika in SD sekcije: Tankoplastna tehnologija, Debeloplastna tehnologija, Keramika, kovine in kompozitni materiali.

Letos je bila posebna sekcija posvečena predstavitvi podjetij in raziskovalnih laboratorijev za mikroelektroniko in elektronske materiale. Namen predstavitve je bil seznaniti širši krog poslušalcev z delom in možnostmi, ki jih nudijo različne raziskovalne skupine v teh laboratorijih. Same predstavitve niso tiskane v zborniku, vendar jih objavljamo v tej številki revije "Informacije MIDEM".

Konferenca je potekala od 28. do 30. septembra 1994 na Rogli. Poleg narave smo imeli priliko občudovati tudi primerne prostorske zmogljivosti, ki jih hotel Planja na Zreškem Pohorju nudi organizatorjem. Če temu prištejemo še prijaznost vodstva in osebja hotela, je vtis, ki ga je pustila konferenca na udeležence, popoln.

Še nekaj suhoparnih podatkov:

- na konferenci je bilo predstavljenih 51 referatov
- celotno število udeležencev konference je bilo 68 in sicer po državah:
  Slovenija: 56
  Italija: 4
  Nemčija: 3
  Švica: 2
  Hrvaška: 1
  Češka: 1 in
  Avstrija: 1

Za konferenčne pogoje, sam potek konference ter strokovni nivo konference lahko trdimo, da je bil visok, število udeležencev in referatov zadovoljivo, le spoznanje, da smo na prste ene roke lahko prešteli število udeležencev iz industrije pa je pustilo grenak priokus.

22nd International Conference on Microelectronics MIEL'94
30th Symposium on Devices and Materials SD'94

The 22nd Conference on Microelectronics MIEL'94 continued the tradition of the annual international conference organized by MIDEM, Society for Microelectronics, Electronic Components and Materials, Ljubljana, Slovenia. For the third time, the Conference was organized jointly with the 30th Symposium on Devices and Materials, SD'94, another annual meeting of the same Society. Traditionally, these conferences have provided an opportunity for experts from all over the Europe to meet and discuss new developments in the fields covered by the Conference. The goal of connection and building of the friendship among the scientists and their companies remained the keystone of the organizer.

Both Conferences are also well known for the distinguished guest speakers.

This time we had the opportunity to hear J. Trontelj, University of Ljubljana, whose paper "Trends in Mixed Signal ASIC Design", covered a topic of utmost interest in today's world of telecommunication ASICs. Next guest speaker, H. Viefhaus, Max Planck Institute für Eisenforschung GmbH, Düsseldorf in the paper "Surface, Interface and Thin Film Analysis in Material Science" dealt with analysis methods which are inevitable in research and development of microelectronic technologies. N. Setter, École Polytechnique Fédèral de Lausanne, in the paper "Ferroelectric Thin Films for Applications in Microelectronics and in Micromechanics" presented the use of ferroelectric films in making nonvolatile memories, integrated sensors and for a variety of micro mechanical devices such as motors and micro pumps. Z. Sitar, Institute of Quantum Electronics, Zürich, in the paper "Molecular Beam Epitaxy for the Growth of Ferroelectric Thin Films" presented recent developments in UHV MBE deposition of ferroelectric thin films. Last invited paper by R. Dell'Acqua, MiTeCo - Microelectronics Technology Consultants, Pavia, "Sensors: A Great Chance for Microelectronic Technologies" covered interesting and important field of thick film and silicon sensors.

The Conference Proceedings which was published along with the Conference is divided into several parts according to the Conference sessions such as MIEL sessions: Integrated Circuits, Technology, Device Physics and Modeling, Photovoltaic Devices, and SD sessions: Thin Films, Ceramics, Metals and Composites, Thick Films.

This year, a special session devoted to presentation of microelectronic and material research laboratories and enterprises was held. The aim of the presentation was getting acquainted with the work and possibilities of different research groups, companies and their projects. These presentations are not published in the Proceedings but appear in this issue of the Jurnal "Informacije MIDEM".

The Conference was held at ROGLA, Slovenia, a picturesque tourist resort, September 28. - 30. 1994. Besides the nature itself, we had the opportunity to admire excellent conference capabilities which were offerd to conference organizers by hotel Planja on Zreško Pohorje, where the conference physically took place. Adding also the kindness of hotel management and its staff, we ger perfect picture of the impression the conference made on its participants.

Let me add some statistical data:

- on the Conference 51 papers were presented
- there were totally 68 participants from the following countries:
  Slovenia: 56
  Italy: 4
  Germany: 3
  Switzerland: 2
  Croatia:1
  Czech Republik: 1 and
  Austria: 1

Conference conditions were ideal, scientific level of the presented articles was high, we also can be satisfied with total number of participants and papers presented, but the fact that number of participants from the industry could be compared to number of fingers on one hand leaves quite a bitter taste behind.

Iztok Šorli

UDELEŽENCI KONFERENCE MIEL-SD'94
MIEL-SD'94 CONFERENCE PARTICIPANTS

	Priimek in ime	Firma	Naslov
1	Aljančič Uroš	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
2	Amon Slavko	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
3	Arzenšek Drago	FNT - Kemija in kemijska tehnologija	Aškerčeva 5, Ljubljana 61000
4	Bassanese Elvis	Fakulteta za elektrotehniko in računalništvo	Tržaška 25,Ljubljana 61000
5	Belavič Darko	Institut Jožef Stefan (ISKRA HIPOT)	Jamova 39,Ljubljana 61000
6	Boscardin Maurizio	IRST	POVO, Trento, Italy 38050
7	Brecelj Franc	IEVT	Teslova 30, Ljubljana 61000
8	Cvelbar Andrej	Institut Jožef Stefan	Jamova 39,Ljubljana 61000
9	Della Betta Gianfranco	University of Trento	Via Mesiano 77, Trento, Italy 38050
10	Degen Andrej	FNT - Kemija in kemijska tehnologija	Aškerčeva 5,Ljubljana 61000
11	Delač Antonija	Mikroiks d.o.o.	Dunajska 5,Ljubljana 61000
12	Dell'Acqua Roberto	MITECO	Corsa Cavioli 96, Pavia, Italy 27100
13	Dražič Gordan	Institut Jožef Stefan	Jamova 39,Ljubljana 61000
14	Drofenik Miha	Institut Jožef Stefan	Jamova 39,Ljubljana 61000

15	Furlan Jože	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
16	Godec Matjaž	IMT	Lepi pot 11, Ljubljana 61000
17	Hladnik Prosenc Carmen	ISKRA SEMICON d.d.	Gabersko 12, Ljubljana 61000
18	Hrovat Marko	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
19	Jan Franc	MIDEM	Dunajska 10, Ljubljana 61000
20	Jenko Marjan	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
21	Jenko Monika	IMT	Lepi pot 11, Ljubljana 61000
22	Kausel Wilfried	Semcotec	Seidlgasse 22/13, Vienna, Austria 1030
23	Kosec Marija	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
24	Kren Brane	Mikroiks d.o.o.	Dunajska 5, Ljubljana 61000
25	Križaj Dejan	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
26	Kristoffersson Thomas	SIEMENS AG	Balanstrasse 73, Münich, Germany D 81541
27	Kuščer Daniela	Institut Jožeg Stefan	Jamova 39, Ljubljana 61000
28	Limpel Meta	MIDEM	Dunajska 10, Ljubljana 61000
29	Lipnjak Gorana	Nikola Tesla	Krapinska 45, Zagreb, Croaria 41000
30	Luther Klaus	SIEMENS AG	Balanstrasse 73, Münich, Germany D 81541
31	Malič Barbara	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
32	Marinšek Marjan	FNT - Kemija in kemijska tehnologija	Aškerčeva 5, Ljubljana 61000
33	Maček Jadran	FNT - Kemija in kemijska tehnologija	Aškerčeva 5, Ljubljana 61000
34	Maček Marjan	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
35	Mozetič Miran	IEVT	Teslova 30, Ljubljana 61000
36	Močnik Vojteh	ISKRA EMECO	Savska loka 4, Kranj 64000
37	Ožbolt Stanislav	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
38	Opara Roman	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
39	Pignatel Giorgio	University of Trento	Via Mesiano 77, Trento, Italy I 38050
40	Pirtovšek Ervin	ISKRA RPI IEZE	Stegne 22, Ljubljana 61000
41	Popovič Pavle	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
42	Porenta Robert	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
43	Raič Dušan	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
44	Resnik Drago	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
45	Rožaj Brvar Alenka	Fotona d.d.	Stegne 7, Ljubljana 61000
46	Ročak Dubravka	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
47	Ročak Rudolf	Mikroiks d.o.o.	Dunajska 5, Ljubljana 61000
48	Setter Nava	EPFL	Ecublens, Lausanne, Switzerland 1050
49	Sitar Zlatko	ETH	Hoengerberg, Zürich, Switzerland 8093
50	Skubic Ivan	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
51	Slokan Milan	MIDEM	Dunajska 10, Ljubljana 61000
52	Slunečko Jaroslav	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
53	Smole Franc	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
54	Sokolič Saša	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
55	Starašinič Slavko	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
56	Strle Drago	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
57	Suhadolnik Alojz	Fakulteta za strojništvo	Aškerčeva 6, Ljubljana 61000
58	Topič Marko	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
59	Trontelj Janez ml.	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
60	Trontelj Janez	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
61	Trontelj Lojze	Fakulteta za elektrotehniko in računalništvo	Tržaška 25, Ljubljana 61000
62	Valant Matjaž	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
63	Viefhaus Helmut	Max Planck Ins.	Max Planck str. 1, Düsseldorf, Germany D 40237
64	Vodopicvec Franc	IMT	Lepi pot 11, Ljubljana 61000
65	Zajc Igor	Institut Jožef Stefan	Jamova 39, Ljubljana 61000
66	Šoba Stojan	ISKRA HIPOT	Šentjernej 68310
67	Šorli Iztok	Mikroiks d.o.o.	Dunajska 5, Ljubljana 61000
68	Šuštaršič Borivoj	IMT	Lepi pot 11, Ljubljana 61000

PREDSTAVLJAMO PODJETJE Z NASLOVNICE

Fotona®

30 let raziskav, razvoja in proizvodnje laserskih sistemov
1964 - Laboratorij za tehnično optiko na Zavodu za avtomatizacijo
1975 - TOZD Elektrooptika v Iskri Industrija za telekomunikacije, elektroniko in elektromehaniko Kranj
1981 - DO Iskra Center za Elektrooptiko d.d. v družbeni lasti
1990 - Iskra Elektrooptika d.d. v mešani lastnini
1994 - Fotona d.d. v mešani lastnini

Vsega štiri leta po iznajdbi laserja* je začela skupina strokovnjakov za optiko, fiziko in finomehaniko na ljubljanskem Zavodu za avtomatizacijo raziskovati in razvijati lasersko tehniko.

V enem letu so izdelali prvi laser, ki se mu je do konca šestdesetih let pridružila vrsta različnih tipov laserjev. Trgu so ponudili plinske laserje He-Ne, ki so našli kupce tudi v ZRN.

V začetku sedemdesetih let sta pridobljeno znanje in laserska tehnologija že omogočila izdelavo prvih daljinomerov in njihovo aplikacijo na tankovskih in artilerijskih sistemih. Podjetje je razvijalo instrumente in vse ključne tehnologije: optiko, naparevanje tankih slojev, izdelavo optičnih vlaken, finomehaniko, elektroniko, saj v tedanjem slovenskem in jugoslovanskem industrijskem okolju ni imelo nikakršne ustrezne tehnološke opore, prenos zahodnih pa je bil omejen.

Na koncu osemdesetih let se je dotlej uspešno podjetje znašlo v krizi. Najmanj dva pomembna vzroka sta upočasnila dotedanji hitri razvoj in uspešno gospodarsko rast podjetja: mednarodni položaj v svetu in investicija v 3. fazo gradnje podjetja. Tu so še visoke obrestne mere in nepripravljenost podjetja na prestrukturiranje.

Po letu 1992 je podjetje nastopilo na novih trgih, z novimi, tehnološko izredno zahtevnimi izdelki. Elektrooptičnim instrumentom za vojaško uporabo, so se pridružili medicinski in industrijski laserski sistemi, pomembno so se razvile tudi optične komunikacije.

Danes

PE Elektrooptika je tradicionalen in še vedno najpomembnejši del Fotone s 70 odstotki celotne realizacije podjetja. Izdeluje tankovske sisteme za kontrolo ognja, laserske sisteme za opazovanje in termovizijo. Vse to so tehnološko najzahtevnejši sistemi. S sistemi za upravljanje ognja za ruske tipe tankov je Fotona vodilni svetovni proizvajalec. Tehnološko zahtevne sisteme pa od leta 1993 prodajamo tudi v države NATO pakta. PE Elektrooptika svojo proizvodnjo v glavnem izvaža.
Naročil je dovolj za nekaj let vnaprej.

PE Laser proizvaja laserske sisteme, ki jih uporabljajo v medicini in industriji. V Fotoni je to mlad program, z intenzivnim vlaganjem v razvoj, trženje in proizvodnjo novih izdelkov. Leta 1993 je program udeležen v skupni realizaciji z vsega 6 odstotki, s srednjeročnim načrtom do leta 1997 pa naj bi skupaj z ostalimi civilnimi programi predstavljal kar polovico skupne realizacije. Razvoj PE Laser temelji na dentalnem laserskem sistemu za lasersko vrtanje zob in lasersko zdravljenje paradontoze, oftalmičnih laserskih sistemih, laserskih sistemih za uporabo v dermatologiji, splošni kirurgiji in ortopediji. Pomemben del proizvodnje so tudi industrijski laserski sistemi za označevanje izdelkov. Tudi na tem področju je Fotona v svetovnem tehnološkem vrhu, predvsem z erbijevimi laserji in dentalnim laserskim sistemom. Fotona je eden večjih svetovnih proizvajalcev trdnih laserjev.

PE Optične komunikacije dosegajo 22-odstotni delež v skupni Fotonini realizaciji v glavnem s prodajo na domačem trgu. Izdelujejo optična vlakna in kable, lahko pa ponudijo tudi inženiring, projekte na ključ, optično linijsko in terminalno opremo, opremo za lokalne računalniške mreže, analogni in digitalni videoprenos, spajalni in instalacijski pribor za optične kable. Danes namreč razvijajo, projektirajo in izdelujejo takorekoč vse, kar je potrebno za prenos telefonskega signala, TV-slike, računalniških podatkov, telemetrije in drugih signalov iz stavbe v stavbo ali iz kraja v kraj.

Nadpoprečna izobrazbena struktura

V Fotoni je 462 zaposlenih. Kar 137 (trideset odstotkov) je fakultetno izobraženih, MBA-jevcev, magistrov in štirje doktorji znanosti. Kar šestdeset odstotkov zaposlenih je končalo štiriletno srednjo šolo, kar 93 odstotkov pa se je po dokončani osnovni šoli še dodatno izobraževalo.

Delavci so za visokotehnološko podjetje najpomembnejši in hkrati najbolj omejen produkcijski faktor. Podjetje je namreč edino te vrste v Sloveniji in širši okolici, šolski sistem ne podaja specialnih znanj za razvoj in izdelavo optoelektronskih instrumentov, zato Fotona svoje ključne kadre vzgaja sama. Strokovnjaki se več let usposabljajo ob delu, da lahko začnejo samostojno delati v razvoju ali proizvodnji. V krogu nekaj sto kilometrov je Fotona edini delodajalec tako usposobljenim delavcem. Medsebojna soodvisnost je zato večja kot v drugih podjetjih.

* 1960 je leto iznajdbe laserja v svetu

Fotona d.d.
Stegne 7, 61210 Ljubljana
tel. 061 15 91 215, faks 061 15 91 610, teleks 39518 FOTONA SI

KONFERENCE, POSVETOVANJA, SEMINARJI, POROČILA

45. POSVETOVANJE O METALURGIJI IN KOVINSKIH GRADIVIH
1. POSVETOVANJE O MATERIALIH
14. SLOVENSKO VAKUUMSKO POSVETOVANJE
Portorož, 5. - 7. oktober 1994

Tradicionalnemu posvetovanju o metalurgiji in kovinskih gradivih, so se po zgledu bolj razvitih okolij pridružili strokovnjaki, ki delajo na področju polimernih in keramičnih materialov in zanj pomembnih tehnologij ter na področju vakuumske tehnike, tankih plasti in površinah materialov. Organizatorji združenega posvetovanja so bili Inštitut za kovinske materiale in tehnologije, Kemijski inštitut, Inštitut Jožef Stefan, Slovensko društvo za materiale, Slovensko kemijsko društvo, sekciji za keramiko in polimere ter Društvo za vakuumsko tehniko Slovenije.

Na slavnostni otvoritvi je spregovoril minister za znanost in tehnologijo prof.dr. Rado Bohinc. Predstavil je smernice raziskovalne politike in poudaril pomembnost aplikativnih raziskav in njihove implementacije v industriji.

V znanstvenem programu posvetovanja je 14 vabljenih predavateljev iz Nemčije, Italije, Francije, Avstrije, Madžarske, Slovaške, Češke, Hrvaške in Slovenije, predstavilo pregledna dela s posameznih področij; 4 mladi vabljeni predavatelji pa so otvorili posamezne sekcije mladih raziskovalcev. Ti so predstavili širši slovenski strokovni javnosti v govornih prispevkih svoja magistrska in doktorska dela, nekaj je bilo tudi predstavitev diplomskih del. Vsi, 39 novih raziskovalcev, so odlično predstavili svoja dela, tako je bila komisija pred resnično težko odločitvijo, kateri je najboljši prispevek tako po strokovni plati kot po sami predstavitvi. V sekciji kovinskih materialov sta bila izbrana Darja Steiner Petrovič IMT Ljubljana in Tomaž Godicelj Odsek za metalurgijo in materiale, FNT, Univerza v Ljubljani, v sekciji polimeri je bila najboljša Manica Ulčnik TF, Oddelek za kemijsko tehnologijo Maribor, v sekciji vakuumska tehnika in tanke plasti je bila izbrana Maja Remškar IJS Ljubljana, v sekciji keramika, steklo, ognjevarna gradiva pa so nagradili vse nastopajoče, z obrazložitvijo, da so bili vsi odlični.

Vsa ostala prijavljena dela, ki jih je bilo 114, so bila predstavljena v dveh posterskih sekcijah.

Letošnja razstava je bila številčno sicer bolj skromna, v tehnični sekciji sta se predstavili tvrdki Fotona (prej Iskra Elektrooptika) s področja optoelektronike in Caburn proizvajalec vakuumske opreme iz Velike Britanije.

Dela predstavljena na posvetovanju bodo recenzirana in objavljena v prvi številki znanstvene revije Kovine zlitine tehnologije, ki bo izšla v letu 1995.

V splošnem bi lahko zaključili, da je bilo posvetovanje uspešno, da si v bodoče želimo več predavateljev iz industrijskega okolja in že zdaj vabimo vse strokovnjake, ki delajo na področju materialov k aktivnemu sodelovanju posvetovanja, ki bo tako kot vsa leta do sedaj v Portorožu, od 4. do 6. oktobra 1995.

Monika Jenko

Drugi mednarodni seminar o močnostnih polprevodnikih
2nd International Seminar on Power Semiconductors
Prague, August 31. - September 2., 1994

Od 31. augusta do 2. septembra je bila v Pragi konferenca (seminar) o močnostnih polprevodnikih. Če po pravici povem, sem bil v začetku rahlo skeptičen o pomembnosti konference, kot pač radi podcenjujemo države za odgrnjeno železno zaveso. Ne smemo se torej čuditi, če nas tudi zahodnjaki obravnavajo na podoben način! V resnici je bila konferenca prav dobro organizirana in tudi obisk je bil na dovolj visoki ravni. Predvsem to ni bila splošna mikroelektronska konferenca z več stotimi udeleženci pač pa bolj "domača", specialistična konferenca z jasnim programom. Prišli so vsi ki so imeli sprejet referat (tudi nekateri brez njih) razen predstavnika iz Niša, ki mu menda ni uspelo dobiti vize zaradi blokade "nove Jugoslavije". Udeleženci so bili iz praktično vseh pomembnejših evropskih držav, ki se ukvarjajo z močnostnimi (visokonapetostnimi) polprevodniki. Seminar je bil sestavljen iz štirih delov (sekcij):

- Device Physics and Technology (silicon direct bonding, junction terminations, SOI, ...)

- Power Bipolar Devices (reverse recovery, temperature distrbution in BJT, BJT contra BMFET, GTO turn-off effects, ...)
- Voltage Controled Devices (IGBT, MCT, SIT, VDMOS, Resurf LDMOS)
- Education and Applications (exercises, simulation tools, ...)

Organizatorju je uspelo pridobiti sponzorstvo IEE, ki pa naj bi se odražalo predvsem v reklamiranju konference prek publikacij IEE ter vključitve abstraktov člankov konference v INSPEC bazo podatkov. Poleg tega bo verjetno določeno število člankov objavljenih v reviji Microelectronics Journal (Elsevier).

Konferenca je bila uspešna predvsem zato, ker so bili na njej zbrani raziskovalci, ki delujejo na istih ali pa vsaj zelo sorodnih problemih. Zato so bile tudi diskusije zelo zanimive in izčrpne, vsi udeleženci so se imeli tudi priložnost dobro spoznati in predpostavljam, da se bo iz razgovorov, ki smo jih imeli, rodilo več koristnih sodelovanj. K dobremu razpoloženju je pripomogel vedno ustrežljivi organizator (prof. Benda) iz Praške tehnične fakultete, uspešnost konference pa je zagotovilo tudi samo mesto Praga, ki je polno življenja in neverjetne lepote.

Recept za dobro konferenco (z manjšim številom udeležencev) bi torej lahko strnili na naslednje ugotovitve:

- prijetno mesto konference (velja za vse konference)
- organizator je aktiven in priznan raziskovalec na področju, ki je tema konference
- organizator mora znati poiskati dovolj dober mednarodni komite, ki bo zagotavljal, da bodo na konferenci prisotni tudi uveljavljeni raziskovalci
- cena konference (ne več kot 200 USD)

V vsakem primeru se mora organizator "boriti" za vsakega potencialnega udeleženca, finančni profit pa lahko išče šele iz dotacij sponzorjev, denar iz kotizacije pa naj bo v celoti namenjen za konferenčne aktivnosti!

The Seminar gathered researchers from several European institutions working on power semiconductor devices. Above all, this was not one of the big conferences covering all areas of microelectronics technology, but rather a small specialised seminar devoted completely to the power semiconductor devices. The attendants came from all over the Europe (Ireland, Great Britain, Spain, France, Italy, Germany, Poland, Czech Republic and Slovenia). All the accepted papers were also presented only a representative from Niš was not able to obtain a visa due to the blockade of "new Yugoslavia".

The seminar was divided in four sections:

- Device Physics and Technology (silicon direct bonding, junction terminations, SOI, ...)
- Power Bipolar Devices (reverse recovery, temperature distribution in BJT, BJT contra BMFET, GTO turn-off effects, ...)
- Voltage Controlled Devices (IGBT, MCT, SIT, VDMOS, Resurf LDMOS)
- Education and Applications (exercises, simulation tools, ...)

The author actively participated by presenting his research work on Resurf junction terminations in the paper entitled "Breakdown Properties of Resurf Structures - An Analytical Approach". He was also a chairman of the session on Voltage Controlled Devices.

The organisers succeeded in gaining the IEE sponsorship that reflected specifically in seminar advertising in IEE publications and incorporation of abstracts of the seminar into INSPEC data base. Besides, several articles will reappear in Microelectronics Journal (Elsevier).

The conference was a complete success since all the participants work in the same field and were interested in the same or very similar problems. This lead to extensive, interesting and very fruitful discussions. The social events, lunches and conference breaks offered an excellent opportunity to establish new contacts that will lead to new cooperations between the laboratories. An excellent atmosphere was another contribution of the organisers, Professor Benda and his staff from the Prague Technical Faculty, who were always ready to advise and help. Success of the conference was rounded off by the wonderful city of Prague, its charm, excitements and overwhelming beauty which would endure comparison with the most beautiful European capitals.

This seminar could also serve as an example of a well organised conference. From my point of view the success can be achieved by fulfilling the following basic criteria:

- the organiser should be an active and known researcher in the field covered by the conference (seminar)
- the organiser should establish a strong international scientific conference committee
- the conference fee should not exceed 200 USD
- the conference should be organised at an attractive location

Dejan Križaj
FER/LEE
Tržaška 25
61000 Ljubljana

VESTI

SLOVENIAN-HUNGARIAN-CROATIAN-AUSTRIAN SIXTH JOINT VACUUM CONFERENCE and Third Meeting of Slovenian and Croatian Vacuumologists Bled, Slovenia, April 4-7, 1995

organizirajo Društvo za vakuumsko tehniko Slovenije, Inštitut za kovinske materiale in tehnologije ter Inštitut za elektroniko in vakuumsko tehniko

Združeni vakuumski konferenci Slovenije, Madžarske, Hrvaške in Avstrije, so se pridružile še Slovaška, Češka in Poljska.

Pokrovitelj mednarodne vakuumske konference je IUVSTA - International Union of Vacuum Science, Technique and Applications.

Na konferenci bodo obravnavana naslednja področja:

- uporabna znanost o površinah
- materiali za elektroniko
- tanke plasti
- znanost o plazmi in tehnologijah
- znanost o površinah
- vakuumska metalurgija
- vakuumska tehnika in pridobivanje vakuuma
- nanometrija

Uradni jezik konference je angleščina.

Na konferenci bodo govorni in posterski prispevki. V plenarnem delu konference bodo svetovno priznani strokovnjaki predstavili posamezna področja.

Vabljeni predavatelji:

K. Wandelt, Institut für Physikalische Chemie, Universität Bonn, Germany

D.P. Woodruff, Physics Department, University of Warwick, Coventry, UK

H. Oechsner, Universitat Kaiserlautern,Technische Physik, Kaiserlautern, Germany

J.Greene, Department of Physics, Linkoping University, Linkoping, Sweden

J.E.Sundgren, Department of Physics, Linkoping University, Linkoping, Sweden

R.A.Langley, International Atomic Energy Agency, Vienna, Austria

Gen'ichi Horikoshi, Tsukuba College of Technology, Tsukuba-shi, Japan

D.G. Bauer, Institut fur Halbleiterphysik, Universitat Linz Austria

E. Gornik, Institut für Festkörperelektronik, TU Wien, Austria

F. Varga, Institut für Allgemeine Physik, TU Wien, Austria

H. Stori, Institut für Allgemeine Physik, TU Wien, Austria

R. Dobrozemsky, Institut für Physik,Österreichisches Forschungszentrum Seibersdorf, Austria

L. Guczi, Research Institute for Isotopes, Budapest, Hungary

M. Menyhard, Research Institute for Technical Physics, Budapest, Hungary

L. Kover, Research Institute for Nuclear Physics, Debrecen, Hungary

K.P. Friedel, Institute of Electronic Technology Wroclaw, Institute of Vacuum Technology, Warsaw, Poland

F. Vodopivec, Institute of Metals and Technology, Ljubljana, Slovenia

B. Koroušić, Institute of Metals and Technology, Ljubljana, Slovenia

B. Navinšek Institute Jožef Stefan, Ljubljana Slovenia

B. Gumhalter, Institute of Physics University Zagreb

N. Radić, Institute Rugjer Bošković, Zagreb, Croatia

U. Desnica, Institute Rugjer Bošković, Zagreb, Croatia

Vsa predstavljena dela bodo recenzirana in objavljena v eni od svetovno priznanih znanstvenih revij.

Vzporedno s konferenco bomo organizirali razstavo, kjer bodo proizvajalci vakuumske opreme lahko predstavili manjše eksponate.

Kotizacija je 320 DEM v tolarski protivrednosti, za študente je 150 DEM in za enodnevno udeležbo 120 DEM.

Vabimo vse strokovnjake, ki se ukvarjajo z enim od naštetih področij k aktivnemu sodelovanju. Drugo obvestilo z natančnimi navodili za izdelavo povzetkov, obvestilo o možnostih nastanitve in prijavnico dobite v tajništvu Inštituta za kovinske materiale in tehnologije, 610001 Ljubljana, Lepi pot 11. Zadnji rok za oddajo povzetkov je 15. januar 1995; rokopise del sprejetih v program konference pa bo potrebno oddati na sami konferenci.

Monika Jenko

TEHNOLOŠKE NOVOSTI

Ball Grid Arrays Begin Proliferating

A packaging licensing agreement between Motorola, Phoenix, and Amkor Electronics, Tempe, Ariz., represents a key toward industry-wide acceptance of the ball-grid-array (BGA) package. Amkor 's move to begin high-volume production of Motorola 's overmolded pad-array carries through its sister company, Anam industrial Co., puts more manufacturing musle behind a technology that is emerging as an alternative to fine-pitch QFPs. With an expanded design center and a prototype assembly line in place at its Buchon, Korea facility, Amkor is ready to roll with 169-, 225-, and 313-ball packages.

With Manufacturing Ramping Up Fast

A pioneer of BGA-packaging technology, IBM Technology Products, Somers, N.Y., recently detailed its push to move the package into the industry mainstream. According to IBM's Theresa Doyle, manager of OEM marketing, the transition from periphera-mount SMT packages to BGAs will be a qick one as system houses push for more manufacturable designs with more I/O. To that end, IBM unveiled a full array of design and manufacturing services for packages including ceramic ball with BGA attachment to boards. The company s offering include packages on 40-, 50-, and 60-mil grid formats with I/O counts ranging from 121 to more than 1700.

POSLOVNE VIJESTI

Napomena redakcije: Članak "Small business opportunities in China's semiconductor industry" od R.A.Sanforda prenosimo u cijelosti iz časopisa "Solid State Technology", august 1994. Nadamo se da će članak pobuditi pažnju naših čitalaca.

Small business opportunities in China' s semiconductor industry

The notion that only big companies could open markets in China was certainly true in the 1980s. Recently, however, a number of significant changes have occurred in China 's economic infrastructure, so that is now possible for smaller manufacturers of semiconductor eqipment, components, and consumables, as well as service businesses, to prosper in the Chinese market.

Before laying out some overall principles of doing business in China, I would like to provide some historical context. China stated its intention of developing a massive electronic industry early in its modern history, and electronics industry has remained a high priority through a succession of seven Five-Year Plans. The China National Electronics Import and Export Corp. (CEIEC) is an impressive example of China's trading capability and muscle, ranking as the eight-largest trade corporation in China. Total value of its imports and exports of finished products, ICs, production equipment, and other goods and services grew from $1.2 billlion to $1.8 billion between 1990 and 1992 (see figure). CEIEC has a particular emphasis on the semiconductor industry, but there are about a dozen other organizations actively involved in importing technology and production equipment. These include the China National Machinery Import/Export Corp., China Great Wall Industry Corp., Xinshidai Co., and China Scientific Instruments and Materials Corp.,

Meanhwile, as most in the industry are aware, China's overall economy has seen very rapid expansion. Industrial output grew at a 24 percent annual rate in the first half of 1993, and

VIJESTI IZ POVIJESTI

Tko je najveći ili tko su najveći svjetski proizvođači poluvodičkih elemenata i integriranih sklopova? Ako mislite da na ovo pitanje možete dobiti odgovor uvidom u neku od statistika koje različiti stručni časopisi objavljuju najmanje jedanput godišnje, vi se varate. U takvim statistikama obično se nigdje ne spominje IBM, a upravo ta kompanija je jedan od proizvođača u poluvodičkoj oblasti. Ne samo najveća, nego i, u mnogočemu tehnološki vodeća.

Podsjetiti ćemo vas samo na nekolko činjenica iz bogate povijesti razvoja i proizvodnje poluvodiča u IBM-u.

1959. godina:
IBM je postavio prvi u svijetu potpuno automatiziranu proizvodnu liniju za proizvodnju tranzistora.

1964. godina.
IBM-ova "flip-čip" tehnologija omogućila je proizvodnju čipova sastavljenih od diskretnih tranzistora.

1967. godina.
IBM je pronašao memorijsku ćeliju od jednoga tranzistora (DRAM) i tako omogućio proizvodnju jeftinijih i minijaturnijih memorijskih čipova.

1969. godina.
IBM je pronašao C-4 tehnologiju (Controlled Collapse Chip Connection) što je omogućilo gušće pakovanje čipova uz superiornu pouzdanost.

1971. godina.
IBM je prvi u svijetu uveo glavnu poluvodičku memoriju u kompjuter.

1979. godina.
RISC (Reduced Instruction Set Computing), pronađen početkom sedamdesetih, IBM je uveo u prvi eksperimentalni sistem.

IBM je predstavio MLC-MCM (Multy Layer Ceramic Multy Chip Module) sa uključenih do 9 čipova i 23 keramička sloja.

1986. godina.
IBM je počeo proizvodnju na 8-inčnim pločicama silicija što je omogućilo povećanje prinosa i produktivnosti.

1990. godina
IBM je predstavio ASIC s 400K sklopova izveden u 0.8 mikronskoj tehnici. Time je bilo omogućeno sve makro logičke funkcije staviti na jedan jedini čip.

1991. godina.
Uvedeno je BGA (Ball Grid Array) pakovanje kao proširenje C-4 tehnologije.

1992. godina
IBM-ov "Power pc 601" mikroprocesor prvi je u porodici RISC mikroprocesora i namijenjen je primjeni na osobnim računalima.

Na kraju spomenimo da IBM danas proizvodi najbrži na svijetu mikroprocesor iz porodice 486.

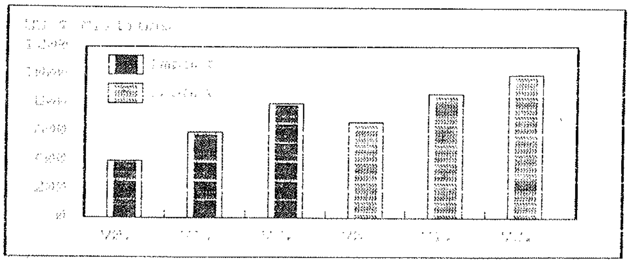
Međunarodne kooperacije

Toshiba, IBM (USA) i Siemens (Njemačka) sporazumjeli su se o zajedničkome razvoju 64 BIT DRAM čipova druge generacije u IBM pogonima u USA. Toshiba već ima razvijen vlastiti 64 MBIT DRAM čip prve generacije. Veličina novoga čipa biti će 20 % manja zahvaljujući primjeni tehnologije finije rezolucije kakva se primjenjuje u proizvodnji 256 MBIT DRAM čipa koji spomenute firme zajednički proizvode na osnovi ugovora iz 1992.godine.

M. Turina

China's gross domestic product grew by 14 percent in the same period. Between 1990 and 1993, US exports to China grew 30 percent overall, and China's export to US grew 60 percent to $30 billion; China now ranks as the US's seventh-largest trading partner, up from 35th in 1979.

Ambitious plans are in place for the Chinese semiconductor industry, which is trying to bring itself gradually up to speed in device technology. Current technology is at the 3.0- to 5.0-micron level on 75- and 100-mm wafers. China is self-sufficient in equipment and materials for these design rules, but requires imports anything more advanced. Plans call for the construction of a relatively small number of major fabs using 125 and 150-mm wafers and 1.0 micron design rules by 1995. Submicron production is to begin in the following five-year period. To get a sense of the expansion, note that overall wafer processing capacity was about 150 million units and 10 million square inches of silicon in 1991; this is expected to grow to 500 million units and 40 million square inches in 1995, when China will have annual IC output of $600 million to $1 billion and a 40 percent growth rate.



Imports and exports by the China National Electronics,

Most of this production will be needed internally for comunications and consumer products. The table shows growth projections for several market sectors.

General business principles

As mentioned, a number of changes have taken place in the Chinese business world over the last decade. One important difference is that a viable managerial infrastructure has been created and is growing at a surprising rate. This infrastructure consisted initially of overseas Chinese who returned to China to set up and manage businesses and of managers from Hong Kong and Singapore who were brought in by joint ventures. More recently, they have been joined by growing numbers of Chinese with training and experience in Western markets-in marketing, sales, operations, and customer-related activities. In addition other Chinese nationals are being trained at home and abroad in response to the rising need for middle managers.

Another important area is the rise of joint cooperative activities with Chinese business partners, ranging from arm's-lenght transactions to joint ventures. The rules governing such ventures are becoming more relaxed, and there are more possibilities and flexibility than ever before in terms of financing tax benefits, and profit repatriation.

With all this in mind, here are some guidelines for planning an approach to the China market:

1. **Define goals and objectives.** Be sure you have a clear picture of what you expect to achieve and in what time frame. Begin with the thought that you are making a three to five year commitment to the China market, particulary if you enter into a cooperative activity with a Chinese associate.
2. **Do preliminary fact-finding and market analysis.** Start by identifying exsisting markets and potential customers. Major fabs dominate the semiconductor industry in China, and any of them are concentrated in the Shangai-Wuxi region. Identify competitors, and determine pricing structure and profit potential.
3. **Profile your product to China.** Eliminate costly and complex non-essential features. The Chinese prefer less automation; simple maintenance and lasting reliability are top priorities. Try to source components or subassemblies locally, and consider local assembly of semi-knocked down equipment. These lower the cost of import items, and there are advantages in tariffs, pricing, and profitability. Consider setting up local sources of spares as a convincing demonstration of your commitment to customers. Service and support are the most important purchase decision criteria. Local components sourcing may also become an exportable advantage for sales to other world markets.
4. **Set up sales channels.** Examine all the options, including representation through an agent based either in the USA, Hong Kong, or elsewhere, or working through a govermental import/export trade organization or jointly with a Chinese partner. In some situations, estabilishing a "direct presence" makes sense either by sharing an office in a major market area or by estabilishing a joint venture for production in China. Do keep in mind the potentially high cost associated with maintaining a local office, and explore a long-term implications, as the situation is changing rapidly.

Case histories

Finally, let's look at some case histories that may help illustrate application of these principles. Company "A" is manufacturer of automated inspection equipment with $18 million in annual revenue, 20 percent of which comes from overseas. Although the firm had a Hong Kong based agent for two years, it had no sales in China. A fact finding trip determined that a Japanese competitor had sold for several years through local agents in the Sanghai and Gounzhou markets. The competing Japanese product was simpler in design and 20 percent less expensive. This crucial information had never been relayed by the agent.

The company decided to work instead with a major trading organization, which located a suitable sales partner. The new partner recommended the several design modifications to lower product complexity and cost. This arm's-lenght joint cooperation has resulted in initial sales in China.

Company "B" provides a specialized barcode reading product and has a strong service orientation. Barcodes are well-accepted.in the West, but are just now being applied in China; the market potential is enormous. Company "B" wanted to determine how it could enter this market and embarked on a fact-finding mission to determine what sector it would fit into and to estimate the potential market and competition.

China electronic equipment production		
	1991	1995
PRODUCT	(actual)	(projected)
Small computers	540	1500
Microcomputers	93 400	400 000
Telephone sets	9.5 million	15 million
Color TV sets	11.9 million	12 million
VCRs	217 000	3 million
Tape recorders	22.9 million	25 million

Building on this research, the company was able to develope a strategy of focusing on niche markets. Competitors were active in two sectors, and we learned that a Chinese company was attempting to develop a local product. A joint cooperation agreement was negotiated that allows to US company enter to China through 48 sales outlets; the Chinese partner benefits by having an immediate product offering for a rapidly growing market.

Company "C", unlike the previous two examples, developed a successful coproduction strategy. The US-based company, a distributor of computer-related products, had terminated a line of unprofitable VGA and TTL monitors, but still owned the technology and manufacturing molds.

The firm signed a coproduction agreement with a Chinese factory, under which 50 percent of production is sold in China and the balance exported to the US partner. Since 1992, over 120.000 units have been produced at a significiant profit because of lowered production costs. The American partner also collects a licensing fee for the Chinese factory's use of the technology and molds.

What about the future?

Small companies can successfuly market and sell a variety of products and services in the China semiconductor market by taking advantage of the offerings to the changing infrastructure and by tailoring offerings to Chinese customers. The expanding mainland economy holds excellent long-term growth potential, especially in the Hong Kong financial and manufacturing power plant plays an effective role in furthering China's global economic position after 1977. Should that occur, China's electronic and semiconductor industries will leap ahead. China's position in the world market continues to improve, and the country will likely became a major trading partner, vying for second or third place in most major industrialized countries. The momentum of massive economic expansion appears to reduce the economic and political downside risk. Time is on the side of the generations of young managers who will provide senior, economic leadership better prepared to compete in the global market place.

We bring some interesting news from latest 1994 issues of ELECTRONICS

MO technology gets global support

Next-generation 3.5-inch optical disks, which exceed compact disks in capacity but add the ability to write and rewrite data, may reach the market as early as 1996. **A consortium of 24 companies has agreed on basic specifications for a 600-Mbyte magneto-optical (MO) disk technology.**

The parties to the agreement include Japan's **Fujitsu, NTT, Canon** and **Hitachi; Hewlett-Packard, IBM**, and **3M** in the U.S.; and Europe's **Philips Electronics NV**. The agreement came out of the efforts of an ISO Working Group at a meeting held in Beijing in late July.

The high-capacity MO drives envisioned by the group would replace the 780 nanometer lasers now used in current MO systems with shorter wavelength 685 nanometer red lasers that are now used in bar code scanners.

The largest current 3.5-inch optical disk systems have a capacity of 230 Mbytes, although **Toshiba Corp.** Of Tokyo recently demonstrated an experimental 3.5-inch drive with a capacity of more than 600 Mbytes (see EL, 23 May, p.3). The Toshiba system uses the rival phase-change optical disc technology.

Supporters of the phase-change approach claim technical superiority, but the MO technology is well established in the marketplace. In addition, the large-capacity MO systems now being planned would be compatible with millions of systems and disks now in use.

MITI AIMS AT 16 -INCH WAFER TECHNOLOGY

Japan's Ministry of International Trade and Industry (MITI) has announced plans to launch a seven -year, US$185 milion research effort to develop 16-inch semiconductor wafers. By doubling the diameter of wafers the number of chips that could be produced from each would be more than tripled. That, in turn, is expected to decrease the cost of chip production by at least half.

Roughly 70% of the funding would be provided by a government- controlled research organization, with the rest coming from 11 Japanese, U.S., and European wafer manufactures. The project does not appear to be motivated by any desire to build market share since the participants already collectively control 90% of the world market.

In order to win funding, the project must be aproved by Japan's conservative Ministry of Finance. If approval comes, it is not expected before December, and the planned launch would not take place until March 1995.

MITI officials say the larger wafers will be particularly valuable for the production of advenced 1-Gbit dynamic RAM memories, a key component for future multimedia applications.

Researchers develop ICs for 600°C

The first results of a semiconductor research project funded by the **BMFT**, Germany's ministry for research and development, have been released: a 20 watt- transistor switch that is able to work at ambient temperatures of 600°C. The transistor is bulit using silicon carbide (SiC), rather than silicon. Due to the fact that SiC's breakthrough voltage is more than 10 times higher than silicon's, **SiC power semiconductors will also be a lot smaller than silicon semiconductors.**

Currently, SiC semiconductors have one big drawback. The 1-inch diameter SiC wafers that are delivered by **Cree Research, Inc.** of Durham, N:C., cost several thousand dollars per wafer.

German companies and organizations that are involved in the DM 15 milion (US$ 10 milion) project include **Siemens AG** of Erlangen, **Daimler- Benz AG** of Frankfurt, the **University of Aachen**, the **Technical University of Ilmenau** and the **Fraunhofer Institut for Applied Solid State Physics** of Freiburg.

One major focus of research is said to be on sensors for high-temperature environments.

Four giants' quixotic pursuit of X-ray lithography

Late last month **IBM Corp.** of White Plains joined **AT&T Corp.** of Holmdel, N.J., **Motorola Inc.** of Schaumburg, Ill., and **Loral Corp.** of New York in the quixotic pursuit of X-ray litography. Robert N. Castellano, president of **The Information Network** in Williamsburg, Va., says X-ray litography has been vying to displace existing lithography equipment since the late 1970s. Spurred on by government funds supporting the project, the four have embarked on a US$ 100 milion project to make X-ray lithography commercially viable.

Castellano asserts that X-rays may be the only method of achieving feature sizes around 0.02 microns. However, conventional lithography equipment, with advances in masks, photo resists and optics, will continue serving the industry's needs until it reaches a feature size of 0.1 micron.

Why do companies continue pushing existing lithography instead of switching to X-ray? Castellano cites the U.S. industry's experience with stepper technology in the early 1980s. "This was a major contributor to the U.S. loss of the dynamic random access memory industry to the Japanese." Castellano asserted. Enamored with new technology, U.S. companies switched to stepper technology to produce 16-Mbit DRAMs and promptly realized a drop in yield from 50% to 10%. Japanese companies chose to gradually switch from scanner technology to stepper technology and maintained their 50% yields.

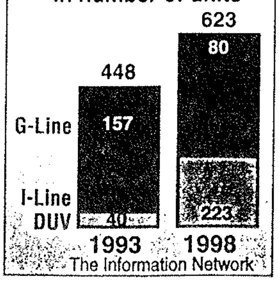
Lessons such as these are not forgotten quickly, and X-ray will have to become the only alternative before the industry switches en masse to the new technology.

LITHOGRAPHY MARKET FAVORS DUV TECHNOLOGY

Deep ultraviolet (DUV) will be the hottest growing lithography technology for the next few years, according to **The Information Network**, a market research firm in Williamsburg, Va. Robert N. Castellano, the firm's president, says **DUV unit shipments will grow 41% from 1993 through 1998.**

However, the largest number of units shipped will be I-line lithography equipment, which has a longer wavelenhgt of light than DUV.

WORLDWIDE LITHOGRAPHY MARKET
in number of units



Castellano said that, to date, only two X-ray lithography machines have shipped, producing US$3.33 million in revenue. Both use a synchrotron lightsource. By 1998, six X-ray units will ship-three will use a synchrotron light source and three will use a laser. The six will produce $5.61 milion in sales.

AMT BUILDING SEMICON R&D CENTER

Hsinchu-based **Applied Materials Taiwan (AMT)** has started construction of Taiwan's first semiconductor processing technology research and develpoment center.

Anticipating 0.25-micron resolution technology beginning in 2000, AMT is putting a class-10 clean room in the center. The completion of this center in Hsinchu Science Industrial Park in August 1995 **will provide maintenance and testing services and improvements on processing technology.**

"The level of Taiwan technology in IC processing is only a few months behind the front-runner countries, no longer behind by two generations,"said Chiam Wu, AMT's general manager. Completion of this US$20 million project will help local IC foundries cut production costs and improve competitive ability, she added.

AMT holds 63% of the Taiwan market in IC processing equipment and technology and is affiliated with Applied Materials Inc. of Santa Clara, Calif.

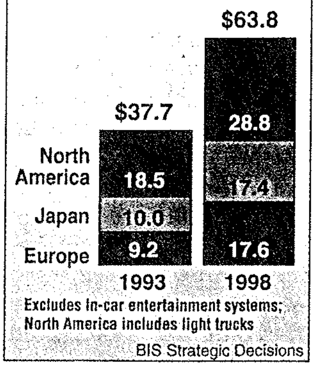
Global auto needs dictate electronics

The evolution of automobiles and drivers is at various stages around the globe, and, as such, the demand for electronics varies. The European market is under pressure by insurance companies to reduce vehicle thefts, requiring immobilization and antitheft systems. The Japan market is honed on comfort and convenience features, such as electronic windows and doors. In North America, emissions-control and safety legislation is to a large extent driving business.

The market with the most potential for auto electronics, though, is the least development-China. Much like the evolving auto industries in Korea and India, the emphasis there is on engine management technology.

Stewart Harris, director of market research for Mountain View, Calif. -based **Tier One**, said he is surprised at how fast the semiconductor companies in Korea and Taiwan have entered the automotive market and the pace of their growth. For now, he added, they're basically supplying their own markets.

AUTOMOTIVE ELECTRONIC SYSTEMS
in billions of U.S. dollars



"Depending on where you go in the world, demands and expectations tend to be different; legislation tend to be different," said Steve Stonestreet, manager of electrical information and control center in **Geneal Motor Corp.'s** North American engineering center in Warren, Mich. Still, GM has to produce vehicles integrating electronic components for all markets.

Stonestreet said this **creates decisions as to how to handle various components-**should instructions be dealt with through software or hardware. GM and its competitors also must decide what software needs to be kept proprietary, and what to distribute with worldwide suppliers. "There are areas where it's important for GM to protect," he added.

MOTOROLA DELIVERS DIVERSITY

Neil Krohn, director of technical sales and engineering with **Motorola Inc.'s** semiconductor product sector automotive segment in Northville, Mich., says Motorola has the edge in supplying the varied global demands for automotive semiconductors. Its IBM (inner module bus) allows auto makers to quickly reconfigure from 16-bit, to 32-bit to PowerPC on one environment.

The **modular architecture offers a span of performance**, he said, and a litany of modules can be plugged into the backplane as design needs mature.

He said the IMB takes the pressure off designers to pick just the right microprocessor for a vehicle that's two to three years down the road. And, from Motorola's perspective, it can produce one architecture at high volume although the uses are as high-end North America or back-to-basics China.

Toshiba to produce ICs in China

Beginning in April 1995, **Toshiba Corp.** of Tokyo will produce bipolar ICs in Wuxi, Jiansu Province, China, in a joint venture with China's largest IC manufacturer, **Huajin Electronics Group Corp.**

A joint venture company, Wuxi Huazhi Semiconductor Co. Ltd, will be incorporated in October with initial capital of US$10 milion. Toshiba will retain a 60% stake in the new company, which will use Toshiba's assembly and test technology.

Wuxi Huazhi Semiconductor will initially produce 2 milion bipolar ICs per month for TV and audio applications. Most of the new plant's production will be earmarked for the rapidly growing Chinese market. Last year, China bought roughly $3 bilion in semiconductors of all types, and that figure is projected to double by 1998.

Toshiba is no stranger to direct investment in China. Threee other joint ventures there manufacture electrical and electronic equipment and parts, including componennts and shadow masks for color TV picture tubes.

Hyundai jumps into TFT-LCD market

Hyundai Electronics Industries Co. has launched a multimilion dolar investement program to develop and manufacture thin-film transistor liquid-crystal displays (TFT-LCDs).

The Seoul-based company announced in early August that it will begin the construction of a plant for TFT-LCD production in September, with total capital spending of 300 bilion won (US$372.3 milion).

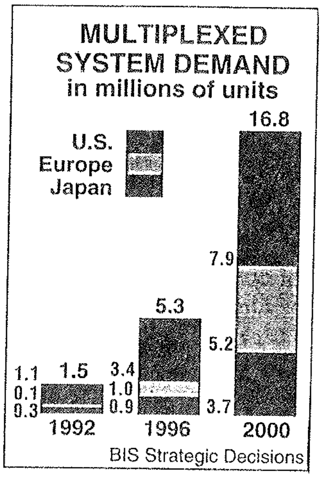
Under the company's plan, the plant, wich is projected to be capable of turning out 40,000 10 -inch TFT LCDs per month, will begin pilot operation in the second half of next year and will start mass production in 1997.

Hyundai's decision to enter the market seems to have been prompted by the success of its subsidiary, Image Quest Technologies Inc. of Fremont, Calif. In June, the company developed a 10.4 inch TFT LCD. It plans to begin sampling in Q4. Recently, Hyundai committed Image Quest to develop a color filter, a key component of TFT-LCDs. Once the filters are developed, Image Quest plans to produce color filters locally.

Multiplexing increases by necessity

Automobiles currently lug around an electrical distribution system that encompasses some 1,500 wires, 1 mile of insulated wiring, 65 pounds of wiring harness, and 2,000 terminals. Given that and the rapid inclusion of more electronic systems in autos, an increased reliance on multiplexed data bus seems inevitable.

Multiplexing enables many electronic signal to use a common databus, thus **eliminating spaghetti-like point-to-point wiring between electronic modules.**



Multiplexed systems are expected to total some 17 milion by the end of the decade, a tenfold increase, according to **BIS Strategic Decisions Ltd.**

The Luton, England, market research firm cites four reasons for the influx of multiplexed systems-increased flexibility and upgradeability, which allows systems to be added without the need for additional wiring; improved test facilities and diagnostics; greater systems integration; and increased reliability and reduced vehicle weight because of reduced size and complexity.

Auto marker have been accused of being too slow to add multiplexing, but they've needed to weigh the advantages, such as design flexibility, against increased costs.

Chuck Hurton, project manager of power generation and wiring for Detroit-based **General Motors Corp.**, said, "Where it makes sense, every one of our three companies is going to include multiplex wiring in vehicles." He said point-to-point systems are an appropriate fit, adding GM has incorporated some multiplexed system since the 1970s.

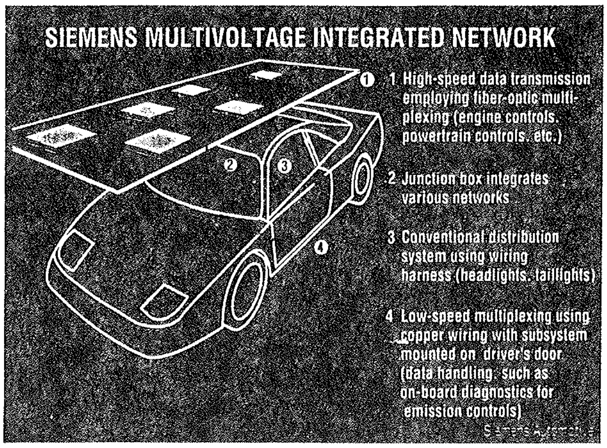
The Big Three are also eyeing multiplexing through the High Speed Serial Data Communication (HSSD) R&D Partnership, which completed a three-year study this spring. HSSD is under the U.S. Council for Automotive Research (USCAR), an umbrella organization for precompetitive research and development. HSSD reviewed six network architectures, communication protocols and both wire- and fiber-optic-based transmission media. It endorsed one protocol and two transmission alternatives, which will remain non-public until they show up on vehicle in about six years, according to Don Walkowicz, executive director of USCAR.

The U.S.-developed J1850 multiplex network protocol could reduce auto wiring size and weight by 25%, says Fred Miesterfeld, HSSD chairman and engineering supervisor for advanced electronics at **Chrysler Corp.**

SIMENS INTEGRATES MULTIVOLTAGE MULTIPLEXING

Simens Automotive in Auburn Hills, Mich., is developing multivoltage systems that combine fiber-optic and copper-wire multiplexed data buses, conventional on-board network solutions and common copper cable harnesses. This, says Siemens, will **allow auto makers to overcome wiring space constraints and implement multiplexing economically.**

The design centers around an electronic junction box that integrates power distribution, diagnostics and bus interfaces, electronic controls (i.e., antitheft alarm), safety functions (fuses), switch functions (relays) and signal distribution. Interference-free data transmitted via fiber-optic multiplexed systems, achieving a rate of more than 125 kbits/s, between engine and transmission control units or airbags. Lower rates, 10 to 40 kbits/s, are carried over copper cable for body electronics and multiline transmission of data.



Multiplex to get diagnostic boot

A multiplexed databus' ability to improve onboard diagnostics capabilities could be the driving factor for more multiplexing in the U.S.

Legislation established by the California Air Resources Board mandates the monitoring of emission control systems and a diagnostic protocol connection for vehicle servicing. That state's requirement could become a national standard and **multiplexed databuses facilitate the transmission of such diagnostic data from control modules.**

The issue of vehicle service ability will also propel multiplexing. As electronic components and systems become more complex, reliance on -board diagnostics will increase.

Multiplexed systems will serve as total communications systems, transmitting diagnostic data into the hands of repairmen. Multiplexing will allow repairmen to **quickly diagnose lamps and switches and electronically recalibrate on-board systems** such as the engine, transmission, breakes, and friction controls.

KOLEDAR PRIREDITEV 1995

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1. V članku je potrebno uporabljati SI sistem enot oz. v oklepaju navesti alternativne enote.

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Dunajska 10, 61000 Ljubljana

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- 4. Ključne riječi na engleskom jeziku (3Key Words) i produženi sažetak (Extended Abstract) na engleskom jeziku.
- 5. Uvod, glavni dio, zaključni dio, zahvale, dodaci i literatura.
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1. U prilogu treba upotrebljavati SI sistem jedinica od. u zagradi navesti alternativne jedinice.

2. Crteže treba izraditi tušem na pausu ili bijelom papiru. Širina crteža neka bude do 7.5 odnosno 15 cm. Svaki crtež, tablica ili fotografija treba imati broj i naziv koji označuje njen sadržaj. Crteže, tabele i fotografije nije potrebno lijepiti u tekst, već ih priložiti odvojeno, a u tekstu samo naznačiti mjesto gdje dolaze.

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Each contribution should include the following specific components:

- 1. Title of the paper and authors' names.
- 2. Key Words and Abstract (not more than 250 words).
- 3. Introduction, main text, conclusion, acknowledgements, appendix and references.
- 4. Authors' names, titles and complete company or institution adress.

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1. Authors should use SI units and provide alternative units in parentheses wherever necessary.

2. Illustrations should be in black on white or tracing paper. Their width should be up to 7.5 or 15 cm. Each illustration, table or photograph should be numbered and with legend added. Illustrations, tables and photografphs are not to be placed into the text but added separately. Hower, their position in the text should be clearly marked.

3. Contributions may be written and will be published in any Yugoslav language and in english.

Authors may send their files on formatted diskettes (1.2 or 1.44) in ASCII, wordstar (3.4 or 4.0), word, wordperfect as text will be formated in Ventura 2.0. Graphics may be in HPL, SLD (AutoCAD), PCX or IMG/GEM formats.

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Uredništvo Informacije MIDEM
Elektrotehniška zveza Slovenije
Dunajska 10, 61000 Ljubljana,
Slovenia

TERMINOLOŠKI STANDARDI

1	2	3	4
2.2.2.14	• Aproksimacija direktne karakteristike pravom • Aproksimacija propusne karakteristike pravcem • Линеарна апроксимација на директната карактеристика • Približek prepustne karakteristike premici	147–0C/IC–2.15 • Staight line aproximation of the forward characteristic • Droite représentant approximativement la caractéristique directe	Približek napetostno-tokovne prepustne karakteristike premici, ki seka to karakteristiko v določenih dveh točkah.
2.2.2.15	• Napon praga • Napon praga • Напон на прагот • Pragovna napetost	147–0C/IC–2.16 • Threshold voltage • Tension de seuil	Vrednost prepustne napetosti, ki jo dobimo s presekom linearnega približka prepustne karakteristike in napetostne koordinatne osi.
2.2.2.16	• Direktna (propusna) struja preopterećenja • Propusna (direktna) struja preopterećenja • Директна струја на преоптоварување • Preobremenitveni prepustni tok	147–0C/IC–2.17 • Overload forward current • Courant direct de surcharge prévisible	Prepustni tok približno iste valovne oblike, kakor ga ima normalni prepustni tok, vendar z večjo vrednostjo od določenega normalnega prepustnega toka. Opomba: Normalni prepustni tok je tok, ki teče skozi element pod stalnimi pogoji.
2.2.2.17	• Udarna direktna (propusna) struja • Udarna propusna (direktna) struja • Ударна директна струја • Udarni prepustni tok	147–0C/IC–2.18 • Surgeforward current • Courant direct de surcharge accidentelle	Tok, ki povzroči prekoračitev mejne virtualne temperature, za katero se predpostavlja, da se pojavi redko ter v omejenem številu takih pojavov v času obratovanja elementa, in ki je posledica nenavadnih pojavov v vezju (npr. stanje napak).

TERMINOLOŠKI STANDARDI

1	2	3	4
2.2.2.18	• Struja oporavka • Struja oporavka • Инверзна струја при исклучување • Zaporni vzpostavitveni tok	147–0C/IC–2.19 • Reverse recovery current • Courant de recourement inverse	Zaporni tok, ki teče v času vzpostavljanja.
2.2.2.19	• Stacionarna inverzna struja • Stacionarna zaporna struja • Стационарна инверзна струја • Uporovni zaporni tok	147–0C/IC–2.20 • Resistive reverse current • Courant inverse résistif	Zaporni tok v stacionarnem stanju brez zapornega vzpostavitvenega toka.
2.2.2.20	• Gubici snage u direktnom smeru, propusni gubici • Propusni gubici • Директни загуби на моќност • Prepustna izgubna moč	147–0C/IC–2.21 • Forward power loss • Perte de puissance directe	Izgubna moč kot posledica prepustnega toka.
2.2.2.21	• Srednji gubici snage u direktnom smeru, srednji propusni gubici • Srednji propusni gubici • Средни директни загуби на моќност • Povprečna prepustna izgubna moč	147–0C/IC–2.22 • Mean forward power loss • Perte de puissance directe moyenne	Povprečna vrednost zmnožka trenutne vrednosti prepustne napetosti in trenutne vrednosti prepustnega toka v eni periodi.
2.2.2.22	• Otpornost definisana nagibom direktne karakteristike • Nadomjesna propusna otpornost • Отпорност на линеарната апроксимација на директната карактеристика • Prepustna naklonska upornost	147–0C/IC–2.23 • Forward slope resistance • Résistance apparente directe	Upornost, ki se izračuna iz naklona linearnega približka prepustne karakteristike.

1	2	3	4
2.2.2.23	• Vreme oporavka • Vrijeme oporavka • Време на исклучување • Zaporni vzpostavitveni čas	147–0C/IC–2.24 • Reverse recovery time • Temps de recouvrement inverse	Čas, ki je potreben za vzpostavitev določene vrednosti toka ali napetosti po trenutnem preklopu iz nič ali označenega stanja prepustnega toka v označeno stanje inverzne polarizacije.
2.2.2.24	• Vreme uključenja • Vrijeme uključenja • Време на вклучување • Prepustni vzpostavitveni čas	147–0C/IC–2.25 • Forward recovery time • Temps de recouvrement direct	Čas, ki je potreben za vzpostavitev določene vrednosti toka ali napetosti po trenutnem preklopu iz vrednosti nič ali označene reverzne napetosti v označeno stanje inverzne polarizacije.
2.2.2.25	• Naelektrisanje oporavka • Naboj oporavka • Полнеж на смирување • Nakopičena elektrina	147–0C/IC–2.26 • Recovered charge • Charge recouvrée	Skupna elektrina, ki se vzpostavi na diodi po preklopu iz določenega stanja prepustnega toka v določeno zaporno stanje. Opomba: To elektrino sestavljajo komponente zaradi kopičenja nosilcev in zaradi kapacitivnosti osiromašenega sloja.
2.2.2.26	• Radni napon (selenskog odvodnika prenapona) • Radni napon (selenskog odvodnika prenapona) • Работен напон (на селенски одводник на пренапони) • Delovna napetost (selenskega omejevalnika prenapetosti)	147–0C/IC–2.27 • Working voltage (of a selenium transient overvoltage suppressor) • Tension de service (d'un limiteur de surtensions transitoires au sélénium)	Izmenična ali enosmerna napetost (razen prehodnih prenapetosti), ki je stalno priključena na selenski omejevalnik prenapetosti.
2.2.2.27	• Napon ograničenja (selenskog odvodnika prenapona) • Proradni napon (selenskog odvodnika prenapona)	147–0C/IC–2.28 • Clipping voltage (of a selenium transient overvoltage suppressor) • Tension d'écrêtage (d'un limiteur de surtensions transitoires au sélénium)	Temenska napetost selenskega omejevalnika prenapetosti pri označenem toku.

TERMINOLOŠKI STANDARDI

1	2	3	4
	• Напон на ограничување (на селенски одводник на пренапони) • Porezalna napetost (selenskega omejevalnika prenapetosti)		
2.2.2.28	• Odvodna struja (selenskog odvodnika prenapona) • Odvodna struja selenskog odvodnika prenapona • Одводна струја (на селенски одводник на пренапони) • Odvodni tok (selenskega omejevalnika prenapetosti)	147–0C/IC–2.29 • Leakage current (of a selenium transient overvoltage supressor) • Courant de fuite (d'un limiteur de surtensions transitoires au sélénium)	Tok skozi selenski omejevalnik prenapetosti pri delovni napetosti.
2.3	Tunelske diode		
2.3.1	Splošni izrazi		
2.3.1.1	• Direktni smer • Direktni smjer • Директна насока • Prepustna smer	147–0/ID–1.1 • Forward direction • Sens direct	Smer toka skozi diodo, kjer ima karakteristika negativno diferencialno prevodnost.
2.3.1.2	• Inverzni smer • Inverzni smjer • Инверзна насока • Zaporna smer, inverzna smer	147–0/ID–1.2 • Reverse direction • Sens inverse	Smer toka skozi diodo, kjer ima karakteristika samo pozitivno diferencialno prevodnost.

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