# ADVANCED METHODS AND TOOLS FOR HANDLING AND ASSEMBLY IN MICROTECHNOLOGY - A EUROPEAN APPROACH IN THE FRAME OF THE FP6 MARIE CURIE RESEARCH TRAINING NETWORK ASSEMIC

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**Key words:** mikrosystems, handling, assembly, training, ASSEMIC network

**Abstract:** Mechatronic competences represent a strong component in Microsystem Technologies, especially in micro-handling and micro-assembly, a field with challenging requirements. An adequate training system for preparing researchers to work in this field must not only integrate all scientific and technical disciplines involved, such as mechanics, control theory, material physics, electronics and micro-systems design, but also provide an industrial perspective and additional skills. The European Research Training Network "Advanced Methods and Tools for Handling and Assembly in Microtechnology ASSEMIC" addresses this need at the European scale, offering an advanced training scheme for early-stage and experienced researchers within an ambitious collaborative research project.

# Napredne metode in orodja za montažo in rokovanje v mikrotehnologijah – Evropski pristop v okviru FP6 mreže šolanja raziskovalcev ASSEMIC

**Kjučne besede:** mikrosistemi, rokovanje, montaža, šolanje, ASSEMIC mreža

**Izvleček:** Mehatronika predstavlja pomembno sestavino v mikrosistemskih tehnologijah, še posebej pri rokovanju in montaži, področju polnem zahtevnih izzivov. Ustrezni sistem šolanja, ki bi pripravil raziskovalce za delo na tem področju naj ne bi vseboval samo šolanja s področja vseh vpletenih tehničnih disciplin, kot so mehanika, kontrolna teorija, fizika materialov, elektronika in načrtovanje mikrosistemov, ampak naj bi tudi postregel z ustreznim industrijskim pogledom in ustreznimi znanji. Prav Evropska mreža šolanja raziskovalcev ASSEMIC na evropskem nivoju ponuja napredne programe šolanja za mlade in izkušene raziskovalce v okviru ambicioznega raziskovalnega projekta.

## 1. Introduction

Handling and assembly of hybrid microsystems has a strongly multidisciplinary nature, requiring a large number of technologies and tools. For tasks relating to microsystem technology alone, it is necessary to integrate expertise in the field of MEMS design, devices for high-resolution positioning and micro-actuators for gripping systems, etc. In addition, many other scientific and technical fields are also involved: material physics (for optimising tool/component interaction and reducing adverse adhesive effects), laser technology (for joining processes, curing glue, etc.), advanced control theory (including artificial intelligence control techniques and visual pattern recognition), and many others.

Micromanipulation techniques can include not only handling of micro-components for assembly of MEMS, but also application fields and challenging tasks. Some examples are microsurgery, manipulation of biological material and micro-robotics. One of the aims of this project is to explore and develop new methods, tools and applications for micromanipulation beyond the limits of traditional assembly techniques for micro-components.

In the last years, MST has turned out to be considered one of the most important technologies. Hybrid MEMS are composed of micro-components with different working principles and functionalities (electronic, optical, fluidic, mechanical…), which need to be integrated and combined into a complete system. As has already mentioned, microhandling and -assembly of MEMS is an issue of relevant importance, since a great part of the total costs in microsystem production is actually derived from the assembly phase.

### 1.1 State of the art

A number of micro-handling stations have been presented in the last years by different institutions and companies. Most of them include on-line image processing, with object recognition and position detection of the tool for closed-loop feedback control, and they can perform certain easy operations in automatic mode. Existing implementations prove the potential and capabilities that such automated micro-assembly stations can offer. However, a number of problems still impede their broad introduction. Some of the topics currently under research include methods to override the limited depth of field in optical microscopes, stereoscopic 3D vision algorithms and calibration procedures for microscopes with adjustable magnification. Relative little work has been made on practical implementation of methods for dealing with the sticking effects in automated systems. On the other hand, some research groups have proposed and tested the use of specific control methods based on artificial intelligence techniques for certain micro-manipulation operations, but the possibilities of these technologies have not yet been fully exploited.

An approach to industrial applications was aimed by a consortium of German institutions (including one of the ASSEMIC participants) in the frame of a national project devoted to the assembly of hybrid Microsystems "Sonderforschungsbereich SFB 440 - Montage Hybrider Microsysteme", focusing on handling and assembly techniques for fabrication of small and medium volumes.

### 1.2 Micro-grippers

In the last years, many research teams have concentrated on the development of new micro-gripper designs. As a result, currently there exist a large variety of tools for micro-handling based on different gripping systems: vacuum, mechanical jaws, making use of the adhesive properties of liquids or ice, etc. The utilized actuation principles also cover a wide range of technologies: a mechanical gripper can be actuated by a piezoelectric element, SMAs, electrostatic combs and many others. However, most methods show disadvantages too, such as hysteresis, heating, too small displacements or limited maximum force. This demands further research to find optimal designs or novel techniques offering improved performance and adaptable functionality.

Some state-of-the-art gripper prototypes comprise also integrated position and force sensors, although most designs are application specific and suitable for laboratory experiments, but lacking the flexibility, robustness and long term performance reliability required for industrial production processes. An effort must be done to create optimised micro-tools with a view to modularisation, exchangeability and closer potential of standardization.

### 1.3 Micro-robotics

In the frame of the project MINIMAN (Nov 1998-Jan 2002), a micro robot was developed with 5 degrees of freedom and a size of a few $cm^3$, able of performing certain manipulation tasks in semi-automated mode. The prototype developed didn't have an immediate short-term market expediency, but the attained experience and results open the way to innovative micro-manipulation technologies with a clearly identifiable route for its take-up by the industry. Further research has been recently started in a concept for a manipulating system consisting of a cluster of miniaturized co-operative robots equipped with wireless communication systems (Micron Project). This and other state-of-the-art results demonstrate the potential of this promising technology. However, it is apparent that a lot of research effort will be needed to bring micro-robotics to a level of maturity, which will enable the real exploitation of its capabilities.

Tele-manipulation is also a topic rising a great interest in the research community. On one hand, it facilitates the task of manual manipulation, as the motion of the operator's hands connected to an adequate haptic interface can be transferred at the proper scale into fine and precise movements needed for micromanipulation. The latest research topics in this field comprise advanced control systems for reduction of hand tremor movement, novel haptic interfaces, 3-D virtual reality systems and utilisation of complementary image systems (such as ultrasound).

## 2. Learning by doing: ASSEMIC's research dimension

The project is structured in several work-packages, defined to address the following main research objectives: ultra-precision positioning, innovative tools for handling and assembly, advanced control methods, application requisites and industrial production. A brief description of the workpackages' content is given below:

WP 1. Micropositioning: Positioning stages and elements with integrated sensors and feedback control, autonomous and mobile systems, microrobotics.

WP 2. Microhandling: Development and test of tools and methods for handling in different environments (normal room conditions, clean room, vacuum, fluids) and applications

WP 3. Microassembly: Innovative tools, special strategies and alternative approaches for efficient high precision and micro-assembly

WP 4. Automation for industrial production: Including production chains, quality assurance, test and characterization issues, etc

WP 5. Know-how management: Technology transfer and dissemination

Some of the expected achievements include the development of a number of system and tools prototypes for handling and assembly in MST, such as an ultrahigh positioning stage using a novel approach, various microgrippers and a haptic interface device for telemanipulation. A number of studies and experiments will be performed to propose and analyse new approaches and improved methodologies (artificial intelligence control, enhanced haptic feedback, optimised industrial production, strategies to prevent adhesion, etc). Finally, several experimental setups will be built to demonstrate and evaluate the developed tools and processes for advanced microhandling operation under different environments (normal room conditions, vacuum, within a fluid…) in various application fields, such as assembly of MEMS and biological applications.

Table 1: Project partners

| | | | |
|---|---|---|---|
| 1. | Institute of Sensor and Actuator Systems, Vienna University of Technology; Co-ordinator | ISAS | Austria |
| 2. | Fondation Suisse pour la Recherche en Microtechnique | FSRM | Switzerland |
| 3. | ARC Seibersdorf research GmbH | Seibersdorf research | Austria |
| 4. | National Institute for Research and Development in Microtechnologies | IMT | Romania |
| 5. | Politechnika Warszawska (Warsaw University of Technolgy) | PW (WUT) | Poland |
| 6. | Instituto de Desenvolvimento de Novas Tecnologias | UNINOVA | Portugal |
| 7. | University of Oldenburg | Uni-OL | Germany |
| 8. | Fundacion Robotiker | Robotiker | Spain |
| 9. | Foundation for Research and Technology – Hellas | FORTH | Greece |
| 10. | Progenika Biopharma | Progenika | Spain |
| 11. | Council for the Central Laboratory of the Research Councils - Rutherford Appleton Laboratory | CCLRC-RAL | United Kingdom |
| 12. | Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.v. | FhG/ILT | Germany |
| 13. | Scuola Superiore Sant'Anna | SSSA | Italy |
| 14. | Nanoscale Technologies GmbH | Nascatec | Germany |

# 4 First research results

## 4.1 Micropositioning

Several issues have been dealt with in this Workpackage till now. The first issue concerning positioning stages was the definition of requirements for the micropositioning system, closely linked to the targeted final application. Thus, several potential target micromanipulation applications (handling of TEM slices, biomedical and biotechnology applications and assembly of optoelectronic components) have been identified with the aim of defining the concrete requirements. Uninova has reported a 3D optical position sensitive sensor, constituted by an array of 1D position sensitive detectors/4/. Further work will focus on its integration in static and/or dynamic positioning systems.

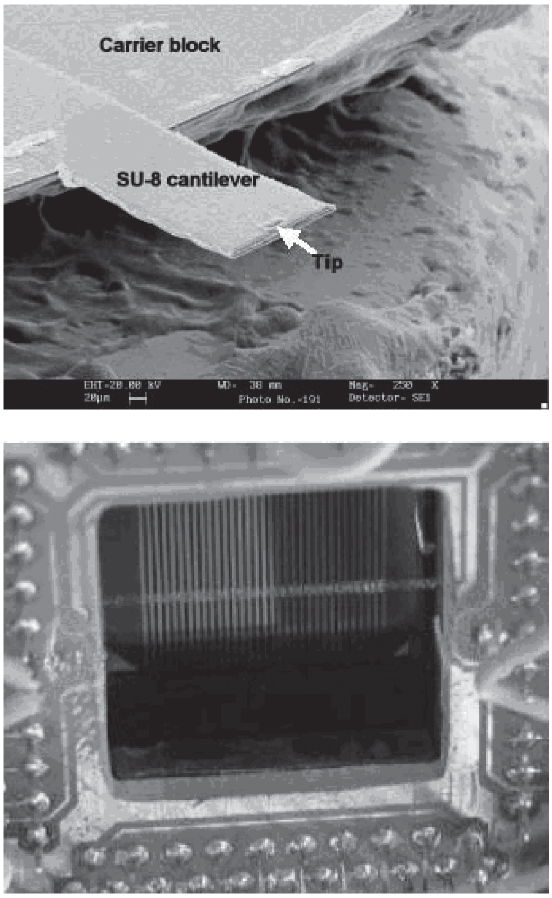


*Fig. 1: Top CCLRC-RAL's cantilever; bottom Uninova's LATFPSD position sensor*

University of Oldenburg has built a new nanomanipulation setup into the vacuum chamber of a Scanning Electron Microscope (SEM), modifying a mobile platform in order to enable its moving around and manipulating the probe on the probe holder.

In addition, work on material issues concerning micropositioning has been carried out by FORTH, including also surface roughness measurements on the microcomponents to analyze friction properties.

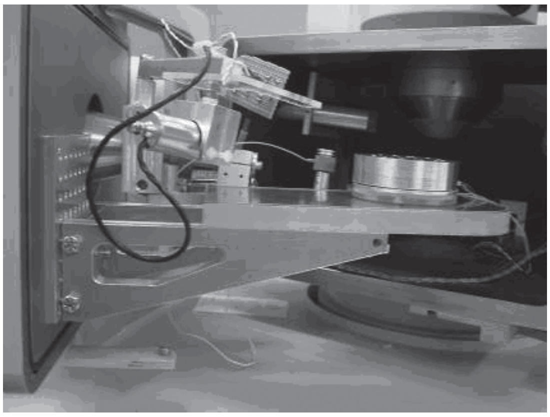

*Fig. 2: University of Oldenburg's set-up for EBD experiments*

## 4.2 Microhandling

Micromanipulation is performed with microgripping tools which can be based on different principles. The most common ones are vacuum grippers and micro-tweezers, but there exist many others, such as adhesive or cryogenic grippers, which make use of the adhesive properties of low viscosity fluids or ice to grip the objects; electrostatic and electromagnetic force grippers, able to handle non-conductive and ferromagnetic objects by exerting on them electrostatic and magnetic forces, respectively; and even more exotic approaches, such non-contact optical pressure object manipulation. Within the task devoted to the development of Advanced Microhandling tools, research has been done on different types of microgrippers, as well as special fabrication methods for such micro-grippers.

Nascatec has reported an electrostatic microgripper and performed additional mechanical simulations by means of Finite Element Analysis (FEM), in order to understand the key contributions to gripper distortion, evaluating the main variables of influence and determine optimum geometrical dimensions and fabrication parameters.

Seibersdorf research recently started experiments to test a microfabrication technology based on combination of LIGA (lithography, electroplating and molding) and PIM (Powder Injection Molding) for producing microgrippers. In contrast with the classical LIGA with injection moulding, used for producing polymer components, this approach enables low cost mass replication of microcomponents in a wide range of materials (including ceramic and metals).

The arms and tips of the microgripper in Fig 4 are fabricated using an amorphous alloy which exhibits excellent soft magnetic and mechanical properties (VITROVAC 7505). Cold laser cutting technique (wavelength $\lambda$=1064, repetition rate 3kHz and power rate P= 123 mW), is used in order to cut both the arms and the tips. The actuator consists of a double layer coil (120 windings in total, wire 70 µm diameter) wound around a highly oriented crystalline

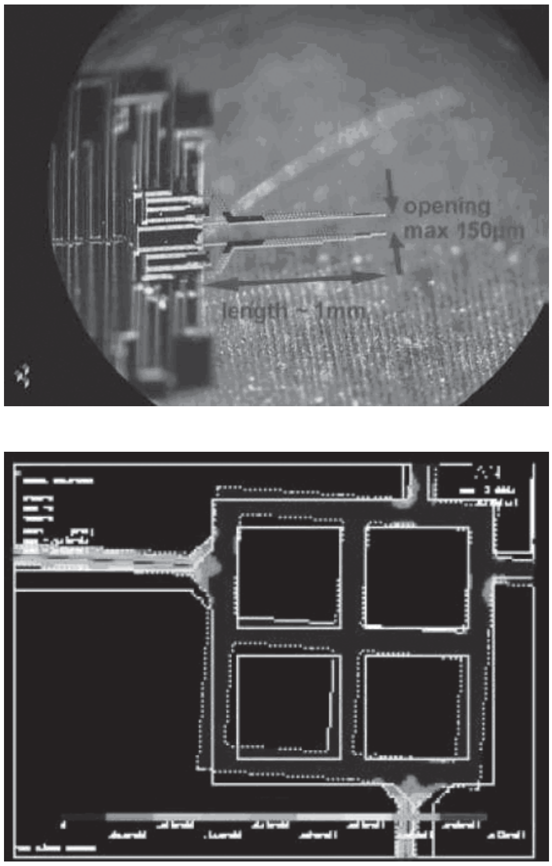


*Fig. 3: Electrostatic gripper and FEM simulation (Nascatec)*

FeSi sheet. Since the easy axis of the FeSi sheet is along its length the core is magnetized longitudinally and therefore generating the desired magnetic field for the actuation of the gripper arms.

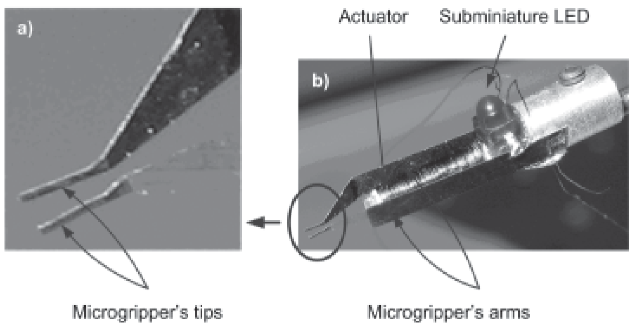


*Fig. 4: Electromagnetic microgripper (TU Wien)*

Politechnika Warszawska–WUT has proposed two solutions for special intelligent coating with controllable adhesion (biomimicry of the handling properties and nano-oscillation substrate of the intelligent coating), applicable for microgrippers. Models were studied and coatings fabricated and tested with AFM /7/. Scuola Superiore Sant'Anna, performed experiments to compare theoretical and real adhesion forces between sample and needle fingertip under different environmental conditions (normal and dry environment).

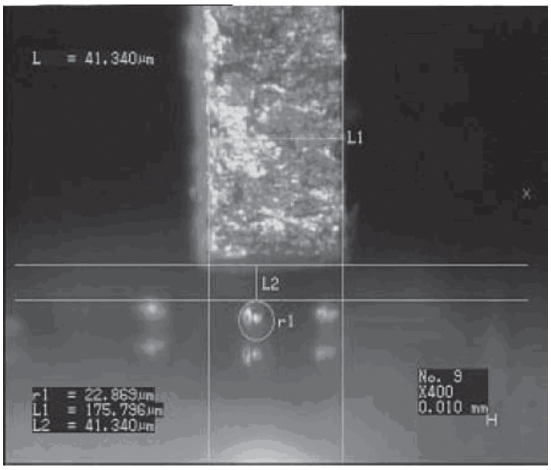


*Fig. 5. Experiments with cubic needle fingertip and spheric object (Scuola Superiore Sant'Anna )*

Sticking effects can be overridden by applying vibration, which helps release the handled object, but have a negative impact in the positioning accuracy. As regards microhandling applications, several application possibilities have been proposed and analyzed by the ASSEMIC participants, in order to test the tools and methods developed in the project. One of them, as reported by the University of Oldenburg, is the manipulation of TEM-lamella in the semiconductor industry. TEM-lamellas are very thin cross-sections of wafers, at specific x-y positions where a fabrication failure has been detected. Such section need to be milled out by using Focused Ion Beam (FIB), extracted from the substrate and finally brought to a Transmission Electron Microscope to be examined.

University of Oldenburg has also adapted and tested tools for manipulation of nanowires (gripping and bonding with the help of Electron Beam Deposition (EBD), with satisfactory results) see Fig. 7.

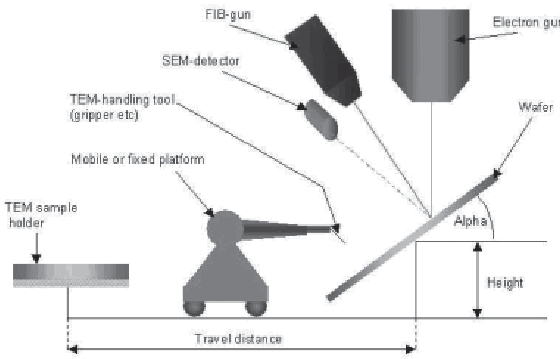


*Fig. 6: General scheme of automated TEM-lamella handling set-up (University of Oldenburg)*

Work has also been done concerning biological and medical applications. A miniaturised fluidic system, lab-on-a-chip (LOC), was designed and fabricated in view of an analytical study of the efficiency of photodynamic therapy on live single cells. Investigations on fabrication processes

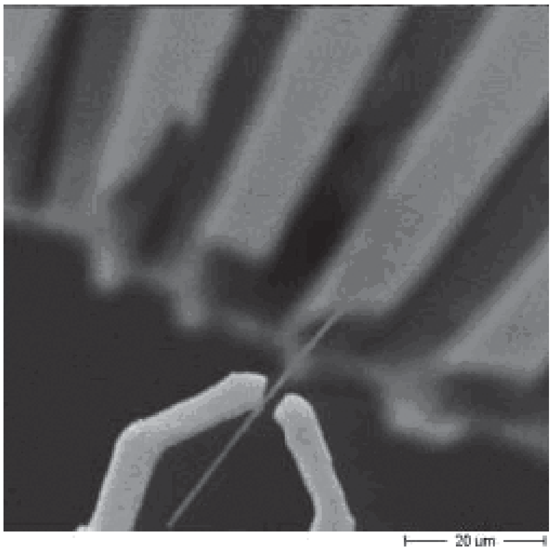


*Fig. 7. Nanowire manipulation (University of Oldenburg)*

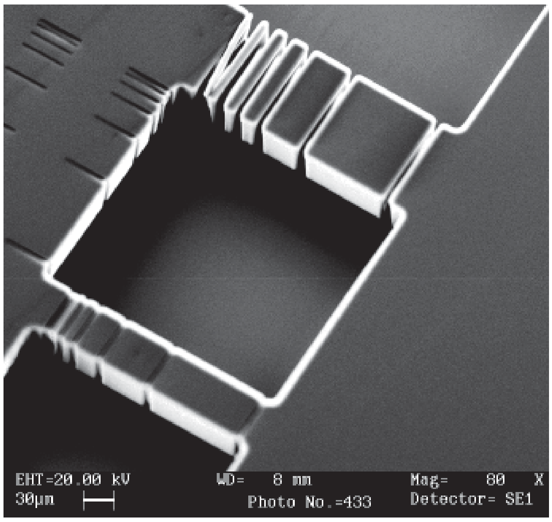


*Fig. 8: SEM images of 5x35µm channels in SU-8 test structure*

were performed and optimal process parameters for polymer SU-8 and over glass bonding technologies were stabilized /8/.

## 4.3 Microassembly

CCLRC/Rutherford Appleton Laboratories and ARC Seibersdorf research plan to cooperate for the use of microstereolithography (µSL) for micro-assembly and packaging applications. µSL technology offers high flexibility and versatility for creation of full 3D complex objects on a microscale.

Further, work related to the assembly, testing and improvement of the 4x4 and 8x8 cross connector switches for optical fibres was done in cooperation between FSRM and the University of Neuchatel. Steps involved in the assem-

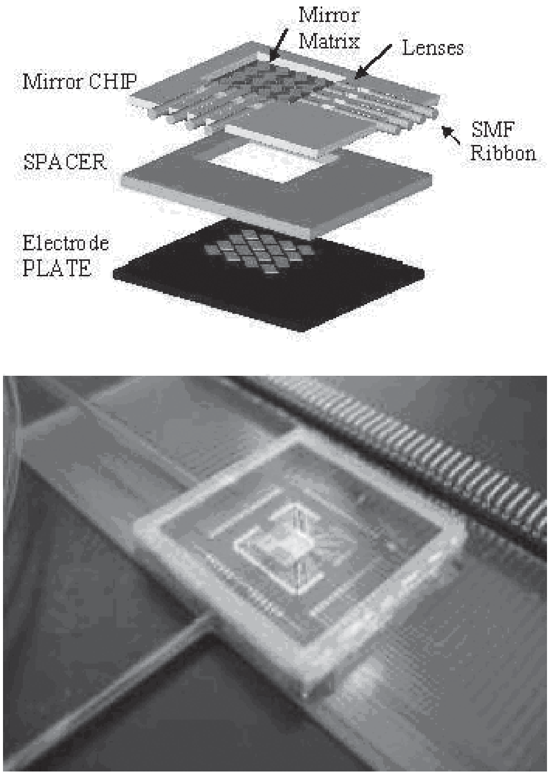


*Fig. 9: Main components to assemble and side view of 8x8 packaged cross connection switch for optical fibre (FSRM/University of Neuchatel)*

bly include cutting, aligning, gluing and testing the different components such as GRIN lenses, mirror chips and fibre ribbon, as well as sealing, wire bonding and integration on the PCB.

A new approach "Multilayer Adhesive Bonding under Hot Air Stream" to adhesive microbonding which can overcome restriction of the conventional MEMS packaging techniques has been investigated. The main advantages of this technique are: low process temperature, localised heating, multi material applicability, partial reversibility, and partial biocompatibility. In proposed technique, the adhesive is deposited on the substrate and then the micro-component is brought and placed at the requested position. Two kinds of adhesives – Polyurethane foil and hot melt glue on the Polyethylene base were investigated /5/.

### 4.4 Automation

A flexible micromanipulation system with stereoscopic imaging was designed, developed and tested aiming to automate the function of a commercially available micromanipulator (Kleindiek Micromanipulator MM3A) and optimize the automation of pick-and-place tasks in the real environment.

## 5. Contact

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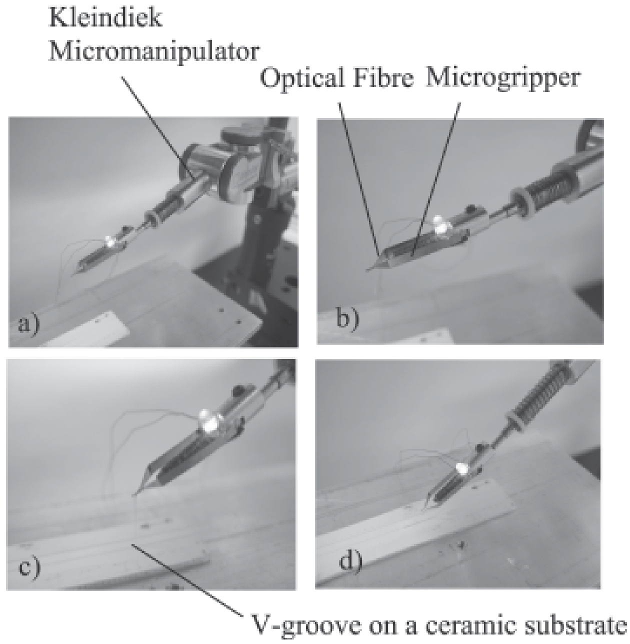


*Fig. 10: Acquired images by the external CCD cameras (left and right camera respectively)*

## 6. Acknowledgment

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