 UDK621.3:(53+54+621+66), ISSN0352-9045

A STUDY OF PLANARIZING PROPERTIES OF THIN BPSG FILMS

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Keywords: IC integrated circuits, microelectronic technologies, planarization processes, topography planarization, BPSG Boro-Phospho-Silicate Glasses, reliability

Abstract: In order to develop a reflow process for planarization of the IC device topography, the reflow angles and structural stability under the influence of humidity of BPSG films have been studied. It has been determined that for planarization purposes the optimal composition of a BPSG film is 3 weight % of boron and 4 weight % of phosphorus. At this composition the transition angles are not minimal, however, structural stability of such films is greatest.

Študija planarizacijskih lastnosti tankih BPSG plasti

Ključne besede: IC vezja integrirana, tehnologije mikroelektronske, procesi planarizacije površine, planarizacija topografije, BPSG stekla boro-fosfo-silikatna, zanesljivost

Povzetek: Z namenom, da bi za idelavo integriranih vezji razvili planarizacijski postopek na osnovi toka plasti borofosfosilikatnega stekla (BPSG) pri visoki temperaturi, smo proučevali nagnjenost nanešene plasti nad stopnico in njeno strukturno stabilnost pod vplivom vlage. Ugotovili smo, da je za planarizacijske namene najprimernejše steklo takšno, ki vsebuje 3 utežne odstotke bora in 4 utežne odstotke fosforja. Pri tej sestavi kot nad stopnico ni najmanjši, toda stabilnost filma je največja.

Introduction

Device planarization, i.e. reduction of distances between topography extremes in the direction normal to the wafer plane and reduction of the side wall slopes in order to facilitate subsequent processing steps, came to the technology forefront as lateral dimensions of ICs began to shrink. Planarization is most critical during the final steps of fabrication, when several metallization and dielectric layers are deposited, and is used primarily to enhance step coverage of these layers. Also, is considerably easier to image fine line geometries on nearly planar surfaces and to etch lithographic patterns into a flat film /1,2/.

There are several planarization techniques used in IC processing /3/. Physical methods include polishing, which is applied where perfect planarization is required, and also different techniques where planarization of existing dielectric layers is attempted by film reflow, etch-back of sacrificial layers etc. Fluidic planarization techniques utilize low viscosity of certain materials, e.g. photoresists, polyimides and spin on glasses, which can fill the trenches in wafer topography. These methods usually require low processing temperatures (below 400 °C) which is frequently advantageous. However, due to poor compatibility of the fluidic materials with the standard dielectric materials in ICs, the application of these methods frequently results in poor device reliability. Therefore, when high processing temperatures are not a consideration, deposition and reflow of doped glasses is still an attractive alternative. In this contribution results of a detailed study, concerning the degree of planarization and defect density, of such a planarization process for a 1.2 μm IC fabrication process is presented.

Experimental

Boron and phosphorus doped glass films (BPSG) were deposited on wafers in a PECVD reactor, Novellus Concept One PECVD System. During the deposition wafers are processed individually in a 6 step process which guarantees physical uniformity of the deposited layers. Silicon source in the process is silane (SiH_4), boron source diborane (B_2H_6), and phosphorus source phosphine (PH_3). Densification and reflow of the deposited films were performed in a Thermco diffusion furnace, according to standard procedures. The composition of resulting films was analyzed by Auger spectroscopy by Balzas Analytical Laboratory, Ca. USA, according to their laboratory specifications.

Transition angles between topography levels were measured directly by electron microscopy; a Hitachi, model 450, SEM was used for taking the micrographs. The number of defects in the deposited films was measured with a Tencor SurfScan, model 4500, surface analyzer.

Results and discussion

It is well known /1,4/ that the composition of the BPSG films critically determines their utilizable properties: addition of boron to phosphorus doped glass film (PSG) reduces the temperature required for the reflow of the film, on the other hand, boron doped glass films (BSG), which possess a conveniently low reflow temperature, are highly susceptible to damage by moisture, resulting in poor reliability of fabricated ICs. Optimization of a planarization process involving BPSG requires a careful balancing of these two tendencies. An optimal composition of the planarization film was sought in the range of 2 – 4 weight percent of boron, and 3 – 5 weight percent of phosphorus in the film. In a preliminary study we have determined that a 650 nm thick BPSG film is sufficient for planarization of surfaces where topography extremes do not exceed 700 nm, and in our study films of this thickness have been used throughout. Deposition parameters and resulting film compositions, as determined by Auger spectroscopy, after a densification (30 min at 920 °C in H_2O vapor atmosphere) and reflow (30 min at 950 °C in oxygen atmosphere) are given in Table 1. All films were deposited at temperature 400 °C, pressure 293.3 Pa and RF power of 1 kW.

Table 1. Deposition parameters and film composition of BPSG films, deposited at temperature 400 °C, pressure 293.3 Pa and RF power of 1 kW, after densification (30 min at 920 °C in H2O vapor atmosphere) and reflow (30 min at 950 °C in oxygen atmosphere).

sample #	w. % B	w. % P	B_2H_6 (lpm)	PH_3 (lpm)	SiH_4 (lpm)
1.	3.1	4.5	0.51	0.49	0.20
2.			0.60	0.47	0.20
3.	2.4	5.4	0.40	0.61	0.20
4.			0.46	0.58	0.20
5.	2.5	3.2	0.40	0.37	0.20
6.			0.46	0.33	0.20
7.			0.32	0.47	0.20
8.	1.6	4.6	0.26	0.49	0.20
9.	2.8	4.4	0.40	0.49	0.20
10.	3.0	4.2	0.40	0.49	0.20

SEM cross-sections samples of planarized structures were treated by a short dip in the Hammond etchant /5/ to increase the contrast. The influence of humidity on the deposited films was determined by exposing films that have not been densified and reflowed to atmospheres of different relative humidity (RH) for different periods of time. The atmospheres were dry nitrogen gas, standard atmosphere in IC fabrication facilities (50 % RH at 21 °C), and atmosphere almost saturated with water vapor (90 % RH at 21 °C).

The degree of planarization, given by the transition angle measured between the normal to the wafer and normal to the sloped side wall of the transition region, was determined on two different test structures. The so called single stack structure is an array of 600 nm thick and 1,2 μm wide parallel aluminum lines formed on a flat, oxidized wafer; in the double stack structure the metal lines are formed on top of oxide lines of the same dimensions, resulting in a 1,2 μm step in topography. Both types of structures were prepared at two different separations of the lines, 1 μm and 2,5 μm (i.e. at spatial frequencies of 2,2 μm and 3,7 μm). The transition angle between the topography levels before the planarization has in all cases been close to 90 deg. The results are given in Table 2. Each number represents the average of measurements on 3 parallel samples and estimated error is around 7 %.

Effects of humidity on the number of defects of different sizes on a 6" wafer is given in Table 3. There is some ambiguity regarding the number of defects, as defects and particulate contamination can not be completely differentiated. An attempt has been made to determine particulate contamination by counting particles under an optical microscope in correspondingly correct the defect count. Complete differentiation could not be achieved, however, our results are in general agreement with published results /1/. From our results a trend regarding the distributions of the defect size with increasing exposure to humidity is apparent: with increasing exposure time the typical defect size is shifted to higher dimensions, implying, that the sizes of individual defects increase due to humidity. After densification and reflow the sensitivity of the film to the humidity is appreciably reduced and is of no further concern. Similar observations have been published elsewhere /6,7/.

On the basis of these results, the optimal composition of a planarization BPSG film has been determined, consisting of 3 weight % of boron and 4 weight % of phosphorus (corresponding to Sample no. 10). At this composition the transition angle between the levels in both kinds of structures is not minimal, however, structural stability of such films under the influence of humidity seems to be greatest. The densification and the reflow times of films prepared for our study are relatively long, which conceivably could be a consideration in their application in a standard production environment.

Table 2. Transition angles in single and double stack structures, after BPSG densification and reflow, at different film compositions.

sample #	w. % B	w. % P	transition angle (deg.)				average angle (deg.)
			line separation 1 μm		line separation 2.5 μm		
			double s.	single s.	double s.	single s.	
1	3.1	4.5	22.7	22.0	19.7	19.0	20.9
3	2.4	5.4	24.6	23.2	23.1	16.4	21.8
5	2.5	3.2	30.8	30.9	33.0	33.5	32.1
8	1.6	4.6	40.0	35.9	36.9	34.3	36.8
9	2.8	4.4	29.8	21.3	30.5	22.2	26

Table 3. Effects of humidity on the number of defects on a 6" wafer at different exposure times.

RH (%)	t (hours)	number of defects of size (in μm)			cumulative
		0.30 - 1.00	1.00 - 2.00	2.00 - 3.00	
90	0	1453	442	109	2004
90	0	2628	904	245	3777
50	0	4716	1324	412	6452
dry N_2	0	2738	823	267	3828
90	2	13627	3623	1569	18819
90	2	3630	687	302	4619
50	2	4627	934	337	5898
dry N_2	2	1138	379	164	1681
90	17	282	528	495	1305
90	17	2020	1415	1310	4745
50	17	1648	2743	1453	5844
dry N_2	17	286	880	710	1876

Conclusion

A detailed knowledge of the processing parameters of the planarization process and planarizing film properties is required in order to develop a successful planarization process. In particular, degree of planarization and influence of environmental humidity on planarizing films should be considered. By a detailed study of both requirements, which by themselves are contradictory, a useful planarization process by reflowing BPSG has been established.

Acknowledgements

The authors gratefully acknowledge the use of IMP, San Jose, Ca., USA, facilities. Special thanks are due to Mr. A. Belič of IMP for illuminating discussions regarding the utility of the developed process. The study has been supported by a grant from the Ministry of Science and Technology of the Republic of Slovenia.

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Prispelo (Arrived): 29.05.2000 Sprejeto (Accepted): 10.06.2000