Application of Chemically Amplified Resists in Direct Electron-Beam Writing for Submicro- and Nanometer Deep Anisotropical Structure Transfer

P. Hudek[a], G. Stangl[b], I. Kostic[a], I.W. Rangelow[c], W. Fallmann[b], W. Friza[d]

[a]Institute of Computer Systems, SK-842 37 Bratislava, Slovakia

[b]Technical University of Vienna, A-1040 Vienna, Austria

[c]Inst. of Technical Physics, University of Kassel, D-34132 Kassel, Germany

[d]Siemens AG, A- 9500 Villach, Austria

In this paper, the performance of single layer Chemically Amplified Resist (CAR) systems in direct write Electron-Beam Lithography (EBL) and Reactive Ion Etching (RIE) for anisotropical structure transfer into bulk silicon, SiO_2, GaAs, and niobium films have been investigated. The resist types we used were AZ PF514 (positive) and AZ PN114 (negative) from HOECHST AG. 30keV electrons were used to study the pre- and post-exposure processing on the resulting resist-relief structures. Direct write, shaped EBL generated, resist patterns at 0.5µm and below were deeply transferred utilising RIE, and RIE with Magnetic Enhancement (ME-RIE).

1. Introduction

The developments in microelectronic manufacturing have shown the need to find simple technological methods to perform conformal deep structure transfer with high anisotropy into the substrate. The most critical processes in this are lithography and dry etching. For both processes, the resist used is the most critical factor. Conventional high-resolution resist materials in the direct EBL process show low sensitivity, poor dry etch durability, and swelling when developed by using organic solvents. It has been shown [1] – [4] that Novolak-based CARs can be used in EBL as well as in the deep UV exposure mode, which can be developed in an aqueous alkaline solution. In this paper, these types of materials are evaluated with regard to its possible application as masks for micromachining as well as for quantum- and cryo-electronics.

2. Experimental

The positive AZ PF514 and negative AZ PN114 deep UV CARs were exposed to electrons by using shaped EBL (modified Zeiss-Jena e-beam pattern generator ZBA 10/1). The pattern transfer by dry etching was carried out using an Oxford Instruments µ-80 RIE-system. Additionally, magnetic enhancement was adopted (ME-RIE). We choose Br_2, Cl_2/HBr and Cl_2/Br_2 and Ar as additives. The temperature of reactor and Br_2 gas line was kept thermostatically at 35°C. The chamber was enclosed within an N_2-purged glove box. Etch rate, selectivity, and etch uniformity were measured by a profilometer. The patterns were estimated using high-resolution FE-SEM (Hitachi S-4000) and Scanning Probe Microscopy (SPM) in AFM-mode.

The 30keV fine-line shaped EBL in single layer AZ PF514 and AZ PN114 is demonstrated on silicon, GaAs and thin Nb-film to realise micromechanical, quantum- and cryo-electronic structures. We optimised the resist handling processes to obtain resist-relief structures in the submicro- and nanometer region with nearly vertical sidewalls and a high aspect ratio, which is an important assumption for a good RIE-transfer. An exposure test was developed [3] to determine the main lithographic resist parameters and to verify the simulation method of the lithographic process. An optimised dose/ geometry proximity correction is required to resolve submicro- and nanometer structures at higher resist thicknesses. To analyse the image distortion (proximity-) effects we applied our EBL-process simulations [5] from previous investigations [3] with some modifications. The computational method is based on the suggestions described in [6], where we have suggested an experience oriented phenomenological modelling. For the evaluation of 3-D developed resist profile, the calculated threshold absorbed energy density level in the resist volume was matched to the experimental resist profile contour. The most obvious discrepancies between simulation and experiment occurred at (i) the resist top surface for positive AZ PF514-resist [1] and (ii) the resist-substrate interface [2] for negative AZ PN114 resist. Figure 1 shows this effect in a 2µm thick AZ PF514 resist for 50nm line-exposure. The resist surface is airborne contaminated mainly by organic amine groups and it is looking like as an orange skin. This creates a low solubility surface layer with regard to the wet chemical developing process and causes the so-called "T-top" line profiles or "filling" and "bridging" effects [7].

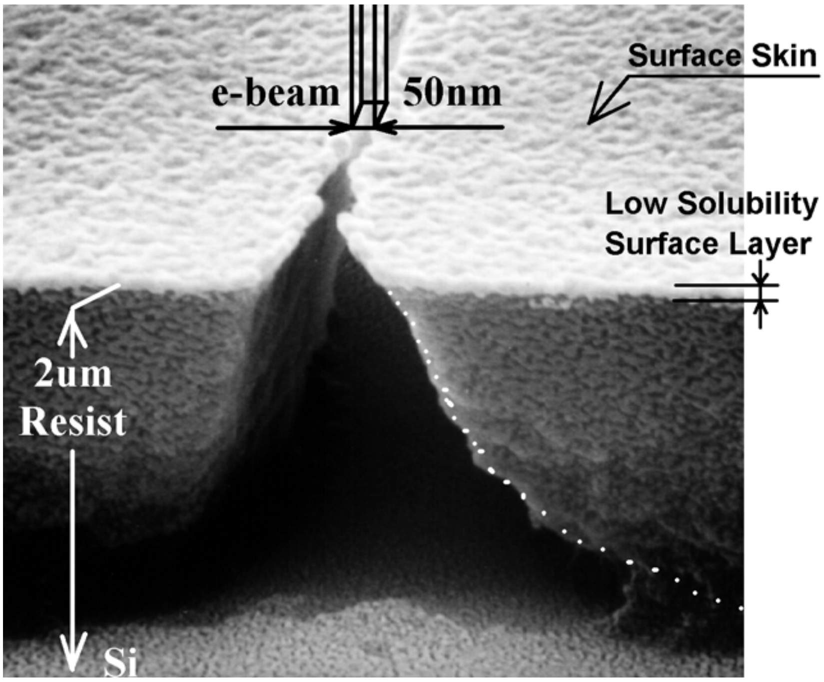

Fig. 1: Surface layer formation.

Fig. 2 shows the effect of gel-formation in 1µm thick AZ PN114 on the resist-substrate interface, which is a badly defined thin film residue outside the exposed area if the structure detail is even slightly overexposed owing to the proximity effect. If the absorbed energy exceeds a certain value locally, then the cross-linking reactions (initialised by post-exposure-bake PEB process [8]) form an insoluble gel fraction visible after development.

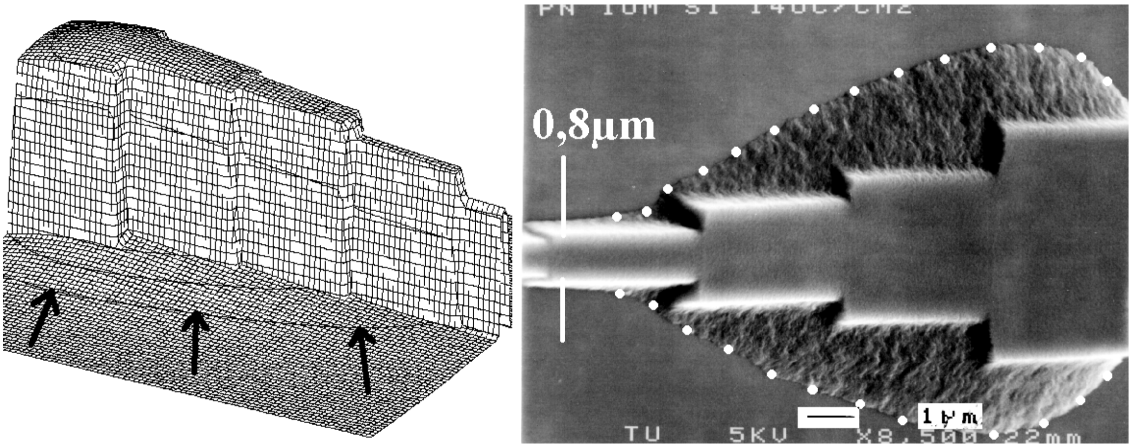

Fig. 2: Effect of gel formation at the resist-substrate interface.

For closely spaced structures both effects cause strong shrinking of the process latitude, and the exposure requires an additional geometrical correction to avoid the resist pattern distortion. Therefore, the CD-control is very strongly dependent on the stability of the EBL-system and on the pre- and post-exposure processing of the resist film. A more powerful proximity correction is required for these materials as for non-chemically amplified conventional resists.

Fig. 3a shows the resist structure from Fig. 2 after RIE-transfer in Cl_2/HBr plasma into silicon. Fig. 3b shows the same RIE transfer of the proximity-corrected resist-relief structure. Fig. 3c shows the quality of the etched structures if the resist relief has nearly vertical side-walls in the requested film-thickness.

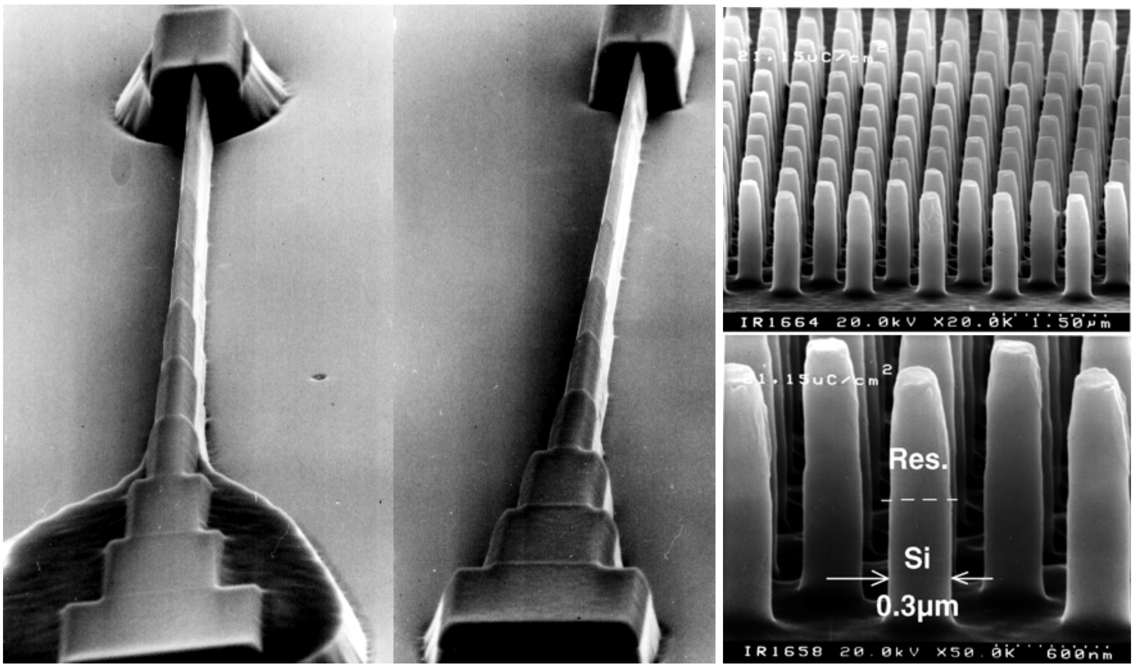

Fig. 3: RIE-transferred resist structures in Si:
a. Uncorrected b. Corrected c. Etched silicon tip-array

3. Conclusion

The advantages associated with the extremely low dose requirements and high selectivity in the plasma etching process are paid for by increased resist pre- and post-exposure complexity and difficulties in CD control. The single layer process presented here can be used for silicon micromachining, high resolution Open-Stencil-Mask fabrication on silicon membranes, grating structures for x-ray diffraction, vacuum-, cryo-, quantum-, and opto-electronic devices, etc. It was demonstrated that both positive and negative resists used here are capable to pattern submicron features down to 0.1µm in relatively thick layers.

Acknowledgements

This work was supported in part by the Austrian East-West-Project (OWP-92 GZ 45.291/ I-IV/6a/93) and in part by the Slovak Grant Agency for Science (Grant No. 2/999486/93).

References

[1] P. Hudek, Z. Borkowicz, I. Kostic, I.W. Rangelow, R. Kassing: "Single Resist Layer for Deep- Submicro- and Nanometer Silicon Structuring", Microelectronic Engineering, Vol. 21, 1993, pp. 283-288.

[2] I.W. Rangelow, P. Hudek, I. Kostic, Z. Borkowicz, G. Stangl: "Submicro- and Nanometer E-Beam Lithography and Reactive Ion Etching with Single Layer Chemically Amplified Resist", Microelectronic Engineering, Vol. 23, 1994, pp. 283-286.

[3] I.W. Rangelow, Z. Borkowicz, P. Hudek, I. Kostic: "Transfer of Single Layer Positive Resist Submicro- and Nanometer Structures into Silicon", Microelectronic Engineering, Vol. 25, 1994, pp. 49-66.

[4] P. Hudek: "Electron-Beam Lithography for Submicrometer Mask Making", EUROFORM Seminar on "Lithography of Submicron Structures", COMETT, Aachen, 8-10. Nov. 1993.

[5] P. Hudek, PhD-Dissertation, Slovak Technical University, Bratislava, 1987.

[6] T.H.P. Chang: "Proximity Effect in Electron-Beam Lithography", J. Vac. Sci. Technol., Vol. 12, 1975, pp. 1271-1275.

[7] P. Hudek, I.W. Rangelow, I.S. Daraktchiev, I. Kostic: "On the Application of Chemically Amplified Positive Resist to Micromachining", Microelectronic Engineering, 1995 (to be published).

[8] Ch. Eckes, G. Pawlowski, K. Przybilla, W. Meier, A. Madore, R. Dammel: "Process Latitude for Chemically Amplification Resists AZ PF514 and AZ PN114", SPIE, Vol. 1466, 1991, 394-407.