Proton beam micromachining on strippable aqueous base developable negative resist

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ABSTRACT

Nowadays a significant amount of research effort is devoted to the development of technologies for the fabrication of microcomponents and microsystems worldwide. In certain applications of micromachining high aspect ratio (HAR) structures are required. However, the resist materials used in HAR technologies are usually not compatible with the IC fabrication, either because they cannot be stripped away or because they are developed in organic solvents. In the present work the application of a novel chemically amplified resist for proton beam micromachining is presented. The resist based on epoxy and polyhydroxystyrene polymers is developed in the IC standard aqueous developers. The exposed areas can be stripped away using conventional organic stripping solutions. In order to test the exposure dose sensitivity and the lateral resolution, various test structures were irradiated.

INTRODUCTION

Most typical resists in P-beam writing: PMMA poly(methylmethacrylate) conventional positive resist
SU-8 chemically amplified negative resist

SU-8 crosslinking chemistry: based on the eight epoxy rings in the polymer chain, which provide a very dense three dimensional network and can be stripped away only with plasma processes or with special liquid removers. Moreover, the SU-8 developer is organic, propylene glycol methyl ether acetate (PGMEA), and thus environmentally non-friendly.

New negative resist formulation developed recently: solubility change is not based solely on cross-linking but also on the differentiation of hydrophilicity between exposed and non-exposed areas. An aqueous base developable (IC standard aqueous developers (tetramethyl ammonium hydroxide - TMAH 0.26N)) epoxy resist based on a specific grade epoxy novolac (EP) polymer, a partially hydrogenated poly-4-hydroxy styrene (PHS) polymer, and an onium salt as photoacid generator (PAG), has been proposed and successfully applied for UV-LIGA. This resist presents less or no swelling and reduced roughness problems compared to the pure epoxy novolac resists and in addition the exposed (crosslinked) areas can be stripped away using conventional organic stripping solutions.

The aim of this work: investigate the exposure dose sensitivity and the lateral resolution of this family of (CA) resists for PBM using the Debrecen Scanning Nuclear Microprobe facility.

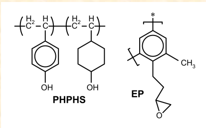
EXPERIMENTAL

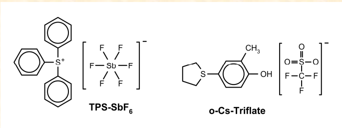
Irradiation: 2 MeV protons, beam currents 5 - 60 pA, 2 - 3 µm spot size, 1000 µm scan size.

Dose measurements: backscattering signals, by PIN detector array, total area 400 mm^2

High count rate ⇨ pixel normalisation

resist A: 35% (w/w) total polymer concentration in ethyl(s)-lactate.
The polymer: mix of 83% (w/w) partially hydrogenated poly(4-hydroxy styrene) (PHS) with 8% degree of hydrogenation
17% (w/w) epoxy novolac (EP)
Photoacid generator (PAG): triphenyl sulfonium antimonite (TPS-SbF_6) 5% (w/w)



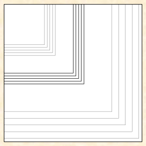


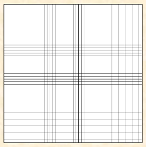
resist B: 35% (w/w) total polymer concentration in ethyl(s)-lactate.
The polymer: mix of 78% (w/w) PHS
12% degree of hydrogenation
22% (w/w) EP
PAG: 1-(4-hydroxy-3-methylphenyl) tetrahydrothiophenium triflate (o-CS-triflate) 3% (w/w)

Compositions of formulations were selected after lithographic performance optimisation for UV-LIGA.

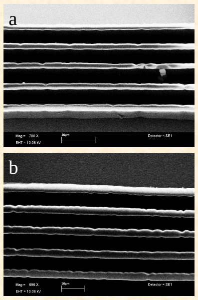
RESULTS AND DISCUSSION

For the evaluation of the resolution and aspect ratio capabilities of the resists A and B suitable irradiation patterns were designed consisting of horizontal and vertical lines at various distances. In particular there were **five lines of *a)* 1 pixel width spaced by 20 pixels, *b)* 3 pixels width spaced by 20 pixels, and *c)* 1 pixel width spaced by 50 pixels.**

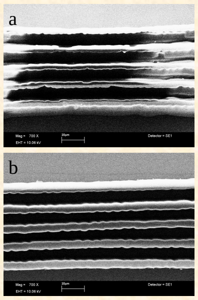




These patterns were irradiated at 10 different doses on 4 samples of each formulation. The scan resolution was 1024 pixels, the scan size was 1000 µm, and therefore the developed line widths were thicker than the pixel size due to our beam spot size. The samples were exposed at doses from 100 to 640 nC/mm^2. Top-down SEM images have been done from both resist formulations on all irradiations.



Representative results in case of PEB at 100°C for 8 min. The resist A (above) needs high dose (344 nC/mm^2) in order to resolve structures as small as 5 µm. Moreover, this resist exhibits swelling and adhesion problems when it is developed for long times. Resist B (below) shows much better results at smaller exposure dose (238 nC/mm^2) without exhibiting adhesion problems.



SEM images of both resists at almost the same exposure dose (116 nC/mm^2 for resist A, and 125 nC/mm^2 for resist B); PEB 110°C for 8 min. The increased temperature of PEB helps significantly the crosslinking reaction (in both resists the necessary exposure dose was smaller for the 110°C PEB than for the 100°C PEB irradiations). The resist A did not fully develop, whereas the resist B is fully developed. Therefore the resist B is more sensitive and also needs less development time than resist A.

CONCLUSIONS

Proton Beam Micromachining was performed at the Institute of Nuclear Research of the Hungarian Academy of Sciences on novel chemically amplified resists. The proposed resists are based on epoxy and polystyrene polymers, and they are developed in the IC standard aqueous developers. The exposed areas can be stripped away using conventional organic stripping solutions, thus these materials are very promising for electroplating. A PIN diode array was used for dose normalisation. The detection efficiency for backscattered ions was so high that we were able to run pixel normalisation.

Both tested formulations in the present work need about 125-238 nC/mm^2 dose. This is higher than that of the SU-8, but the tested formulations have the advantage of using IC industry developer solutions and easy stripping in acetone. Using this formulation 5-8 µm wide lines with aspect ratio 4-6 were resolved.

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