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Applications of Novel High-Aspect-Ratio Ultrathick UV Photoresist for Microelectroplating

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***Abstract*—The new acrylic photoresist named AZ 125 nXT is a serious option for low-cost high-aspect-ratio UV LIGA applications. It offers advantages compared to SU-8 like good adhesion to Si substrates, rapid processing, and easy removal after electroplating. Film thicknesses of 400, 800, and 1400 μm with an aspect ratio of 20 : 1 have been shown by the authors. The photoresist's excellent electroforming behavior has been proved in an extremely acid copper electrolyte at room temperature as well as in an almost neutral nickel electrolyte at 50 °C. The easy removal (wet: dimethyl sulfoxide or acetone, dry: plasma with reactive radicals) releases freestanding metal structures with aspect ratios of 13 : 1 and 16 : 1. [2010-0307]**

***Index Terms*—Microelectroplating, negative photoresists SU-8 versus AZ 125 nXT, UV LIGA, wet removal.**

I. Introduction

Microcomponents often require a high aspect ratio. Hence, the requirements on thick UV photoresists for applications in microsystems have increased. In recent years, the LIGA process with an SU-8 negative photoresist has been preferred for low-cost fabrication of components like electroplated gears [1], [2], microcoils, and micro-heat exchangers [3].

Positive thick resists, e.g., the AZ 9200 series, are not suitable for layer thicknesses beyond 150 μm [4]. SU-8 is well known for low optical absorption in the UV range and excellent vertical sidewalls. Further advantages are good mechanical properties. Microstructures with thicknesses exceeding 1000 μm with aspect ratios of 30 : 1 have been reported [5], exceptionally even 50 : 1. For electroforming applications, SU-8's main disadvantage is its high chemical resistance when cross-linked. Wet chemical stripping without harming the metal microstructures is usually not possible [6]–[8]. A dry-etching process (20 μm/min) for SU-8 with a special remote plasma source is available [9]. These difficulties in stripping should be eliminated by the new negative photoresists KPMR 1000 and AR-N4400 (CAR44). However, both resists could not prevail in practice for reasons such as complex stripping with many steps or impractical storage at -10 °C [10]–[12].

In prior publications, the new photoresist AZ 125 nXT is characterized with respect to a maximum thickness of 200 μm, with electroplating level up to 160 μm. Optimized lithography parameters achieve straight and nearly vertical sidewall profiles. The photoresist has been found to be easily stripped without residues in solvent-based solutions [13].

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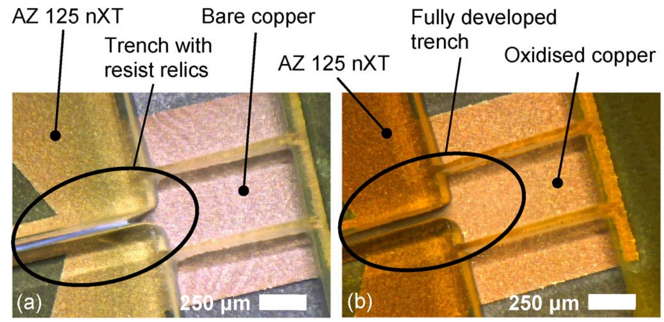

Fig. 1. Small cavity with (a) a partly cross-linked photoresist due to optical diffusion and (b) a fully developed photoresist free of residues.

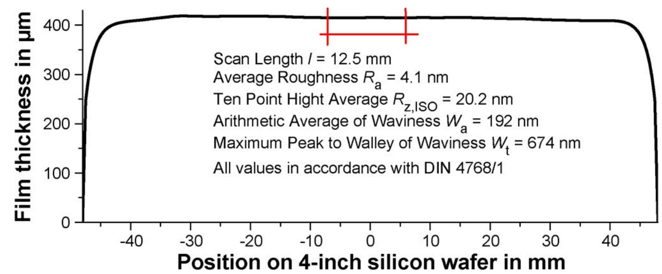

Fig. 2. Film thickness homogeneity along the entire diameter of a 4-in Si substrate.

This letter focuses on ultrathick AZ 125 nXT microforms up to 1400 μm in thickness for electroplating that represent an adequate SU-8 alternative.

II. Spin Casting

In this work, 4-in silicon and printed circuit board (PCB) material are used as substrates. The electrical plating base consists of copper or nickel. To some substrates, a copper sacrificial layer of 25 μm thickness is added by electroplating.

If the substrate reflects diffusively, the surface has to be darkened, e.g., by oxidation in the case of copper. This ensures developing even small cavities with a width of 50 μm and a height of 400 μm (see Fig. 1). The same procedure can be used for SU-8 UV lithography. No other special substrate pretreatment is necessary to process AZ 125 nXT.

The photoresist is applied using a slow ($<$ 100 r/min) spin cast process (SUSS Delta 80 BM GYRSET). Thus, all the resist remains on the substrate, and no edge bead appears. Putting the substrate on a justified hot plate covered by a Petri dish, the surface levels due to the gravitation (see Fig. 2).

III. Softbake

The remaining liquid part is an adequate indicator for the softbake time using aerated hot plates. Duration and temperature have to be tailored for a remaining liquid amount between 12.5% and 25% (see Fig. 3). Below 12.5%, the photoresist is not developable; beyond 25%, the photoresist is too soft to be handled. The remaining liquid percentage was determined by a high-precision balance.

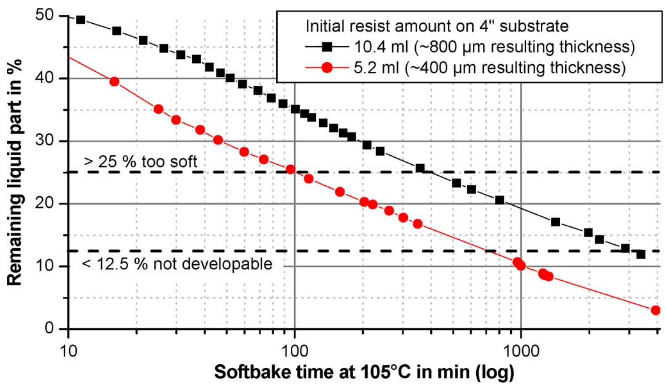

Fig. 3. Measurements of liquid mass fraction versus softbake time at 105 °C.

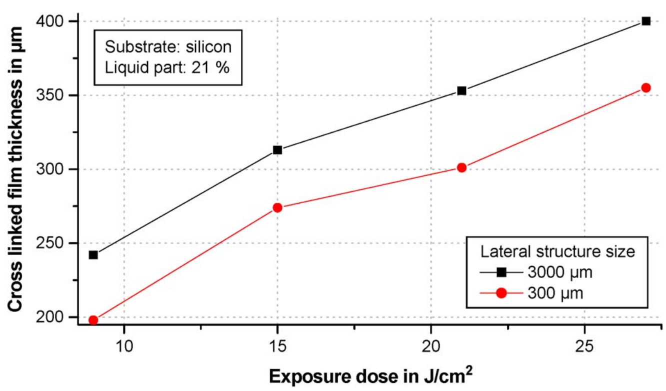

Fig. 4. Remaining film thickness after development as a function of the exposure dose in respect to aspect ratio (pillars).

IV. UV Exposure

The exposure is done on a SUSS MA56 M mask aligner with a high-pressure mercury lamp (G-, H-, and I-lines) in contact mode. The average output light power density is 11.5 mW/cm^2. Chromium masks with a transmission of 92% are used. In order to avoid sticking, a thin plastic film (12 μm) is applied in between the chrome mask and the photoresist; thus, the transmission is diminished to 87% (10 mW/cm^2).

The required exposure dose for AZ 125 nXT (see Fig. 4) clearly exceeds the one for the corresponding SU-8 photoresist film (SU-8 at 500 μm: 6 J/cm^2 using the same equipment [5]). The dose mainly depends on the film thickness and is influenced by the structure size (see Fig. 4) and the substrate material. For high reflective materials (e.g., bright copper), less dose is needed in comparison to low reflective materials (e.g., oxidized copper). The resist structures show sidewall angles ranging from 87° to 88.5°. The angle mainly depends on the gap between the mask and photoresist; the smaller this gap, the steeper the angle.

The cross-linking takes place at room temperature during exposure, so a postexposure bake does not apply. Compared to SU-8, this lack significantly reduces the resist layer's intrinsic stress and its processing time. In comparison to SU-8, the softbake time is similar [6], [14], so the overall fabrication time essentially decreases.

V. Development

We have carried out the development with the following three different setups using AZ 326 MIF (2.38% aqueous tetramethylammonium hydroxide solution):

1) spray development—little developer consumption, convenient for freestanding structures (e.g., pillars), inadequate for narrow trenches (bubbles inhibit electroplating), and fast;

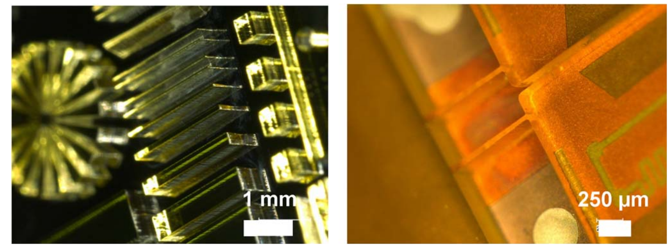

Fig. 5. Photoresist structures of 400 μm thickness with a maximum aspect ratio of 20:1 (freestanding walls).

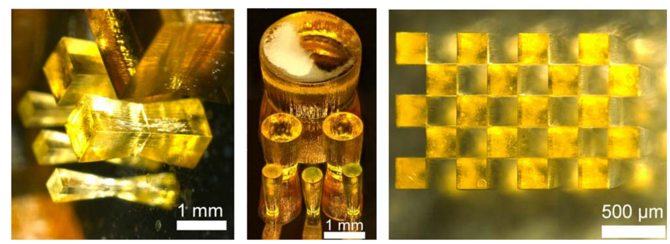

Fig. 6. Photoresist structures of 1400 μm thickness.

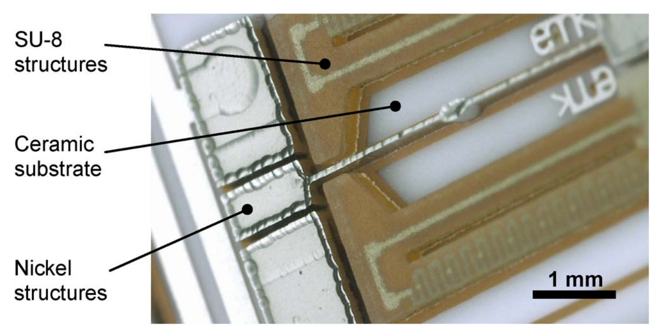

Fig. 7. Example: Microrelay with nickel structures (AZ 125 nXT resist already removed, 300 μm height) and SU-8 as electrothermal actuators on a ceramic substrate [15].

2) orbital-shaker-supported development—convenient for freestanding structures (e.g., pillars), inadequate for narrow trenches (poor mass transport), slow, and replace developer when milky;

3) megasonic-supported development—adequate for trenches and freestanding structures (good mass transport), fast, and replace developer when milky.

Best results have been achieved by a combination of orbital-shaker- (15 min) and megasonic-supported (35 min) development for a film thickness of 400 μm (see Fig. 5). Microstructures with thicknesses of up to 1400 μm have been realized (see Fig. 6).

VI. Microelectroplating

The photoresist mold is stable in extremely acid electrolytes (copper), as well as in warm ambiance (50 °C, nickel), and shows excellent electroplating results using a microelectroforming unit (MOT μGalv, similar to a Technotrans microform) (see Figs. 7 and 8).

VII. Stripping

Ultrasound-supported wet stripping with dimethyl sulfoxide (DMSO) at 80 °C for 15 min shows excellent results. The cross-linked photoresist becomes soft and removes as small flakes, guarding very fine electroplated pillars. Even wet stripping in acetone at

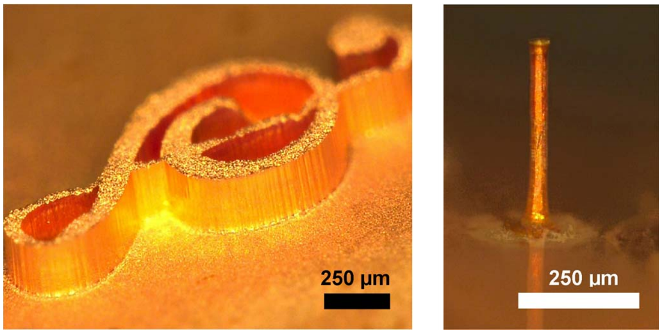

Fig. 8. Copper microstructures, resist already removed, without lapping, (left) 300 μm and (right) 400 μm heights.

room temperature for 20 min removes the photoresist reliably. As the photoresist expands during this process, multilayer structures are at risk. Established for dry SU-8 removal, the plasma treatment with reactive radicals (R3T) shows a brilliant outcome for the removal of ultrathick AZ 125 nXT after electroforming.

VIII. Conclusion

The new acrylic photoresist AZ 125 nXT is an adequate alternative to SU-8 for low-cost high-aspect-ratio UV LIGA applications. It offers aspect ratios of 20 : 1 as well as easy fabrication of film thicknesses exceeding 1 mm without T-topping. The sidewall angles are constantly good for all microform heights since the exposure duration mainly depends on the film thickness. Compared to SU-8, the new photoresist provides a significantly better adhesion to silicon and metal substrates because of the low internal stress. Thus, the substrate material can be varied in a wide range (e.g., glass, silicon, PCB material, steel, and ceramic). The developer for AZ 125 nXT is water based. Thus, the wetting of trenches with the electrolyte in the subsequent electroplating process can be done without any effort. The electroforming can be conducted in neutral to extremely acid electrolyte, from room temperature to 50 °C, providing excellent contour accuracy. Finally, the microform can easily be removed by the common solvent DMSO or acetone in a single step.

Compared to [13], we show that it is possible to produce an ultrathick resist mold well suited for microelectroplating by using spin casting instead of a spin coating process. Due to the high process robustness, AZ 125 nXT is well suited for industrial applications.

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