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Comparisons of the new thick negative resist to Su8 resist

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ABSTRACT

This work deals with recent advances in the microfabrication process technology for medium to high-aspect ratio structures fabricated by UV photolithography using different kinds of photoresists. The resulting structures were used as molds and will be transformed into metal structures by electroplating. Two types of photoresists are compared: epoxy-based (negative) SU-8 and acrylate-based (negative) Intervia BPN. This work was prompted by the need to find an alternative to SU-8 photoresist which is difficult to process and remove after electroplating. The results presented in this paper open up new possibilities for low-cost processes using electroplating in MEMS applications.

Keywords: High aspect ratio, Thick photoresist, Micromolds, SU-8, Acrylic photoresist, Electroforming, Intervia BPN

1. INTRODUCTION

The nineties saw the advent of MEMS, the MicroElectroMechanical Systems (MEMS). To support the development of these new devices, leading edge technologies were devised. Among these, high thickness resists were utilized particularly in etching or electrochemical processes. At present, these 3D technologies are applied to numerous fields ranging from passive power devices to microwaves, etc, ...

The first developments highlighted the limits of positive resists in terms of vertical sidewalls, mechanical resistance and aspect ratio. To address this issue, negative resists have been extensively researched over the last ten years.

In this respect, SU-8 is by far the most used resist due to its versatility and outstanding 100:1 aspect ratio (certain X-ray exposure conditions) [1]. Its chemical composition (epoxy) features very good mechanical and chemical resistance properties and equally allows very high thicknesses more than 1 mm. Its drawbacks are due to internal stress inducing cracks in the patterns that can even result in layer delamination. Also, it tends to exhibit poor adhesion to metal layers and takes time to process. Above all, it is extremely difficult to strip the resist without damaging adjacent structures. As a result new negative resists have been proposed over the past years such as KMPR[2,3], BPR 100[3,4], WBR.[5] etc,... These negative resists are thick and can more or less easily be dissolved. However they fail to offer the same performance standards as SU-8 particularly in terms of aspect ratio.

BPN is a fairly recent negative resist that easily dissolves, without inducing any alteration of adjacent patterns. Initially it was designed for the fabrication of bumps and pillars on printed circuits and its use in the creation of high aspect ratio patterns had not been considered. In its datasheet, DOW Electronic Materials highlights a high 2:1 aspect ratio. [6] The easy dissolution feature seemed highly promising to us, so we decided to devise a process likely to improve the aspect ratio values.

In this paper, the process used with this new resist is presented. Although it only focuses on problems related to a particular application, we believe that it could equally benefit other applications.

All the steps used in our process will be described by comparison with a similar process involving the SU-8 resist.

In the first section, the implemented processes are described.

Then in the second section, a possible application is presented through an electrochemical process.

The third section deals with stripping

Prior to concluding, the functional validation of the devices fabricated with this resist is detailed.

2. RESIST

2.1 The implemented process

To develop the process, 4" inch. (100) oriented n-type Silicon wafers were used.

After classical cleaning in a Piranha mixture, a 500Å-thick titanium layer is first deposited on the Si-wafers' surface. Then a 1000Å-thick gold layer is also coated on the surface by evaporation. Titanium is used to facilitate adhesion of gold to silicon while the gold layer enhances electrical conductivity. These layers have been referred to as «seed layers». Prior to each exposure, the mask is cleaned in a sulpho-chromic bath to remove all organic residues likely to cause UV diffraction during exposure and loss of resolution. To carry out the photolithographic step, an Ma 150 type Karl Suss Mask Aligner is used. Beam intensity is 10 mW/cm² at 365nm wavelength. Both resists are developed by immersion in their specific developers. One is based on PGMEA for the SU-8 resist and the other on TMAH (0.26 N) for BPN.

The process used to implement the BPN resist is quite conventional, involving four consecutive operations: coating, annealing, exposure and development with no specific conditions in terms of equipment or process.

To implement the SU-8 resist, further steps are carried out (7 operations) along with specific conditions, namely:

- application by spin coating of an adhesion promoter to enhance the SU-8 resist resistance metals. To achieve this adhesion, the AP300 promoter distributed by SILICON RESOURCES has been retained ;
- annealing under specific conditions: a hotplate with monitored temperature ramp up and temperature ramp down is essential in order to avoid thermal shocks likely to create internal stress;
- UV filter with a unique wavelength (365nm) ;
- additional annealing (post exposure bake, 'PEB') to complete cross-linking;
- hard-bake to correct for defects happening during development.

The processes used for a resist thickness of 30, 90 or 160µm have been compared to highlight their potential use at different steps in the microtechnology (electrochemistry, wet etching, plasma etch ...). For thickness in excess of 160 µm, two BPN layers are utilized to enhance thickness homogeneity.

These operations were repeated on several wafers. Thus it appears that the developed processes can be repeated. They have been used in numerous projects within our laboratory without undergoing requalification.

Table 1: Major parameters for BPN and SU-8 processes

Thickness	Coating	Pre-bake	Exposure	Post-exposure bake	Development	Hard cure
BPN						
30µm	2200 tours/min 30s BPN 65 A	1 min30s à 120°C	300mj/cm ²	X	2 min TMAH	X
90µm	800 tours /min 30s BPN 65A	3 min à 60°C 3 min à 120 °C	1250 mj/cm ²	X	5 min TMAH	X
X	1800 tours / min 30s BPN 65A	1 min 30s à 120 °C	X	X	X	X
160µm	800 tours /min 30s BPN 100A	3 min à 60°C 4 min à 120°C	2500 mj/cm ²	X	10 min TMAH	X

Thickness	Coating	Pre-bake	Exposure	Post-exposure bake	Development	Hard cure
Su8						
30 μm	3800 tours/min 30s Su8 3025	1 min à 65 °C 3 min à 95 °C	170 mj/ cm ²	1 min à 65 °C 3 min à 95 °C	10 min PGMEA	1 min à 65 °C 2 min à 125 °C
90 μm	1500 tours/min 30s Su8 3050	1 min à 65 °C 44 min à 95 °C	360 mj/ cm ²	1 min à 65 °C 3 min à 95 °C	15 min PGMEA	1 min à 65 °C 2 min à 125 °C
160 μm	850 tours/min 30s Su8 3050	1 min à 65 °C 180 min à 95 °C	870 mj/ cm ²	1 min à 65 °C 5 min à 95 °C	25 min PGMEA	1 min à 65 °C 2 min à 125 °C

Table 1 shows an easier fabrication process using the BPN resist. It requires less steps resulting in a shorter process time. For a thickness of 90 μm , it takes 180 min to fabricate the SU-8 resist but only 32 min for the BPN resist.

2.2 Results and discussion

2.2.1 Internal stress

One of the main drawbacks of SU-8 lies in its internal stress. Indeed, this epoxy-based structure features a chemistry leading to a highly cross-linked resist after exposure and Post Exposure Bake (PEB).

The BPN resist is based on an acrylate polymer. As a result, it is less 'rigid' which in turn limits its internal stress.

Table 2: Comparison (in MPa) of SU-8 and Intervia BPN photo resist stress at different thicknesses

Thickness	30 μm	90 μm	160 μm
BPN	0,405	1,08	2,74
SU-8	12,6	20,43	21,82

Table 2 compares stress values exhibited by both resists as a function of thicknesses. Stress measurements were carried out using mechanical profilometer Tencor P15. The measurement principle relies on comparing the deflection difference before and after deposition.

In spite of all the precautions taken during the process to limit stress during anneals with temperature ramps and 24 hr relaxation for SU-8, one can note a factor of 10 or more between the internal stress in both resists.

The low stress value exhibited by the BPN resist is an interesting feature in many respects, namely:

- resist molds do not break during electrolytic growth under deposition stress.
- for the photolithographic step, the contact between the mask and the unstressed substrates is homogeneous. This results in a higher aspect ratio.
- As the substrate is not hardly stressed by the resist even at a high thickness, it remains compatible with all automatic loading machines.

2.2.2 Aspect ratio

To allow observations and determination of the aspect ratio, a variable pressure HITACHI S-3700N Scan Electron Microscope is used.

A mask featuring 10 μm to 50μm negative and positive patterns was used with different forms, leading to the results given in Fig. 1 and Table 3.

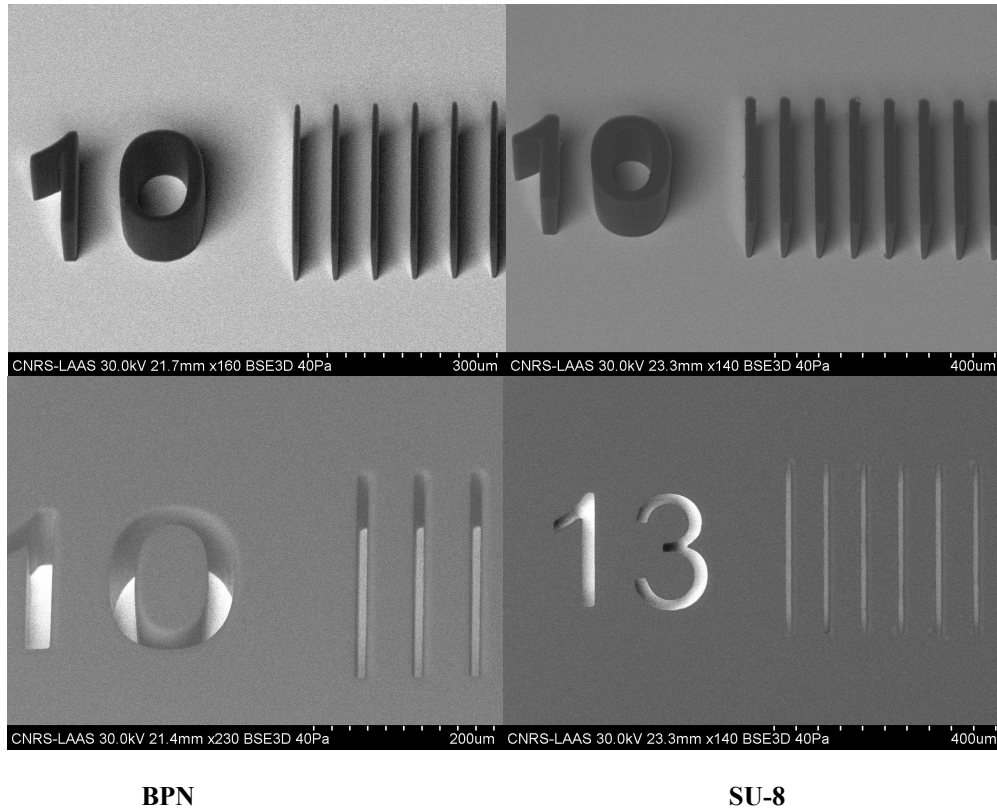


Figure 1 Best aspect ratio obtained for a thickness of 90 μm

Tableau 3: Maximum aspect ratio obtained versus thickness

Thicknesses	Shortest open line	Aspect ratio	Smallest wall	Aspect ratio
SU-8 30 μm	10 μm	3:1	10 μm	3:1
BPN 30μm	10 μm	3:1	10 μm	3:1
SU-8 90 μm	13 μm	7:1	10 μm	9:1
BPN 90 μm	10μm	9:1	10 μm	9:1
SU-8 160 μm	40μm	4:1	10 μm width > 10μm	16:1
BPN 160 μm	40μm	4:1	10 μm	16:1

It can be pointed out that for the three thicknesses under investigation, the aspect ratios secured with the BPN resists are comparable to those of the SU-8 even showing a slight advantage to BPN at a thickness of 90 μm . Also, the BPN process is easier to implement (4 regular steps), with a lower stress than the SU-8 and the aspect ratios obtained for different thicknesses are comparable to those of the SU-8. In other words, BPN is a serious competitor for certain applications related to materials forming

3. ELECTROLYTIC PLATING PROCESS

The primary objective of our study was to develop a resist for electrolytic plating molds for applications in the field of passive power devices where a thick copper deposition is needed.

All depositions were carried out using RENA's deposition reactor. The vertical reactor used on RENA stations has been specially designed to secure inhomogeneities less than 7 percent on a 4" wafer.

The electrolytic bath contains 25 g/L of copper that can be used at temperatures from 20 to 30°C with current densities of 0.5 at 6 A/dm² (Microfab 200 Cookson Electronics).

In this study, deposition conditions were optimized to avoid damaging the resist molds, deposition rates being rapidly achieved to secure low internal stress. Operating conditions were a temperature of 25°C and a current density of 2A/dm². Deposition time is therefore a function of the final thickness desired.

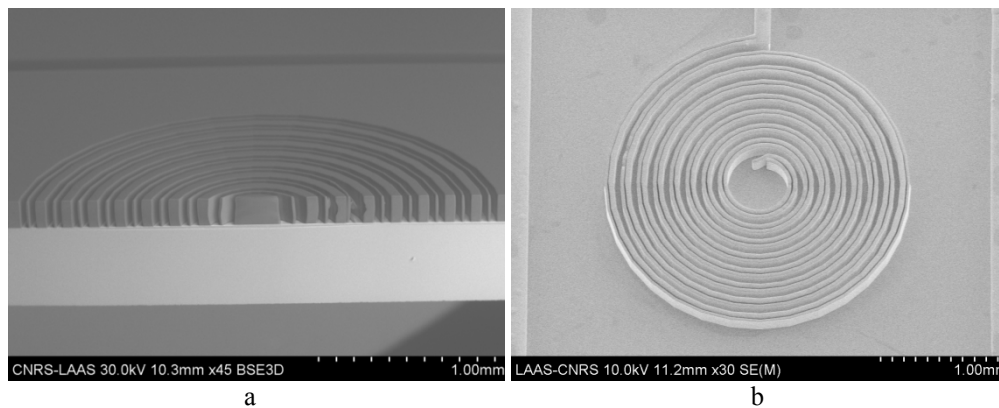


Figure 2: 160 μm -thick BPN resist mold featuring a 10:1 aspect ratio (a) and 160 μm -thick copper inductance obtained from the same mold (b).

During electroplating the mold did not break or get detached as a result of deposition growth. With the implementation processes shown in Table 1, both resists remained unaffected by copper deposition. Likewise the BPN resist properties are equivalent to those of the SU-8 resist.

4. STRIPPING PROCESS

The epoxy-based SU-8 resist which is both exposed and annealed becomes highly cross-linked. As a result, removing it with normal strippers becomes extremely difficult without damaging the surrounding structure. Over the years numerous studies have been devoted to this resist to figure out how to properly remove it.

MicroChem proposes an *N*-methyl pyrrolidinone (NMP)-based solvent under the name 'PG remover', but it does not fully dissolve the resist.[7-9]

As a complement, MicroChem offers another product, OmniCoat [8] designed to produce a sacrificial layer between the seed layer and the SU-8 resist: the aim is to lift off the SU-8 resist film rather than dissolve it. This yields correct results when the layer can be easily accessed but this is no longer the case when electrolytic plating has been carried out. One can also use acids such as anhydrous nitrous acid or a piranha mixture [10,11] designed to retain the whole SU-8 resist

but they are extremely aggressive for the surrounding components. This technique can only be used with resistant substrates like Au, platinum, ...

RT3 or TePLA have been marketing SU-8 plasma etch reactors using CF₄/O₂ mixture [7,12]

This technique features extremely interesting etching rates in the order of 20 μm/min. However, selectivity may turn out to be problematic according to the materials used. For example copper and the oxide can equally be attacked as the pictures show

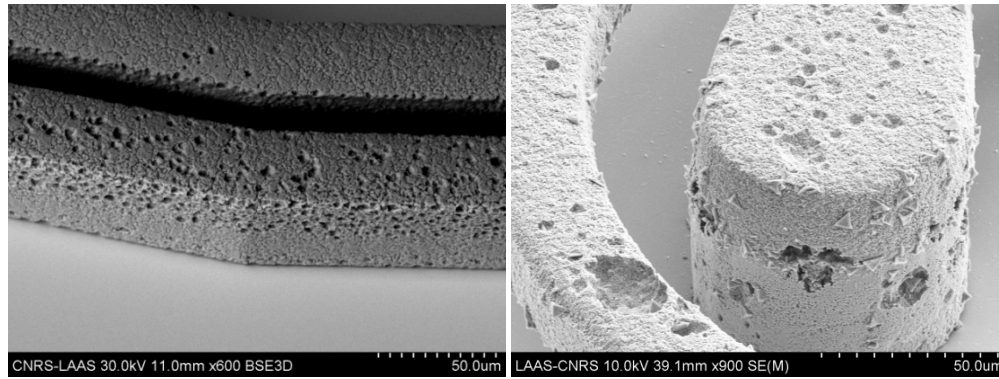


Figure 3: Copper surface following Plasma etch of 90 μm thick SU-8 .

Numerous techniques have been put forward but no universal solution has been found to dissolve the SU-8 resist film without damaging its surrounding components.

BPN is an acrylate-based polymer making it resistant but still easy to dissolve. DOW Electronic Materials proposes an *N*-methyl pyrrolidinone (NMP) type-based stripper [6]. The wafer only needs to be immersed in a stripping bath at 50 °C for the BPN to be thoroughly dissolved. This stripping is highly selective when it comes to the surrounding materials. It does not damage electroplated metals and even copper is not attacked. Dissolution rate is also rapid: by way of example for a 90μm-thick layer, it takes 5 min for the immersed resist film to be thoroughly dissolved including even in the area of high aspect ratio patterns.

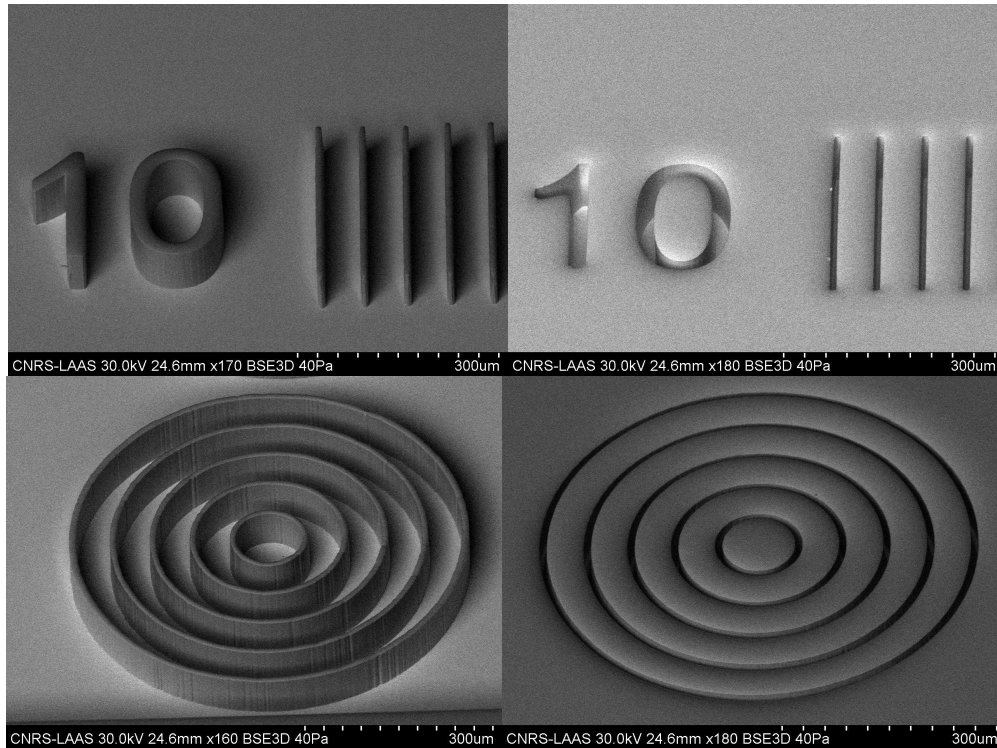


Figure 4: Positive and negative copper structures 10 μm wide and 90 μm high obtained using BPN resist. These structures were characterized using HITACHI S-3700N scan electron microscope.

The BPN dissolution process appears to be very simple. It can easily be achieved and does not require heavy investments (as a plasma reactor would). One gets a complete, fast dissolution with no damage to surrounding materials. This result cannot be achieved with SU-8.

5. THE DEVICE

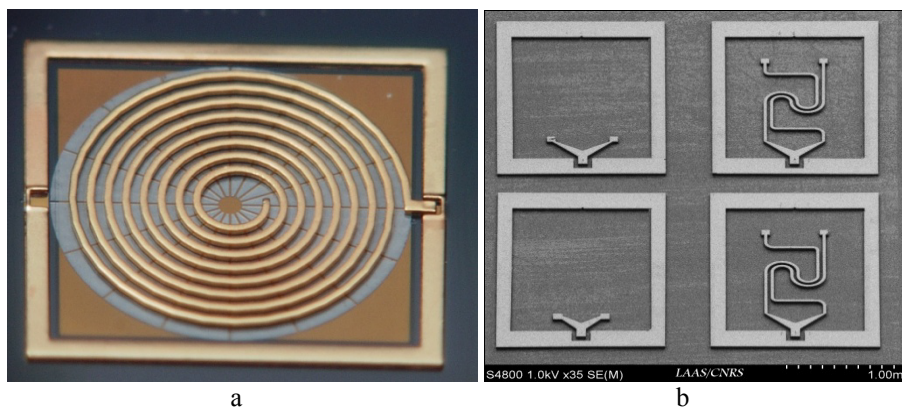


Figure 5: Integrated L+C filter(a), High quality factor inductances (b)

Among other things, the BPN resist has led to the creation of an integrated L+C filter for DC-DC applications [13] and high quality factor inductances [14]. The fabrication of these devices could not have been contemplated with the SU-8

for many reasons. Firstly, because an SU-8 layer is already used as dielectric under the inductances and as the latter are made of copper no stripping solution could be envisaged.

6. CONCLUSION

In this article, a process has been described for the use of a new negative resist, BPN, which in many respects, constitutes a very good alternative to the SU-8 resist film.

First, it is easy to fabricate by utilizing standard microelectronics equipment. It can be used quickly: it is six times quicker to fabricate. It yields aspect ratios that are equivalent to those obtained with SU-8 which is used as reference. It also features very low stress values, by a factor of 10 relative to the SU-8. And last but not least, it can be removed very quickly without damaging the surrounding materials.

This new resist will support the development of new processes in the field of electrochemistry applied to microsystems. It has been validated for use as a mold in electrochemical depositions. But it also offers a great potential in other domains such as Deep Reactive Ion Etching (DRIE), packaging, etc, ...

This resist also presents a development potential: indeed, one can still optimize the parameters of use to increase the aspect ratio for regular thicknesses and also to develop much higher thicknesses.

This is the first study devoted to the use of the BPN resist and we are still in the early stages of its development. Its main features already support the view that it could be a very good candidate to replace SU-8 resists in the field of electrochemistry.

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