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Process research of high aspect ratio microstructure using SU-8 resist

J. Liu, B. Cai, J. Zhu, G. Ding, X. Zhao, C. Yang, D. Chen

Abstract SU-8 is a negative, epoxy type, near-UV photoresist. This resist has been specifically developed for ultrathick, high-aspect-ratio MEMS-type applications using standard lithography equipment. However, in practice, SU-8 has shown to be very sensitive to process parameter variation. The orthogonal array was used in our experiments in order to improve the lithography quality and analyze the interaction among the parameters. The analyses show that the interaction between the exposure dose and post exposure bake has played an important role in adhesion between SU-8 resist and the substrate. The proposed process conditions are given. The output structure has straight sidewall profile, fine line and good space resolution. The aspect ratio is larger than 20. Moreover, several metallic films are used as substrates. The Ti film with oxidation treatment was found to have the strongest adhesion to the resist. The result will help to open possibilities for low-cost LIGA-type process for MEMS applications.

Keywords UV-LIGA, SU-8 resist, Orthogonal array experiments, High aspect ratio

1 Introduction

High aspect ratio micromachined structures have many useful applications, but there are only a few techniques to achieve such structures. A well known technology for high aspect ratio structural components is LIGA (Lithographie, Galvano-formung, Abformung), which includes three processes – X-ray lithography, microelectroplating, and microembossing. This technology was proposed and developed by Karlsruhe Nuclear Research Center of Germany. By using LIGA technique, some three-dimensional microstructures of many lateral shapes and several hundreds micrometers in height are fabricated in many fields, such as microgear, microsensors and microactuators. This technology allows producing a mold using electroplating. This mold is then used for a large-scale production of desired components [1–4].

However, LIGA fabrication is very expensive. Such X-ray is generated by complicated synchrotron facilities. Also, the masks involved for X-ray lithography are substantial three-dimensional microstructures which need to be fabricated by electroplating a thick gold layer onto a thin beryllium membrane. To reduce fabrication costs, some alternative micromachined methods have been investigated recently, such as reaction ion etching, inductive coupling plasmas, excimer lasers, and UV-LIGA, etc. Among these methods, UV-LIGA has shown great potential for industrial application due to its wide availability and low cost. UV-LIGA uses the standard lithography equipment instead of X-ray synchrotron source of LIGA. Of course, LIGA still yields better results but low-cost application will undoubtedly benefit from SU-8 resist to some degree [5–7].

SU-8 is a negative, epoxy type, near-UV photoresist that has been originally developed and patented by IBM. Due to its low optical absorption in UV range, this photoresist can form very thick film. The SU-8 resist contains a few percent of photoacid generator that will produce a strong acid when a photochemical transformation takes place upon absorption of a photon. This photoacid acts as a catalyst in the subsequent crosslinking reaction that takes place during post exposure bake (PEB), that is, crosslinking occurs only in regions that contain acid catalyst and mainly during PEB. This high-aspect-ratio resist, SU-8, leads itself well to MEMS applications [8–14].

However, SU-8 has been proven to be very sensitive to variations of process in practice. In this paper, the experiments for the thick films of SU-8 were carried out in order to improve the lithography quality and analyze the interaction among the parameters, which were based on the orthogonal array in experimental design. The analyses show that the interaction between the exposure dose and post exposure bake has play an important role in adhesion between SU-8 resist and the substrate. The proposed process conditions are given. The output structure has straight sidewall profile, fine line and good space resolution. The aspect ratio is larger than 20. Moreover, several metallic films were used as substrates. The Ti film with oxidation treatment was found to have the strongest adhesion to the resist.

2 Experiments

2.1 Prepare for the experiments

Prior to the experiments, the objectives of our experiments are determined, which are the dimensional precision and

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J. Liu (✉), B. Cai, J. Zhu, G. Ding, X. Zhao, C. Yang, D. Chen
The State Laboratory of Micro/Nanometer Fabrication Technology, Information Storage Research Center,
Research Institute of Micro/Nanometer Science and Technology,
Shanghai Jiao Tong University, Shanghai, 200030, PR China
e-mail: dyzljq@163.com

adhesion quality between the SU-8 resist and the substrate. In past experiments, we found that the adhesion plays an important role in improving the aspect ratio. Fig. 1 is a pattern of SU-8, in which the pattern with low aspect ratio can stand well, but the pattern with high aspect ratio collapses owing to its poor adhesion with the substrate though it has precise dimension and straight sidewall profile. So the aspect ratio is restrained for the adhesion. In our experiments, we obey the following rules–keeping the dimensional precise first, then trying to improve the adhesion to get high aspect ratio microstructures.

2.2 Orthogonal array experiments

Based on the experiments above, we defined the scope which the experiment should have. The substrate of silicon was adopted first. In order to improve the lithography quality and analyze the interaction among the parameters, Taguchi optimization was used, which is an experimental technique and can get the maximal experimental information at the lowest numbers of experiments.

SU-8 photoresist (SU-8 50) supplied by MicroChem Corporation was spun up to a thickness of 200 μm–210 μm on a silicon wafer. First, dehydration bake was carried out. Then 3 ml photoresist was dispensed on to the 3″ silicon wafer. The experiment was performed on the Karl Suss RC8 Coating. The resist was allowed to spread at a low speed (~300 rpm) for 15 s. Then the wafer was accelerated to final spin speed (750 rpm) and spinning was carried out for 20 s. Before softbake, the wafer coated with SU-8 resist should better relax for 10 min at room temperature in order to reflow.

Softbake is necessary to remove solvent from the resist layer after spin coating. To keep internal stresses of SU-8 resist to a minimum, the complete soft bake was as following. First, the wafer was put into the convection oven at room temperature, then the temperature rose to 65 °C. It took 15 min, and then held for 10 min at 65 °C. Second, the temperature rose to 95 °C. It took 10 min, and held for 1 h. This temperature is greater than the glass transition temperature (Tg = 55 °C) of SU-8 resist unexposed. Last the wafer was cooled down to room temperature with the oven. It usually took more than 1 h. It also required that the oven was flat in order to produce smooth, uniformly coated substrates. Thickness non-uniformity of the resist would yield exposure non-uniform in later processing. The resist is very sensitive to the planarity of the devices used during the whole process. For good results, the equipment has to be carefully leveled. Sometimes we needed to use the precise lathe to cut the resist flat.

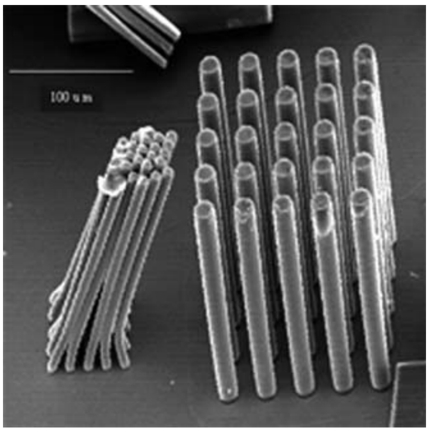

Fig. 1. A pattern shown poor adhesion with substrate taken by SEM

SU-8 is optimized for near UV exposure. The Karl Suss MA6 aligner was carried out. Because SU-8 is sensitive at 365 nm wavelength, we usually use the intensity of 365 nm as a parameter to measure the exposure dose. The exposure intensity in experiments was 8.5 mW/cm^2 at 365 nm wavelength. PEB was done in convection oven. The development solvent was PGMEA provided by MicroChem Corp. In our experiments, three parameters at three levels were selected which are shown in Table 1. The purpose of the experiments was to find the influence of varying process parameters on the pattern dimension and adhesion with substrate. In order to know the interaction between two factors, the orthogonal array technique $L_{18}(3^7)$ was adopted, which needed to do 18 experiments.

Based on the experiments, the normalized results are shown in Figs. 2 and 3 which are given by the conventional variance analyses of orthogonal array [15]. Here "EXP" expresses exposure; "PEB" indicates post exposure bake; "DEV" means development; "EXP * PEB" indicates the interaction of exposure and post exposure bake.

The width difference is the absolute value of the mask's dimension minus the pattern's dimension, which is used to express the dimensional precision of the pattern. The dimensions were measured by OLYMPUS Measuring Microscope (STM-MJS2). Figure 2 shows that exposure plays an important role in width difference. Therefore, we should control the exposure dose very carefully. The secondary is the development. The development time should be controlled well. If the time is longer, the pattern will be swelled; and if it is shorter, some unnecessary remainder will adhere on the pattern. Such will decrease the lithography quality. In our experiments, the development should be no more than 18 min. The interaction between exposure and PEB has a little influence on the width difference.

Figure 3 shows the adhesion quality between the substrate and resist which is evaluated by calculating the percent of the remainder of the pattern on the substrate. The interaction between exposure and PEB plays large part in the adhesive quality. It should be paid good attention. The temperature of PEB has the direct relation with the exposure dose. We found that the temperature of PEB has a threshold under a constant exposure dose. The temperature should be lower than this threshold. If it is higher, the pattern flows and is destroyed. Figure 4 shows a pat-

Table 1. Conditions of orthogonal array experiments

Parameters levels	Exposure time (s)	Post exposure bake	Development (min)
1	180	85 °C for 40 min	16
2	200	90 °C for 40 min	18
3	220	95 °C for 40 min	20

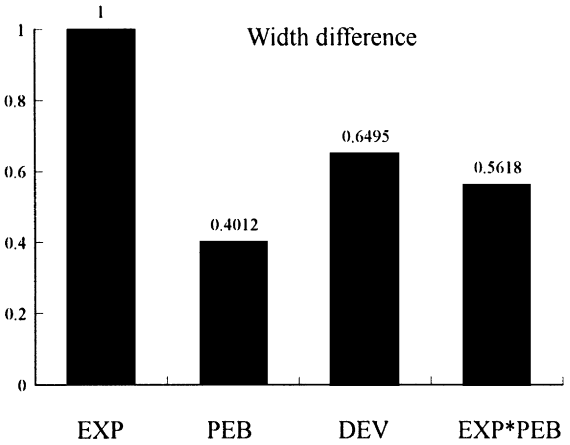

Fig. 2. Influence of process parameters on width difference

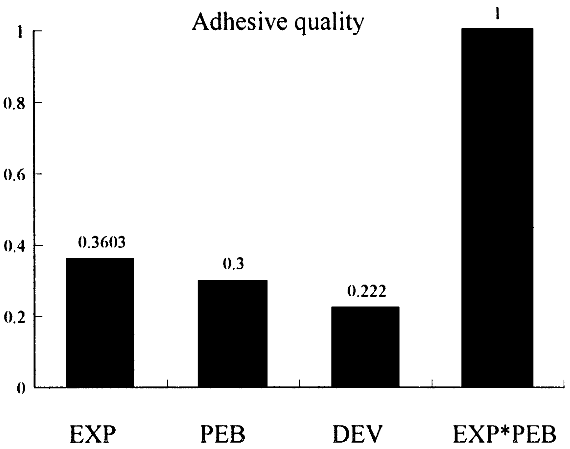

Fig. 3. Influence of process parameters on adhesion

tern owing to such reason. In our experience, lower temperature with comparatively longer time during PEB will produce better results.

Based on the analyses above, we try to improve the pattern quality and adhesion. The proposed process conditions are that the exposure time is 200 s, PEB is carried out under 85 °C for 40 min, and the development time is 18 min. Two resist patterns with 210 μm thick, 10 μm width are as shown in Fig. 5, which were made under the optimizing conditions. The aspect ratio is 21. The patterns have straight sidewall profile, fine line and good space resolution, and the maximal aspect ratio is larger than 20.

SU-8 has been proven to have weak adhesion with metallic substrate, but sometime we need to electroplate metallic microstructures. In order to improve the adhesive quality, several metallic substrates were used in experiments. These substrate were FeNi, Cu, Cr, Ti and Ti with oxidation treatment (Ti film substrate was put into the 40% KOH solution at 65 °C, and added 30% H_2O_2 into the solution. Parts of the Ti film were oxidized, but the substrate was also conductor). All the substrates above were experimented in the same process conditions, such as soft bake, dose of the exposure, PEB, and development. We found that the Ti substrate with oxidation treatment has the strongest adhesion with the resist.

3 Summary

In this paper, the fabrication processes of high-aspect ratio microstructure using SU-8 resist were introduced. SU-8 resist is very sensitive to process variations, so the experimental optimizing technique was used in the process. Using process parameters as control factors, orthogonal array experiments were performed and results were evaluated. As the results being analyzed, a proposed fabrication process was derived from optimizing the control factors. The analyses show that the interaction between the

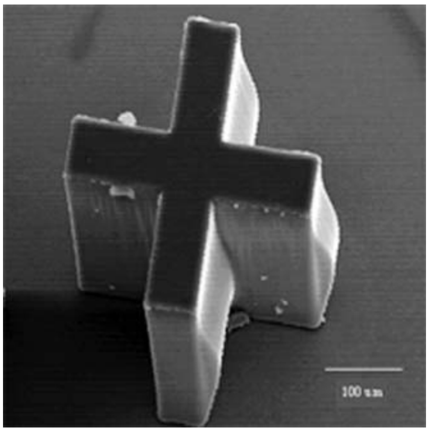

Fig. 4. A pattern destroyed by flowing

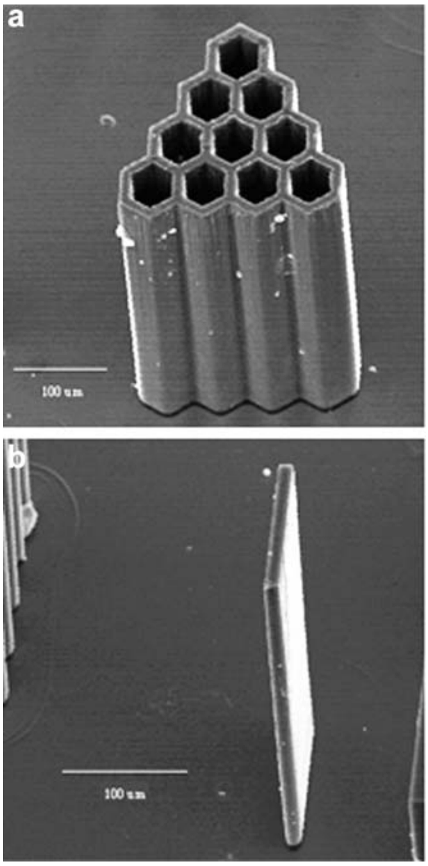

Fig. 5. Some microstructures of SU-8 resist

exposure dose and post exposure bake has played an important role in adhesion between SU-8 resist and substrate. The output structure has straight sidewall profile, fine line and good space resolution. The aspect ratio can be larger than 20. Moreover, several metallic films were used as the substrates. The Ti film with oxidation treatment was found to have the strongest adhesion to the resist. The result will help to open possibilities for low-cost LIGA-type process for MEMS applications.

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