FABRICATION OF HIGH-ASPECT-RATIO MICRO STRUCTURES USING UV-LIGA TECHNOLOGY

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Abstract. Thanks to almost transparent property of SU8 for wavelength of 365-400nm, UV-LIGA technology using this photoresist has been applied to fabricate high-aspect-ratio (HAR) microstructures. This allows transferring patterns with vertical sidewall from masks to the photoresist. This paper introduces UV-LIGA and its application in fabricating comb drive structure for an angular rate sensor of linewidth and thickness of 50μm and 120μm, respectively.

Keywords: UV-LIGA, HAR, SU8, comb structure

1. Introduction

The LIGA process (Lithographie, Galvanoformung, Abformung) that stands for deep-etch X-ray lithography, electroplating, and molding, is a micromachining technology developed in the early 1980's at the Karlsruhe Nuclear Research Center [1]. Based on this technique, it is possible to produce microstructures from a variety of materials (metals) with very high-aspect-ratio (more than 100), very small features (in the submicron range) and very smooth sidewalls (surface roughness less than 50nm) due to reduced diffraction, low resist absorption and minimal proximity effects. Because the synchrotron for X-ray is very expensive, and many structures require very neither HAR, nor fine linewidth, the UV-LIGA technique with wavelength of 356-405 nm (UV) is applied instead. The cost for the UV-LIGA process is much cheaper than the LIGA process.

In the UV-LIGA approach, a proximity UV aligner is used with a thick resist in place of the synchrotron X-ray exposure step. After the lithography process, electrodeposition and planarization are used to produce metal microparts or a metal replication tools. This approach has the advantage of achieving HAR patterns using standard lithography processing tools instead of a synchrotron. However, modifications and/or improvements of available resists along with modified processing techniques are required to successfully achieve a high quality, resist-to-parts process.

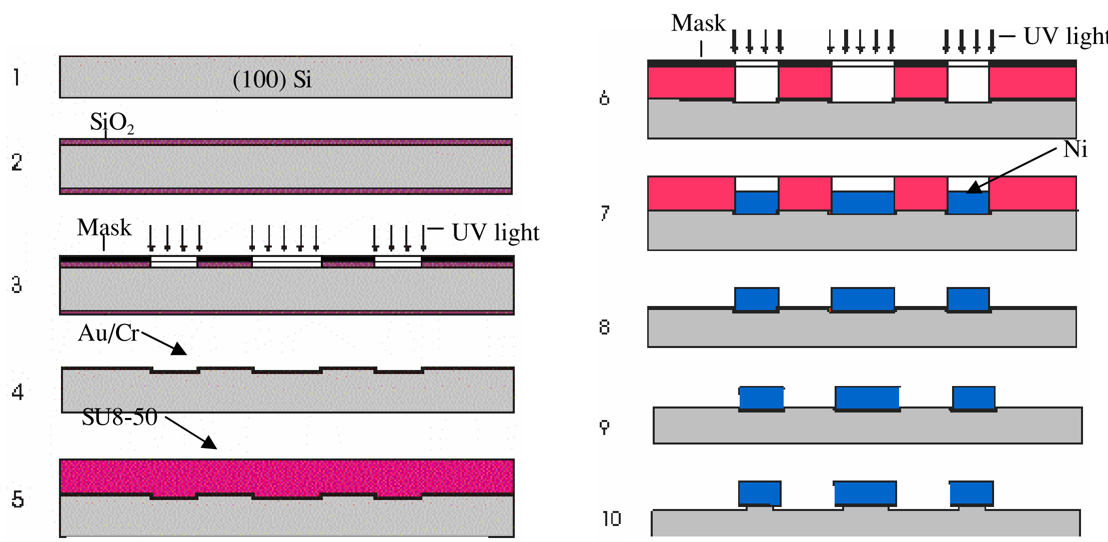
As a low cost alternative to the LIGA technique, the UV-LIGA process based on SU8 is studied. SU8 is a negative-tone epoxy-based chemically amplified resist with excellent sensitivity that can produce high-aspect-ratio microstructure

(HARM) for a variety of MEMS applications. Modifications and/or improvements of the UV lithography system and processing techniques are required to achieve high quality microstructures.

In this work, experiments have been studied based on the UV-LIGA technology with SU8 as a mold for fabricating HAR comb structures. SU8-50 has been chosen to ensure the thickness of the mold layer of more than 300µm. Nickel has been selected for growing the metal comb structure by electroplating. The combination of root technique and a right ratio between thicknesses of the mold and the structure [2] has been applied for better mold SU8 removal. The process for making novel structure will be presented in this paper.

2. Experiments

SU8 is a photoresist with high viscosity, which is hard to be stripped after being cross-linked. Processing SU8 takes a long time. As the SU8 is transparent with wavelength 365-400 nm, and very hard in mechanical and chemical treatments, so it is used in the UV-LIGA to make mold for HARM. In our experiments, the SU8-50 was used to fabricate the nickel comb structure. Properties of SU8 photoresist can be found in [3]. The schematic fabrication process for this structure is shown in Fig.1.



6. Standard cleaning Si wafer
7. Masking Si wafer with SiO_2
8. Photolithography for patterning root
9. Au/Cr deposition
10. SU8 coating

1. Photolithography for patterning structure
2. Ni deposition
3. Removing SU8
4. Etching Au/Cr
5. Undercutting Pyrex by isotropic etching

Figure 1. Process for making a UV-LIGA nickel comb structure

The process started with a standard cleaning process for silicon wafer as the substrate. The wafer then was wet-thermally oxidized for opening the windows for patterning the embedded roots. As mentioned above, the roots are very important to increase resistance of Nickel structure against the lift-off force in next steps [2]. The silicon anisotropic etching in KOH was the next step for the necessary depth of the roots. The wafer was then coated with sputtered adhesion and seat layers of chrome (Cr) and gold (Au), with the thicknesses of 300Å and 3000Å, respectively. The layers have two important roles. The first is to increase adhesion of the material in sequential steps. The other is a base for Ni electroplating. For more information of the process, one can refer to the Table 1.

For the good removal of SU8 after electroplating, the root technique was applied and the SU8-50 mold layer should be two times thicker than the necessary metal structure [2]. For the nickel structure with thickness of 100-120μm, the thickness of SU8-50 mold layer was 200-250μm. Fig. 2 illustrates the relation between thickness and spin speed for coating SU8-50. The SU8-50 was exposed and then developed with the SU8 developer.

Soft and hard bakes were conducted to make the SU8 layer hard for the electroplating step. The soft bake temperature and time are important to ensure the uniformity and hardness of the SU8-50 layer for exposure step. Post exposure bake was necessary to make SU8 pattern strong for the next developing and electroplating steps.

For thick PR layer, the exposure can be performed in one stage or multistage, so that the PR could be exposed well for whole thickness. Time of developing and exposure was calculated carefully. Agitation was necessary to ensure PR removal at the bottom.

Fig. 3 shows the silicon wafer with patterned SU8-50 layer as the mold for the nickel comb drive structure. The parameters used in performing the UV-LIGA process illustrated in Fig. 1 were shown in Table 1.

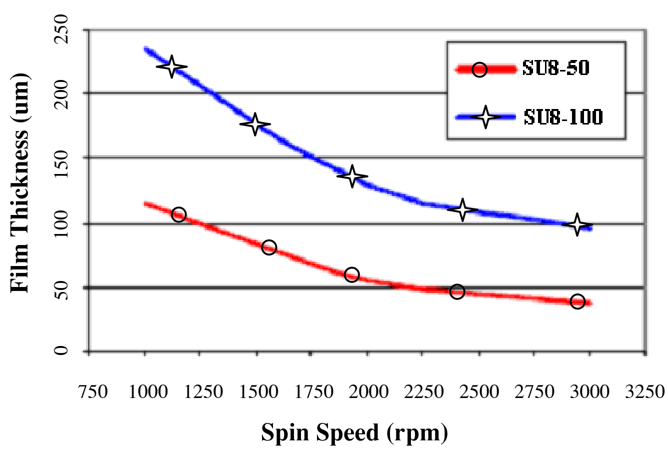


Figure 2. Thickness vs. spin speed curves for SU8

Table 1. Process parameters of the UV-LIGA process with SU-8 mold.

Process step	Process parameters
Thermally wet oxidation	1050°C, 4h → 1μm thick SiO_2
SiO_2 lithography	Standard recipe
SiO_2 etching	BOE etchant
Si anisotropic etching for roots	KOH etchant → 10μm deep
Deposition of adhesion/seed er/Au	Physical sputtering, 300Å/3000Å
SU8-50 coating/Soft bake/UV-lithography/Post- exposure bake/Development	300rpm, 15min+500rpm, 25min/90°C, 8h/Dose 1350mJcm-3/90°C, 8h/SU Developer, 30min → 200μm Su8-50 layer
Nickel electroplating deposition	Nickel sulfamate electrolyte, 45-52oC, 1ASD, agitation → 100μm Ni structure
Su8-50 removal	Remover PG in 10h at temperature 80°C
Au, Cr removal	AU-5, 20°C/Phos+Sult
Si isotropic etching	Trilogy etchant, 20°C, agitation

3. Results and discussions

A 4” (100) n-Si wafer was chosen as a substrate for the HAR structure. With the process layout mentioned above, the Nickel comb structure was successfully fabricated.

For the SU8-50 with the thickness of 200μm the soft bake was carried out in two stages with a pause point at 55°C, close to glass point of SU8. The relax process went down in the same manner. Then the exposure was done by multistage with five cycles of 20s exposure and 5s pause. This technique avoids cracks used to occur at the corners of features due to fast soft bake and long exposure (Fig. 3).

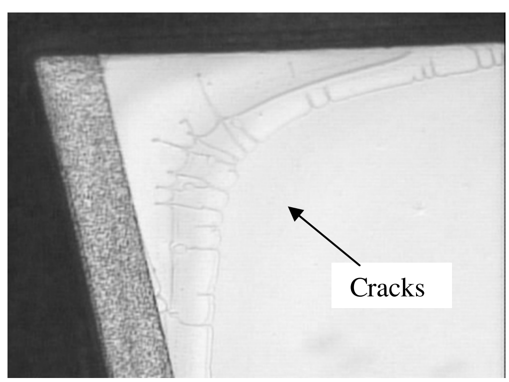
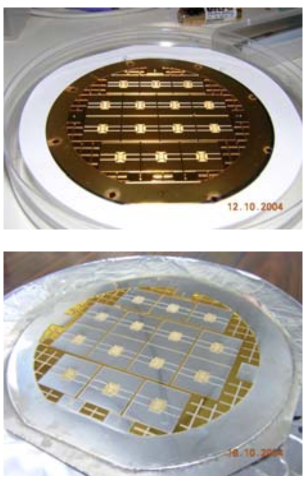


Figure 3. The cracks appeared on the corners

The nickel structure (Fig. 4) was formed by electroplating technique in nickel sulfamate electrolyte. The value of applied current density was in the range of 1-10ASD. Temperature of 52°C and pressure of 4Kg/cm^2 would help to make a better interface between nickel and substrate, and to limit the bubbles on nickel. The structure of 100-120µm is two times thinner than SU8 mold.

The wafers were immerged in Remover PG in 10hrs at 80°C and the SU8 mold was removed totally (Fig. 5). In the next steps, the adhesion/seed layers were removed and the isotropic etching was conducted to make the comb structure suspended. The etchants for Au and Cr should be selected so that they would not attack nickel structure: AU-5 (5% I_2 + 10% KI + 85% H_2O) and Phos+Sult (1 part 96% H_2SO_4: 1part 85% H_3PO_4) at 160°C. The isotropic etchant for silicon was Trilogy. The experimental etch rate was estimated at about 20µm/h.



(a)

(b)

Figure 4. SU8-50 mold (a) with electroplated nickel inside (b)

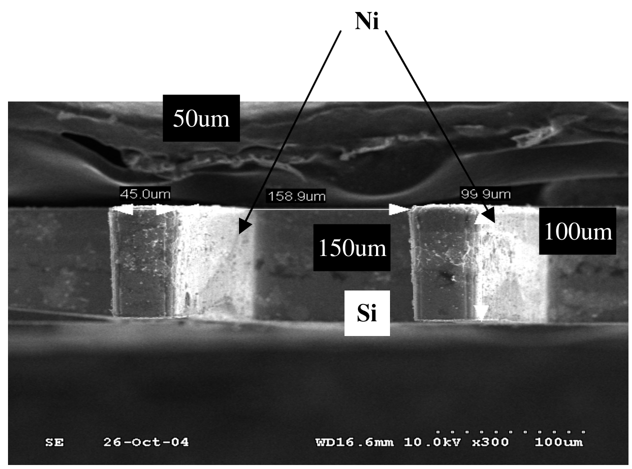
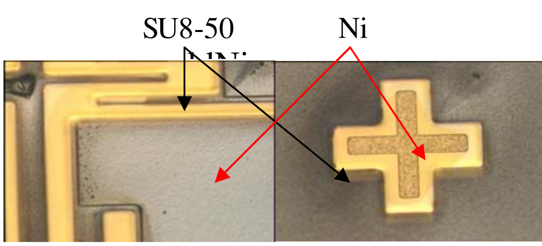


Figure 5. Nickel fingers of comb drive structure

The electroplating for 100µm nickel deposition lasted for about 15hrs at 45°C in ambient atmosphere. The images of nickel patterns on SU8 molds are shown in Fig.6. The thickness of SU8 (light color) is about 200µm while the thickness of nickel (dark color) is 100µm. The narrowest trenches are 50µm wide.



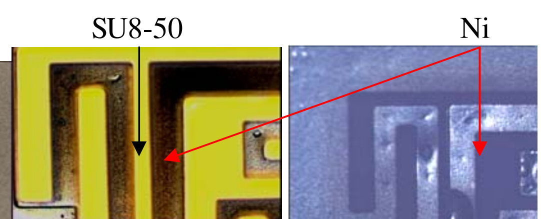


Figure. 6. Nickel features inside SU8-50 patterns

Figure. 7. Nickel comb structure before (a) and after (b) stripping SU8-50

The SU8 mold was then removed by heating in PG Remover in 10hrs. Fig. 7 illustrates the SEM image of nickel comb structure with the figures of 50μm wide and 500μm long.

4. Conclusions

The UV-LIGA technology for HARM fabrication has been presented. The nickel comb structures with the fingers of 50μm wide, 500μm long and 100μm thick for micromachined gyroscope have been fabricated using photoresist SU8-50 as a mold.

For better removal of SU8 after electroplating, the root technique and the selection of right ratio between SU8 mold and nickel structure thicknesses have been implemented.

The evaluated temperature of 52°C and pressure of $4Kg/cm^2$ have been applied for improving the surface smoothness of deposited nickel and obtaining a better interface between nickel and substrate.

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Reference

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