한국전기전자재료학회 2002년도 하계학술대회 논문집

Fabrication of high aspect ratio metallic structures for optical devices using UV-LIGA Process

광소자 응용을 위한 UV-LIGA 공정 기반의 MEMS 소자 제작

강호관*, 채경수*, 문성욱*, 오명환**
(H. K. Kang*, K. S. Chae*, S. O. Moon*, M. H. Oh**)

Abstract

This paper presents metal structure that is fabricated using UV-LIGA process with PMER N-CA3000. In order to fabricate metal structure with high aspect ratio, the systematic optimization method was adopted and then the structure of 36 ㎛ thick mold with aspect ratio 7:1 (trench) and 32 ㎛ thick nickel structure was obtained. This structure is applied to the fabrication of optical switch.

Key Words : MEMS, UV-LIGA, nickel, optical switch

1. Introduction

Optical switches applicable for all optical communication have to fulfill several requirements, such as long-term stability, low insertion loss, and low crosstalk. The device should also be inexpensive and compact in size. Micromechanical optical switches fabricated using MEMS technology can satisfy the required optical properties, and can show long-term stability and robustness against environmental interferences[1]. Among various MEMS technology, UV-LIGA process allows a low-cost micromechanical components with high aspect ratio required in optical applications.

In general, UV-LIGA process consists of seed layer deposition, mold formation, electroplating and etching the sacrificial layer. In this study, PMER N-CA 3000(TOK. Co) was selected as a mold material in order to obtain high-aspect-ratio and vertical sidewall. PMER N-CA 3000 is a negative thick photoresist and it contains novolak resin (48 wt%) and PGMEA (52 wt%). It was developed by organic alkali solution, PMER DEV 7-G, and easily removed by hot stripper or acetone. In the electroplating step, a nickel sulfamate bath was used and the stress and the brightness of the structure were controlled by commercial agents, SN-1000 and SN-2000.

2. Basic process

Common 4-inches (100) silicon wafers were used with deposited seed layer. First, dehydration bake was performed in an oven. The temperature was 115℃ and the baking time was 15 min. Next, the photoresist was spun cast as follows: 1) Flood center of wafer with 4 ml of PMER N-CA 3000, 2) Spin at 500 rpm for 15 sec., 3) Instantly change the spin speed to desired value for 15 sec., 4) Relax less than 10 min. Step 2 is very important for obtaining a uniform thickness of the photoresist. At step 3, the spin speed is selected in order to obtain the desired thickness. Step 4 is to release some of stress built up during spin coating of

---

* : 한국과학기술연구원 마이크로시스템센터
(서울 성북구 하월곡동 39-1,
Fax:02-958-6910
E-mail:hkkang@kist.re.kr)

**: 단국대학교 전기전자 컴퓨터 공학부

thick photoresist.

Pre-bake is necessary to remove solvent from the spin-coated photoresist layer and carried out using a hot plate with the following conditions:
1) 10 min. at 110 ℃ for 10~30 ㎛
2) 12 min. at 110 ℃ for 30~40 ㎛
The pre-bake is also related with the adhesion of photoresist to the substrate. If the baking time is not enough, then photoresist molds can come off from the substrate. Also, for a smooth and uniformly coated substrate, the hot plate should be flat.

After pre-bake, UV light exposure on photoresist layer is performed by a contact mask aligner (MA6) with the UV light source which has the wavelength of 365 nm and the intensity of above 15 ㎽/㎠. In order to achieve mold patterns with high aspect ratio and vertical sidewall, it is needed to optimize the exposure dose. In the experiments, several mold patterns are fabricated by changing the exposure dose from the maximum value of 345 mJ/㎠ at 23 ㎽/㎠. After inspecting the mold patterns, the optimal exposure dose is found to be located between 184 mJ/㎠ and 207 mJ/㎠ for the 36 ㎛ thick photoresist. If the exposure dose is excessive, it can be extremely difficult to develop the mold pattern after post-exposure bake. On the other hand, the insufficient exposure dose may result in an over-develop only with a short time. During the development, insufficient PEB (Post Exposure Bake) would result in the PMER N-CA 3000 peeling from substrate and an erosion of image, while over-PEB would increase the difference between top and bottom width of the developed pattern. Therefore, several experiments were performed with varying PEB time and the PMER N-CA 3000 thickness to obtain an optimum PEB temperature with 36 mm thick PMER N-CA 3000. As a result, the PEB at 100 ℃/ 9min. was chosen as an optimum condition.

Development was done in the solution special for the PMER N-CA 3000 at 27 ℃. Whether the exposed area can be completely removed in a short period depends on the exposure dose and the post-exposure bake. Development time was determined by examining the patterns with eyes.

Table 1. Process conditions to pattern PMER mold.

Process steps	Conditions
Spin rate	500rpm/15sec., 1400rpm/15sec.
Pre-bake	110℃/ 12 min.
Relaxation	<10 min.
Exposure	8~9 sec. (23mW/cm^2)
PEB	100℃/ 9 min.
Development	10 min./ 27℃
Final thickness	36 ㎛

Above process conditions are described in table 1. After completing the pattern generation in the photoresist, nickel electroplating was performed. Therefore, chemical compatibility of the photoresist with the electroplating chemical is important.

Nickel plating is the electrolytic deposition of a layer of nickel on a substrate. The process involves the dissolution of one electrode(the anode) and the deposition of metallic nickel on the other electrode(the cathode). Direct current is applied between the anode (positive) and the cathode(negative). Conductivity between the electrodes is provided by an aqueous solution of nickel salts. When nickel salts are dissolved in water, the nickel is present in solution as divalent, positively charged ion(Ni^{2+}). When current flows, divalent nickel ions react with two electrons (2e-) and are converted to metallic nickel (Ni^0) at the cathode. The reverse occurs at the anode where metallic nickel dissolves to form divalent ions. The electro-mechanical reaction in its simplest form[2] is:

$$Ni^{2+} + 2e^- = Ni^0$$

Because the discharged nickel ions at the cathode are replenished by the nickel ions formed at the anode, the nickel-plating process can be operated for long periods of time without interruption. Table 2 is composition electrolytic solution for our work as nickel sulfamate bath. Nickel surfamate is the principle source of nickel ions; nickel chloride improves anode dissolution and increases solution conductivity; boric acid helps to produce smoother, more ductile deposits. Antipitting agent is required to reduce the pitting due to the clinging of hydrogen bubbles

Table 2. Composition electrolytic solution[4].

Component	Quantity
$Ni(SO_3NH_2)_2 \cdot 4H_2O$	650 mℓ/ℓ
$NiCl_2 \cdot 6H_2O$	5 g/ℓ
H_3BO_3	45 g/ℓ
Antipitting agent(NP-A)	2 mℓ/ℓ
SN-1000	1.7 mℓ/ℓ
SN-2000	1 mℓ/ℓ

to the products being plates. SN-1000 and SN-2000 is commercial agents for stress reducing and brightness controlling. Plating was operated at pH of 3.6, temperature of 60 ℃ and at current *densities of 10 mA/㎠.*

Nickel electroplated structure was released from silicon substrate using xenon difluoride(XeF_2) gas etching. As a silicon etchant, XeF_2 has unique properties: (1) the etch selectivity is extremely high; (2) the etch is isotropic; (3) etching is a gentle dry reaction. By taking advantage of these unique properties, the fabrication of unprecedented three-dimensional microstructures can be realized. XeF_2 is a white solid material at room temperature and atmospheric pressure. In a vacuum environment, solid XeF_2 instantly sublimates and isotropically etches silicon with no physical excitation[3]. Process flow is illustrated in Fig. 1. Mold pattern and metal structure were fabricated by optimized process condition as shown in Fig. 2. Mold patterning processes are reproducible as long as the temperature and the humidity of the room are stable around 23℃±2℃ and 45%± 2% respectively.

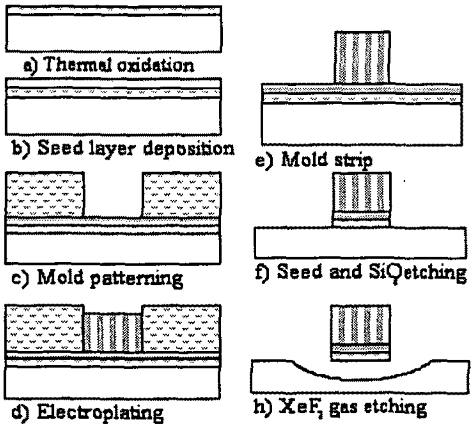
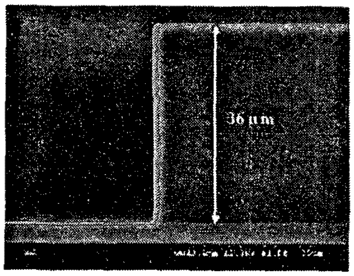
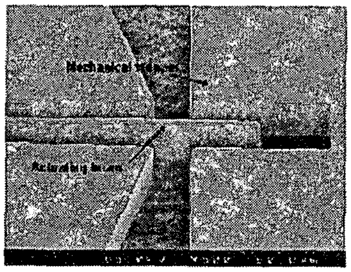


Fig. 1. The Schematic drawings of fabrication processes.



(a) Mold pattern with vertical sidewall



(b) Nickel electroplated structure

Fig. 2. SEM images of Fabricated structure at optimum condition.

3. Application

In order to apply to optical switch, metallic structure was fabricated using UV-LIGA process. This structure consists of a double-side reflecting mirror, a comb actuator and grooves to guide optical fibers as shown in Fig. 4. In these components, the comb actuator changes the position of the double-side reflecting mirror. Therefore, mirror can be moved in and out optical path. When the mirror stays out of optical path, the light out of the two pairs of fibers is coupled in a straight path between the fiber In-1 to Out-1 and between the fiber In-2 to Out-2, Fig. 3 (a). On the other hand, when the mirror state is switched into optical path, the light is coupled in a reflected path, Fig. 3 (b). In conventional optical switch[5], the mirror has a thickness that may introduce a lateral offset of the light beam and this results in an loss in the coupling between fibers Out-1 and Out-3.

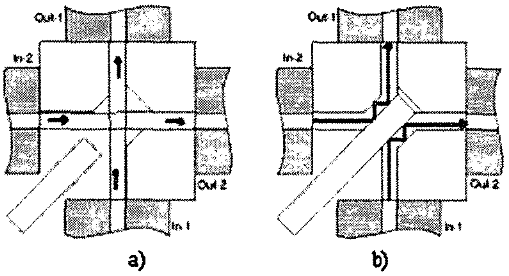
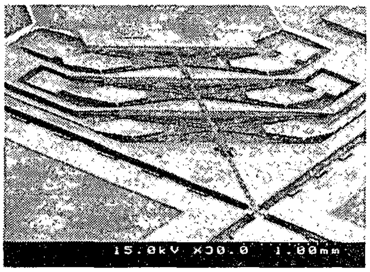
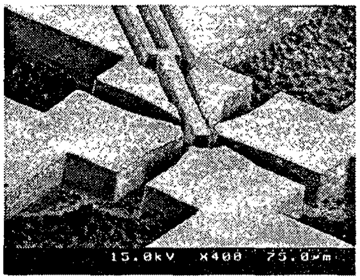


Fig. 3. The schematic top view of optical switching method.



(a) SEM image of metal structure for optical switch



(b) Enlarged view of switching parts of fabricated structure.

Fig. 4. Fabricated metallic structure for optical switch application.

But our switch has not lateral offset because it is eliminated by multiple reflection as shown in Fig. 3 b).

4. Summary

This paper presented a low-cost fabrication process for optical switch using UV-LIGA with PMER N-CA 3000. The UV-LIGA process consists of seed layer deposition, the formation of the mold pattern, nickel electroplating, and release by XeF_2 gas etching. Optical switch was fabricated by optimized process conditions. This switch has no lateral offset because it uses the noble method of multiple reflections.

References

[1] Ming C. Wu, "Micromachining for Optical and Optoelectronics Systems", Proc. IEEE, Vol. 85, No. 11, Nov. 1997, pp. 1833-1856.

[2] George A. DiBari, "Nickel Plating", International Nickel Inc., Saddle Brook, N.J.

[3] R. Toda, K. Minami and M. Esashi, "Thin-beam Bulk Micromachining Based on RIE and Xenon Difluoride Silicon Etching", Sensors and Actuators, A66, 1998, pp. 268-272.

[4] Hyun-Kee Chang, "Optimization of fabrication process for high aspect ration metallic comb actuator using UV LIGA process", Thesis, M. S. Seoul National University, Feb. 1999

[5] C. Maxer and N. F. de Rooij, "Micro-Opto-Mechanical 2 × 2 Switch for Single-Mode Fibers Based on Plasma-etched Silicon Mirror and Electrostatic Actuation", J. Lightwave Tech., Vol. 17, No. 1, January 1999, pp. 2-6.