SU-8 BASED UV-LIGA FABRICATION PROCESS FOR REALIZATION OF NICKEL BASED MEMS INERTIAL SENSOR

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Abstract. This paper reports the complete fabrication process flow based on UV-LIGA technology for realization of metal based MEMS inertial sensor. In this process, nickel is used as the structural layer and copper as the sacrificial layer. The economical three mask process has been optimized and the detailed step by step procedure for carrying out the fabrication is presented. The optimized process parameters to achieve void free copper and nickel electroplated layers with extremely low roughness have been reported. Footing problem associated with lithography process has been analysed and its solution discussed. The fabrication results after each process step have been presented and discussed. Scanning electron micrograph images of the released prototype inertial sensor devices have been presented to demonstrate the successful fabrication of the prototypes using the economical UV-LIGA process.

Keywords: MEMS, UV-LIGA, SU-8 2010, Cu and Ni electroplating

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1 Introduction

LIGA is a micro fabrication technique used to fabricate micro structures with high aspect ratio, from a variety of materials (plastics, metals and ceramics). LIGA is the German acronym for Lithographie, Galvanoformung (electro deposition), Abformung (molding). It was developed in the early 1980s at the Institute for Nuclear Process Engineering at the Karlsruhe Nuclear Research Center [1]. LIGA process is one of the few processes that offer lateral precision below one micrometer.
LIGA finds application in the MEMS industry due its capability of forming molds from various materials with complex shapes and with high aspect ratio and reasonably good absolute tolerances, which is essential for the realization of high aspect ratio MEMS devices. The advantage of LIGA over other microfabrication techniques such

as bulk and surface micromachining is its capability of forming structures with comparable dimensions not just in the lateral direction but also in the *z*-direction defining the thickness of the device.

There are two major variations of LIGA namely, X-ray LIGA and UV-LIGA. X-ray LIGA is used for fabrication of microstructures with aspect ratio as high as 500:1 with lateral precision below one micrometer and parallel, smooth side walls. But the synchrotron source used to generate X-rays is expensive, hence rendering it out of reach for low cost production [2, 3]. However UV-LIGA has paved way for implementation of LIGA process in an economical manner [4]. Unlike the expensive X-ray absorbing mask plates used for X-ray lithography, UV lithography uses relatively cheaper counterparts made of chromium. In UV-LIGA, the thickness of the resist that can be used is limited to 150 to 200 μm, as the pattern suffers from distortion with increasing thickness of the resist, thereby limiting the aspect ratio of structures that can be realized. Hence there is a trade-off between the fabrication cost and process requirements.

UV- LIGA process uses a polymer resist sensitive to UV-rays, which can be patterned using lithography techniques. After development of the resist, 3-dimensional structure with trenches is left behind on a conductive substrate into which the metallic structures are electroplated. The resist can be coated to a thickness as per the required thickness of plating, considering practical limitations of the process. After electroplating process, the resist is stripped leaving behind a metallic mold insert. This is followed by electroplating of the structural layer. This process can be used for realization of high aspect ratio metal based MEMS inertial sensor.

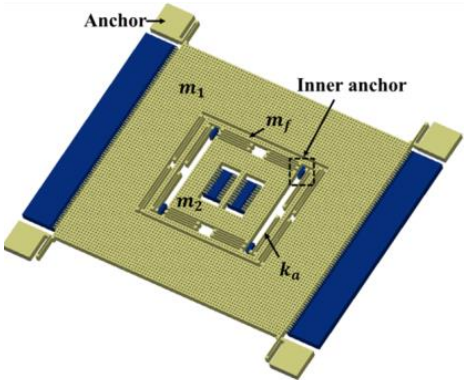


Fig. 1. Solid model of the device

Inertial sensor is used for measurement of angular rate of any moving object and finds application in diverse fields from consumer electronics to strategic applications such as Inertial Navigation systems. The device presented here is based on multi-DOF architecture to provide decoupled motion and increased robustness to fabrication and environmental variations. In this work, we present the process flow for fabrication of the inertial sensor using the economical fabrication technique, UV-LIGA. SU-8 mold formation and electroplating form the backbone of this in-expensive process, consisting of just three masking steps. Fabrication results after each unit process step have been presented and also the SEM images of the final released structure. Technology of computer optics [5-12] is unable to provide the required parameters of MEMS-structures.

2 Design

The schematic representation of the proposed inertial sensor structure is shown in Fig. 1. In this design, the structure is comprised of two masses, m_1 and m_2, supported by flexures as shown in the figure. There is an intermediate frame mass, m_f which acts as a decoupling mass. The spring, k_a in the *x*-direction, connects the decoupling frame mass, m_f, to an inner anchor.This structure is based on anchoring of the frame mass, which acts as a decoupling mass between the drive and sense masses. This configuration provides a reduced bandwidth and decoupled motion of the sense mass. The device has been designed considering fabrication compatibility with UV-LIGA process. The minimum feature size in the structure is 4µm gap between the comb fingers. The structure is designed with 8 µm x 8 µm perforations to aid in the sacrificial release process.

3 UV-LIGA based fabrication process flow

UV-LIGA process mainly consists of the well-established UV- Lithography process and Electroplating process. The process flow based on UV-LIGA implemented for fabrication of the MEMS inertial sensor is shown in Fig. 2.

3.1 Steps in UV-LIGA

a) Silicon wafer is thermally oxidized in a furnace to form silicon-di-oxide layer of 1 µm thickness, for electrical isolation of the device from the substrate.
b) 200 Å- 2000 Å Ti-Au is deposited, patterned and etched to form the metal interconnects of the device.
c) Again 200 Å- 2000 Å Ti-Au is deposited to form a seed layer for copper electroplating (sacrificial layer).
d) 8 µm SU-8 2010 photoresist mold is formed using optimized Lithography process for selective copper electroplating.
e) Copper is electroplated to a thickness of 6 µm in the SU-8 resist mold using copper sulphamate bath with optimized process parameters to achieve non-porous copper layer.
f) SU-8 resist is stripped using PG-remover and Plasma Asher.
g) 11 µm SU-8 2010 photoresist mold is formed using Lithography for electroplating Nickel structural layer.
h) 9 µm nickel electroplating is carried out in the SU-8 resist mold to form the structural layer.
i) SU-8 resist is stripped using PG-remover & Plasma Asher. This is followed by dicing operation to singulate the dies from the wafer. Sacrificial etching of copper

is carried out followed by etching of seed layer of Ti-Au (step c), leaving the nickel structural layer freely suspended.

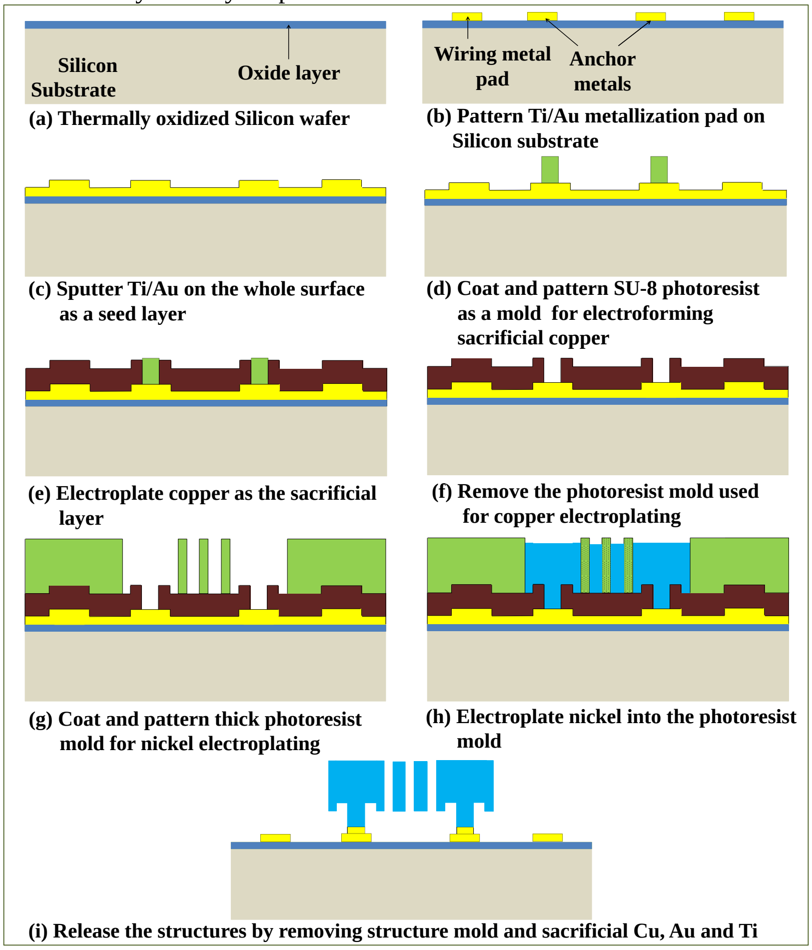


Fig. 2. Fabrication steps of MEMS inertial sensor using SU-8 based UV-LIGA process

4 Fabrication results

The prototype device has been fabricated using the process flow presented in this paper. Images of the fabricated device have been captured using Zeta optical profiler after each process step during fabrication. Fig. 3 (a) shows the image of the device after first lithography of the metal pattern and Fig. 3(b) shows the device after metal etch process. The formation of SU-8 2010 photoresist mold after UV exposure is shown in Fig. 3(c). Fig. 3(d) shows electroplated copper layer (captured after SU-8 2010 resist stripping). The bright portion is the Ti-Au layer while the rest of the area is plated with copper. The Ti-Au layer forms the anchors for the structural layer. The structural layer mold formation using SU-8 resist is shown in Fig. 3(e). The device after Nickel electroplating and stripping of the SU-8 2010 resist is shown in Fig 3(f). The SEM image of the fabricated structure after sacrificial release is shown in Fig. 4.

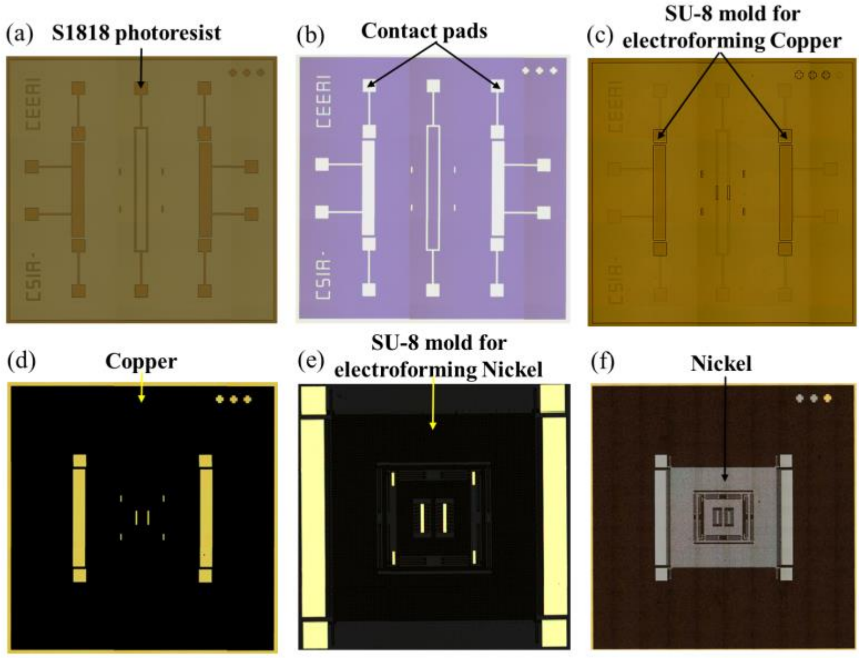


Fig. 3. Zeta optical profiler images of a MEMS inertial sensor captured after process

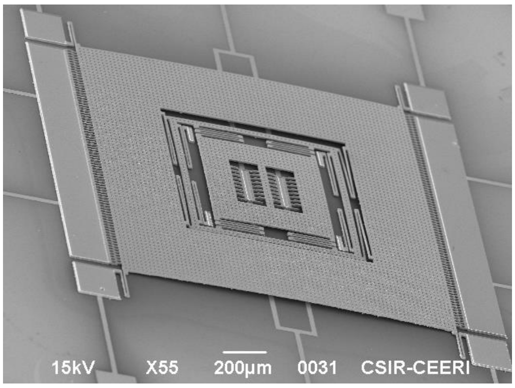


Fig. 4. SEM image of the fabricated complete structure

5 Copper and Nickel electroplating results

Copper electroplating is done at room temperature using copper sulphate solution to achieve ~6 µm thick sacrificial layer (Fig. 3(d)). Table 1 summarizes the operating conditions for copper electroplating process.

The above process parameters have been optimized after several electroplating trials by varying temperature, current density etc., to achieve a void free copper layer with fine grain size which is a very challenging art [13, 14]. Figure 5 shows the average surface roughness of the plated copper after (0.2 μm) process optimization measured using Zeta optical profiler.

Similarly, the process parameters such as applied current and temperature have been optimized in order to achieve a shiny and uniform nickel layer using nickel sulfamate bath. The optimized parameters are summarized in Table 1.

Figure 6 shows the surface roughness of the electroplated nickel layer during optimization trials, profiled using Zeta optical profiler.

Table 1. Operating conditions for copper and nickel electroplating process

Parameters	Condition for Cu	Condition for Ni
Plating current type	DC	DC
Plating current density	10 A/ cm^2	5 A/ cm^2
Deposition rate	0.16 μm/min	0.1 μm/min
Solution agitation	Off	150 rpm
Anode-cathode spacing	6.8 cm	6.4 cm

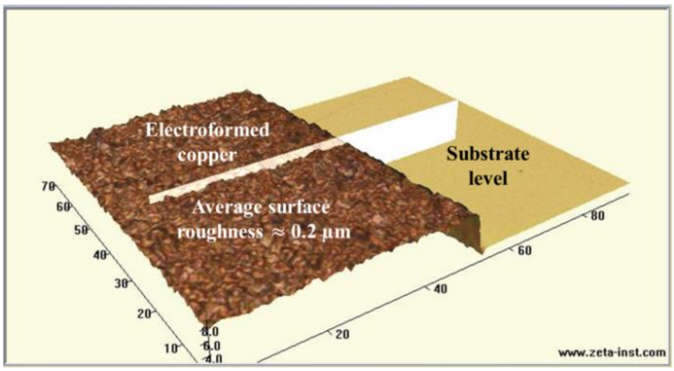


Fig. 5. Improved surface of the deposited Cu after optimization.

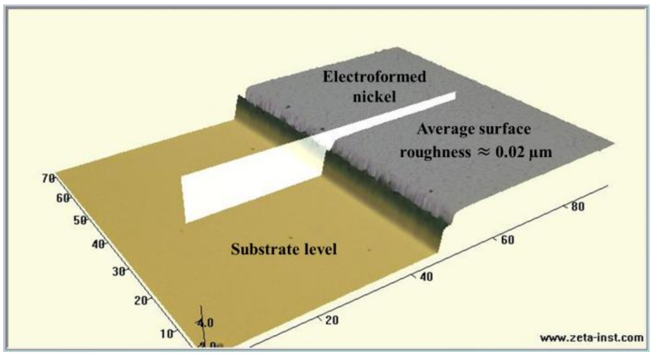
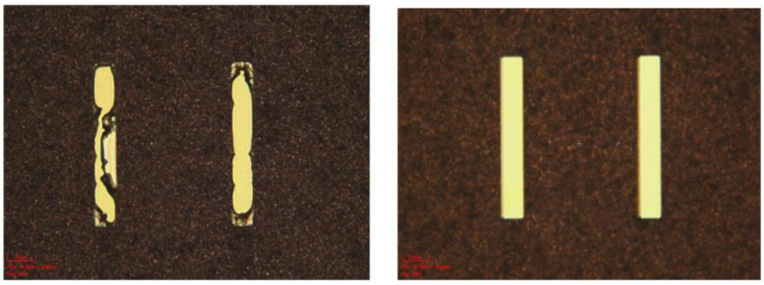


Fig. 6. Improved surface of the deposited Ni after optimization

6 SU-8 2010 Removal

After selective plating, SU-8 photoresist is removed. During stripping, a major concern is to ensure that the electroplated structure does not get damaged. This is arguably the most challenging step, because no solvent has been found that can simply dissolve SU-8 after hard bake. Several methods of striping SU-8 molds have been suggested and employed such as burning at 450-600 °C [15, 16], dissolving in molten salt bath at 350 °C [16], downstream chemical etching (DCE) at 225 °C [17, 18], plasma etching [Engelke et al. 2008] or solvent cracking at 75-80 °C. Therefore, difficulties associated with the removal of polymerized SU-8 remains a serious issue. In the fabrication of prototypes, *N*-methyl pyrrolidinone (NPM) based solvent Remover PG [http://www.microchem.com] at 75 °C has been used for removal of SU-8, which basically is peeled-off from the electroplated structures. To enhance the stripping, the implosion of ultrasonic agitation during the rinsing process is employed, which strikes the surface of the SU-8 mold and dislodges it from the electroplated structure. But, wet technique alone is found to be in-sufficient, as SU-8 residue still remained on the surface as shown in Fig. 7(a). For complete removal of resist, the wafer is ashed in a plasma stripper using CF_4 and O_2 gasses. This ensures the complete removal of SU-8 photoresist as shown in Fig. 7(b).



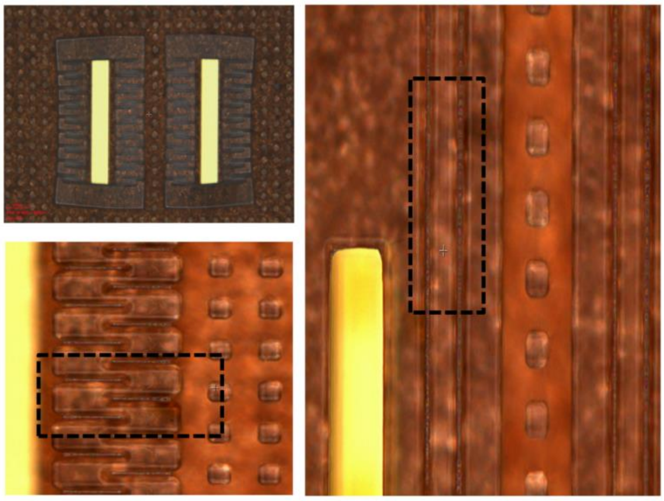
(a) **(b)**

Fig. 7. SU-8 photoresist stripping after Cu electroplating: (a) results after SU-8 removal in Remover PG; (b) results after plasma removal of SU-8 residue

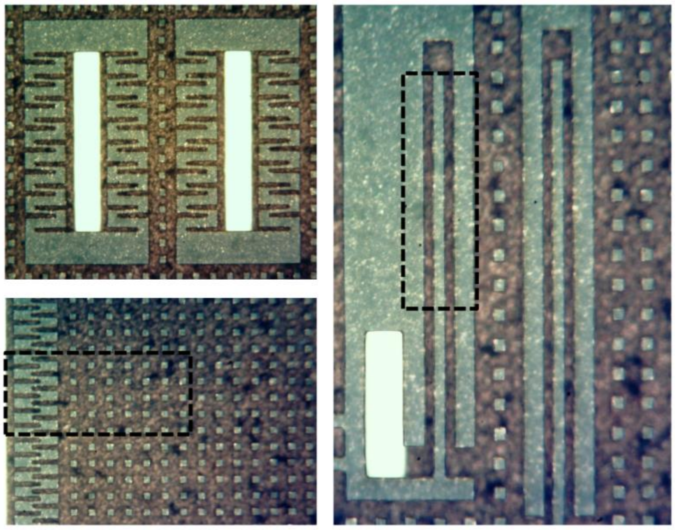
7 SU-8 mold for realization of fine features in the structure

The selectively Cu plated wafers are coated with primer (Omnicoat) in order to improve the adhesion between the electroplated copper and SU-8 photoresist. This is followed by drying the Omnicoat and coating of SU-8 photoresist at 1500 rpm and subsequent soft bake process which is done at 65 °C for a period of 7 min and then at a ramped up temperature of 95 °C for 14 min. The wafer and mask plate are held in-hard contact mode and exposed to UV light with wavelength of 365 nm. To ensure development at the bottom of the pattern, double exposure is given with each exposure lasting for 1.4 s with a brief interval of 10 s between the exposures. This is followed by a post exposure bake which is done in exactly the same conditions as soft bake explained above. After the post exposure bake, the resist is developed in SU-8

Developer [http://www.microchem.com] for 30 s in stable condition and then stirring the solution for 30 s. The treated wafers are then immersed in Isopropanol for 30 s in stable condition and then stirred for 30 s.



(a)



(b)

Fig. 8. Optimization for structure layer mold: (a) before optimization; (b) after optimization

During this process, footing problem is encountered in comb fingers and beams (Fig. 8(a)). After some experiments, it is found that insufficient soft bake and post bake are the reason, which caused the resist to stick to copper. The baking processes have been optimised by increasing the baking time up to 14 min for both 65 ^{o}C and 95 ^{o}C in soft bake and post bake respectively. This has resolved the issue (Fig. 8(b)).

Conclusion

Fabrication process based on UV-LIGA technique has been presented for realization of metal based MEMS inertial sensor. The process flow has been optimized after several trials and the same is presented in this paper. The structural nickel layer thickness implemented in the process is 9 μm and the minimum feature size is 4 μm, which is between the comb fingers. The process parameters optimized to achieve Copper and Nickel electroplated layers with surface roughness less than 0.2 μm and 0.02 μm respectively, have been presented. Footing problem associated with lithography process has been analysed and its solution discussed. The results of unit process steps and finally the SEM images of the fabricated MEMS inertial sensor are presented, demonstrating the successful fabrication of the prototype using UV-LIGA process.

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