UV-LIGA FABRICATION PROCESS FOR REALIZATION OF METAL BASED MEMS GYROSCOPE

Payal Verma [1], K. Zaman Khan [2], S.N. Khonina [1], R.V. Skidanov [1], N.L. Kazanskiy [1], R. Gopal [3]

[1] Samara State Aerospace University, Samara, Russia
[2] Semiconductor Technology and Applied Research Centre, Bangalore, India
[3] *CSIR – Central Electronics Engineering Research Institute, Pilani, India.*

This paper reports the complete fabrication process flow based on UV-LIGA technology for realization of metal based MEMS gyroscope. 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 fabrication results after each process step have been presented and discussed. Scanning electron micrograph images of the released prototype gyroscope devices have been presented to demonstrate the successful fabrication of the prototypes.

Keywords: MEMS, UV-LIGA, SU8.

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 um, 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 plating of the structural layer. This process can be used for realization of high aspect ratio metal based MEMS gyroscope.

Gyroscope 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 gyroscope design 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.

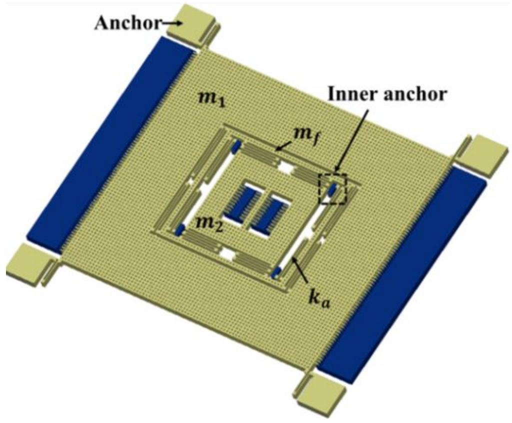

Fig. 1. Solid model

Design

The schematic representation of the proposed gyro-accelerometer 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 8μm x 8μm perforations to aid in the sacrificial release process.

LIGA based Fabrication process flow

UV-LIGA process mainly consists of the well-established UV- Lithography process and Electroplating process. A typical process flow based on UV-LIGA for fabrication of MEMS structure is shown in Fig. 2.

Silicon substrate is used as the starting material for the process which is thermally oxidized to form a 1 μm thick insulation layer of SiO_2. Next, Ti/Au interconnect metallization layer is sputter coated and patterned using S1818 photoresist and etched using wet chemical etching. This forms the anchoring points for plating and also metal pads for characterization and packaging. This is followed by seed layer metallization of Ti/Au and 8 μm mold formation of SU-8 2010 photoresist for copper electroplating as a sacrificial layer. The copper layer of about 6 μm thickness is, then, electroplated selectively within the mold. After this, the photoresist is stripped and again the 11 μm SU-8 2010 photoresist [5] is coated and patterned to form the mold for nickel structural layer. Thereafter, 9 μm thick key nickel structure is built by electroforming process. This is followed by stripping of photoresist and etching the sacrificial copper using wet chemical etching to release the structure. Finally, the Ti/Au seed layer is etched out selectively to electrically isolate the fixed and movable structures.

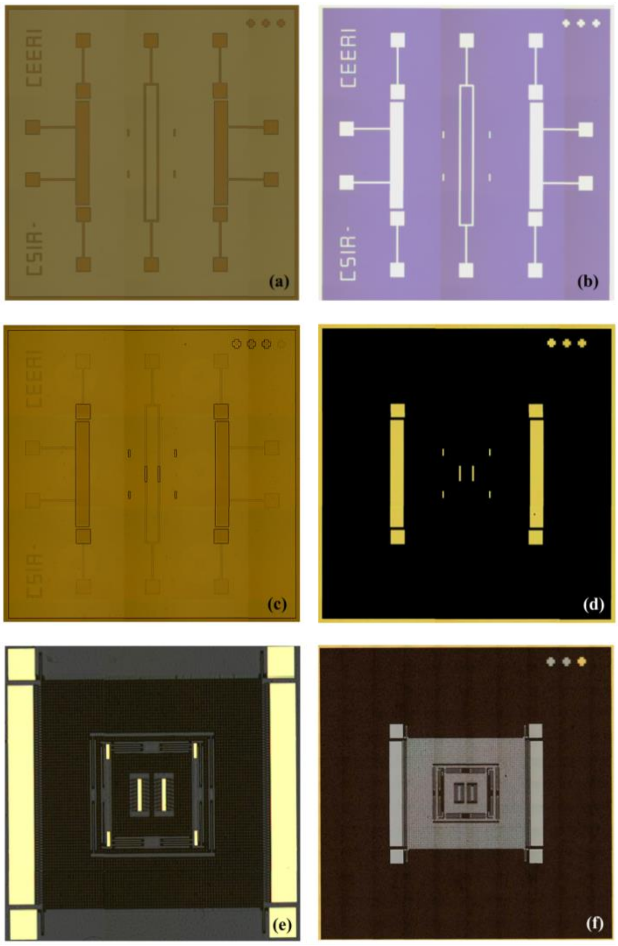

Fig. 2. Zeta optical profiler images of a 2-DOF drive and 1-DOF sense modes with decouple frame mass anchoring gyro-accelerometer captured after process: (a) pattern for metallization; (b) metal connection realization; (c) pattern formation of sacrificial layer mold; (d) Cu plating; (e) pattern formation of structural layer mold; (f) Ni plating.

Results

The prototype gyro-accelerometer 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. 2(a) shows the image of the device after first lithography of the metal pattern and Fig. 2(b) shows the device after metal etch process. The formation of SU8-2010 photoresist mold after UV exposure is shown in Fig. 2(c). Figure 2(d) shows electroplated copper layer (captured after SU8 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 SU8-2010 resist is shown in Fig. 2(e). The device after Nickel electroplating and stripping of the SU8-2010 resist is shown in Fig. 2(f). The SEM image of the fabricated structure after sacrificial release is shown in Fig. 3. The gap under the proof mass indicates that the structure is released. The comb fingers and beams are well defined and resolved, indicating the perfect definition of the Lithography pattern.

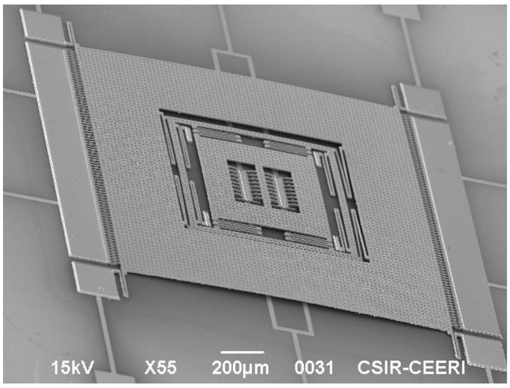

Fig. 3. SEM image of the fabricated complete structure

References

1. Madou MJ. Fundamentals of microfabrication. CRC Press; 2002.
2. Becker EW, Ehrfeld W, Hagmann P, Maner A, Munchmeyer D. Fabrication of microstructures with high aspect ratios and great structural heights by synchrotron radition lithography, galvanoforming, and plastic moulding (LIGA process). Microelectronics Engineering 1986; 4: 35-56.
3. Kupka RK, Bouamrane, Cremers C, Megtert S. Microfabrication: LIGA-X and applications. Applied Surface Science 2000; 164: 97-110.
4. Verma P, Shekhar C, Arya SK, Gopal R. New design architecture of a 3-DOF vibratory gyroscope with robust drive operation mode and implementation. Microsystem Technologies 2015; 21: 2175-2185.
5. http://www.microchem.com