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Research and Application of MEMS Technique at BSRF

YI Fu-ting, PENG Liang-qiang, ZHANG Ju-fang, HAN Yong, XIAN Ding-chang

(Institute of High Energy Physics)
Email: yift@ihep.ac.cn
Tel: 010-68235983

Abstract: LIGA technique has been developed since 1993 at BSRF, including the fabrication of LIGA mask, deep X-ray lithography, electroplating, the pouring molding and the applications in some fields. The LIGA mask with gold absorbing structures of 20μm thickness and 5μm width and Kapton membrane of around 5μm thickness has been successfully fabricated and applied to the deep X-ray lithography with the PMMA structure of 1mm thickness or above. The beamline from a wiggler is used for the deep X-ray lithography of LIGA station and is open to other institutes researching the deep X-ray lithography. The normal process of LIGA technique with the exception of molding has been established with the PMMA structures of 500μm thickness at BSRF. The largest aspect ratio of PMMA structures can reach about 50 with the height of 500μm and the lateral size of 10μm. The nickel and copper structures with the thickness of 0.5mm and 1mm have been made by using the electroplating technique. The SU 8 as a resist material of deep etch lithography with UV light is also developed in the fabrication of LIGA mask and some devices at BSRF. Electromagnetic stepping micro motor, heat exchange, accelerator, structures used in the EDM (electro discharge machining) are being developed for the future applications.

Key words: LIGA; MEMS; microfabrication; microsystems
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1 Introduction

LIGA process, which is a powerful method to make the microstructres with the highest aspect ratio of several hundred in MEMS field, was invented and reported in 1986, and many devices have successfully been made with it, such as micromotor, micro-pump, micro-fiber connect and so on. This technique was developed at BSRF (Beijing Synchrotron Radiation Facility) from 1993 and many results have been achieved, including the fabrication of LIGA mask, deep-etch X-ray lithography, electroplating, the technique of moulding, and its applications. Meanwhile the SU 8 technique is also under development to make the microstructures for the fabrication of LIGA mask with the structure height of 20μm and some application devices with the structure height of 500μm. In this paper, we will present our activities about the LIGA technique and the SU8 technique, and we also wish that these techniques could be widely used by other users in different institutes and universities by the cooperation with us on any situations.

2 Mask fabrication of LIGA technique

The fabrication of LIGA mask is a very complex process and will use many techniques, such as

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the metal deposition, dry and wet etching, gold electroplating. The SR (synchrotron radiation) light had to be used to copy the LIGA mask from an intermediate X-ray mask at the beginning stage of LIGA technique at BSRF because there were not any other techniques chosen to make the structures with the thickness of 20μm. However, SU8 and AZ4650 resists have been developed for this purpose and can be used directly to make the LIGA mask with the structure thickness of 20μm once. The fabrication of the LIGA mask has been a normal process with the SU8 technique.

The SU8 has been used to make the structures with the thickness of 20μm for the absorbing structures of LIGA mask. The gold structure is chosen to be the absorb material of the mask, and can be made with the gold deposition into the gaps of SU8 structures by electroplating. The polyimide as the membrane for the mask is spun on the wafer and polymerized in a oven at high temperature. Fig. 1 shows the gold absorbing structures of LIGA mask with thickness of 17μm.

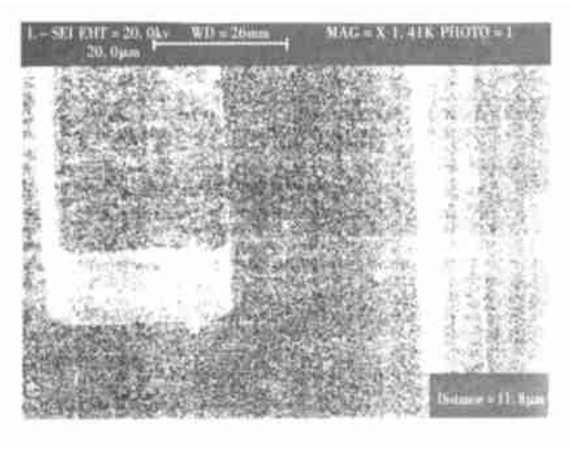


Fig. 1 Gold absorbing structures of LIGA mask

3 Deep-etch X-ray lithography

3.1 Properties of SR source

The beamline for the deep X-ray lithography of LIGA technique is extracted from a wiggler which has the 5 period number and the 1.5T magnetic field. The LIGA station is located at 24m from the source and receives the SR light with 1mrad in horizontal direction and 0.2mrad in vertical direction. A scanner built in a chamber on the beamline periodically moves in vertical direction to form a uniform X-ray spot on the sample with the speed of 10mm/s and the distance of 40mm because the distribution of SR in this direction is the Gauss shape. The scanner is cooled with water to reduce the X-ray heat effect on the PMMA. The exposure area, which is mainly limited by the receiving angle in horizontal direction, are $24 \times 40 mm^2$.

Fig. 2 shows the X-ray spectrum of the beamline after a Be window used to separate the ultra high vacuum from the scanning chamber with 1/3bar He gas. The spectrum consists of large part of very hard X-ray and is not suitable for the deep X-ray lithography with the structure height of 500μm. Therefore a nickel film with 4μm thickness is selected to modify the spectrum of the beamline before the mask by its absorb edge at 8KeV.

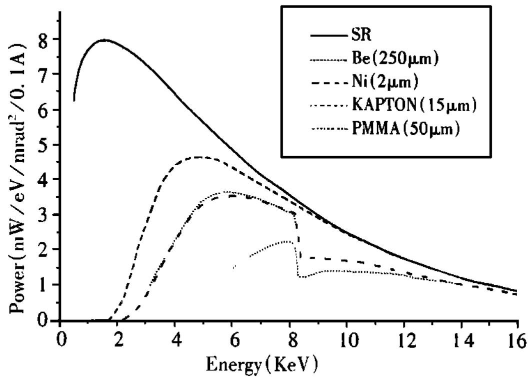


Fig.2 X-ray spectrum of the 3W1A beamline after a Be window, nickel film, KAPTON film and PMMA resist

3.2 Deep X-ray lithography of LIGA technique

3.2.1 PMMA resist system

The PMMA is usually used as the X-ray resist in the LIGA process but its thickness should be several hundred micrometers which is different from the normal X-ray nanolithography with the PMMA resist below 1μm thickness. The PMMA resist layer is polymerized directly on a metallizing base plate by using a casting resin in which 30%

polymethylmethacrylate (PMMA) of a mean molecular weight of 100000g/mol is dissolved in methyl methacrylate (MMA). Polymerization takes place at room temperature using benzoyl peroxide (BPO) as the hardener and dimethylanlline as the starter. The resist layer produced in this way exhibits a relatively low number of stress induced cracks in the development process and the high stability with the cross- linked structures.

The PMMA and MMA were produced by the chemical institute through the cooperation at the first stage of LIGA technique, but now the PMMA can be bought from commercial company with mean molecular weight of 100000g/mol. To ensure adequate adherence of the microstructures on polished untreated surfaces, internal coupling agents must be used which are chemically bound to the metal surface and can be integrated in the polymer matrix.

3.2.2 Deep X-ray lithography

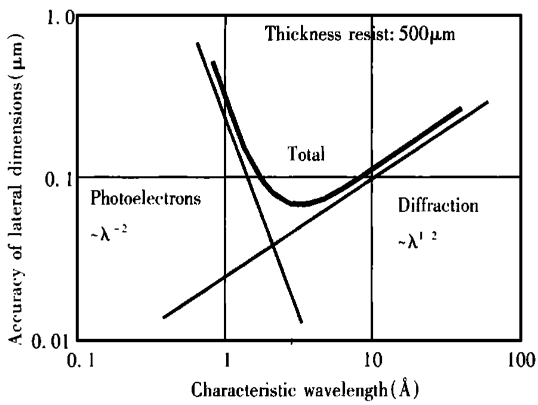
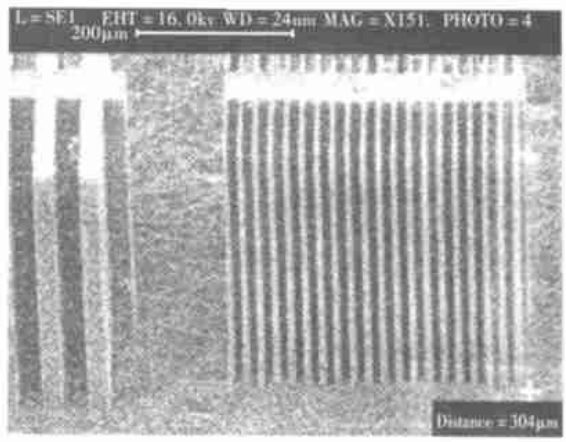
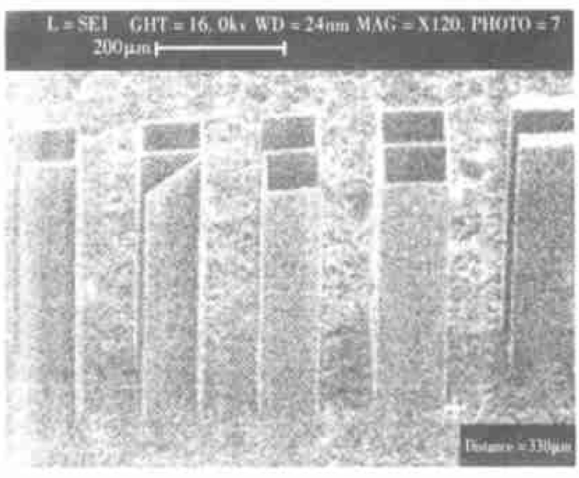


Fig. 3 Influence of the X-ray on the accuracy of lateral dimensions with Fresnel diffraction and photoelectrons

The precision of the final product will be determined by the accuracy and spatial resolution in each fabrication step. Fig. 3 shows the influence of the SR light on the accuracy of lateral dimensions with Fresnel diffraction and photoelectrons. The diagram exhibits the typical asymptotic increase of cross- section for the creation of photoelectrons at shorter wavelengths and the domination of Fresnel diffraction at larger wavelengths. The best accuracy is achieved in between 2- 3 angstrom. Meanwhile the X-ray with much shorter wavelength will penetrate the absorb structure of the mask and produce the fluorescence radiation from the plating base. This fluorescence radiation will expose the PMMA thin layer near the plating base and cause the PMMA structures to be removed off when they are under development. To improve the spectrum, the nickel film is used to cut the harder X-ray with its absorb edge at 8KeV (see fig. 2). This measure produces a good effect in the process of deep etch X-ray lithography.



(a)



(b)

Fig. 4 PMMA structures made in the LIGA station at BSRF

4 Electroplating process

Fig. 4(a) shows the PMMA comb structures made in the LIGA station at BSRF with the thickness of around 500μm and fine lateral size of 10μm, and fig. 4(b) the PMMA structures with the letters BSRF. The largest aspect ratio the PMMA structures can reach 50.

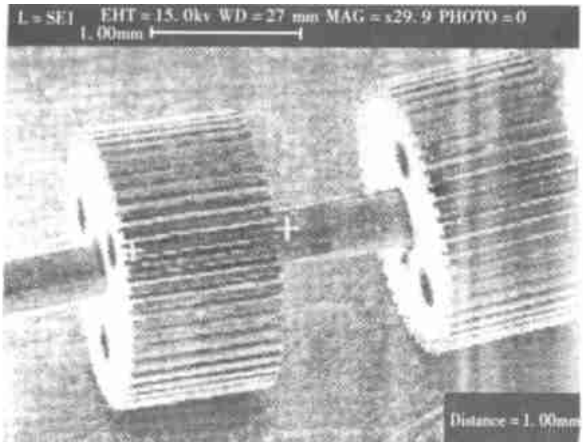


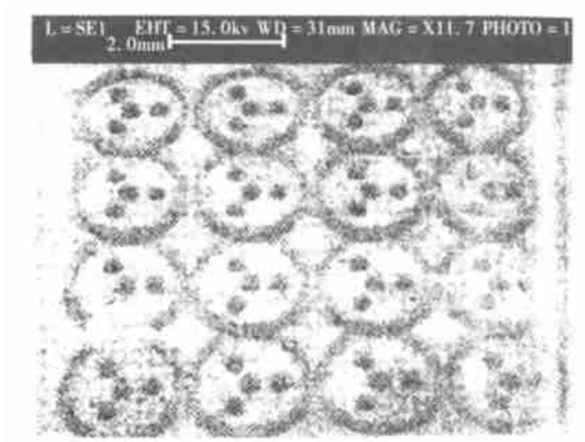
Fig. 5 Nickel structure with the height of 1mm and the lateral size of 50μm

The resist structures had to be transformed into the metal structures for the application devices by metal electrodeposition in the gaps of resist structures. The metal deposition must start on the bottom of the structures. To get the low stress nickel structures, the sulphamate bath is chosen to be the electrolyte with 400g/l nickel sulphamate, 40g/l boric acid as buffer, and small quantities of a wetting agent. The electrolyte should be continuously circulated with the filter of 0.5μm holes. The current densities for metal deposition range between 1- 10A/dm at the temperature of 52℃, depending on the microstructure. Fig. 5 exhibits the nickel structure with the height of 1mm and the lateral size of 50μm.

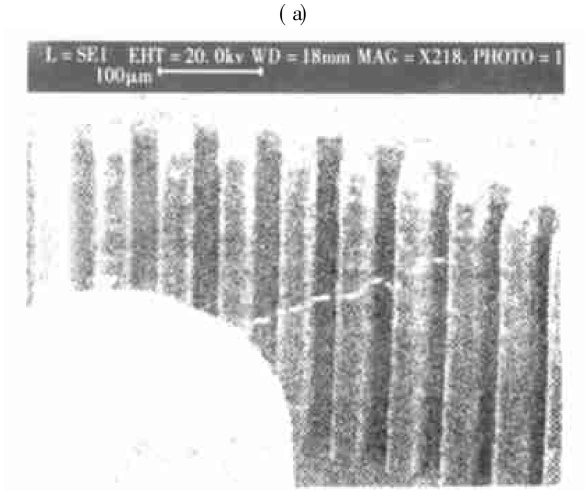
Besides the nickel deposition, the copper electroplating is done with the electrolyte of 220g/l copper sulphate, 60g/l sulphate acid.

5 Pouring moulding

Moulding is a very important step in the LIGA process, and can provide a great number of plastic structures to be deposited with metal for the metal parts of many devices in a large scale. In order to get experience about moulding, the pouring moulding with PMMA is in research because there are not complex and expensive moulding equipment. Fig. 6(a) shows the moulding insert of nickel structures made with the nickel electrolyte, and fig. 6(b) exhibits the PMMA structures with the nickel moulding insert by the pouring process.



(a)



(b)

Fig. 6 Nickel moulding structures and the PMMA structure with the pouring process

6 SU8 technique

SU8 as a negative resist is used to make resist structures with the height above several hundred micrometers in MEMS technique on large scale. Fig. 7 shows the SU8 structure with the thickness of 320μm and the width of 10μm. The largest aspect ratio can reach 32. The SU8 resist should be baked at 900C for 20- 50mins before exposure depending on its thickness and at 800C for 20mins after the exposure. The high internal stress of SU8 after exposure to the UV light is a tough problem for its application, and often causes the removal of structures off the substrate after the development.

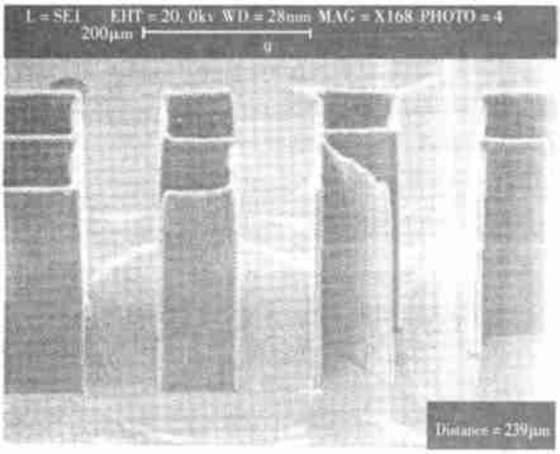


Fig. 7 SU8 structure with the thickness of 320μm and the width of 10μm

7 Application of LIGA technique

The aims of the MEMS technique is to make the devices for applications in many fields. During the research of LIGA technique, the applications are also considered and developed at BSRF. Fig. 8 shows the SEM structures of electromagnetic micro stepping motor with 8 stators around the rotor of diameter of 2mm. This micro motor is just a prototype needed to be improved and can run with the pulse power.

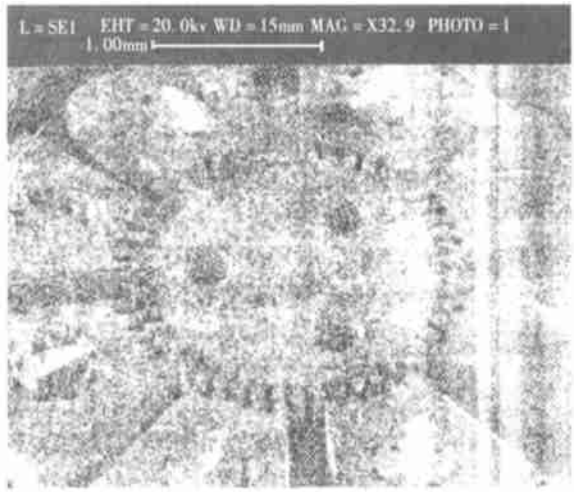


Fig. 8 SEM structures of electromagnetic micro stepping motor

8 Conclusion

The LIGA technique has been developed at BSRF for many years, and can be used to make some parts for applications, such as the electromagnetic stepping micromotor, the micro gripper and micro head exchange. LIGA technique is superior to other technologies in many aspects such as high aspect ratio, large thick structure, great profile of structures, and can be used to make the structure in most MEMS fields.

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