Available online at www.sciencedirect.com
SCIENCE DIRECT
Nuclear Science and Techniques, Vol.17, No.1 (2006) 11–15
NUCLEAR SCIENCE AND TECHNIQUES

Preliminary design of multi-function LIGA beamline

WANG Na-Xiu[1] ZHENG Hong-Wei[2]
1 (Shanghai Institute of Applied Physics, the Chinese Academy of Sciences, Shanghai 201800, China)
2 (Institute of High Energy Physics, the Chinese Academy of Sciences, Beijing100049, China)

Abstract One design of multi-function LIGA beamline has been reported. In this design, two plane mirrors and a series of filters have been employed. One can choose the spectrum range of X-ray easily according to the exposure requirement by adjusting the grazing angle of mirrors and the thickness of filters. And the spot size in the horizontal direction is up to 120mm, which is large enough for exposing 5 inch silicon slice. The typical exposure time is about 1.2h, 1.8h, 0.5h, corresponding to PMMA thickness of 500 μm, 200 μm, 20 μm, respectively.

Key words Synchrotron radiation, Beamline, Lithography electroforming micro molding, X-ray lithography
CLC numbers TN42, TH73

1 Introduction

Lithography Electroforming Micro Molding (LIGA, abbreviation of three German words of Lithographie Galvanoformung Abformung) technology, which mainly includes three processes of X-ray lithography, electroplating, and molding, is one of the promising micro-fabrication technologies for producing extremely tall three-dimensional microstructures with a large aspect ratio and high throughput[1]. It has been developed rapidly in recent years. Microstructures with a height of over a few hundred microns have been widely applied to various fields such as micro-mechanics, micro-optics, sensor and actuator technology, and chemical, medical, and biological engineering. In order to fabricate such microstructures, deep X-ray lithography (DXRL) using synchrotron radiation (SR) is one of the most promising techniques.

DXRL allows the production of high aspect ratio three-dimensional structures in polymer with quasi-perfect sidewall verticality and optical quality roughness. These structures can be used as templates to mass-produce micro-parts made of various metals, alloys, or ceramics. It opens a wide variety of potential applications in the field of micro-electromechanical systems (MEMS), fiber and integrated optics, microfluidic devices, and interconnection technology.

LIGA technology was invented in Germany, and quickly spread to UK, United States, Japan, Russia, Taiwan etc. In the Chinese mainland, the research on LIGA has started at BSRF in Beijing, NSRL in Hefei, Shanghai Jiaotong University, and Changchun Institute of Optics, Fine Mechanics and Physics. Several results have been obtained. The X-ray source used for DXRL directly comes from a bending magnet of BSRF and a superconducting bending magnet of NSRL. The X-ray exposure size on the sample in the horizontal direction is only about 40mm. No mirror is installed on both beamlines. Without mirror, the hard X-ray, which is harmful to the resist of DXRL technology, will penetrate through the absorber of mask and PMMA to the substrate surface, reduce the PMMA adhesion to the substrate, and cause the difficulty of controlling exposure dose in the development of resist [2, 3]. So it is better to solve the problem on the phase of beamline design. The X-ray light with an adjustable spectrum will be provided to the research of DXRL technology at Shanghai Synchrotron Radiation

Received date: 2005-06-30

Facility (SSRF).

2 Preliminary design of beamline

2.1 Requirement of LIGA technology for X-ray light

Using PMMA as X-ray resist material, a minimum radiation dose of 3.5 kJ/cm^3 on the bottom of the resist is required in the development process. On the surface a maximum dose of 25 kJ/cm^3 should not be exceeded. The dose ratio of the maximum to minimum should be less than 6 [4]. In order to avoid standing wave effect and reduce exposure time, the X-ray for DXRL process cannot be monochromic. Therefore, the spectrum range of white light should be chosen carefully for DXRL technology.

The energy range is about 2—8 keV for the fabrication of “standard” LIGA microstructures with 500 μm thickness. With the spectrum range softer than 2—8 keV, excessive dose will exist on the surface of the resist until the bottom of resist gets enough doses of exposure. The resist on the surface with excessive dose cannot be dissolved away in the development process. The X-ray spectrum harder than 2—8 keV will penetrate the absorber of mask and resist to the substrate surface and produce secondary electrons, which will reduce the resist adhesion to the substrate[2,3].

The thickness of about 200 μm is enough for thin structures of many microsystems or microparts. The energy range for the above purpose is 2—6 keV, which is softer than that used for the fabrication of the 500 μm thick structures and should be considered while designing the LIGA beamline.

Mask making is an important step for DXRL research. The mask for DXRL research should have the absorber structure of above 15 μm thickness with steep and smooth sidewall. This work is currently done with SU8 or AZ4650 resist for about 10 μm width pattern size. The SR lithography is needed to fabricate the mask with about 1 μm pattern size. For the fabricating, an intermediate X-ray mask with absorber structure about 2 μm thickness is first made with UV lithography or e-beam writer. Then the final X-ray mask, having an absorber structure above 15 μm thick and 1 μm pattern size, can be copied with the intermediate mask by using SR lithography. For the coping of X-ray mask, the energy range is very different from that for DXRL. It is 1—2 keV.

The "standard" thickness of LIGA structures is about 500 μm. But the ultra-deep structures with millimeter or centimeter thickness are needed for further applications. To meet this requirement, the high end of energy should be up to 40 keV. The X-ray, which emits from the SSRF bending magnet, should be provided without any high energy filter. It can irradiate the sample directly through a Be vacuum window.

For the above purposes, the energy range of the LIGA beamline is at 1—8 keV, and also the X-ray light emitted from the bending magnet can be directly transmitted to the sample through a Be vacuum window. The beamline length should be as short as possible to increase the X-ray power intensity on the sample.

Parameters of the bending magnet of SSRF storage ring are listed in Table 1.

2.2 Design specification of the beamline

The design specification of the beamline is shown in Table 2.

Table 1 Parameters of the bending magnet at SSRF

Energy / GeV	Current / mA	Magnet / T	Radius / m	Size and divergence of electron beam			
				σ_x / μm	σ_y / μm	σ_x' / μrad	σ_y' / μrad
3.5	300	1.2217	9.549	65.56	21.18	108.62	2.77

Table 2 Specification of the LIGA beamline

Source	Accepted angle / mrad	Energy range / keV	Spot size (mm×mm)	Scanning distance of exposure / mm
Bending magnet	Horizontal 4 Vertical 0.3	1～8 (white light)	120×8	140

2.3 Layout of the beamline

At the first construction phase of SSRF, it is impossible to build two or more beamlines for LIGA technology. We must realize the above adjustment demand on energy range by one beamline. One multi-function LIGA beamline with two mirrors is designed as shown in Fig.1. Both mirrors can be rotated at the grazing angle of 8.7—35 mrad in vertical direction, respectively. Every mirror, installed in an ultra-high vacuum chamber, receives the X-ray from the source in the horizontal direction of 4 mrad and in the vertical direction of 0.3 mrad, and is cooled by water. The first mirror lies at 18.5 m and can be moved down to 10 mm. The second mirror is two meters far from the first mirror and can be moved up to 140 mm in vertical direction. A long bellow is installed between two mirror chambers. All the optical components behind the second mirror can be transferred to the vertical direction of 140 mm according to different height requirements. In addition, there are two apertures, called front and back water-cooled aperture, on the beamline. They are located at 17.5 m and 29 m from the source respectively.

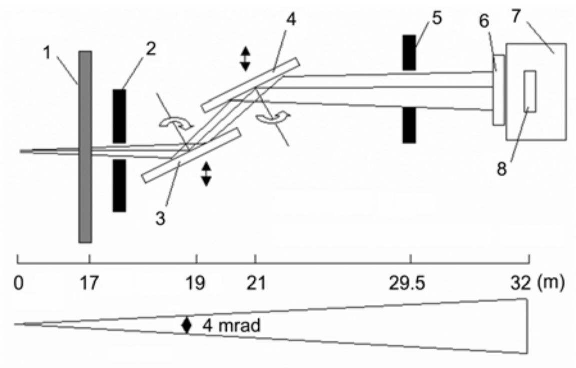

Fig.1 Layout of LIGA beamline.

1. Shield wall, 2.Front aperture, 3.Front mirror,
4. Back mirror, 5. Back aperture, 6.Be window assembly,
7.scanning chamber, 8.Sample

The X-ray is extracted from the source through two mirrors and a set of filters. To meet the different requirements for DXRL and X-ray mask coping, the X-ray spectrum range can also be adjusted by changing the mirror grazing angle and the thickness of filter. A set of filters with different thickness should be added before the PMMA sample for DXRL.

For the deep lithography with the 200 μm thick structure, both mirrors can be rotated at a grazing angle of 14 mrad in the vertical direction and a Be filter of 200 μm thickness is installed before the PMMA resist.

For the deep lithography with the 500 μm thick structure, both mirrors can be rotated at a grazing angle of 8.7 mrad in the vertical direction and a Be filter of 300 μm thickness and a 2 μm thick Ni filter are installed before the PMMA resist.

For the deep lithography with above 1 mm thick structures, both mirrors are rotated in the horizontal direction and the first one is moved down to 10 mm; thus the SR white light up to 40 keV passes through the vacuum tube and directly exposes the sample.

For X-ray mask coping, both mirrors can be rotated at the grazing angle of 35mrad in the vertical direction and a Be filter of 20 μm thickness is installed before the PMMA resist.

A Be vacuum window can be regarded as a filter, so a Be window assembly of 20 μm thickness is put in the scanner chamber for the vacuum isolation, which is only subjected to low vacuum pressure.

3 Result of simulation

3.1 Spot of sample

Fig.2 shows a spot of the sample at 32 m from the source, which is traced by SHADOW software. The horizontal size is up to 128 mm.

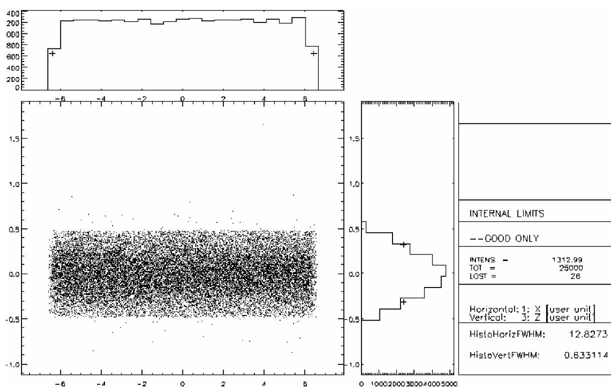

Fig.2 Spot of the sample.

3.2 Power distribution of optical components

Fig.3 shows the incidence power spectra of 1—8 keV with the mirror grazing angle of 8.7 mrad behind a Be filter of 300 μm and a Ni film of 2 μm. Two mirrors coated with gold material accept the SR light at the vertical angle of 0.3 mrad. The 2 μm Ti film is the membrane of the mask. PMMA with 500 μm thickness is used as the resist. The power density on the sample of scanner is 0.159 W/cm^2.

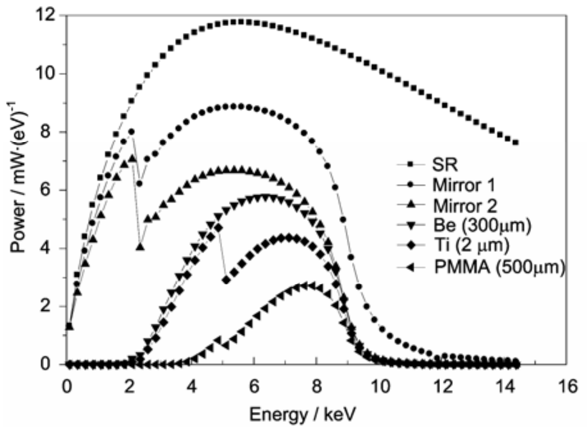

Fig.3 Incidence power spectra with the mirror grazing angle of 8.7 mrad.

Fig.4 shows the incidence power spectra of 1-8keV at the mirror grazing angle of 35mrad behind the Be filter of 250 μm thickness. Two mirrors accept the SR light at the vertical angle of 0.3mrad. PMMA with 20 μm thickness is used as the resist. The power density on the sample of scanner is 11.2mW/cm^2.

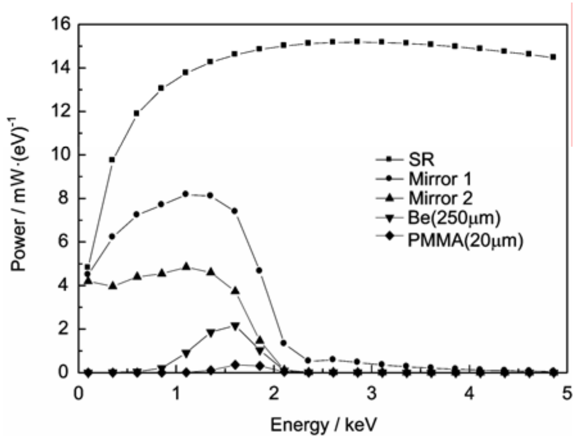

Fig.4 Incidence power spectra at the mirror grazing angle of 35 mrad.

Fig.5 shows the absorbed power spectra of 0.1-20keV on the upper and lower surface with 10 μm thickness of 500 μm PMMA resist, respectively. It is concluded that low energy photons must be absorbed by the filter in order to keep the dose ratio of upper surface to lower surface smaller than 6.

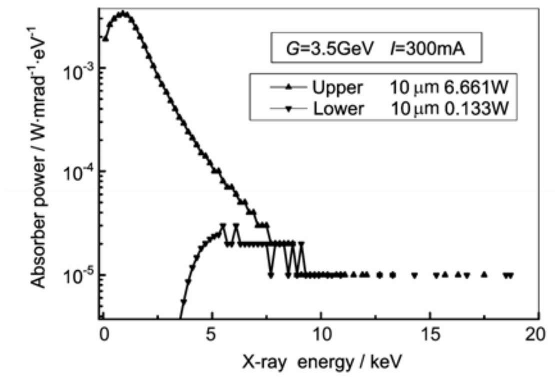

Fig.5 Absorbed dose of upper and lower surface in 10 μm thickness of PMMA resist from SSRF bending magnet source.

3.3 Dose of PMMA resist

The X-ray absorption powers on the beamline, especially those of optical components and PMMA resist, are important features. Table 3 shows the absorption power of two mirrors, Be filter, Ni film, and PMMA at different mirror grazing angles and vertical accepting angles.

3.4 Determination of the coating material on mirrors

The coating material on mirrors is a very important element to affect reflectivity. Two plane mirrors are coated with gold. Other material such as nickel, platinum, and chromium can be used as the coating material besides gold.

Table 3 Absorption power of optical components (W)

Mirror grazing angle / mrad	Vertical accepted angle / mrad	Exposure time / h	Mirror 1	Mirror 2	Be filter (thickness)	Mask (Ti 2 μm)	PMMA surface (10 μm)	
							Upper	Lower
8.7	0.3	1.14	156.0	20.35	20.70 (300 μm) *	6.45	0.67	0.12 (500 μm) +
14	0.3	1.77	192.6	14.10	13.04 (250 μm) *	1.31	0.32	0.08 (200 μm) +
35	1	0.46	246.6	6.69	5.83 (20 μm) *	—	1.07	0.30 (20 μm) +

Note: * The thickness of Be filter
\+ The total thickness of PMMA resist.

Fig.6 shows the spectra reflected by mirrors with the coating material of gold or nickel at the mirror grazing angle of 8.7 mrad. Reflectivity of the mirrors coated with nickel is higher than that with gold at the energy range of 3—7 keV. The high energy edge of spectra for nickel coating is very sharply decreased at 7 keV. If an extension above 7 keV is needed, the grazing angle of mirrors coated with nickel has to be decreased. The decreasing of the grazing angle will imply that a long mirror is needed. But a system with two large-length mirrors will be very difficult to build. So gold is chosen as the mirror's coating material.

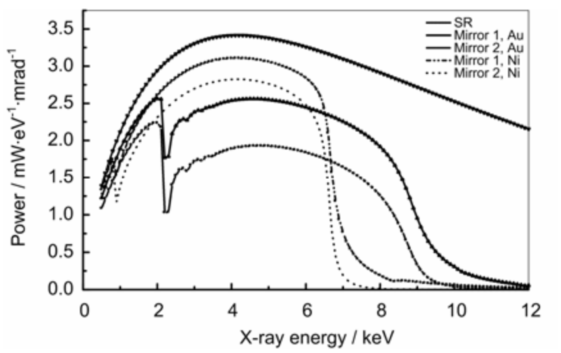

Fig.6 Spectra reflected by mirrors with the coating material of gold and nickel at the mirror grazing angle of 8.7 mrad.

4 Electric control system of the beamline

The electric control system is the brain of the beamline. Two scanning models are run on the beamline. Model 1 works in a high vacuum chamber, while model 2 is operated in 33 kPa He gas.

The total exposure dose on the sample must be controlled. A power detector should be installed on the beamline. It is better to set an X-ray flux detector on the beamline behind the two mirrors in order to indicate the X-ray flux. There are two main factors, which may lead to the reduction of the X-ray flux. One is the reflectivity decrease of two mirrors due to the mirror's surface pollution. The other is the electron current attenuation of the storage ring. If the detector is designed to work on line, a part of the X-ray light on the edge will be used to measure the power. The power on the X-ray spot edge is dependent not only on the power in the X-ray spot center but also on the collimation of two mirrors. So it is not proportional to the former. Additionally, the detector on line has to be subjected to long exposure of X-ray light, and its performance of detecting X-ray power will be affected seriously.

For the above reasons, the detector could not work on line. At the beginning of exposure, the detector moves in the horizontal direction to catch X-ray light and measure its power. The total exposure dose will be determined by the measuring result of the detector and by the electron current attenuation of the storage ring. The shutter will be closed when the total exposure dose is satisfied.

A computer should be used to control all the elements on the beamline. The elements to be controlled are mirror, filter, vacuum pump, beam position detector, vacuum valve, shutter, and so on. All elements should be controlled in a logical order.

5 Conclusion

One type of multi-function LIGA beamline has been designed. In this design, two plane mirrors and a series of filters have been employed. One can choose the spectrum range of X-ray easily according to the requirement of exposure by adjusting the grazing angle of mirrors and thickness of filters. The spot size in horizontal direction is up to 120 mm, which is large enough for exposing a 5 inch silicon slice. The typical exposure time is about 1.2 h, 1.8 h, and 0.5 h corresponding to PMMA thickness of 500 μm, 200 μm, 20 μm, respectively.

Acknowledgment

The authors thank colleagues of Beamline Division at SSRF for their useful discussions and suggestions.

References

1 ANKA Lithography Methods, Beamline: ANKA-Litho I, ANKA-Litho il, ANKA- Litho III.

2 Pantenburg F J, Chlebek J, El-Kholi A, *et al*. Microelectronic Engineering, 1994, **23**: 223-226

3 Yi F, Jin M, Tang E, *et al*. Microsystem Technologies, 1996, **3**: 7-9

4 Lehr H, Ehrfeld W. LIGA-Technique, An overview. The 6th Chinese International Summer School of Physics Application of Synchrotron Radiation, Lecture Notes, 23-46