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Micromachining program status at the SRRC

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Abstract This paper describes the micromachining program status of the micromachining laboratory at the SRRC.
A preliminary LIGA process has been established. Many joint projects with local and foreign institutes to develop devices for domestic industries have been started. The interests in the application of the LIGA technology is continuously growing in Taiwan. Two-millimeter ultra-deep microstructures have been achieved.

1
Introduction

The electron energy of the Taiwan Light Source has been upgraded to 1.5 GeV (Cheng 1996). The micromachining beamline and exposure system have been installed. Routine deep x-ray exposure started in August 1996. The manufacturing process of the x-ray mask of 1 micron precision has been established. We constructed six plating baths which were clean room compatible. Nickel, copper and Invar plating are intensively studied. The nickel mold has been accomplished in house. A hot embossing machine manufactured by the company JENOPTIK is in operation. A team cooperating with domestic injection molding industry focusing on the molding has been formed. Ultra deep micro structures up to a depth of 2 mm have been accomplished by a process of multiple exposures and multiple developments. The major R&D efforts are developing the following devices: 1. spinnerettes for microfibers, 2. leadframe for IC packaging, 3. micro gyroscope, 4. micro pump, 5. separation column for chemical elements, 6. Dielectric-based laser-driven particle accelerator (Huang et al. 1997). Those projects are supported by the domestic industries, research institutes for industrial technology and the National Science Council.

A Taiwan national program for the micromachining technologies will be granted in fiscal year 98. The total budget is 40 million dollars for the first year. Among them, 4 million dollars will be granted for academic research. LIGA process is considered to be one of the main activities for academic research and industrial application. The SRRC will certainly play a major role in the Taiwan national program. In the following sections, the efforts at the SRRC are reported.

A program of LIGA foundry in Taiwan has been submitted to the National Science Council. It is planned to support 20 different projects per year. Mass production will be entrusted to other institutes. The SRRC provides only microstructures made of PMMA or metal.

2
Exposure modeling

The power spectrum emitted from a synchrotron is the universal function $G_2(y)$. The variable y is a dimensionless parameter normalized to the critical energy of the synchrotron light. The values of $G_2(y)$ can be obtained from a table, for values of y between 0 and 10 (Winick 1980). Figure 1 shows an analytical expression $G_2^A(y)$ of $G_2(y)$ for further analysis (Cheng et al. 1997, Shih et al. 1997).

$$G_2^A(y) = \sqrt{\frac{\pi}{2}}(y^{1.5} + 0.2135\,y + 0.1993\,y^{0.5})\exp(-y) \tag{1}$$

For the heat load analysis, we would like to know the penetrated power after the end window and the inserted filters. The attenuated power depends on the properties and thickness of the materials. The materials of window, filters, and photoresist contain elements of low atomic numbers such as beryllium, hydrogen and oxygen. The x-ray absorption coefficient μ at an energy above the K edge can be treated as a simple function (Michette 1986),

$$\mu(y)T = ty^{-3} \tag{2}$$

where T is the thickness of the material. The dimensionless variable t as the equivalent thickness, combining the properties

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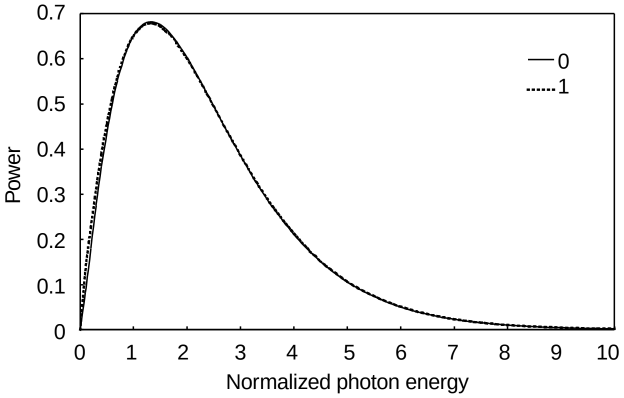

Fig. 1. The universal function of the synchrotron radiation. Line 0 represents the numerical result and line 1 is the analytical approximation of (1)

of materials and geometry, is the product of the absorption coefficient at the critical energy and the thickness. The power penetrating a material can be described by an integral of the product of attenuation and $G_2(y)$

$$P(t)=\int \exp(-ty^{-3})\,G_2(y)\,\mathrm{d}y \tag{3}$$

which has an approximation as

$$P(t)=P(0)\,(0.7681\,z^{1.5}-2.2842\,z+1.5003\,z^{0.5}+1)\exp(-z)$$

$$z=1.599\,t^{0.25} \tag{4}$$

This formula is obtained by the following considerations. We know that the peak position of the integrand can be approximated by a function of t to the one fourth power (Cheng et al. 1997). Then, we treated the integral of (3) like an incomplete gamma function to arrive at (4). Comparison of the numerical integration and the analytical approximation in (4) is shown in Fig. 2. The dosage distribution can also be approached by an analytical formula in the similar way (Cheng et al. 1997). Figure 3 shows the comparison between the numerical result and analytical approach.

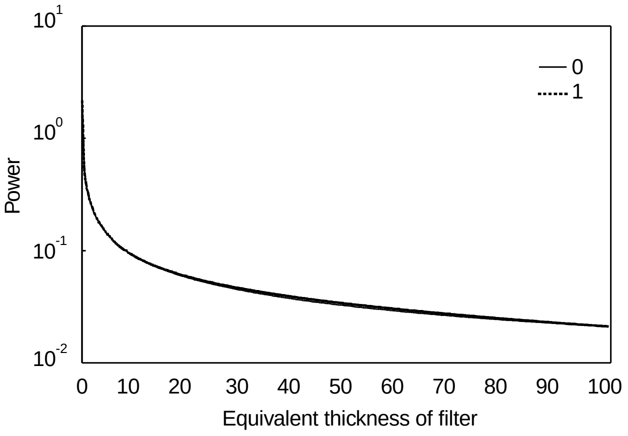

Fig. 2. The transmitted power of the synchrotron radiation through a filter. The abscissa is equivalent thickness t of (2). Line 0 represents the numerical result and line 1 is the analytical approximation from (4)

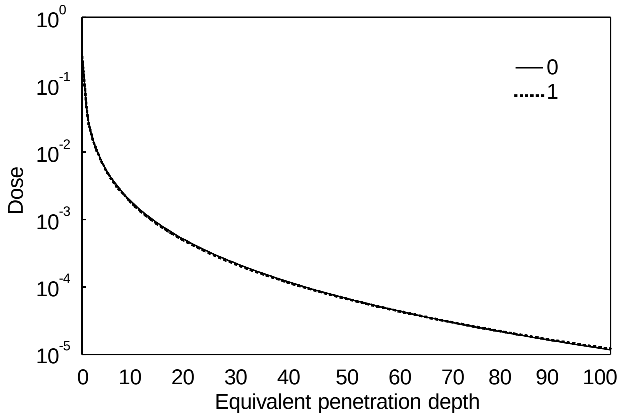

Fig. 3. Universal dosage distribution along the penetration depth. The abscissa is equivalent deptht t of (2). Line 0 represents the numerical result and line 1 is the analytical approximation from (5)

$$D(t)=\sqrt{\frac{\pi}{2}}\,(z^{-1.5}+4.6892\,z^{-2}-4.2386\,z^{-2.5})\exp(-z)$$

$$z=1.599\,t^{0.25} \tag{5}$$

Equation (5) is an analytical approximation defined by (6).

$$D(t)=\int \exp(-ty^{-3})\,y^{-3}\,G_2(y)\,\mathrm{d}y \tag{6}$$

A program utilizing this analytical approach to calculate the exposure dose has been written. The program can calculate the exposure time, penetration depth, filter requirement, and absorber thickness for the processes of the single exposure and the multiple exposures (Shih et al. 1997).

3
X-ray mask

There is no mirror employed in the micromachining beamline to reduce the unwanted high energy x-rays. The required thickness of the photoabsorber has to be increased to prevent the back-scattered electrons on the substrate induced by the penetrated high energy x-rays from reaching the photoresist. It is very difficult to produce a thick absorber such as a 20 μm gold layer without losing precision. Therefore, a special method is developed for fabricating the x-ray mask. A two-layer absorber structure was introduced to solve this problem (Shew et al. 1997). The first thick layer defines the structure edge to be exposed with high precision. The second thick layer is designed to stop penetration of the hard x-rays. Precision of the microstructures is controlled by the first layer. The thick UV photoresist THB-37 of JSR is applied to achieve 1 μm resolution for the first layer absorber of 20 μm height. Figure 4 shows the negative photoresist of THB-37 with a thickness of 32 μm. The wall of the pattern is 89 degree. The mask membrane is made of low-stress silicon-rich nitride with a thickness less than 1 μm. The nitride film is treated with oxidation to support a very large area (Chou et al. 1996). At present, an area larger than 6 cm by 6 cm has been achieved.

For the ultra deep application (a couple of millimeters), multiple exposures with a conformal mask is adopted. The

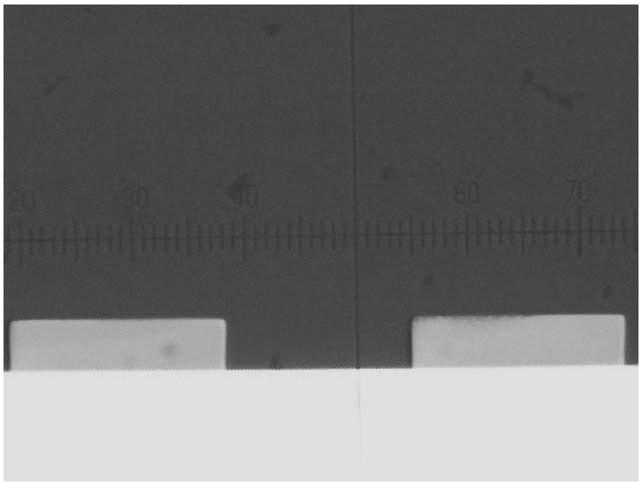

Fig. 4. Thick film photoresist for x-ray mask manufacturing

absorbers are plated directly on the photoresist. The depth of the exposed area can be increased by multiple exposures and multiple developing processes. From the exposure model analysis, it is found that the depth of exposure will increase superlinearly because of accumulation of doses through the steps.

For the low precision applications, the dry-film technology to manufacture the x-ray mask is adopted. The dry-film technology is broadly employed in the manufacturing process of the low cost lithography for the PC board and the leadframe in Taiwan. The thickness of dry films ranging from one mil to two mils is suitable for the thickness requirement of the mask absorber. The absorber material is replaced by the lead/tin alloy because of the plating compatibility with the dry film. The precision of dry films is lower than the above mentioned spin coated photoresist. However, the cost is low and the manufacturing process is broadly available around the area of Hsinchu. Shih et al. (1997) described the details to apply dry film on the manufacturing of x-ray mask. With a rough estimation, an edge precision of 2 μm and a line width of three mils can be achieved in the low cost environment, such as a simple exposure source and a class 10,000 cleanroom.

4
Photoresist and substrate

In deep x-ray lithography, the thickness of photoresist ranges from tens of microns to millimeters. We use the commercial PMMA sheet manufactured by the domestic industry with certain wanted additives for those thickness from 1 mm to 3 mm. The photoresist thinner than 1 mm is made in the laboratory.

To reduce the number of the back-scattered electrons, the material of the plating base should have a low atomic number. Titanium and aluminum are preferred. Rough surfaces of both materials can be created by chemical etching to increase the adhesion with PMMA. The aluminum substrate has a lower density and a smaller absorption coefficient than those of titanium, thus producing less back-scattered electrons. The aluminum substrate is treated by the 1 M HCl sequentially to create a very rough surface. For some case, we don't need such a rough surface. We use 0.5 M NaOH plus 0.2 M H_2O_2 to achieve a surface with less roughness. However, preprocessing procedure on the substrate surface for nickel plating is needed. The conventional method is using Zn to replace Al_2O_3 after exposure and development. This conventional method is not convenient for the HAR microstructure. Instead of wet surface treatment, we applied the titanium sputtering to achieve a very nice result.

Casting and gluing, are broadly used in the LIGA process developed in Germany and the USA (Mohr et al. 1989). The aluminum substrate is mainly applied to the thin microstructures requiring very strong adhesion. The preprocessing procedure of nickel plating is not easy to obtain a good effect.

Methods to attach the photoresist to the substrate is evaluated. We developed chemical plating of copper to create the metal layer with good adhesion directly on the PMMA. Before the chemical plating, we treated the PMMA with hydrogen plasma to improve the plating. In this case, we use the stainless steel as the substrate and glue the substrate with the copper plated photoresist together.

5
Exposure and development

To reduce the flux of the unwanted high energy x-rays, we developed a special silicon nitride window coated by a thin layer of nickel. The *K* edge of nickel to absorb the hard x-rays is located at 8.33 keV (Henke et al. 1993). This window can be rotated such that the thickness of nickel in the exposure direction varies from 2 μm to 6 μm (Fig. 5). The nickel thin film is carefully treated to have a smooth and uniform surface. Figure 6 shows the spectra at the SRRC micromachining beamline. The synchrotron light is filtered by the beryllium window and the rotational Ni-filter. Using this rotating window filter, the maximum exposure depth for single exposure can be continuously adjusted from 450 μm to 900 μm for the 1.5 GeV TLS storage ring (Fig. 7).

For the multiple exposure approach, the exposure depths are optimized by 4:5:1 ratio, i.e. 0.4 mm, 0.5 mm and 0.1 mm for 1 mm microstructure as well as 0.8 mm, 1 mm and 0.2 mm for

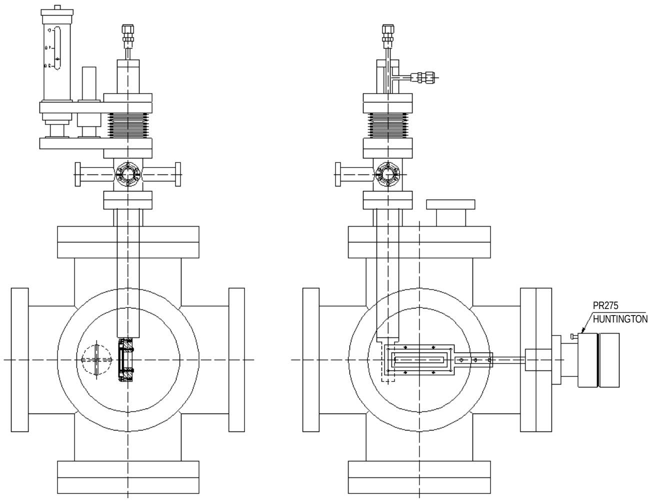

Fig. 5. Beam position monitor and rotational filter on the micromachining beamline at the SRRC

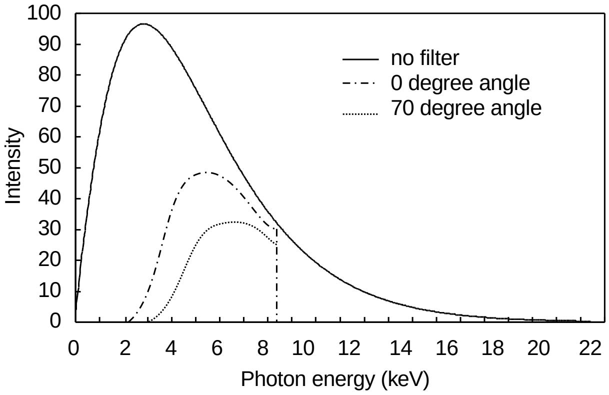

Fig. 6. Spectra of the 1.5 GeV Synchrotron light at SRRC. The rotational Ni-filter will change the spectrum continuously by turning the angle from 0 degree to 70 degree

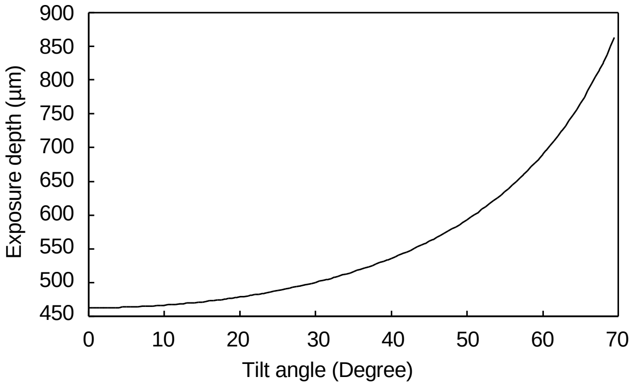

Fig. 7. Exposure depth can be controlled continuously by the rotational Ni-filter via turning the angle form 0 degree to 70 degree

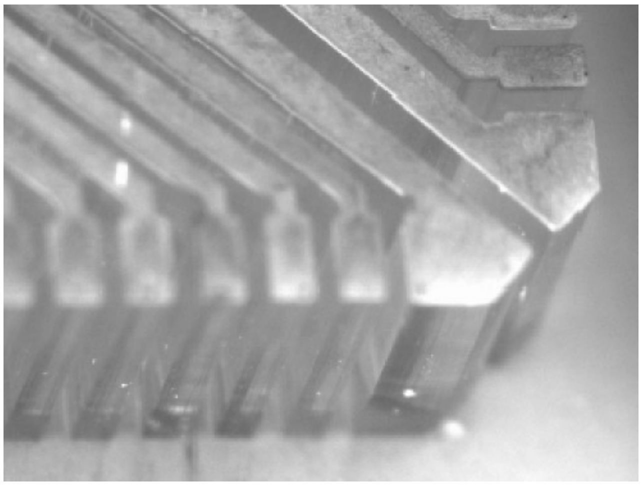

Fig. 8. The leadframe structure with 2 mm height

2 mm microstructure, respectively. The dosage of the first two steps are the same. The last step is to clean the residual photoresist with a short exposure time and no filter. The detailed study is reported by Shih et al. (1997). The most important issues by the multiple exposure process is actually the development. We are still working on the optimization of development.

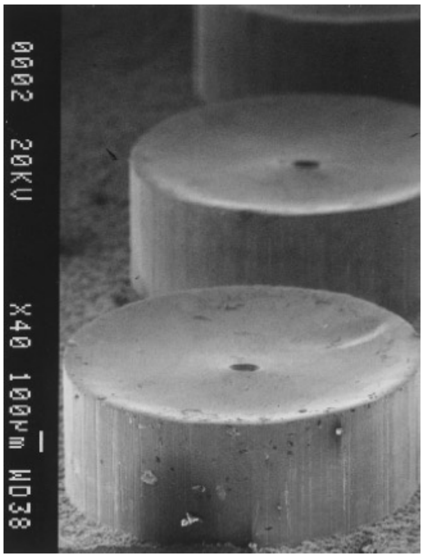

Fig. 9. Plated nickel structure with 1 mm height

Figure 8 shows the result of multiple exposures. The mask is made only by tin/lead plating made by the dry-film technology. There is an undercut after development between the mask absorber and photoresist. We didn't observe the step-structure between the multiple exposures-development process which proved a thermal stability of the mask absorber during the developing process. The developing system contains 1 MHz supersonic transducer and a shaker. We use submarine type supersonic transducer which can be moved with the to-be-developed substrate together. Therefore, the same transducer is also applied to rinsing and cleaning tanks. The temperature of the developer is controlled at 35°C.

6
Electroplating

Six plating baths have been constructed. A two-tanks design: one for plating and one for control, is adopted. The material of tank is polypropylene. The electrolyte is continuously filtered by a 0.2 µm filter. The cathodes are located in the middle of the plating bath so that we can plate on both sides of substrates. Some of the tanks contain moving cathode. We are studying methods to relax the pin hole caused by hydrogen bubbles. Nickel, copper, and Invar are the major focuses of plating. Invar plating is considered for devices with the characteristic of a low thermal expansion.

7
Summary

This paper summarizes the new aspects of LIGA technology developed for those projects which the SRRC collaborates with other institutes.

The routine LIGA exposure was started in August 1996. At present, the work is emphasized on the ultra deep microstructures with 2 mm ∼ 3 mm via the process of multiple exposures and developments for spinnerettes and leadframe.

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