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# FABRICATION OF MICRO-WELL IN PMMA BY PCM AND X-RAY LITHOGRAPHY

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**Abstract-** During the last decade there has been a rapid development in Micro-Fabrication Technology driven by the need for low-cost Micro-Components and Micro-Systems. Micro-Components will be required in a range of new products such as medical devices, Micro-Well, Micro-Pillar Micro-Fluidic Systems. Applications for Micro-Systems have stimulated innovative developments, created new markets and a demand for low-cost components. These are particularly important in manufacturing industries such as the automotive, chemicals, medical instruments, computer parts and telecommunication sectors. The drive towards miniaturization places is increasing demand for new techniques and novel processing technologies. This paper describes the Manufacturing of X-ray Mask with Photo-Chemical Machining (PCM) and the Fabrication of Poly-Methyl-Meth-Acrylate (PMMA) structures with X-ray Lithography Technology. Fabrication of low cost X-ray mask has been done on Copper sheet and Brass sheet using PCM. X-ray Lithography is used to obtain high aspect ratio Micro-Well, Micro-Pillar and Micro-fluidic channel. Synchrotron radiation of Beam line BL-07 at INDUS-2, RRCAT Indore is the source of X-ray for Lithography.

***Index Terms-*** *Photochemical Machining (PCM), Poly-Methyl-Meth-Acrylate (PMMA), High Aspect Ratio (HAR), Beam Line (BL)*

## I. INTRODUCTION TO PHOTOCHEMICALMACHINING

Photochemical machining is an engineering production technique for the manufacture of burr free and stress free flat metal components by selective chemical etching through a photographically produced mask [1].

The major steps are:

- Preparation of phototool
- Selection of metal
- Preparation of workpiece
- Masking with photoresists
- Etching
- Stripping and inspection

The PCM process is depends upon following factors:

- Etchant concentration
- Etchant temperature
- Etching time
- Material to be used

TABLE 1. PCM ETCHANTS [2]

| Aqueous Etchants | Materials etched in the PCM process |
|---|---|
| Acidified ferric chloride | Aluminium, Alloy 42, copper and copper alloys, HyMu, Inconels, Invar, Kovar, Permalloy, Monel, Mumetal, nickel, Nimonics, phosphor bronze, stainless steels and other steels, tin. |
| Acidified cupric chloride | Beryllium copper, copper and copper alloys including brass and bronze, lead. |
| Alkaline potassium ferricyanide | Aluminium, molybdenum and tungsten. |
| Sodium hydroxide | Aluminium, anodized aluminium. |
| Hydrofluoric acid | Beryllium, columbium (niobium), titanium, zirconium, glasses and ceramics. |

**X-ray Mask preparation with PCM Process:**

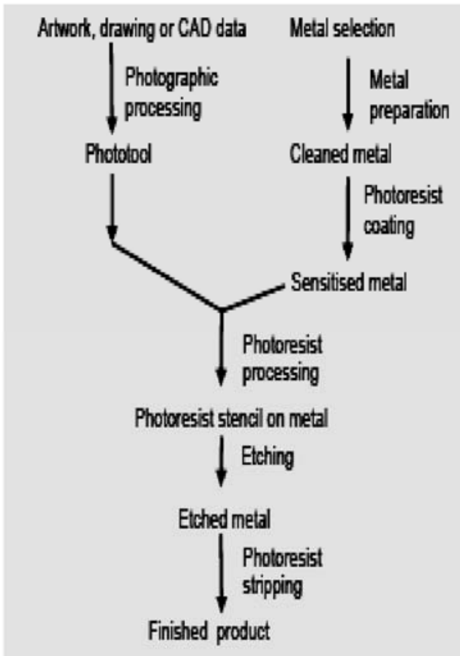


Fig.1. The PCM process[1]

**Specimen**

Specimens are cut in square or rectangle with required size of Brass material having thickness 100 micron.

**Artwork creation**

On Auto Cad artwork of given size is prepared. Print out is taken on trace paper.

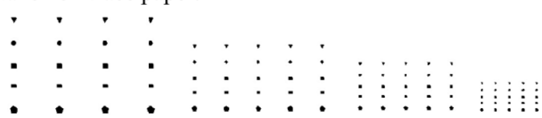

Fig.2. Basic shapes drawn with Auto CAD software

**Negative preparation**
Drawing on trace paper will become negative for our mask preparation.

**Cleaning & Lamination**
Before the Cu metal surface is coated with photo resist, clean the surface thoroughly, so as to make it completely free of physical & chemical contamination. It is advisable to clean the metal by solvent like Trichloroethylene to remove traces of Grease or oil. Contaminants such as Cupric – Oxide, Dirt etc, can be removed. Traces of such cleaning powder should then be removed by washing the metal plates under running water & scrubbing it with a soft brush. The surface should be quickly & thoroughly dried with forced warm water.

**Coating & Lamination**
Photo resist can be applied precisely and economically by using a dipping process, done by a photo resist dip coater.After coating it is taken of from tank & dried it for 15 min.

**U.V. Exposure**
The coated laminate is normally exposed in contact with photographic negative. Photo resist is sensitive to U.V. radiation & therefore an U.V tube based, U.V exposure unit can be used for exposure. The time of exposure depends upon many factors e.g. The source of light, thickness of coating, distance between the source of light & printing down frame etc.

For double side exposure unit it is desirable to use double sided sandwich glass for printing frame. In sandwich plate negative & coated work piece placed for three minute & then taken off.

**Development**
Exposed plate should be placed into solvent based developer. This will remove unexposed areas of the photo resist & will show a colorless resist image which has plastic like appearance. The total development time is between 60-90 sec.

**Washing**
Immediately after development is over, wash it in running water on neutral pH. After washing & drying, dyeing is carried out to improve the visibility to the image & to find out any cracks or broken line & to facilitate the same for the purpose of re-touching before etching.

**Etching**
This is an important and critical step in PCM process. Although basically this operation aims at chemical removal of unwanted Cu portion .Good results can be obtained by carefully studying the various aspects of the operation. Ferric Chloride is one of the most widely used etchant for Cu & Cu alloys. The main reason for its popularity is the low cost.

Fig.2. Brass Mask of Basic shapes

**Experimental Setup**
During experimentation temperature, the time of etching and concentration of etchant is necessarily to be changed. For this heating bath as shown in figure is used in which varies temperature from $20^0$C to 125 $^0$C. In this heating bath heater is used to change the temperature of water which can be sensed by sensor. In this heated water, four beakers can be placed for experimentation. These instruments are used in place of etching machine shown in following figures.

Fig.3. U V Exposure


Fig.4. Laminate Coater

Fig.5. Etching Machine

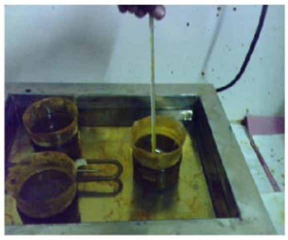

Fig.6. Set for etching

Fig.7. Chemicals

Fig.8. Etching machine set up

## II. INTRODUCTION TO X-RAY LITHOGRAPHY

X-ray lithography is a process by which an image is transferred from an absorbing mask to a radiation-sensitive resist film (Fig.9). Alignment of x-ray mask to the substrate is required for multi-layer x-ray lithography applications and so called mix-and-match techniques, when different types of microlithography are used for different technological layers. The resulting latent image in the resist is then developed to produce a patterned resist mask which acts as a shield in the next step of microfabrication, when material is either removed from the substrate by etching through the resist mask or additional material is deposited[3].

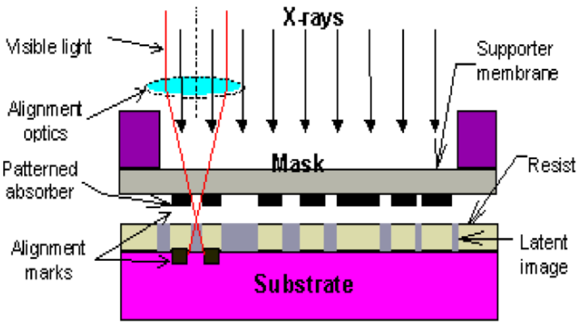


Fig.9. Schematic view of the proximity X-ray lithography process

Dr. Guckel contributed significantly to the original effort in Xray lithography at the university. and was a member of the Sematech Center of Excellence in X-ray lithography. His interests in micromechanics involve two research areas: surface micromachining and deep X-ray lithography. His efforts in deep X-ray lithography and electroplating are contributing significantly to three-dimensional micro mechanisms[4].

Y. Cheng and B.Y. Shew informed on Deep X-ray lithography (DXL). They used to manufacturing much deeper and more precise microstructures than those produced by the conventional LIGA process[5]. C.Y. Lin, M.K. Chyu gave the technical focus of LIGA lies mainly on the use of X-rays low diffraction and high penetration features to generate a molding die for high-aspect-ratio microstructures. As a general notion in X-ray lithography, the fabricating depth is deemed to be only a function of the irradiating X-ray wavelength[6].

Timo Mappes and Sven Achenbach focused on X-ray lithography for devices with high aspect ratio polymer submicron structures. X-ray lithography fabrication sequence process conditions for polymer structures and metal replica with submicron feature size and high AR were determined[7].

M.C. Chou and C.T. Pan explored the Study of deep X-ray lithography behaviour for microstructures. The aim of their study was to investigate how the exposure dosage and developing temperature affect the developing rate for microstructures, with and without ultrasonic stirring, when the photoresist is exposed to X-ray radiation[8]. Physically the process of exposure in X-ray lithography is the same as in ordinary optical lithography, but the wavelengths involved are much shorter (0.1 - 10 nm in X-ray lithography versus 150-450 nm in the optical case). The current position of X-ray lithography in the spectrum of microfabrication techniques is still a technique for tomorrow. However, demands for a high throughput lithography tool capable of resolution beyond 0.18 µm will almost certainly arise by the year 2001, and X-ray lithography with its resolution limit of nearly 30 nm will always remain an attractive possibility and may even represent the last resort for planar technology. While the use of X-ray lithography in commercial manufacturing of ULSI ICs is probably only a matter of time, its use for nanostructuring is already required in orderto avoid the use of slow and expensive e-beam lithography in cases where large volumes of nanostructures are to be produced. Most of these nanostructures can only be of high scientific and commercial value, if a parallel method for their mass replication is used. Compared to sequential e-beam writing, X-ray lithography at wavelengths of 1-1.5 nm with a synchrotron as a radiation source can gain about two orders of magnitude in throughput and also improve the process quality due to virtually nonexistent proximity effects.

Just as 1960s planar technology made a revolution in the electronics industry, the same technology is now bringing about revolutionary advances in the manufacturing of miniaturized tools and other micromechanical devices. LIGA, which stands for Lithographie Galvanoplastie Abformung, is a method for making such structures.

The main feature of the method is that it allows the manufacture of structures with high aspect ratios and with micron lateral resolution. A broad variety of materials can be machined, including metals, plastics, glasses, and ceramics. In order to be able to expose the thick resist layers used in LIGA, X-rays hard enough (2-10 keV) to penetrate through the whole depth of the resist must be used. To have reasonable exposure times the intensity of the radiation is required to be as high as 0.5-1W/cm2. For these two reasons synchrotron radiation from storage rings with 1-2 GeV energy of electrons appears to be the only suitable source for LIGA exposures.

Another important property of collimated synchrotron radiation is its small (about 1 mrad) angular dispersion, which in an ideal case permits exposures with 1:1000 (width : height) aspect ratio.

The BL beamline (Fig.10) was designed to conduct the beam of X-rays from the bending magnet of the MAXII ring to the lithography set up. It has two Be windows for vacuum insulation as well as beam-shaping baffles and the usual equipment for pumping and pressure monitoring. A high speed X-ray scanner has been built and commissioned. One of the most important features of the scanner is its high scanning speed up to 200 mm/s. Maximum exposed area is 76 x 76 mm.

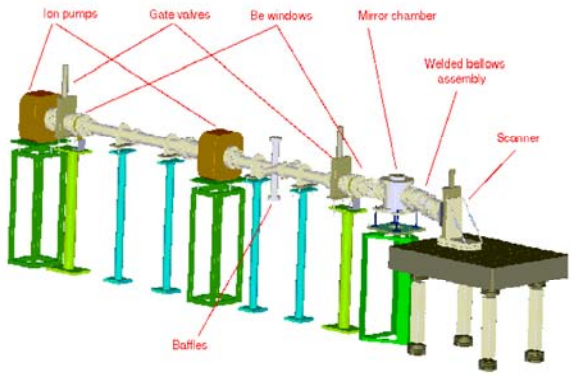


Fig.10. Fragment of the BL beamline with exposure station

X-ray Lithography is used to obtain Micro-Well, Micro-Pillar. In India, Synchrotron radiation of Beam line BL-07 at INDUS-2, RRCAT Indore is the source of X-ray for Lithography.

X-ray Mask: X-ray mask consist of low z membrane material for transmission of x-rays and high z absorbing material for absorption of hard x-rays. For experimental work, low cost x-ray PCM Brass and Copper masks are used. PCM based X-ray mask is made from Copper and Brass using Photochemical Machining. Fig. shows the PCM based Brass x-ray mask used for the x-ray exposures.

Fig.11. PCM Based X-ray Brass mask of 100µm thickness

This mask was prefabricated and contains various general patterns. It contains basic shapes of Pentagon, Rectangle, Square, Circle and Triangle which varies in sizes of 1000µm, 700µm, 500µm and 300µm. X-ray Exposure: PCM based X-ray mask is fastened on PMMA sheet with the help of KEPTON TAPE

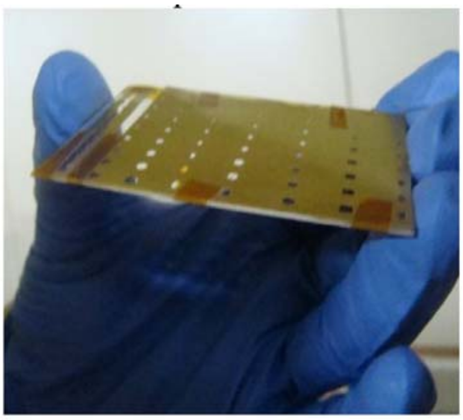

Fig.12. The X-ray Mask is fastened on PMMA sheet

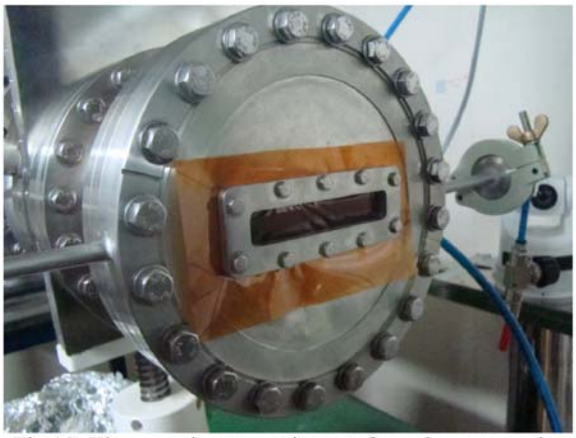

Fig.12. The x-ray beam coming out from the rectangular

Fig.13. The x-ray mask and PMMA in mounted

Fig. 14. The x-ray mask and PMMA in mounted on LM guide ways and ready for X-ray Exposure

PMMA sheet of 12 mm thickness is used for X-ray exposure. Table gives detail of the exposure dose in units of mA.s/cm. Indus-2 was running at 2.5 GeV operations during exposures.

Table 2: X-ray Dose Data

| Sr. No. | Name of Mask | Exposed Dose |
|---|---|---|
| 1. | Brass Masks to achieve Micro well structures in PMMA of 300µ, 500µ, 700µ and 1000µ | 1,76,228 mA.s/cm |

**Development of PMMA samples:**

After X-ray dose exposure to PMMA then development of PMMA is done the help of PMMA Developer. The composition PMMA developer is described in Table.

Table3: The PMMA developer used which consists of:

| Sr. No. | Name of Chemical | % Vol. |
|---|---|---|
| 1 | Di-ethyleneglycol mono-butylether | 60 |
| 2 | Morphelene | 20 |
| 3 | Ethanolamine | 5 |
| 4 | Water | 15 |

After development we get the micro-structures on PMMA. Following fig.15 shows fabricated Micro-Well with X-ray Lithography at BL-07 RRCAT, Indore

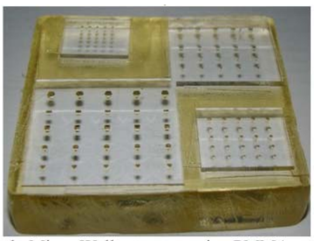

Fig.15. Fabricated Micro-Well structure in PMMA with PCM X-ray Lithography Brass Mask

Depth achieved in PMMA Mould for Basic Shapes Shape Copper Mask

PMMA Development Time: 120 Hours

Micro-Well readings are taken with the help of **RAPID I-Vision Measuring Instrument.**

**Table 4:** Measurement result

| Sr. No. | PMMA Micro-Well | Depth | Aspect Ratio |
|---|---|---|---|
| 1 | Circle of 300 Micron by Copper Mask | 1.5474 | 5.158 |
| 2 | Circle of 500 Micron by Copper Mask | 1.1844 | 2.3688 |
| 3 | Circle of 700 Micron by Copper Mask | 1.414 | 2.02 |
| 4 | Circle of 1000 Micron by Copper Mask | 1.4228 | 1.4228 |

Average Depth achieved in PMMA Micro-Well Mould=1.39215 mm

## CONCLUSION

This paper gives brief information about PCM and X-ray lithography in general. For X-ray Lithography technique, Brass mask can be prepared by using PCM process with cost effective way. Micro-well be fabricated which are giving maximum aspect ratio as 5 for 300µ size. This paper gives guideline for fabrication of micro-structures in PMMA material with precise accuracy. Micro-Pillar, Micro-Channel also can be fabricated with the same method which is mentioned in this paper.


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