BEAM SIZE MEASUREMENT USING HIGH ASPECT RATIO LIGA APERTURES IN AN X-RAY PINHOLE CAMERA

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Abstract

For optimal brilliance, third generation light sources operate at a low emittance and low coupling. Commonly transverse beam profile measurements are provided by direct imaging of the electron beam using X-ray pinhole cameras. From these beam size measurements and given knowledge of the lattice parameters the emittance, coupling and energy spread are calculated. Ideally the pinhole aperture should be formed in an infinitesimally thin screen. However, due to the penetration of X-rays in the keV spectral range, stacked tungsten blades are often used to form the pinhole aperture. In this arrangement the absolute size of the pinhole aperture is unknown and cannot be directly measured which affects the spatial resolution of the imaging system. Here we investigate the use of X-ray lithography, electroplating and molding known as LIGA to fabricate high aspect ratio pinhole apertures in a gold screen of approximately 1 mm thickness.

INTRODUCTION

At Diamond, transverse beam size measurements are provided by X-ray pinhole cameras. The source has a spectrum from approximately 15 keV to above 60 keV [1]. To form the pinhole aperture, materials which are opaque to keV X-rays must be used.

Presently the pinhole apertures are formed by stacking two orthogonal sets of (25 mm(h) $\times$ 1 mm(v) $\times$ 5 mm(d)) tungsten blades separated by precisely machined shims. The thickness of the shims between the tungsten blades sets the aperture size e.g. to form a 25 μm aperture a pair of 25 μm thick shims are positioned between the ends of a pair of tungsten blades [2]. In this arrangement, only the thickness of the shims is known. The absolute size of the pinhole aperture is unknown and cannot be directly measured.

Ideally the pinhole aperture should be a rectangular or cylindrical hole in a screen where the edges of the hole through the bulk material are perpendicular to the screen surface. For sufficient contrast of the keV X-rays which are passed through the aperture versus those that are blocked, a material with a high atomic number is required with a thickness $\geq$ 1 mm. The aspect ratio of a 10 μm aperture in a 1 mm thick screen is 1 : 100.

It is extremely difficult, if not impossible, to meet these specifications using traditional techniques such as drilling, laser-machining and chemical etching. Instead we propose to make these high-aspect ratio structures using the process known as LIGA, which is the German acronym for X-ray lithography (X-ray lithographie), electro-deposition (galvanoformung), and molding (abformtechnik) [3].

LIGA

The LIGA process involves a thick layer of X-ray resist, typically SU-8 or Polymethylmethacrylate (PMMA), which is exposed to high energy X-rays through a mask. Post-exposure, the resist is developed to obtain a three-dimensional resist structure. Metal deposition fills this resist mold with metal. The resist is later removed such that a free-standing metal structure is obtained, which is in this case the final product of the pinhole screen [3].

The steps involved in X-ray lithography are very similar to those for photolithography. The main difference being that an X-ray exposure is used instead of visible light. The reason for this is to minimise the diffraction of the light passing through the mask such that high-aspect ratio structures may be fabricated.

In this paper the X-ray exposures were done using synchrotron radiation from a bending magnet on the B16 beamline at Diamond Light Source.

PINHOLE SCREEN DESIGN

In [1] the relationship between the pinhole aperture size and point spread function (PSF) is discussed. To maximise the spatial resolution of the optical system, the PSF must be at a minimum. From [1], aperture sizes from 15 to 22 μm are optimal for imaging the electron beam using synchrotron radiation in the 15 keV to 60 keV spectral range.

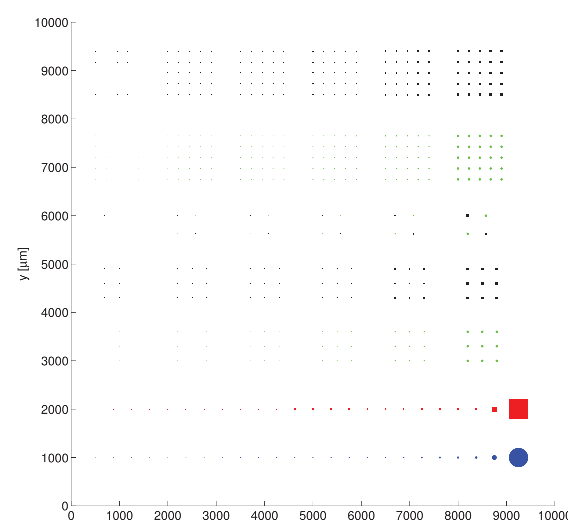

Figure 1: Screen design for direct imaging of the electron beam using circular or square apertures. The aperture sizes range from 10 μm to 400 μm.

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Figure 1 shows the layout of the pinhole screen to be used for imaging. The outer dimensions of the screen are 10 mm by 10 mm. Square and circular pinhole apertures from 10 μm to 400 μm have been included to investigate the PSF for different aperture sizes and shapes. Using the Touschek lifetime as a proxy for the actual vertical beam size, the PSF for each aperture can be determined and later compared to that expected from simulation [2].

The screen design also includes square and circular pinhole arrays for averaging of the transverse beam size measurement at a specific location in the storage ring.

In addition to imaging the electron beam, a second screen has been designed to investigate the beam parameters using interferograms from single and double-slits as shown in Fig. 2. The slit widths range from 10 μm to 50 μm. The slit length is 1 mm. A 400 μm by 400 μm square aperture is also included for initial alignment of the beam through the optical system.

The screens will be made from gold with a thickness of 1 mm.

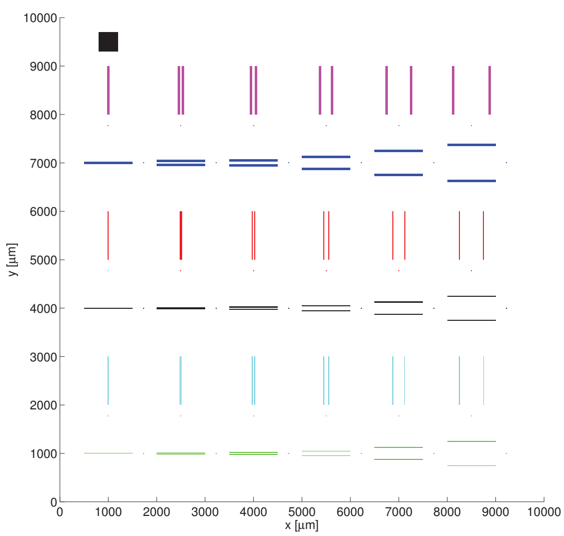

Figure 2: Screen design for interferometry and direct imaging using slits and square apertures.

DEVELOPMENT STATUS

A 4 inch (101.6 mm) chrome mask was fabricated given the design of the 50 mm diameter disc to be exposed as shown in Fig. 3. The mask consists of an alternating pattern of the imaging and interferometry screen designs. There are 6 screens of each design per PMMA resist sample.

Using photolithography and the chrome mask, a 25 μm thick X-ray mask was prepared. The X-ray mask is made of gold. This gold mask was then used for the X-ray exposures of the PMMA resist on the beamline.

Both the chrome and gold masks are reuseable and transferable such that multiple resist samples may be exposed.

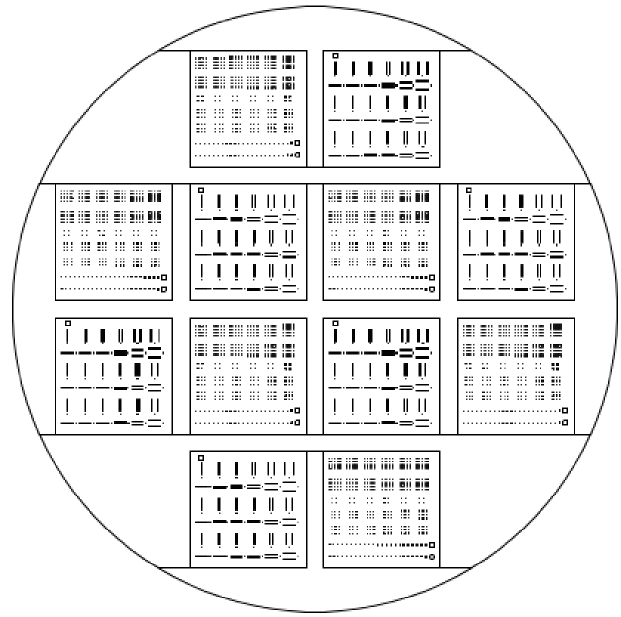

Figure 3: Mask layout. The diameter is 50 mm.

This is particularly important since the X-ray mask production is one of the most difficult aspects of X-ray lithography [3].

In Fig. 4 a photograph of the partially developed resist is shown. The rectangular apertures of the imaging screen (see Fig. 1) are clearly visible.

Since the gold screens are made by electroplating the developed resist, it is assumed that the aperture sizes in the final 1 mm thick gold screens must be equal to the structures of the developed resist. Thus before electroplating, all structures of the resist (which become holes in the gold screen), are measured using a Scanning Electron Microscope (SEM).

In this way, the absolute size of all of the pinhole apertures in the screen are known to a high degree of accuracy.

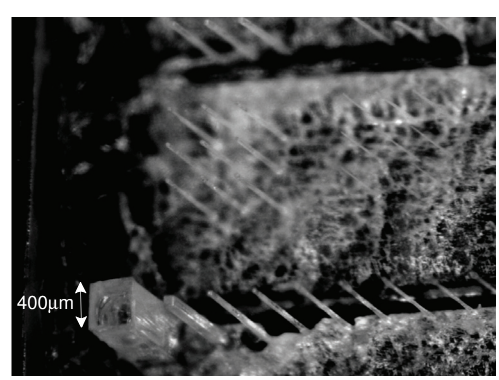

Figure 4: A photograph of the partially developed PMMA resist. The observation angle is approximaely 30 degrees such that the depth of the structures is visible.

With this knowledge, the PSF of the pinhole system can be simulated and compared to measurement.

An image from the SEM of the developed PMMA resist is shown in Fig. 5. In this image the slit structures of the interferometry screen (see Fig. 2) are seen. The high aspect ratio and reproducibility of the structures is also observed.

In Fig. 6 a measurement from the SEM of one of the circular structures is shown. The diameter of this structure should be 50 μm. It is measured to be approximately 40 μm at the top of the pillar.

The images of the developed resist indicate that the developer may be too strong. Therefore investigations are currently underway on optimising the ratio of the developer mix. Once this step is complete, the developed resist will be electroplated.

It should be noted that the pinholes do not need to exactly match those specified in the design. It is far more important to ensure that the resulting apertures are measured so that the dimensions are known.

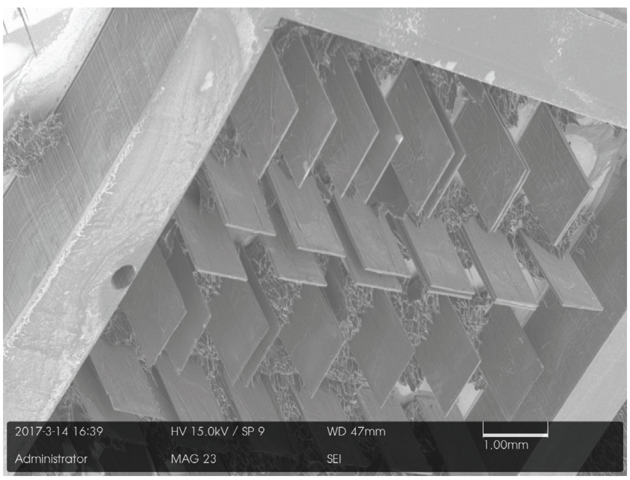

Figure 5: An SEM image of the partially developed PMMA resist as viewed at an angle of 60 degrees.

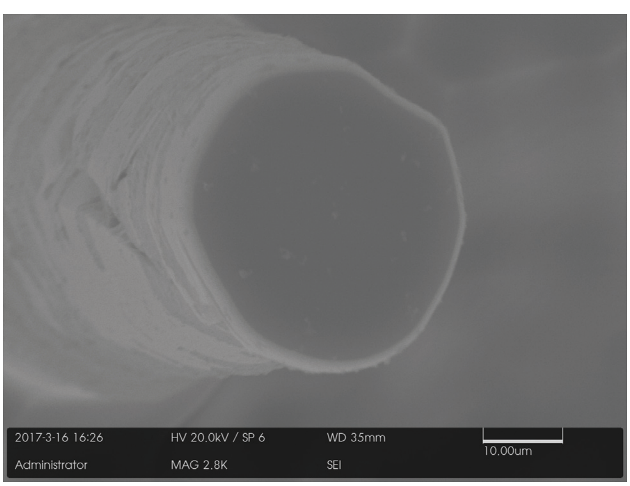

Figure 6: An SEM image of the partially developed PMMA resist as viewed at an angle of 3 degrees.

CONCLUSION

In this paper the present status of the on-going development of new pinhole screens using the LIGA process is described. An X-ray mask has been fabricated. Initial X-ray exposures using synchrotron radiation have shown that the dose applied to the PMMA resist is sufficient for later development. Currently, investigations to optimise the developer strength are on-going based on scanning electron microscope measurements of the resist structures. Upon completion, the final developed PMMA sample will be electroplated to obtain pinhole apertures of known dimensions in gold screens of approximately 1 mm thickness. These screens will then be used for direct imaging of the electron beam and interferometry studies in the X-ray spectral range.

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