LIGA & Thick Film Lithography for Thick Structures

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1. Introduction

A capability for optical and deep X-ray lithography has been implemented by JPL to fabricate device components that cannot be fabricated by any other method. Optical lithography is capable of generating photoresist patterns of up to 200 µm in thickness[1] and deep etch X-ray lithography has been used to create patterns in PMMA of over 1 centimeter[2]. These capabilities along with the opportunity for highly accurate lateral dimensionality make them ideal for some of the projects at Jet Propulsion Laboratory.

We are fabricating sub-collimating X-ray grids that are to be used in an instrument for the High Energy Solar Spectroscopic Imager (HESSI)[3] , a proposed NASA mission. This instrument will promote the understanding of solar particle acceleration and explosive energy release in the magnetized plasmas at the Sun. These grids have a required minimum pitch that is determined by the expected angular resolution of the imager and have a required minimum, and maximum, thickness that is governed by the photon energy bandwidth desired for the X-ray imager. The HESSI instrument consists of twelve rotating pairs of high aspect ratio, high Z grids, each pair of which is separated by 1.7 meters and backed by a single Ge detector. The pitch for these grid pairs ranges from 34 µm to 317 µm with the grid slit openings being 60% of the pitch. Each grid must be almost perfectly identical; the RMS pitch of the grids in each pair must correspond to within 1 part in 10000. For maximum grid X-ray absorbing with minimum loss of the solar image, the grid-thickness-to-grid-slit ratio must be approximately 50:1, resulting in grid thicknesses of 1 to 10 millimeters. We are currently in the process of developing these *thick* grids using the LIGA technology (Lithographie, Galvanoformung and Abformung). In addition to the thick grids for collimating high-energy X-rays, the instrument requires collimation of photons with energies of less than 4 keV such that free-standing *thin* grids are required that have no material between the grid slats. Using optical lithography, we have fabricated these 25 *micrometer* thick gold grids that can collimate photons from visible light up to 30 keV X-rays.

2. Thick grid requirements and fabrication

The pitch of the coarsest thick grids will be 2 millimeters with a corresponding thickness of 2.5 centimeters, allowing collimation of photons of up to 20 MeV. Techniques such as electrodischarge machining (EDM) and tungsten foil stacking using spacers can be used to fabricate grids with pitches from 2 millimeters down to approximately 100 µm. However, the 10^{-4} correspondence for the RMS pitch for any grid pair has not yet been met by the above methods for grids with pitches below 100 µm.

The LIGA processing technique provides a unique and ideal method for fabricating the three required grids with pitches smaller than 100 µm. An X-ray mask is fabricated by depositing an electroplating strike on to a silicon wafer. A patterned layer of photoresist is put down on the strike and gold is then electroplated into this photoresist mold. The X-ray mask is used to pattern the light from a synchrotron X-ray radiation source directed at a sheet of PMMA. The exposed areas of the PMMA are developed away and the remaining PMMA, in the form of a grid, is placed on a conducting substrate and used as a mold for electroplating up from the substrate.

For proof-of-concept thick grids we are currently in the process of implementing a "reversed" grid design in which a 34 μm pitch, free-standing *PMMA* grid is fabricated with 20 μm wide slits and an 600 μm thickness. This design consists of a very rigid mold structure which does not require a substrate. A free-standing sheet of PMMA that is not mounted on a substrate is exposed such that, after developing away the exposed material, the mold structure is a free-standing single cell PMMA grid mold as shown in Fig. 1. Stiffeners that run perpendicular to the grid are placed every 500 μm. After exposure and developing of the PMMA, metal, ideally gold, is electrodeposited into the free-standing PMMA grid slits. The PMMA is *not* removed and the metal in the slits acts as the X-ray absorber grid while the PMMA holds the individual metal pieces in place. The PMMA slats between the electroplated metal are acceptably transparent to high energy X-rays down to approximately 10 keV photons. This grid can collimate X-rays from 10 keV to 300 keV, meeting the specifications for the 34 μm pitch grid. For lower energy X-rays, a grid must be used that has no material between the absorbing slats[4] and is described later.

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All electroplating for the HESSI grids is performed at Sandia National Laboratory, Livermore using a copper plating bath. Once this process is fully stable, the grids will be plated using a gold bath which has electroplating characteristics similar to that of copper baths but providing the high Z gold absorber necessary for the thick grids.

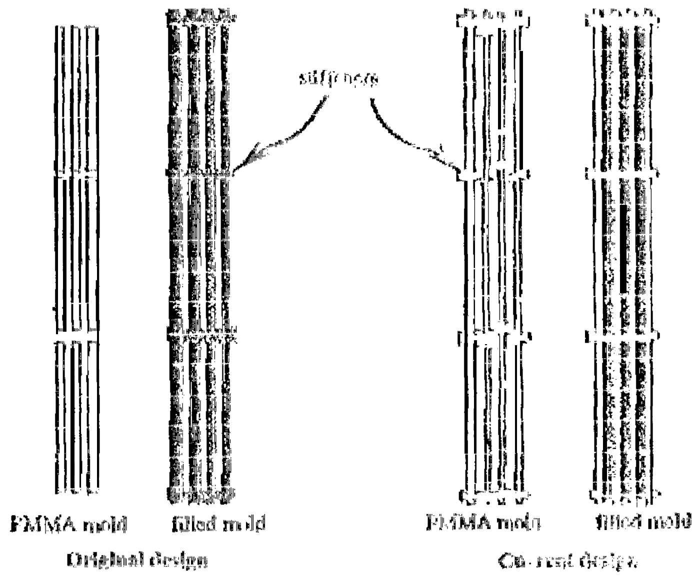

Figure 1. Schematic of original and current mold designs for HESSI grid electroplating.

3. Thin grid requirements and fabrication

grids because the fluence of the X-rays from the sun increases greatly with decreasing photon energy. Further, the necessary active area for X-rays in the 2 keV range can be several orders of magnitude smaller than that for X-rays in the 30 keV range. This has an important implication; the gold grid can be supported by a substrate that is semi-transparent to X-rays in the 10 keV to 30 keV and has a number of openings in it which allow lower energy X-rays through. This allows a sufficient number of photons through in each energy range.

Serendipitously, the fabrication technology of the gold grid section for the grid-and-substrate configuration described above had already been developed for making X-ray masks for LIGA[5]. These masks consist of a gold absorber on a 200 μm thick silicon wafer. The same absorber pattern used for the thick grids can also be used to define the thin grids. The gold absorber pattern for the X-ray mask process is 25 μm thick and grids of this thickness can effectively collimate X-rays up to 30 keV.

For proof-of-concept fabrication, a three inch (7.5 cm) diameter wafer of silicon was chosen for the substrate. Due to processing and mounting limitations, the gold grid on the substrate is limited to 6 centimeters in diameter and the area with holes through the substrate is approximately 5.5 centimeters in diameter. Nominal size for each hole is 1 mm wide by 4 mm long with each end rounded as shown in Fig. 2. For characterization purposes, the holes must be placed such that a portion of each gold slat across the whole Si wafer is visible through the holes. This means that the holes must be staggered so that no grid slot is blocked by the solid parts of the wafer the full distance across the wafer.

The fabrication process starts with 200 micrometer thick 3 inch wafers onto which a 50 angstrom chrome, 300 angstrom gold electroplating strike is e-beam evaporated. A 25 micrometer thick optical resist is deposited on the wafers using a low spin rate. The resist is exposed and developed and an oxygen plasma clean is performed to fully strip resist residue from the strike. 25 micrometers of gold is then plated in the resist mold, resulting in a gold grid with photoresist between each gold slat. The wafer is turned over and a 50 micrometer dry resist is patterned such that it has a array of 1 by 4 millimeter openings to the silicon. The silicon is etched through to the chrome/gold strike using a xenon difluoride etching process. Both types of photoresist are removed with acetone followed by a piranha clean and the chrome/gold strike is removed with a hydrochloric acid and hydrogen peroxide chrome etch which also slowly etches gold.

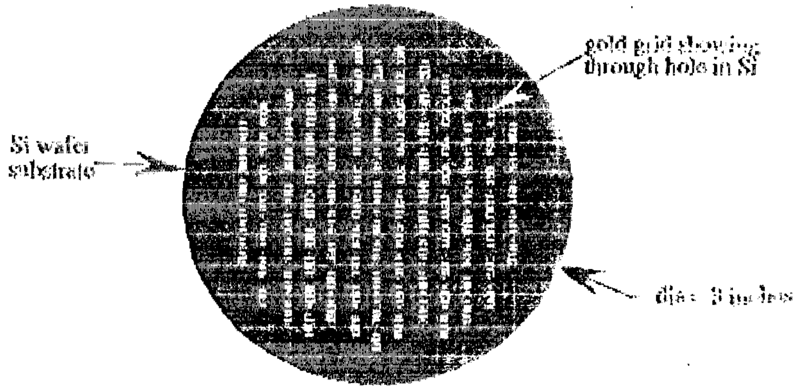

Figure 2. Schematic of grid assembly. Each hole is 1 mm wide by 4 mm long.

5. RESULTS AND CONCLUSION

Many X-ray masks for HESSI grid patterns have been successfully fabricated and used in exposures with synchrotron X-ray radiation sources. The absorber thickness on the masks ranged from 20 to 27 μm. For exposures at SSRL, 25 µm thick gold absorber is acceptable but should ideally be closer to 40 µm for optimum contrast between exposed and unexposed areas and therefore better geometric definition in the developed part.

For the thick grids, the method in which PMMA sheet is exposed, developed, and then attached to a conducting plate and used as an electroplating mold, is successful in allowing structures to be plated, although individual free-standing features of PMMA were not attempted. Results of this process are mixed. Fabricated sample grids, actually the reverse of stiffened PMMA grids, are approximately 400 µm thick (tall) and show moderate plating uniformity except for a few features which plated much faster than the rest. This is probably due to an electric field concentration at the entrance to the slit delineating the features, since the features that plated faster are usually smaller than the rest of the features[6]. The current issues to be examined for this project include the uneven exposure and development of large exposed areas, uneven electroplating in the PMMA grid mold, and methods for increasing the development rate.

Two thin grids have been fabricated that meet or exceed the required specifications have been fabricated and have been delivered to HESSI project. The gold grid was robustly self-supporting over the open holes in the silicon wafer and on one test wafer the grid was accidentally partially detached from the silicon wafer but retained its structural and dimensional integrity.

4. ACKNOWLEDGMENTS

The research described in this paper was performed by the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, and by Sandia National Laboratory, Livermore, and was sponsored by the National Aeronautics and Space Administration, Office of Space Access and Technology. Synchrotron X-ray beam time was provided by the Center for X-ray Optics in the Material Science Division at Lawrence Berkeley Laboratory and by the Stanford Synchrotron Radiation Laboratory at the Stanford Linear Accelerator Center.

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