Developing an Antiscatter Grid for Mammography by Using Deep X-ray Lithography

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Introduction

Deep x-ray lithography and electroforming allow the production of tall, high-aspect-ratio structures with a high degree of precision. One of the important applications for high-aspect-ratio microformed metal structures is mammography. In mammography, an ideal diagnostic image is produced by local reduction in the x-ray intensity as a result of attenuation without scattering by the breast tissue. Because of the large amount of scattered radiation, image contrast is lowered, making diagnosis of diseased tissue subjective and difficult. The quality of mammogram images can be significantly improved by using an antiscatter grid that is transparent for primary radiation and opaque to scattered radiation from all directions [1-4].

In this report, we summarize our results in developing an antiscatter grid for mammography by using deep x-ray lithography and electroforming. The results were presented at international conferences HARMST 2001 [5, 7] and MEMS 2002 [6] and have been submitted for publication. Our goal is the fabrication a freestanding copper grid that is 2.5-mm tall with 25-μm-thick lamellar walls oriented toward an x-ray point source and with periodicity of 550 μm in two directions. This is a challenging task because a very-high-aspect-ratio structure has to be fabricated, and no technique exists to obtain a focused grid (i.e., one in which all lamellar walls are oriented toward a point placed away from the grid plane). To obtain gradually slanted lamellar walls, we are developing a dynamic double-exposure technique. Another novel approach deals with using rigid graphite as a substrate and plating base. This allows fabrication of high-aspect-ratio, freestanding copper structures, which was not possible by using conventional methods.

Methods and Materials

Commercially available rigid graphite sheets (Goodfellow) ranging from 0.25 to 1 mm in thickness were used as the substrate and as the plating base for the microfabrication. Two resists were used: (1) polymethylmethacrylate (PMMA) sheets (Goodfellow, CQ grade) with a thickness of 1 mm or more and (2) the negative photoresiststs XPSU-8 25 (63% of solids) and XPSU-8 500 (75% of solids) from Micro Chem. The PMMA sheet was solvent-bonded [8] to the graphite substrate with methylmethacrylate. The negative resist was spin-coated onto a silicon wafer and the rigid graphite sheet and then soft baked according to manufacturer's recommendations.

Hard x-ray exposures were performed at bending magnet beamline 2-BM [9] of the APS. The beam size was 100×6 mm^2, and the photon energy range was 10-20 keV, after passing through a 1-mm carbon filter and reflecting from a 0.15° grazing-incidence chromium mirror.

X-ray masks used for patterning were fabricated by conformal mask technology [10]. The mask consisted of a 250-μm-thick silicon wafer with a 45- to 60-μm-thick patterned gold absorber layer.

The substrate/mask assembly was mounted on a scanner stage driven by a servomotor that allowed x-y translation and rotation along each axis during exposure. In order to obtain trenches in PMMA oriented toward the point x-ray source of the mammography system, the substrate/mask assembly was rotated to the appropriate angle along the x-axis during sample scanning.

The exposed PMMA was developed by using the GG developing system [11]. Irradiated SU-8 samples were post-baked according to manufacturer's recommendations and developed in the magnetically stirred Nano XP-SU-Developer (Micro Chem) at room temperature.

Copper electroforming was performed by using a copper sulfate plating bath. After electroforming, the copper microstructures, along with the PMMA mold, were released from the plating base by abrasive removal of graphite. Both sides of the copper microstructure were polished by using aluminum oxide pads. Then the PMMA mold was dissolved in acetone, resulting in the finished freestanding metal structure.

Results and Discussion

Fabrication of very high-aspect-ratio microstructures is a challenge. Good adhesion of the resist to the plating base is critical for the process. We have found [5, 6] that PMMA adhesion is much stronger to graphite than to metal-coated silicon because of graphite's high porosity and microroughness. In addition, the adhesion between the resist and the substrate does not fail during the exposure since the fluorescence radiation generated during exposure is significantly less from graphite than from sputter-coated silicon because of graphite's smaller density and atomic number. Graphite's conductivity was found to be sufficient to perform electroplating directly without a metal base layer. The electroformed part must be separated from the plating base to provide a freestanding metal structure. The advantage of graphite as a substrate is its easy sacrificial removal by abrasion once electroforming is complete. This broadens the range of metals suitable for electroforming and subsequent release. For example, freestanding copper and lead microstructures, which cannot be obtained by using a titanium sacrificial layer on a silicon substrate, can be easily fabricated by using a graphite substrate.

We have been successful in the development of a graphite substrate process, obtaining a freestanding copper grid with parallel lamellar walls more than 1-mm tall. The scanning electron microscopy (SEM) image of a $60 \times 60\text{-mm}^2$ freestanding copper grid (polished on both sides) with an aspect ratio of more than 40 is presented in Fig. 1. The grid walls are perfectly shaped, smooth, and void free.

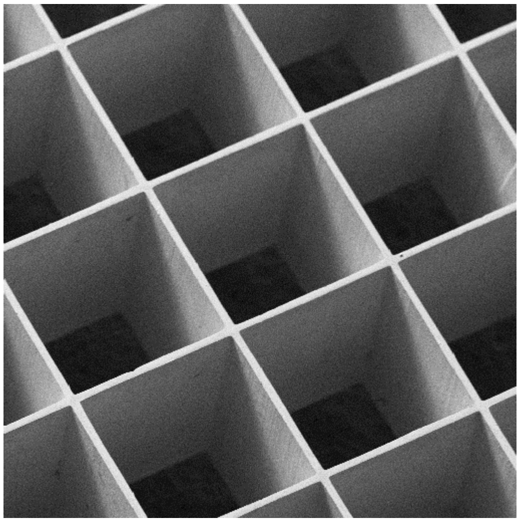

FIG. 1. A SEM image of a freestanding copper grid polished on both sides. The grid has 25-μm lamellae and a 550-μm periodicity and is 1-mm high.

To create a grid with lamellar walls oriented to a single point, we are developing "dynamic double exposure" of the PMMA by using a line mask. Double exposure here means that the substrate/mask assembly is placed in the x-y plane with the lines of the line mask aligned in the x-y direction, forming exposed line patterns in the PMMA during the first exposure. A second exposure is performed with the substrate rotated by 90° in the x-y plane while the line mask is kept in the same position. After development, square patterns with parallel lamellar walls perpendicular to the substrate are obtained in the PMMA. Dynamic exposure is required to obtain focused walls. To start the dynamic exposure, the substrate/mask assembly is positioned parallel to the x-axis but allowed to be oriented at an angle θ with respect to the y-axis; the lines of the line mask are parallel to the x-axis. A single dynamic exposure consists of rotating the substrate/mask assembly as it moves up and down in the y-direction; the exposed PMMA pattern consists of lamellar walls oriented to a line. Dynamic double exposure combines dynamic exposure with double exposure (i.e., repeating a single dynamic exposure described above after rotating the substrate in the x-y plane by 90°). The dynamic double-exposure technique creates square-shaped openings oriented to a point.

A number of double exposures and dynamic exposures were performed. The angle of rotation was ± 3.82° along the x-axis for the scan length of 80 mm (center of rotation is a sample center). Development of the sample was a challenge. Only a small part of the exposed grid was developed through to the substrate. Consequently, only a small area was electroplated. The slope of the walls was varied gradually from 1.43° to 2.87° from perpendicular relative to the substrate over a 15-mm section of electroplated material.

In order to reduce the cost of fabrication, we have started to work with more sensitive negative SU-8 photoresist. Exposures of PMMA that normally take hours can be accomplished in minutes by using SU-8. The resist was developed for near ultraviolet (UV) lithography to make structures less than 0.5 mm. X-ray lithography is required when the height of the SU-8 structure is greater than 0.5 mm and when the uniformity and vertical straightness of the wall structure are important. Our first results showed excellent adhesion of SU-8 on graphite for high-aspect-ratio structures, and the structures have been successfully electroformed by copper. More work has to been done on obtaining a uniform resist layer more than 1-mm thick and finding optimal processing parameters.

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