Fabrication of a Needle Array Using a Si Gray Mask for X-ray Lithography

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We succeeded in fabricating a needle array of polymethylmethacrylate (PMMA) resist by using only a single X-ray exposure. Usually, in order to fabricate 3-dimensional (3-D) resist structures it is necessary to make more than one exposure while continuing 3-D scanning and rotating of X-ray mask and resist substrate. We have now consolidated the 3-D processing into the fabrication process of an X-ray mask and developed a gray mask for X-ray lithography without having to move the exposure stage.

Si can be diagonally etched by optimizing the etching recipe in deep-RIE techniques other than the Bosch process. Fig. 1 shows the fabrication process of an X-ray mask using this technique. Dot patterns were then transcribed on the surface of the active Si layer on a silicon-on-insulator (SOI) wafer by photolithography after spin-coating a positive-tone resist. A deep-RIE etching system (Alcatel 601E System, Alcatel Vacuum Technology France) was used where the active Si layer was etched in $SF_6/C_4F_8/O_2$ mixed gas at a pressure of 5.8 Pa. Next, SU-8 negative-tone resist was spin-coated to form a membrane. A frame was formed with deep-RIE of the Si substrate and the SiO_2 layer was removed with RIE. At the end, the resist was removed by O_2 plasma ashing.

X-ray lithography experiments were executed by using this X-ray gray mask in the beamline BL-4 of TERAS synchrotron radiation facility of AIST. Fig. 2 shows the calculated output beam spectra from BL-4. When the thickness of an X-ray absorber is locally different as shown in the insertion figure of fig. 2, the spectrum of X-rays that penetrate an X-ray mask can be changed within the range in area III. As a result, the processing depth of resist changes because the dose energy is locally different even if X-rays are irradiated during the same time.

Fig. 3 shows a photograph of a Si gray mask for X-ray lithography to fabricate a needle array. Fig. 4(a) is a cross-sectional SEM image of a Si absorber before SU-8 spin-coating. A square gimlet structure with sidewalls inclined at 60 º is observed. The cross-sectional SEM image of a needle structure transcribed on a PMMA sheet by using this X-ray gray mask is shown in fig. 4(b). In this figure, a cross-sectional SEM image can be compared with the calculated results shown in the black curve. Actual and calculated shapes corresponded well. Thus, we proposed a new fabrication method of an X-ray gray mask using MEMS technologies.

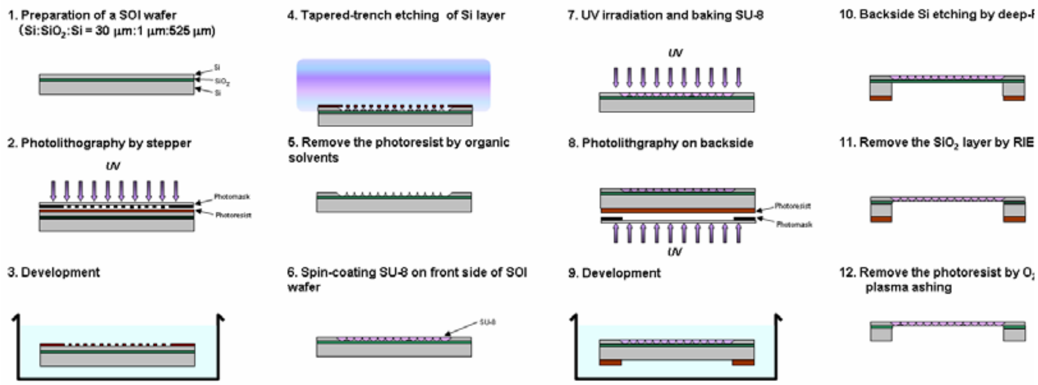

Fig 1: Process flow for fabricating a Si X-ray gray mask by MEMS technology

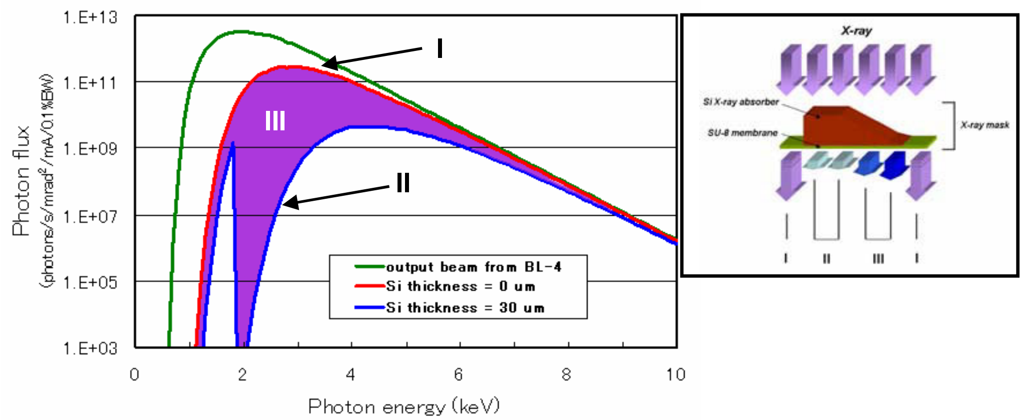

Fig 2: Calculated spectrum of output beam form beamline BL-4 in TERAS. Right figure is a cross-sectional structure of X-ray absorbers on Si mask. Spectra I is an output beam through SU-8 membrane. Spectra II is an output beam through Si absorber. Area III is output beams with Si the gray mask.

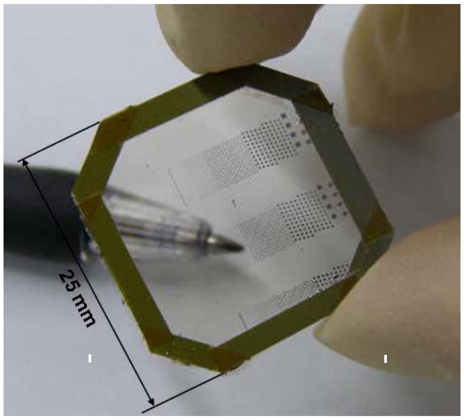

Fig 3: Photograph of a gray mask for X-ray lithography to fabricate a needle array

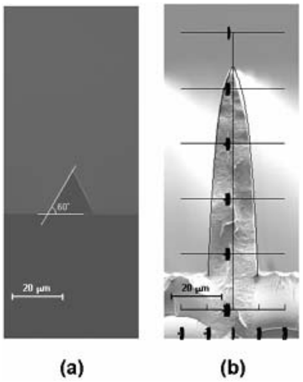

Fig 4: Cross-sectional SEM images of a Si absorber and a PMMA structure. A black curve is a shape estimated by calculation.