Fabrication of 3-D Structures of Resist by Proton Beam Writing

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Proton Beam Writing (PBW) is a promising method for micro-fabrication by a direct writing of focused beam of protons [1]. Since the direct-write technique doesn't need expensive masks required for the case of X-ray and UV lithography, micro-machining using PBW is a relatively low-cost process with a fast prototyping capability. In addition, for exposure of thick resists with several tens of micrometers, the focused proton beam accelerated with energy of MeV order has the following advantages over other sources such as electrons and photon: (i) the scattering of protons [2] is suppressed compared with electron [3] penetrating into the same depth as shown in Fig. 1, (ii) the projected range of the ions can be controlled with the acceleration energy, and (iii) arbitrary patterns can be written with electrostatic or electromagnetic scanning of the beam.

In this paper, we report fabrication of 3-D structures using PBW with these advantages at a micro-beam facility of TIARA, JAEA Takasaki, Japan. The PBW was performed on typical negative resists, SU-8 on silicon with a thickness of 50 µm purchased from MEMS CORE Co. The 3-D structures after development were evaluated by a scanning electron microscope (SEM). Fig. 2 shows the principle of 3-D structures by multiple exposures of protons with different energies. In the beginning, we performed beam writing with 3.0-MeV protons with a projected range larger than a thickness of SU-8 layer on silicon for fabrication of a supporting post from the substrate. Next, we made beam writing with 1.2-MeV protons with a range of 29 µm predicted by SRIM 2003 simulation for making floating structures from the substrate. After the two-step PBW at multiple energies shown in the case of Fig. 2, a T-shaped 3-D structure can be formed after development.

Fig. 3 (a) shows SEM images of the 3-D structures of SU-8 on silicon after PBW of grid patterns over the 350-µm squared area. We confirmed the formation of a 3-D structure consisting of overlaid grid with different pitches. The thickness of 28 µm for the upper layer grid is consistent with the range of 1.2-MeV protons predicted by SRIM 2003 simulation. Figs. 3 (b) and (c) show the magnified SEM images of the edges obtained at different parts of the 3-D structures. The supporting grid standing from the substrate written by the 3.0-MeV protons shows a smooth and vertical (~91.8 deg) sidewall since the ion range (~129 µm) is much greater than the thickness of SU-8. We observed the increased width of the lines at the bottom of the upper grid due to the scattering of protons at the end of range.

These data show the 3-D micro-fabrication capability of PBW and suggest possible applications to devices for micro-photonics, micro-fluidics, and MEMS.

References:
[1] F. Watt et al. Proc. SPIE Int. Soc. Opt. 3138, 128 (1997)
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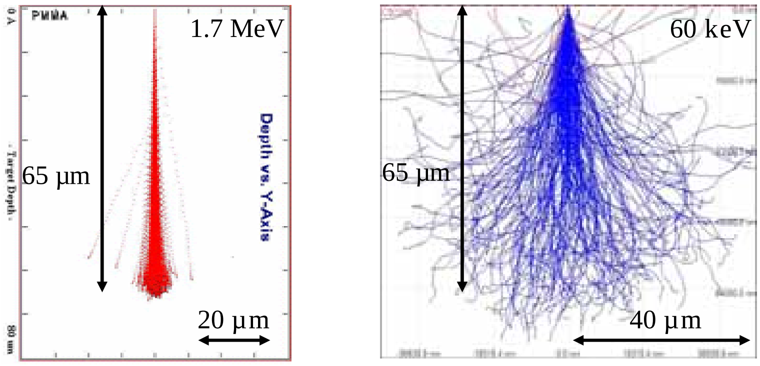


(a) Proton beam (b) e-beam

Fig. 1 Beam trajectories of proton beam and e-beam obtained by simulations with SRIM 2003 and CASINO v2.42, respectively.

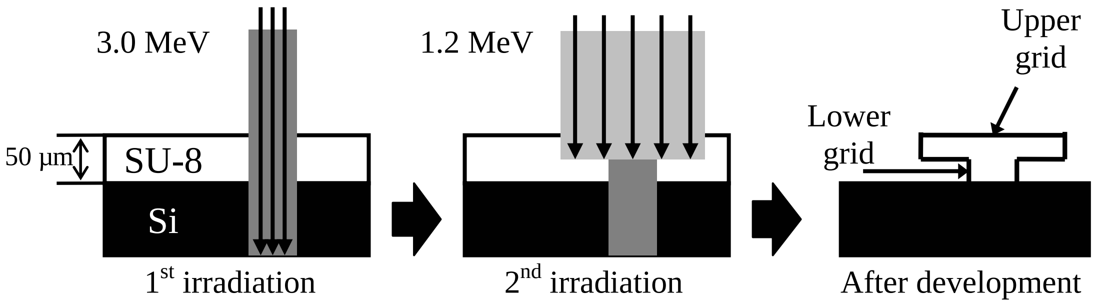
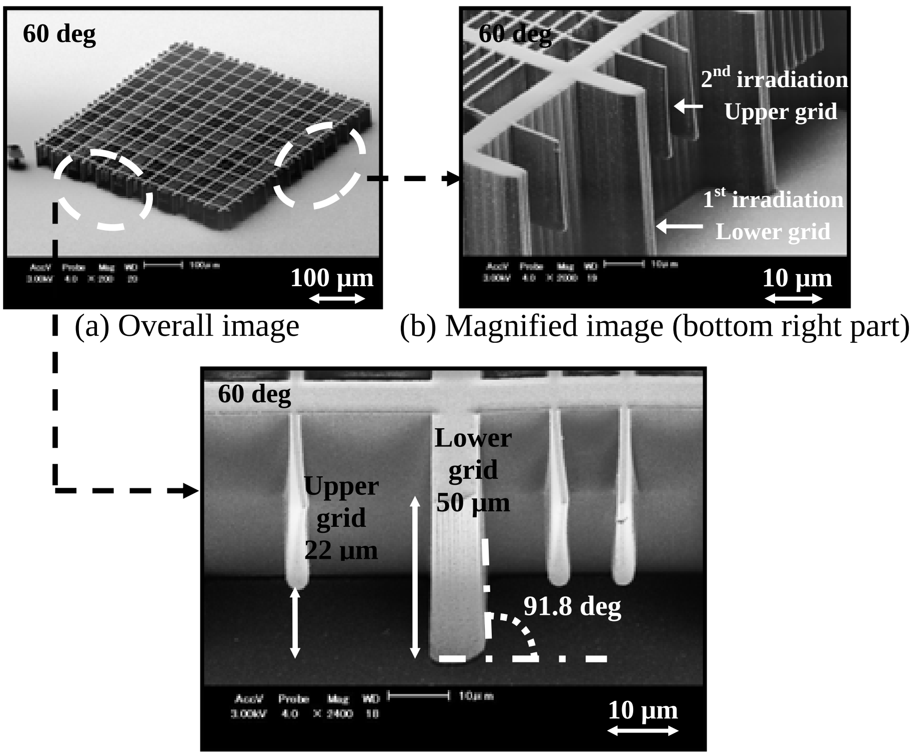


Fig. 2 The principle of fabrication of 3-D structures using protons with multiple energies.



(a) Overall image (b) Magnified image (bottom right part)

(c) Magnified image (bottom left part)

Fig. 3 SEM images of 50-µm-thick SU-8 on silicon developed after proton beam writing. (Fluence: Upper grid 40, 80 nC/mm^2 and Lower grid 200 nC/mm^2)