12-9 Fabrication of a Micro-Scale Arc de Triomphe by MeV Focused Proton Beams

— Development of a 3-D's Fine Fabrication Technique Using High Energy Submicron Ion Beams —

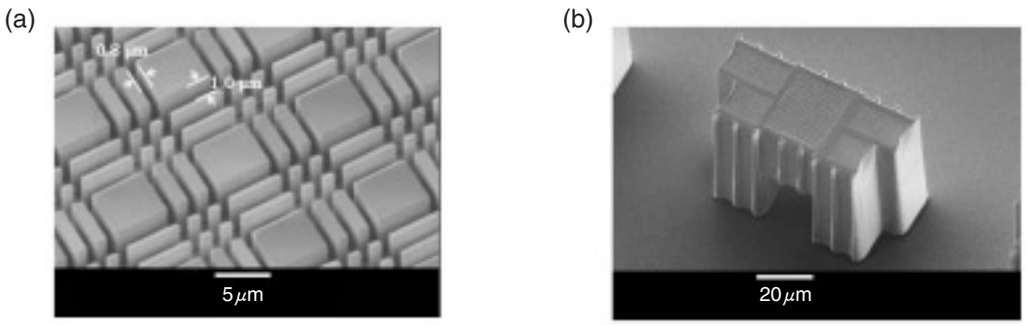

Fig.12-20　Fine polymer structures fabricated of a polymer using PBW
(a) grid structure, (b) Arc de Triomphe structure

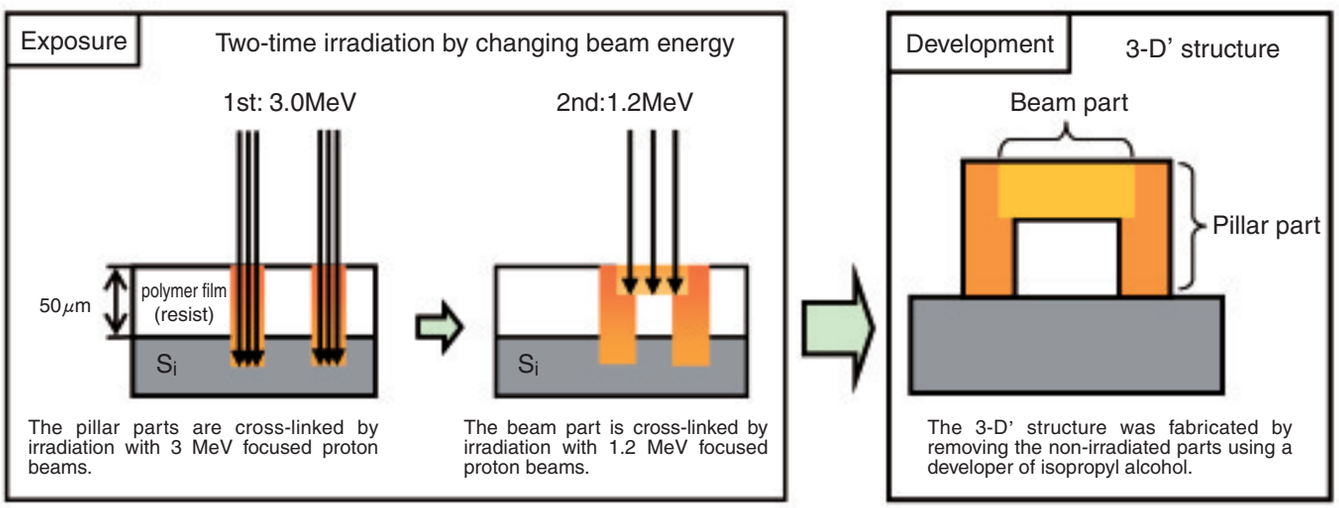

Fig.12-21　Fabrication process for 3-D polymer structure (negative resist; non-irradiated parts are removed)

Fine polymer fabrication at a scale of micrometer or less has been performed using electron beams. The fabrication with long penetrable ranges is, however, difficult due to large straggling effects of the beams in the polymers. The MeV focused proton beams with a diameter of micrometer or less have longer range of penetration into materials of over 100 μm, and highly straight trajectories. These advantages allow us to fabricate not only high aspect-ratio structures, but also 3-D structures with cavities by changing the penetration range which depends on the proton beam energy. The technique of focusing proton beams of 3 MeV at a maximum into an area of hundreds of nanometers in diameter has been developed at "TIARA" (the Takasaki Ion Accelerators for Advanced Radiation Application) in the Takasaki Advanced Radiation Research Institute. We, a group of a joint research between JAEA and the Shibaura Institute of Technology, used these advantages for fabrication first in Japan, and through research starting in 2005 have developed a proton beam writing (PBW) technique to fabricate 3-D structures with polymers. The PBW is a detailed fabrication technique using the MeV focused proton beam scanned following the predetermined patterns over a polymer resist. Fine structures are produced by carrying out the PBW and then removing the irradiated or non-irradiated parts using a developer.

We fabricated the 3-D structures with horizontal resolution on the scale of hundreds of nanometers or maximum processing depth of 50 μm. The fine 3-D structures fabricated by PBW are shown in Fig.12-20; (a) a thin PMMA film (a positive resist; irradiated parts were removed) coated on a silicon substrate and (b) a 3-D structure with a cavity (Arc de Triomphe shape) using the irradiation of SU-8 (a negative resist; non-irradiated parts were removed). The former shows that the spatial resolution of PBW reaches the scale of hundreds of nanometers. The fabrication process of Fig.12-20(b) is development after exposure to 3 MeV and 1.2 MeV focused proton beams 1 μm in diameter and then performing the development, as illustrated in Fig.12-21. This 3D structure fabrication method demonstrates that the PBW technique at JAEA has reached the top-level in the world.

Reference

Uchiya, N., Ishii, Y. et al., Micro-machining of Resists on Silicon by Proton Beam Writing, Nuclear Instruments and Methods in Physics Research B, vol.260, issue 1, 2007, p.405-408.