Application of Proton Beam Writing to a Direct Etching of PTFE for PDMS Replica Molding

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Proton beam writing is a direct write technique with unique capabilities in fabricating deep, high-aspect-ratio microstructures of various materials, such as resists and semiconductors.[1] One of the drawbacks of the PBW is that the processing steps involve a wet etching. Polytetrafluoroethylene (PTFE) is a material of choice for microstructures which are useful in MEMS and microfluidics, because of its high chemical, mechanical, and thermal durability. Direct etching techniques of PTFE have been reported using either X-ray or a focused ion beam (FIB) lithography.[2,3] In this report, we investigate the capability of proton beam writing (PBW) in the direct etching of PTFE.

The PBW was performed using a dedicated PB writer installed at the Center for Flexible System Integration, Shibaura Institute of Technology. The proton beam at beam energy of 1.0 MeV was focused to 2.0 μm and was scanned with a beam current of 80 pA over 5-60 μm squared areas on a 1-mm-thick PTFE film at fluence up to 2.1 μC/mm^2. The PTFE surface was studied by a confocal laser scanning microscope (CLSM) and a scanning electron microscope (SEM).

After PBW above fluence of 0.9 μC/mm^2 coupled with heat treatment in air, direct etching of the PTFE surface was observed by SEM observation as shown in Fig. 1(a). We observed the decrease of CF_2 and CF_3 bonds in the composition of PTFE by FT-IR analysis. This indicates the decomposition of PTFE was involved in the direct etching process. With increasing fluence up to 2.1 μC/mm^2, the depth of micromachining increase up to around 30 μm measured by CLMS, which is larger than the projected range of 16.5 μm for 1.0 MeV protons incident to PTFE. Fig. 1(b) shows a PDMS replica mold obtained from the PTFE with smooth surfaces. The direct etching of the PTFE may open a new possibility of the micromachining of PTFE by PBW for MEMS and microfluidics.

Acknowledgments

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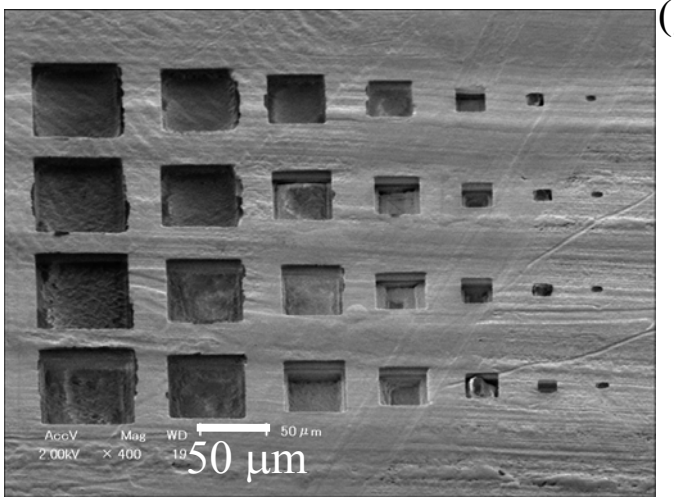
[1] F. Watt et al., Materials Today 10 (2007) 20.
[2] Y. Ukita et al., Microsystem Technologies 14 (2008) 1567.
[3] N. Miyoshi et al., Radiation Physics and Chemistry 80 (2011) 230.



Fluence ($\mu C/mm^2$):

0.9

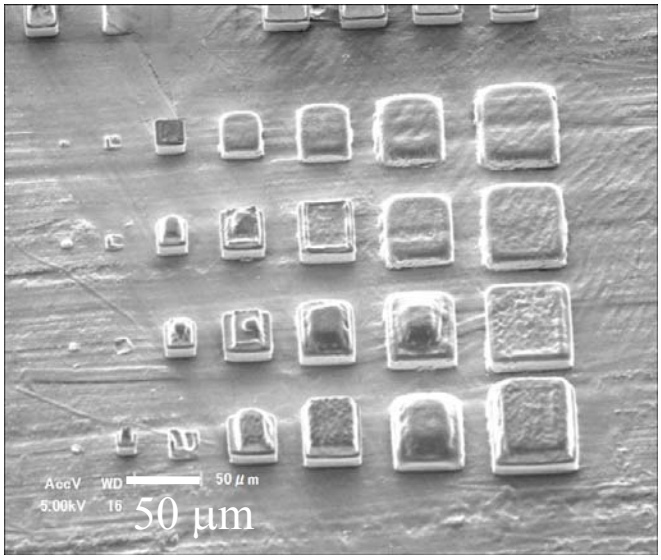
1.2

1.5

2.1

Size (μm): 60 50 40 30 20 10 5

(a)



Fluence ($\mu C/mm^2$):

0.9

1.2

1.5

2.1

Size (μm): 5 10 20 30 40 50 60

(b)

Figure 1: SEM images of (a) a PTFE film with square holes micromachined by PBW (1.0 MeV, beam size of 2 μm) with varied fluence from 0.9 to 2.1 $\mu C/mm^2$ and subsequent annealing at 300 ℃ for 30 minutes in air, and (b) the replica mold surface of the PDMS.