Direct Micromachining of Inorganic Transparent Materials Using Laser Plasma Soft X-Rays

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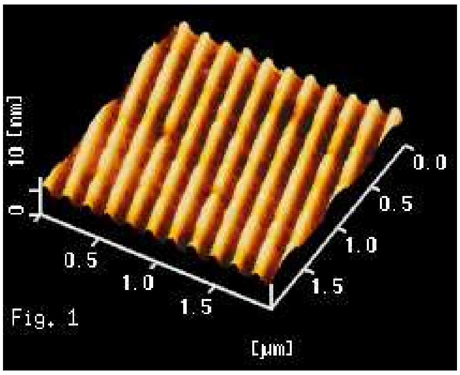

Inorganic transparent materials are highly valued for their use in the fields of nanometric chemical analysis or chemical reactions in medicine and biotechnology, and for optical materials such as gratings, photonic crystals and optical waveguides. Although a limited number of materials can be machined, it is required to machine a wide variety of materials precisely at low cost. We have investigated direct micromachining of inorganic transparent materials using laser plasma soft X-rays. The soft X-rays were generated by irradiation of Ta targets with 532 nm Nd:YAG laser light with a pulse duration of 7 ns, at an energy density of $\sim 10^4$ J/cm. The soft X-rays were focused on specimens, using an ellipsoidal mirror that we desined so as to focus soft X-rays at around 10 nm efficiently. We found that synthetic quartz glass, fused silica, Pyrex, LiF, CaF_2, Al_2O_3, $LiNbO_3$ can be machined smoothly. Typically, quartz glass is ablated at 40 nm/shot, and has a surface roughness less than 10 nm after 10 shots. In order to investigate lateral resolution, we fabricated a WSi contact mask with 200-nm-pitch line-and-space patterns on quartz glass. Figure 1 shows an atomic force micrograph of the quartz glass plate after a single shot of laser plasma soft X-rays and etching the WSi mask. We found that quarts glass plates can be machined at a resolution less than 100 nm. With further development of imaging optics, nanomachining of inorganic trasparent materials should be achieved by direct irradiation of laser plasma soft X-rays.

[1] T. Makimura, S. Mitani, Y. Kenmotsu, K. Murakami, M. Mori, and K. Kondo, Appl. Phys. Lett. **85**, 1274 (2004); T. Makimura, H. Miyamoto, Y. Kenmotsu, K. Murakami, and H. Niino, Appl. Phys. Lett. **86**, 103111 (2005).