Figuring and smoothing capabilities of elastic emission machining for low-thermal-expansion glass optics

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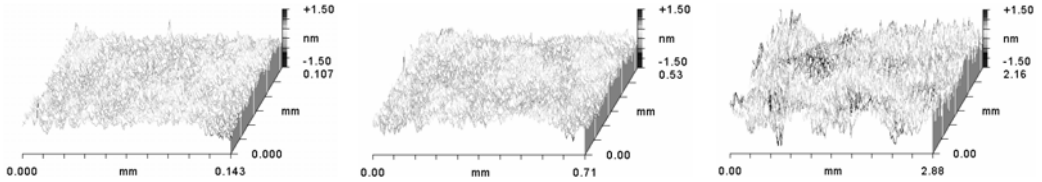
Extreme-ultraviolet lithography systems require the high-precision optics made of low-thermal-expansion materials such as ULE and/or Zerodur. The demanded figure accuracy and surface roughness are both on the level of 0.1 nmRMS. Elastic emission machining (EEM) has been successfully developed for the fabrication of hard-X-ray mirrors, by which sub-30 nm focusing was established under diffraction-limited conditions at the X-ray wavelength of 0.08 nm [1]-[4]. In this achievement, the material of the mirror surface was single-crystal silicon, on which EEM is known to realize an atomically well-ordered surface.

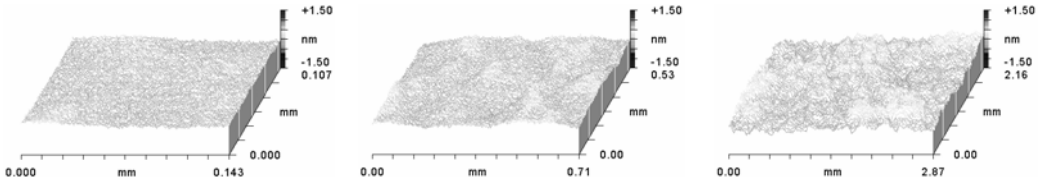
In this study, the removal performance of EEM was tested on ULE and Zerodur surfaces from the viewpoints of the smoothness and removal rates. The EEM head employed was a type of rotating sphere[5]. Several areas of 5 mm × 5 mm on the ULE and Zerodur surfaces were processed by raster scanning for different lengths of time. The depths and roughnesses were measured using a 3D optical profiler (ZYGO NewView). The removal volumes were found to be precisely proportional to the process time, and the rates were 0.83×10^{-4} mm^3/h and 1.0×10^{-4} mm^3/h on the ULE and Zerodur surfaces, respectively. The roughness of the Zerodur surface was reduced to approximately 0.1 nmRMS in the spatial wavelength range from 100 μm to 1 mm.

[1] K. Yamauchi et al., Rev. Sci. Instrum., **73** (2002) 4028-4033.
[2] K. Yamauchi et al., Rev. Sci. Instrum., **74** (2003) 2894-2898.
[3] H. Mimura et al., Rev. Sci. Instrum., **76** (2005) 045102.
[4] H. Mimura et al., Jpn. J. Appl. Phys. Part 2, **44** (2005) No.18 539.
[5] M. Kanaoka et al., Sci. Tech. Adv. Mater., in press.



0.229 nm RMS 0.268 nm RMS 0.542 nm RMS

(a) pre-processed surface



0.085 nm RMS 0.116 nm RMS 0.178 nm RMS

(b) EEM-processed surface

Fig. 1: Surface height profiles before and after EEM processing observed using 3-dimensional optical profiler (ZYGO NewView) for three measurement ranges of spatial wavelength. The material of the glass was Zerodur. The removal depth was about 30 nm.