Low energy ion beam machining of Si layer deposited on an ULE® substrate for EUVL optics

- Evaluation of surface roughness -

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Aspherical substrates for Extreme Ultra Violet Lithography (EUVL) optics require ultra high shape accuracy of about 0.15 nm rms and surface roughness of about 0.15 nm rms [1]. Ion beam figuring (IBF) is adapted to final shape correction of the substrate at low spatial wavelength of 1-30 mm, where the substrate is machined within depth of 50 nm. Ultra-low-expansion material such as Zerodur® and ULE® are candidate for substrates of the EUVL optics. However, in our previous experiment on ion beam machining of those substrates, the ion beam machined surface of both substrates become rougher. Moreover, their surfaces are positively charged during ion beam machining due to positive charges of the impinging ions. Therefore we have proposed a method in which thin Si layer deposited on that. In the case of Ar+ ion beam energy of 3-10 keV, we revealed that the surface roughness of the machined Si decreases with decreasing the ion beam energy.

In this experiment, the Si layer was deposited on the mechanically prefinished ULE® substrate by ion beam sputtering. The ULE® substrate was prepared for ultra-low-expansion material, because it is easy to prepare the surface roughness less than 0.1 nm rms by mechanical polishing. The experiments were conducted in an ion beam machining apparatus which has an ECR discharge type ion source to generate an Ar^+ ion beam with an energy of 1 keV. To evaluate the mid-spatial frequency roughness (MSFR: wave period of 1 mm-1 μm) quantitatively, the surfaces were measured by a white light interferometer. Moreover, to evaluate the high-spatial frequency roughness (HSFR: period of 1-0.02 μm) quantitatively, the surfaces were observed and measured by an atomic force microscope (AFM).

Fig.1 shows the dependence of the MSFR on ion beam machined depth. The MSRF of the machined substrates shows no systematic change in increasing machined depth. The each average MSFRs for the machined surface is 0.06 nm rms, which is comparable to that of unprocessed one. Fig.2 (a)-(d) show AFM images of unprocessed surface (a) and machined surfaces (b)-(d). The HSFR of the surface machined with a depth of about 50 nm shows (a) 0.10 nm, (b) 0.15 nm, (c) 0.10 nm and (d) 0.08 nm respectively. Fig.3 shows dependence of the HSFR of surface on ion beam machined depth. The HSFR of the surface machined with ion beam energy of 1 keV shows slightly larger than that for the surface of the unprocessed substrates. On the other hand, HSFR of the substrate machined with Ar+ ion beam energy less than 0.5 keV maintains the unprocessed one. We conclude that this process using Ar+ ion beam energy less than 0.5 keV can produce minimum surface roughness less than 0.10 nm rms on EUV optics.

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References:

1 Banqiu Wua and Ajay Kumar, J. Vac. Sci. Technol. B 25 (6), 1743 (2007).

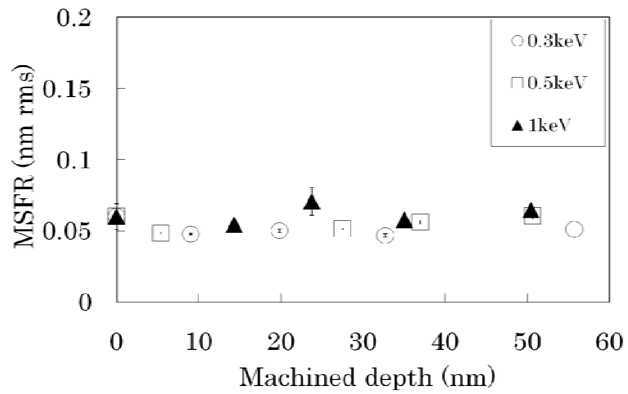
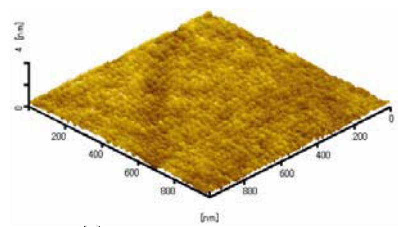
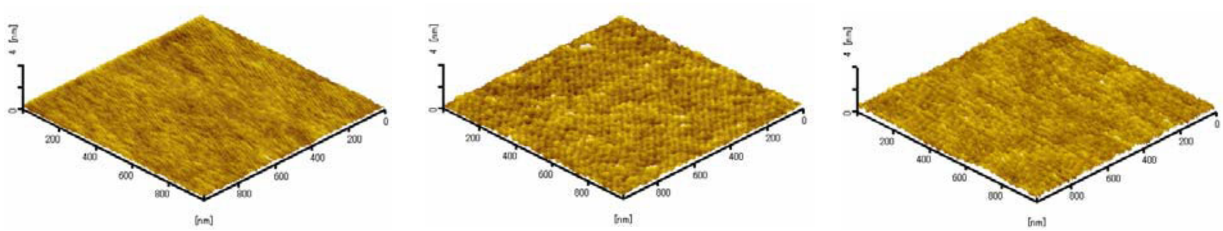


Fig.1 Dependence of the MSFR on machined depth.



(a) Unprocessed surface



(a) Ar⁺ ion beam energy of 0.3 keV. (b) Ar⁺ ion beam energy of 0.5 keV. (c) Ar⁺ ion beam energy of 1.0 keV.

Fig.2 AFM images of unprocessed surface (a) and machined surface (b)-(d) with an Ar^+ ion beam of energy from 0.3 keV to 1.0 keV.

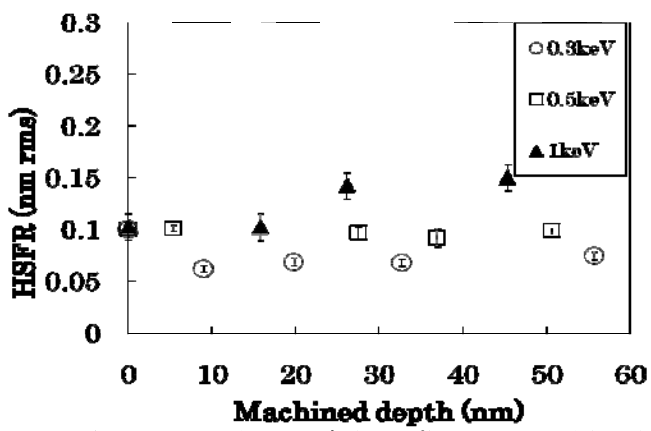


Fig.3 Dependence of the HSFR on machined depth