Evaluation of surface roughness of Zerodur substrates machined by Ar^+ ion beam with energy of 3~10 keV

Y. Kurashima, *R. Uozumi, I. Miyamoto, A. Numata*※ *and M. Ando*※
Tokyo University of Science, 2641 Yamazaki, Noda, Chiba 278-8510, Japan
※EUVA, 23-10, Kiyohara-kogyodanchi, Utsunomiya-shi, Tochigi 321-3298, Japan

Aspherical substrates of the projection optics for Extreme Ultra Violet Lithography (EUVL) require ultra high shape accuracy of about 0.2 nm rms and surface roughness of about 0.2 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 100 nm. Zerodure which has the low thermal expansion material is candidate for substrates of the projection optics for EUVL. However, Zerodur is composed of SiO_2 and β-quartz solid solution(Li_2O-Al_2O_3-nSiO_2, $n \geq 2$) grain. Therefore, the ion beam processed Zerodur surface is considered to become rougher due to the difference of the sputter machining rate between SiO_2 mother solid and β-quartz solid solution grains of about 50-100 nm. Surface roughness of Zerodur substrate which was machined within depth of 100 nm by ion beam almost has not been reported [2]. In this report, we quantitatively examined surface roughness of Zerodur substrates machined within a depth of 60 nm by Ar^+ ion beam.

The experiments were conducted in an ion beam machining apparatus which has a high-voltage discharge type ion source to generate Ar^+ ion beam of energy from 3 keV to 10 keV. The Ar^+ ion beam was focused on the work-piece with a beam diameter of about several mm. To evaluate the mid-spatial frequency roughness (MSFR: wave period of 1 mm-1 μm) quantitatively, ion beam machined surfaces of Zerodur substrate were measured by a white light interferometer. Moreover, to evaluate the high-spatial frequency roughness (HSFR: period of 1-0.02 μm) quantitatively, machined surfaces of Si deposited Zerodur were observed 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 MSFR for the unprocessed surface is 0.23 nm rms and that average of machined surface is 0.24 nm rms. We concluded that the slight increment in the MSFR of the substrate is due to the system error of the white light interferometer. 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 60 nm shows (a) 0.26 nm, (b) 0.44 nm, (c) 0.39 nm and (d) 0.34 nm respectively. Fig.3 shows dependence of the HSFR of surface on ion beam machined depth. The HSRF of the substrate machined shows slightly lager than that for the surface of the unprocessed substrates. In Fig.3, each HSRF of the machined surface increases with increasing of ion beam machined depth.

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References:

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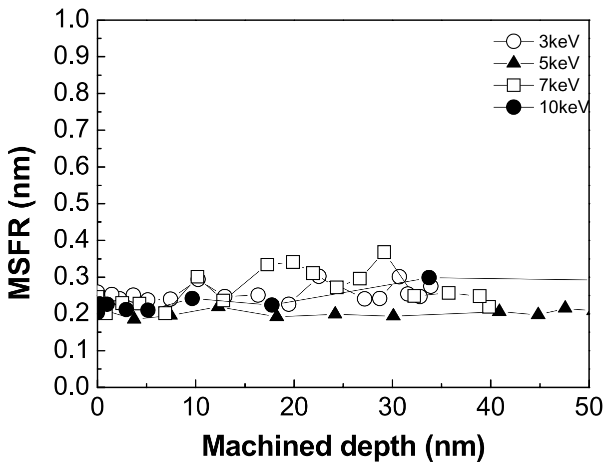
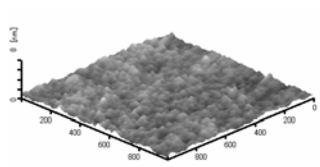
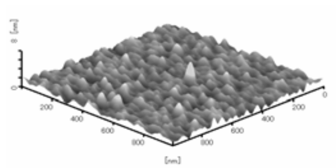


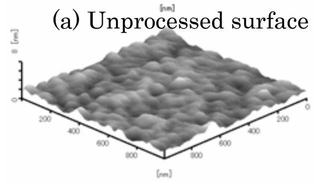
Fig.1 Dependence of the MSFR of the Zerodur substrate machined with an Ar^+ ion beam of energy from 3 keV to 10 keV on machined depth.



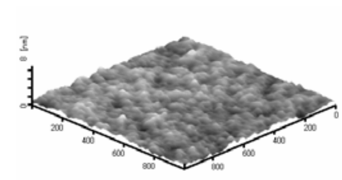
(a) Unprocessed surface



(a) Ar^+ ion beam energy of 3 keV. Machined depth of 54 nm.



(b) Ar^+ ion beam energy of 5 keV. Machined depth of 56 nm.



(c) Ar^+ ion beam energy of 10 keV. Machined depth of 60 nm.

Fig.2 AFM images of unprocessed surface (a) and machined surface (b)-(d) with an Ar^+ ion beam of energy from 3 keV to 10 keV.

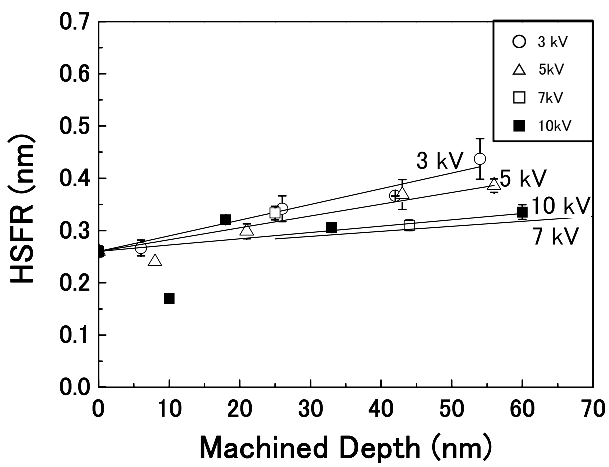


Fig.3 Dependence of the HSFR on machined depth