Low energy Ar^+ ion beam machining of ULE® and CLEARCERAM® substrates for TMT primary mirrors

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The primary mirror of the 30 m telescope (TMT) [1, 2] will be composed of 492 ultra-low expansion glass hexagonal segments (specification of shape accuracy: 20 nm rms; surface roughness: 2 nm rms). Usually, conventional mechanical pre-finishing have several problems such as edge effects, tool wear, force loading effects, and generation of sub-surface damage. Therefore, ion beam figuring (IBF) [3] may be adapted to final shape error correction of the substrates of ultra-low-expansion glass material such as Zerodur®, CREACELAM® and ULE®.

In this experiment, mechanically pre-finished ULE® (surface roughness R = 0.06 nm rms) and CREACELAM® (R = 0.30 nm rms) substrates were machined by Ar^+ ion beam with energy of 0.2-3keV.

Fig.1 shows the dependence of HSFR of the ULE® substrate on the machined depth. The HSFR of the machined substrates becomes about two times higher than that of pre-finished one. However, the HSFR does not show non systematic change with increasing machined depth. Fig.2 shows AFM images of unprocessed surface (a) and machined surfaces (b)-(d), where, small protrusions (several tens nm in width) are formed on the machined surfaces. Morphology of the machined surfaces are almost same at machined depth of 500 nm and 3000 nm. Fig.3 shows the PSD of the substrate before and after machining. PSD at spatial frequency from 0.01 to 0.001 1/nm, the PSD rises about 0.01 nm^2 than pre-finished ULE® substrate. Fig.4 shows the dependence of the HSFR of the CREACELAM® substrate on the machined depth. The HSFR of the machined substrates becomes larger than pre-finished one. However, it does not show non systematic change in increasing machined depth.

The HSFR of ULE® and CREACELAM® machined with 1.0 keV Ar^+ ions at normal ion incidence to the depth of 3μm satisfies the specification of 2nm rms. However the machining rate is too slow (3μm/h at ion current density of 1.65mA/cm^2). Therefore, we must consider a new ion beam machining conditions to achieve more high speed (100-1000times faster) machining rate.

References

[1] F.Y. Pan, J. H. Burge, R. Zehnder, and Y. Wang Appl. Optics **43** (2004) 13.
[2] S. E. Kendrick, H. P. Stahl Proc. SPIE 7010 (2008) **70102G**
[3] J. Ullom, Advance Opt. Manufacturing and Testing II, SPIE 1531 (1991) **195**

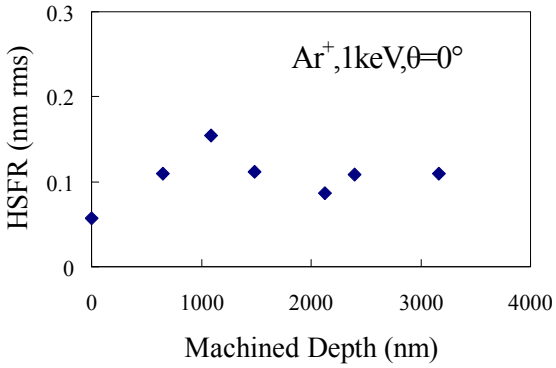
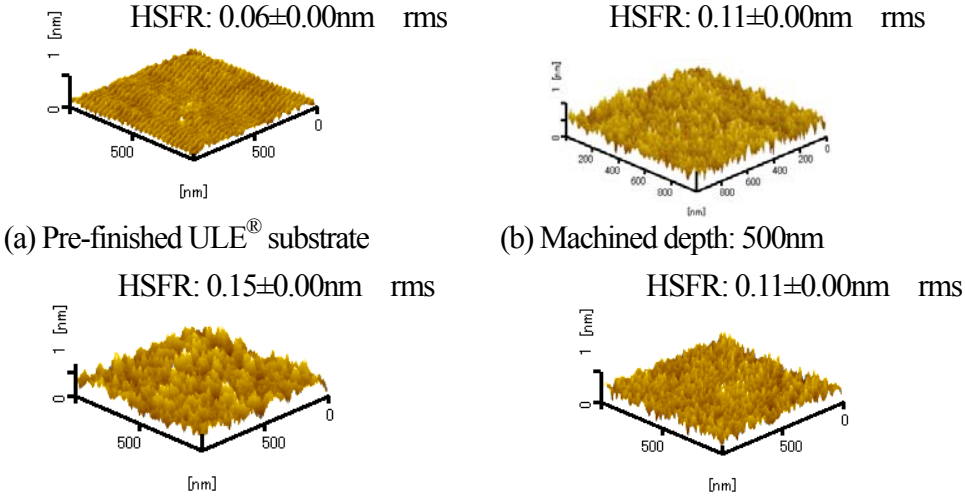


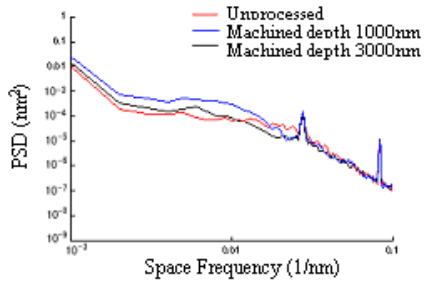
Fig1. Machined depth dependence of high spatial frequency surface roughness(HSFR) (wave length of less than 1 μ m) (Substrate: ULE®)



(a) Pre-finished ULE® substrate (b) Machined depth: 500nm

(c) Machined depth: 1000nm (d) Machined depth:3000nm

Fig2. AFM images before and after ion beam machining (Ar^+, 1keV)



Ar^+,1keV,θ=0°

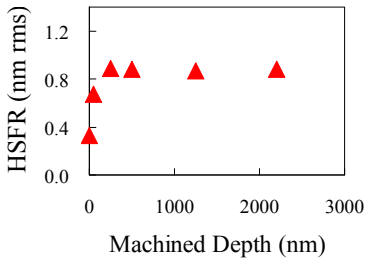


Fig3. PSD of ULE® surface before and after ion beam machining (Ar^+, 1keV)

Fig4. Machined depth dependence of HSFR
(Substrate: CLEARCERAM®)