Surface smoothening of single crystal diamond chip by 0.50-3.0 keV Oxygen ion beam for XFEL projection optics

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Introduction

Single crystal diamond has exceptional properties such as ultrahigh hardness, ultra high tensile strength and high thermal conductivity in materials on the earth, and chemical inertness. Therefore, single crystal diamond chips with high quality surface may be used as molds for nano-imprint. Moreover, diamond has high X-ray reflectivity (>0.95) and high crystal perfection (need to increase more), and it can be one of the strong candidates for the optics of X-ray free electron laser [1, 2] and so on. Generally, diamond tools and devices are mechanically polished using lap plate of soft material and fine diamond powder. However, the conventional mechanical process cannot be applied to engrave nm-patterns into a diamond chip and also very difficult to thinning it to the order of 10μm. Ion beam is considered as one of the strong tools for smoothening of almost all materials. Smoothening of diamond was performed by Ar^+ ion beam [3], however the processing speed was very slow. Therefore, we proposed a high speed smoothening technique of single crystal diamond by 0.50-3.0 keV Oxygen ion beam.

Experiment and results

The experiment was performed by an ECR type ion beam machining apparatus to generate Ar^+ ion beam. After generating the ion, the diamond sample was bombarded by 0.50-3.0 keV Ar^+ ion beam at different angles of ion incidence and selected 0.5 keV oxygen, 0º ion incidence for the ultra smooth optics fabrication. Then, the un-processed and processed surfaces were observed by an atomic force microscope for the measurement of surface roughness. The fabrication process of 10-50 μm thick mirror is shown in Fig. 1. Fig. 2 shows the dependence of surface roughness on ion incidence angle. Fig. 3 shows the AFM images of processed diamond substrate at different angles of ion incidence. As shown in the figures, the smooth surface with the roughness value of 0.096 nm rms was obtained by 0.5 keV oxygen ion beam at 0º ion incidence. Fig. 4 shows the comparison of roughness vs. machined depth curve for Ar^+ and oxygen ion beam. As shown in the figure, the machining rate of oxygen is almost three times higher than that of Ar^+ due to presents of both physical and chemical sputtering. In the case of oxygen processing, the surface roughness increases with increasing the machine depth and it becomes 0.21 nm rms at 15 μm machined depth. The roughness may increase further if the machined depth exceeds 30 μm. Therefore, after machined depth of 25 μm, we will apply the same process on lower part of the sample and can get ultra smooth mirror with 10-50 μm thickness (Fig.1). The smoothening and roughening mechanism will be discussed by height height correlation and PSD analysis of the processed samples.

Conclusion

By our proposed technique, it is possible to btain an ultra smooth diamond substrate with the surface roughness of about 0.20 nm rms and thickness of 10-50 μm for XFEL projection optics.

References

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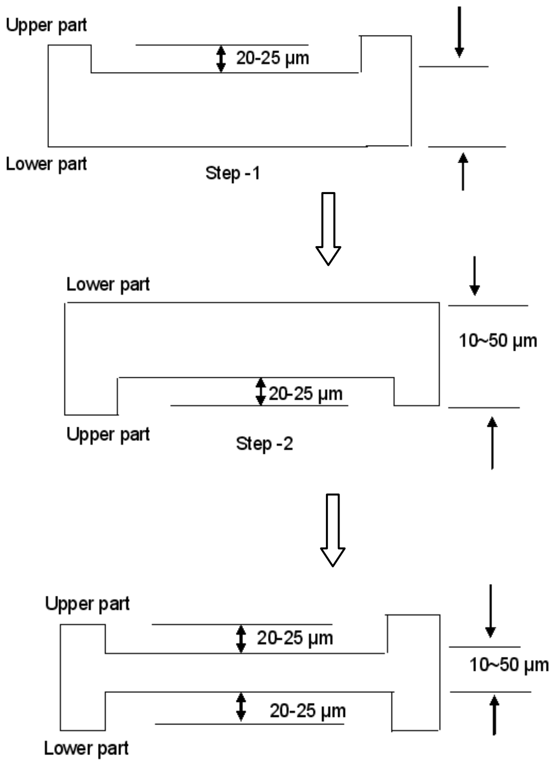

Fig.1. Fabrication processed of XFEL diamond optics by low energy oxygen ion beam.

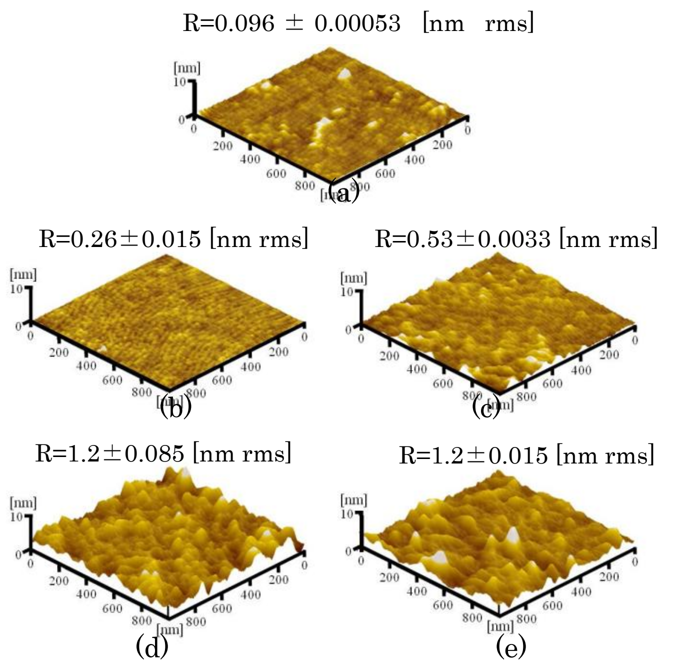

Fig.3. AFM images of unprocessed and processed diamond substrate at different angles of ion incidence

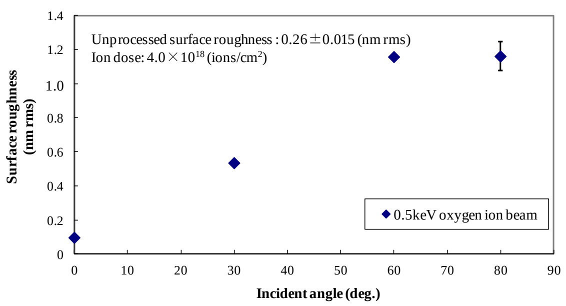

Fig.2. Dependence of surface roughness of the diamond chips with ion incident angle at ion dose of 4.0×10^{18} ions/cm^2.

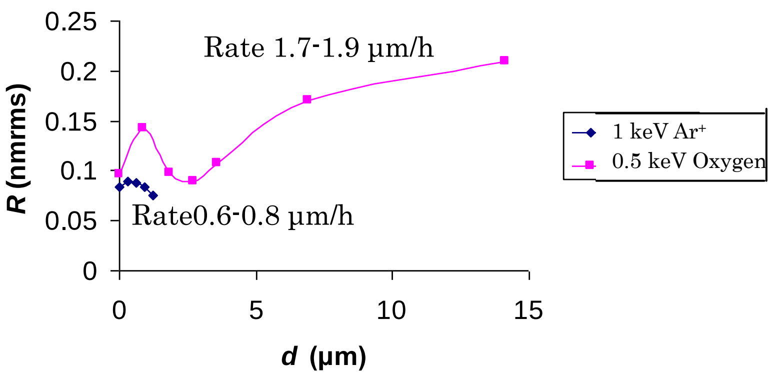

Fig.4. Dependence of surface roughness of the diamond chips on machined depth.