Influence of High Power Ion Beam on Alumina Ceramics

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Abstract – The effect of high power ion beam irradiation on alumina ceramics is experimentally investigated. Optical microscopy was used to analyse fracture morphology at volume irradiated sample. The influence of average ion current density and the number of pulses on the fracture of the alumina ceramics was studied. Results are discussed on basis of fracture mechanics principles and high power ion beam induced generation of stress wave and the quasi-static thermal stresses.

1. Introduction

Irradiation of metals and alloys by high power ion beam is a high efficient and promising method for their surface modification [1]. In the case of using nanosecond a high power ion beam the main factors responsible for the improvement in performance of materials are high-rate ($\sim 10^9$–10^{10} K/s) heating/cooling and temperature gradients ($\sim 10^9$ K/m) in the subsurface layers of the target material [2]. Such rates are high enough to promote formation of non-equilibrium microstructure like amorphous and metastable phases. In the case of high power ion beam irradiation the stress wave with amplitude $\sigma \leq 50$–60 MPa and the quasi-static thermal stresses which reach $\sigma_{qs} \leq 3$–5 GPa appears in target [3]. At present most of investigations about the modified of target materials after exposure to high power ion beam mainly focus on surface morphology and smoothing [4], crater behavior [5] and defects induced by HPIB [6]. High temperature gradients and stresses may lead to cracking subsurface layer brittle targets. However, investigations dealing with the effects of high power ion beam irradiation on cracking behaviour brittle materials (first of all inorganic dielectrics) have not all inorganic dielectrics) have not yet been fully undertaken.

In the present work surface morphology, surface and volume fracture of alumina ceramics at high power ion beam irradiation was studied.

2. Experimental

The target materials was alumina ceramics (α-Al_2O_3). Speciment were cut into 10×24×0.5 mm plates mechanically polished on the one hand. Irradiation was performed in technological accelerator "Temp" with one or three pulses of duration τ_b = 50 ns and average ion current density 50, 100, 150 A/cm^2. The reproducibility of ion current density from pulse to pulse is better than 20%. The beams consisted of carbon ions (70%) and proton (30%) and had elliptic cross section. Investigation of the surface relief, surface and volume fracture alumina ceramics irradiated high power ion beam were carried out by optical microscope "Neophot-2". Phase state of the unirradiated and irradiated samples were inspected by X-ray diffraction "Dron-3M" with Cu-K_α radiation.

3. Results and Discusion

Figure 1,a shows the surface morphology of the unirradiated sample alumina ceramics. As shown in Fig. 1,a on the surface were present defects that were brought about polishing. Fig. 1,b–c shows the surface morphology of samples irradiated high power ion beam with different average ion current density. Fig. 1 indicates that the observed fracture morphology depends on the average ion current density and the number of pulses. The surface morphology of irradiated

a b c

Fig. 1. Surface morphology of: the unirradiated samples (a) and the irradiated by: one pulse with average ion current density 150 (b), and three pulses with average ion current density 150 A/cm^2 (c) (x 750)

samples was characterized by presence of the fragments with different shapes and size. The samples had cracks as perpendicular so and parallel to irradiated surface. Some fragments were raised on the surface of the irradiated sample. In this case the interference picture were observed at reflected light. When the number of pulses is increased the fragment size decreases. The surface melting were not observed for one pulse irradiation with average ion current density up to 150 A/cm^2. Such morphology of fracture is typical for thermal shock fracture [7]. The surface layer is under compressive stresses during the heating stage followed by tensile stresses arising during the cooling stage. The surface peak temperature can be estimated by measuring the size of fragments bounded by cracks and the gap between them [8]. The relative temperature deformation is known to be equal to $\Delta b/b = \alpha(T_f - T_0)$, where α is the thermal expansion coefficient, T_f is the fracture temperature, at which a crack separating adjacent fragments originates, and T_0 is the initial sample temperature. The fracture temperature is then determined from the expression: $T_f = T_0 + \Delta b/b\alpha$. The gaps between fragments of alumina ceramics are often very small, particularly between small fragments so it is difficult to resolve them under an optical microscope. It lead to significant inaccuracy of the estimation. In our experiments the surface peak temperature was estimated as ~1700 K. The XRD investigation of the unirradiated and irradiated samples showed that the phase composition of alumina ceramics did not show a observable difference between the unirradiated and irradiated samples. A change of reflex intensity after high power ion beam irradiation was observed.

4. Conclusion

Thus the high power ion beam irradiation caused the surface and volume fracture alumina ceramics targets. In this case, the main factor responsible for fracture of alumina ceramics are the quasi-static thermal stresses. Optical analysis of fracture samples indicates that the morphology of fracture and crack density in alumina ceramics are substantially depended on average ion current density.

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