X-RAY ANALYSIS OF IPIB INSTABILITY AND IPIB IRRADIATION INFLUENCES ON TARGET SURFACE MICROSTRUCTURE

Xiaoyun Le, Xiang Yu, Shijian Zhang, Mofei Yu
School of Physics, Beijing University, Beijing, 100191, PR China

Scanning electron microscope (SEM) and atomic force microscope (AFM) are usually used to analyze the surface and cross-section morphology of ceramics under IPIB treatment. X-ray diffraction (XRD) is an efficient method for analysis of phase structure of ceramics after IPIB irradiation. A modified layer with thickness of around 1 μm would be created after IPIB irradiation. Cracks and craters are main defects produced by IPIB irradiation. The anisotropy of materials would impact the formation of defects. The cracks on single crystal silicon appear in quadrilateral shape. While the shape of cracks on ceramics which is polycrystal is irregular. 6-fold rotational symmetrical crater can be formed on single crystal silicon due to its anisotropy in thermal conductivity. The phase structure in near-surface region would be more heavily influenced comparing the results of XRD and GIXRD analysis which indicate that the main working region of IPIB focus on the near-surface region.

Keywords: IPIB; beam monitoring; material modification; cracks.

Introduction

In recent decades, the applications of IPIB encompass a wide range of fields, including but not limited to microelectronics, aerospace, biomedicine, and energy, primarily due to its remarkable flash heating effect. IPIB stands out with its unique characteristics, including short pulse duration of less than 1 μs, a limited range of influence within the micrometer scale, and an astonishingly high-power density of up to 10^{11} GW/m^2.

When IPIB interacts with the surface of a material, it deposits a concentrated amount of energy in a shallow layer. This leads to an exceptionally rapid surface heating at an astounding rate of up to 1011 K/s. Consequently, the surface layer undergoes swift melting within mere tens to hundreds of nanoseconds, followed by an equally rapid cooling process at a rate of approximately 109 K/s. These extraordinary properties make intense pulsed ion beam technology an immensely promising approach for surface modification purposes. The short pulse duration of IPIB ensures that the energy deposition occurs within an extremely brief timeframe. This characteristic enables precise control over the heating process, preventing excessive heat transfer to the bulk of the material. Consequently, the surface modification achieved through IPIB treatment remains localized, focusing on the desired surface area without affecting the structural integrity of the material's core. The high power density associated with intense pulsed ion beam enables efficient energy transfer to the material surface. This concentrated energy deposition induces rapid and intense heating, surpassing the limits of conventional thermal treatments. The resulting flash heating effect enables various surface modifications, such as phase transformations, crystal structure modifications, and the creation of unique microstructures with enhanced properties. Furthermore, the subsequent rapid cooling stage of the surface layer contributes to the formation of desirable material properties. The quick solidification process preserves the modified surface structure and reduces the occurrence of unwanted reactions or phase separations.

Results and discussion

The phase structure of Al_2O_3 ceramic before and after IPIB irradiation was detected by XRD and GIXRD technique, as shown in Fig. 1. Comparing the XRD and GIXRD pattern, no new peak appears in XRD pattern while an obvious new peak can be detected at around 46° which means that phase transformation occurred in near-surface region after IPIB irradiation. According to the powder diffraction file for γ-Al_2O_3 (PDF #75-0921), the response intensity of (200) (45.911°) is comparable to that of (220) (66.949°) which was in good agreement with the new peak. It means that phase transformation from α-Al_2O_3 to γ-Al_2O_3 was induced by IPIB irradiation. The high cooling speeding and thermal stress caused by IPIB might be the reason for phase transformation [1-3].

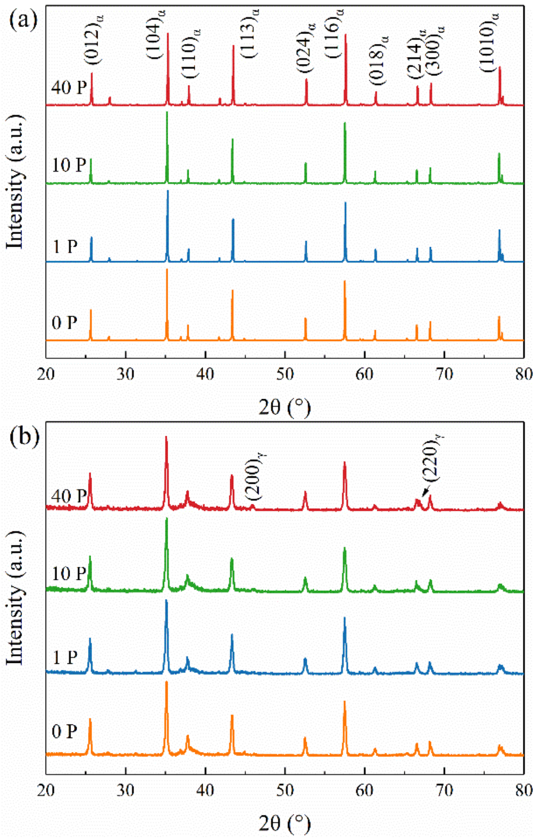

Fig. 1 XRD and GIXRD pattern for ceramic before (a) and after (b) IPIB irradiation

The influence of IPIB irradiation with current density of 80 A/cm^2 on surface morphology of alumina ceramic was investigated using SEM method. Micro veruucate structure and holes can be observed on the surface of the original sample (Fig. 2a).

The most obvious change occurred on the surface of Al_2O_3 ceramic after IPIB irradiation is the appearance of micro-holes (Fig. 2b-d). The edge of micro-holes turns out to be rounder when more pulses of IPIB were performed. The surface tension during melting stage of IPIB irradiation forces the edges of micro-holes rounder and smoother. Some new micro-holes could be produced inside existed ones when more pulses of IPIB

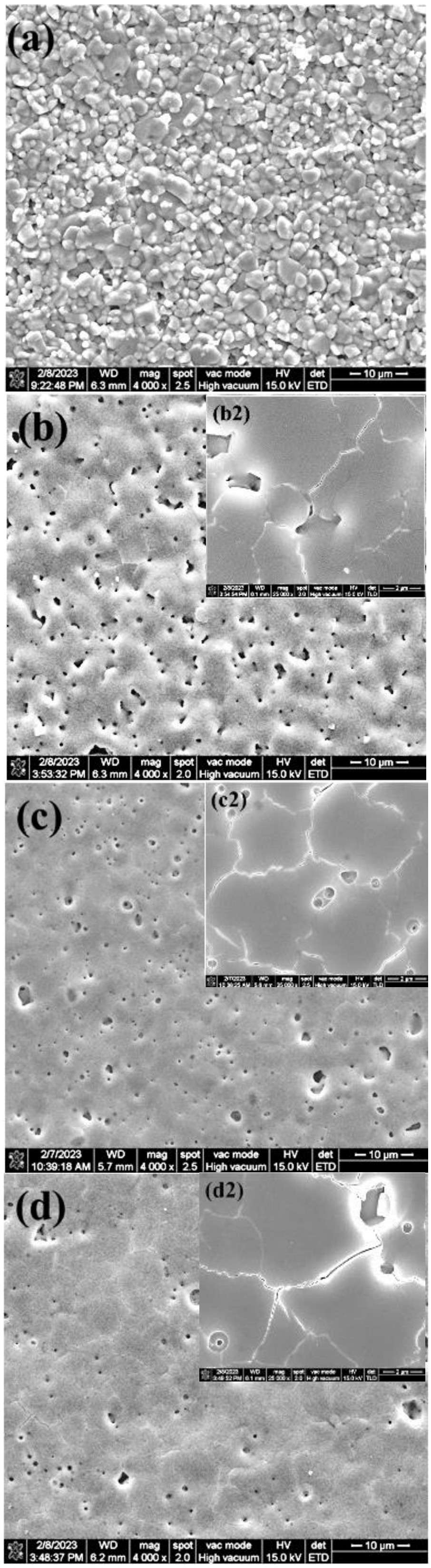

Fig. 2. SEM images of Al2O3 ceramic. (a) without IPIB irradiation, (b) after 1 pulse IPIB irradiation, (c) after 10 pulses IPIB irradiation, (d) after 40 pulses IPIB irradiation. The insert pictures in b-c are higher magnification. The IPIB current density is 80 A/cm^2

were carried out (Fig. 2(c2), 2(d2)). The number of micro-holes decreases with more pulses' irradiation which might increase the properties of ceramic due to less defects. Cracks were also produced by IPIB irradiation according to SEM images with higher magnification (Fig. 2(b2-d2)). The sharp decrease of surface temperature would result in shrinkage and give rise to a rapid stress load which exceeds the elastic deformation limitation of material and the crack is initiated to release the stress energy [4, 5]. Additionally, the local high thermal stress caused by the defects, like grain boundaries and holes, might be another reason of the appearance of crack.

Conclusion

The phase structure and surface morphology of Al_2O_3 ceramic under IPIB irradiation were investigated in this work. γ-Al_2O_3 was formed from α-Al_2O_3 directly because of the rapid re-solidification and thermal stress caused by IPIB irradiation. The component of γ-Al_2O_3 increased with the increase of pulse number of IPIB irradiation. The micro verrucate structure disappeared due to the surface tension during liquid stage of ceramic under IPIB irradiation. Meanwhile, micro-holes and cracks appeared on the surface of samples after IPIB irradiation. The edge of micro-holes turned out to be rounder and the quantity of micro-holes decreased with more pulses' irradiation.

References

1. Le X.Y., Zhao W.J., Yan S., Han B.X. Numerical analysis of thermodynamical process in the thin metal samples irradiated by IPIB. *Curr. Appl. Phys.* 2001; (1): 219-223. https://doi.org/10.1016/ S1567-1739(01)00022-0.
2. Le X.Y., Zhao W.J., Yan S., Han B.X., Xiang W. The thermodynamical process in metal surface due to the irradiation of intense pulsed ion beam. *Surf. Coatings Technol.* 2002; 158-159: 14-20. https://doi.org/10.1016/S0257-8972(02)00199-8.
3. Cao S., Pedraza A.J., Lowndes D.H., Allard L.F. γ-Al_2O_3 formation from pulsed-laser irradiated sapphire. *Appl. Phys. Lett.* 1994; 65: 2940-2942. https://doi.org/10.1063/1.112960.
4. Shen J., Shahid I., Yu X., Zhang J., Zhong H.W., Yu X., Huang W.Y., Liang G.Y., Cui X.J., Yan S., Zhang X.F., Le X.Y. Surface exfoliation analysis on single-crystal silicon under compressed plasma flow action. *Laser Part. Beams*. 2018; 36: 129-135. https://doi.org/10.1017/S026303461800006X.
5. Shen J., Shahid I., Yu X., Zhang J., Zhong H., Cui X., Liang G., Yu X., Huang W., Yan S., Zhang G., Zhang X., Le X. Fracture analysis of surface exfoliation on single crystal silicon irradiated by intense pulsed ion beam. *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms.* 2017; 413: 6-12. https://doi.org/10.1016/j.nimb.2017. 09.031.