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Surface modification by 10^{-2} to 10^{2} TPa impact pressure using ultra-intense Laser
高強度レーザーを用いた10^{-2}から10^{2} TPa衝撃圧力による表面改質

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We started research to aiming at the surface modification by ultra-intense laser. We gave the laser driven shock compression pressure of 10^{-2} to 10^{2} TPa by counter-irradiation using the ultra-intense LD-pump laser to the single crystal Yttria-Stabilized Zirconia. We found that at 10^{2} TPa the irradiated area is changed from the single crystal to the polycrystalline. 2-dimensional simulation code STAR2D including a radiation transport well explained the resulting surface modification. In addition, the X-ray diffraction peaks of irradiation sample have shifted at several lattice planes. These peak shifts suggested the residual stress, which was dependent on laser energy.

1. Introduction

We describe the laser driven shock compression aimed at the surface modification of ceramics by using an ultra-intense laser. Specifically, adjusting the ultra-intense laser with the pulse width of 15 ns, 300 ps and 110 fs were counter-irradiation to the single crystal yttria-stabilized zirconia (YSZ) in 10 mm × 10 mm × 0.5 mm-thickness. The impact pressure on the single crystal YSZ calculated with those pulse-width and energy that obtained by using of the formula shown in Prof. S. Atzeni et al. [1,2], and which are 78 GPa, 722 GPa and 114.9 TPa.

The irradiated YSZ surface and inside was observed by using a microscope, scanning electron microscope (SEM) and scanning transmission electron microscope (STEM). Also the observation of the crystal structure analysis performed with the X-ray diffraction (XRD) by using the synchrotron radiation X-ray source.

2. Experimental procedure

We used the laser system HAMA [3] for the experiment. A seed is a titanium:sapphire laser BEAT [4]. Output beam of BEAT is pumped by the second harmonics of a KURE-1 [5] (with 4.4 J in energy, a wavelength of 1053 nm a width of 15ns). Output beam of a HAMA is divided into two beams. One is a picosecond laser of “ps-Beam” (1.14 J, 820 nm, 300 ps). Another is a femtosecond laser “fs-Beam” (0.84 J, 820 nm, 110 fs) which is pulse compressed of a ps-Beam. Moreover, a KURE-1 fundamental wave "ns-beam" (2.6J, 1053 nm, 15 ns) is also used which remains by amplification of

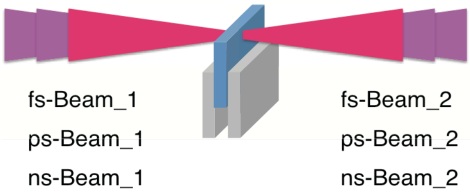

Fig. 1. Irradiation layout on the YSZ

HAMA. Each beam is divided into two-direction and irradiated on YSZ with counter-irradiation as shown in Fig.1.

For the estimation of counter-irradiated YSZ surface and internal structure, we observed using a microscope, a SEM and a STEM. For the crystal analysis, we observed an X-ray diffraction by using a beam line (BL5S2) of the Aichi Synchrotron Radiation Center. Irradiation angle to the YSZ was 10.000 ± 0.004 deg. In a grazing incidence, beam size was 0.6 × 0.5 mm, energy was 12.4 keV, irradiation time was 10 minute, and the skin depth of the X-ray at this time was 10.1 μm.

3. Results and discussions

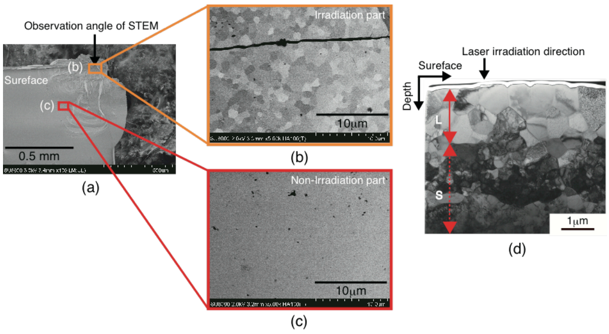

Fig. 2. (a) SEM image on the OAP1 side of irradiated with fs-Beam. (b) Enlarged view of reflection electron image at irradiation area with fs-Beam of (a). (c) Enlarged view of reflection electron image at non-irradiation area of (a). (d) Cross-sectional of irradiated part with fs-Beam observed by STEM: L is large crystal grain layer. S is small crystal grain layer

The striped pattern appeared on the sample near the laser irradiation area by laser irradiation. This pattern size was dependent on laser pulse-width. We focused on the irradiated sample with highest energy with fs-Beam, which surface and inside observed. As shown in Fig. 2, in the laser irradiation area of (b) is observed a grain boundary, but the non-irradiation part of (c) isn't observed it. Cross-sectional image of irradiation part of (d) observed grain boundary, and polycrystalline is seen to double layered. We can explain the double layered polycrystalline structure if we assume that, initially the ultra-intense laser irradiation formed the small crystal grains in the S Layer, and then a laser-induced thermal wave roasted the surface, which melted and condensed surface crystal grains to sizes as large as those found in the L layer. We also assume that the striped pattern was formed by the heat emitted by the generated plasma. We also performed the 2 dimensional simulation STAR2D [6] including the radiation transport. The simulation result suggests that the generated high-density plasma was spreading in the laser incidence direction with time. Then, it spreads along the sample surface up to radius limited. The simulation results well explains this phenomenon.

We next performed the XRD analyisis shown in Fig. 3. As against a non-irradiation YSZ, a ns-Beam is shifted to the low diffraction angle side. A fs-Beam is shifted to the high diffraction angle side. However ps-Beam isn't shifted. These peak shift suggests that the residual stress is remaining on the surface of YSZ.

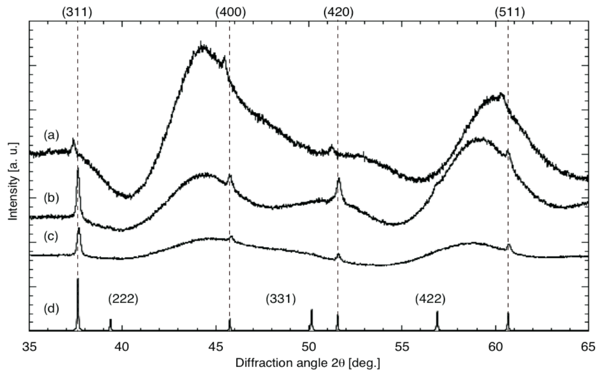

Fig. 3. The X-ray diffraction one-dimensional profile from the YSZ. (a) Irradiated with ns-Beam. (b) Irradiated with ps-Beam. (c) Irradiated with fs-Beam. (d) Non-irradiated YSZ.

4. Conclusions

We aimed for the material modification, and gave the compression pressure of 10^{-2} to 10^{2} TPa by counter-irradiation using the ultra-intense LD-pump laser to YSZ. From observation results of surface and internal structure analysis, we found that the YSZ is changed to polycrystalline by fs-Beam. And the 2-dimensional simulation results were useful to explain the resulting surface modification. The XRD observation result suggested the residual stress remained on the YSZ, which is depending on the laser pulse width.

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