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Crack formations inside a LiF single crystal by focusing a femtosecond laser pulse with controlled astigmatism

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1. Introduction

After the photoexcitation inside a LiF single crystal by a focused femtosecond (fs) laser pulse, cracks are generated from the photoexcited regions [1]. Because the cleavage plane and direction in a LiF crystal are (100) and <100>, respectively, four cracks are generated in the four <100> directions when a fs laser pulse is incident normal to the (100) plane of the crystal. To apply fs laser induced crack formation to scribing of the crystal, unnecessary cracks must be suppressed, and formation of cracks only in a single direction is desirable. One possible method to suppress unnecessary cracks is to modulate the intensity distribution of fs laser pulse at the focus, because the distribution of thermal stress depends on the distribution of photoexcited volume. The simplest method to modulate the intensity distribution of laser beam at the focus is to make a line-shaped intensity distribution at the focus by inducing astigmatism in the beam. A line-shaped intensity distribution could generate larger stress in the specific regions and induce crack formation in the specific direction. In this study, we investigated the possibility that the fs laser induced crack formation inside a LiF single crystal could be controlled by a fs laser pulse with controlled astigmatism.

2. Method

Arbitrary astigmatism was induced by adding a cylindrical Fresnel lens phase pattern to a fs laser pulse (pulse width of 100 fs, wavelength of 800 nm, and pulse energy of several μJ) by a spatial light modulator (LCOS-SLM; Hamamatsu K. K.) [2]. The fs laser pulse with astigmatism was focused inside a LiF single crystal with an objective lens (50X, N.A.=0.9). To observe the transient stress distribution after fs laser irradiation, birefringence distribution was observed by a pump-probe polariscope [3].

3. Conclusions

Figures (a) and (b) are the simulated intensity distributions of laser beam with astigmatism at the focus. The cracks generated after focusing fs laser pulses of these intensity distributions are shown in Figs. (c) and (d). When the intensity distribution extended in the [100] direction [Fig. (a)], the cracks in the [100] and [-100] directions became longer. On the other hand, in the case of the 45° tilted intensity distribution [Fig. (b)], cracks were generated from the edge of the photoexcited regions [Fig. (d)]. The observed transient birefringence distributions at 3 ns after the photoexcitation are shown in Figs. (e) and (f). In Fig. (e), the stress distributions around the crack tips were observed in all the <100> directions from the photoexcited region. On the other hand, the stress distributions were modulated drastically in the case of the 45° tilted intensity distributions [Fig. (e)]. The transient birefringence distribution suggests that the transient distribution and crack formation can be modulated by modulating light intensity distribution at the focus. However, the crack propagation always occurs parallel to the <100> direction and the origin of the crack is located at the region where transient stress had been largest. Therefore, the intensity distribution should be elongated in the <100> direction to select the crack propagation direction.

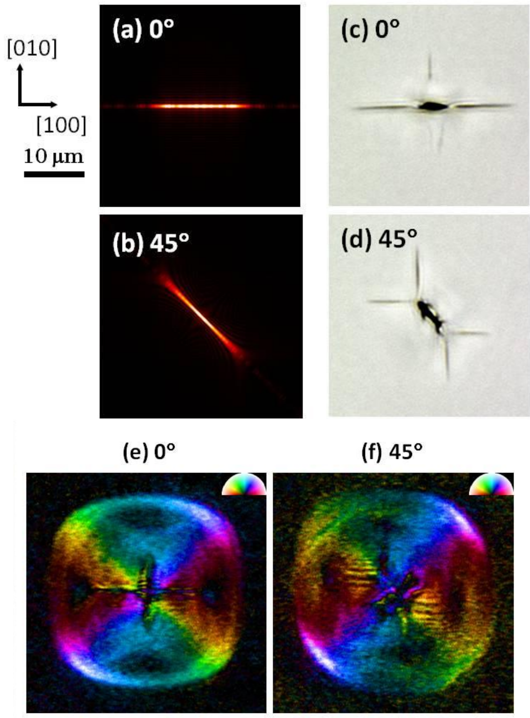

Figure (a), (b) Intensity distributions at the focus of laser beam with astigmatism. (c), (d) Cracks generated inside a LiF single crystal after focusing a fs laser pulse of (a) and (b), respectively. (e), (f) Observed birefrigence distributions at 3 ns after photoexcitation by a fs laser pulse of intenisty distribution of (a) and (b), respectively.

References
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