Preliminary study of the damage resistance of type I doubler KDP crystals at 532 nm

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This Letter is concerned with the influence of polarization on the damage performance of type I doubler potassium dihydrogen phosphate crystals grown by the conventional growth method under 532 nm pulse irradiation. Pinpoint density (ppd) and the size distribution of pinpoints are extracted through light scattering pictures captured by microscope. The results show that the ppd of polarization that parallels the extraordinary axis is around 1.5× less than that of polarization that parallels the ordinary axis under the same fluence, although polarization has no influence on size distribution of pinpoints. We also find that the size distribution is independent of fluence, although the number of pinpoints grows with fluence.

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At present, KH_2PO_4 (potassium dihydrogen phosphate, also known as KDP) and its deuterated analog DKDP crystals are the only nonlinear materials suitable for frequency conversion in high-power large-aperture laser systems, due to their fast growth rate and the large size that they can be grown[1]. However, these crystals suffer bulk damage rather than surface damage, and the bulk damage threshold is significantly lower than the intrinsic threshold[2]. The detriments of bulk damage that is composed of pinpoints can be described in terms of enhanced beam contrast[3] and beam obscuration[4]. It is widely accepted that precursors in KDP/DKDP crystals are responsible for damage initiation during laser irradiation, and precursor that limit the lifetime of these crystals may be constituted of metallic impurities, such as Fe, Ba[5], derived from the growth environment[6], but the nature of the precursors is yet unknown. In recent years, laser-induced damage characteristics in bulk KDP crystals is a popular subject of research. The influence of beam parameters, such as wavelength[7–9], pulse width[10–12], pulse shape[13,14], etc., on damage performance was investigated. However, only a few researchers studied the influence of polarization on bulk damage when irradiating the crystals with nanosecond laser pulses[15–17]. When the laser beam polarization is along different orientations, the literature data becomes ambiguous. For example, Barkauskas *et al.*[12] revealed that the damage threshold for 532 nm pulses had a strong dependence on laser polarization. However, Yoshida *et al.*[15] obtained the opposite conclusion.

The objective of this Letter is to investigate the influence of polarization on the damage resistance of KDP crystals. By measuring the density of pinpoints resulting from 532 nm pulses, the differences in the dependence of damage resistance on polarization orientation were obtained. Meanwhile, the size distribution of pinpoints was also investigated. The results indicated that the pinpoint density (ppd) is polarization dependent, while the pinpoint size (pps) distribution is independent of polarization.

The damage test laser pulse train is directed from an Nd:YAG laser that has an approximate output energy at 532 nm of 1.4 J. The laser pulse has a Gaussian temporal profile with a pulse width of 6.5 ns (FWHM). As seen in Fig. 1, the polarization orientation of the laser pulse is adjusted by a half-wave plate after polarized by a Glan prism. The beam is focused by a cylindrical lens to the bulk of a KDP crystal. The samples used for the experiments were conventional growth KDP oriented for type I doubling at 1064 nm, and these samples were cut to 10 cm × 10 cm × 1 cm in size plates and polished on all sides. Images of the bulk damaged region were captured orthogonally to the direction of propagation of the lasers, through the side of the sample using a microscope with a resolution of ~10 μm. Bulk damage was detected online using a probe light that was counter collinear with the damage beam. Figure 2, captured by the microscope depicted in Fig. 1, is resulting from a single-shot 532 nm, 6.5 ns laser pulse with a fluence of around 7.76 J/cm^2.

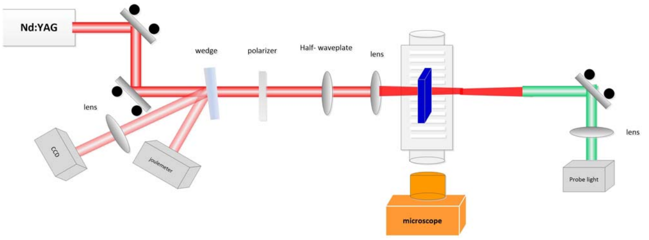

Fig. 1. Schematic diagram of the experimental bench used for the characterization of the bulk damage of KDP crystals.

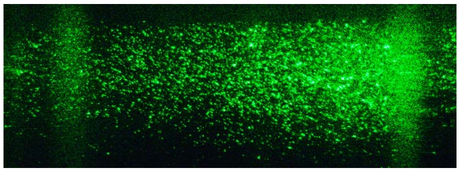

Fig. 2. Scatter image of the bulk damage sites resulting from a single-shot 532 nm, 6.5 ns laser pulse with fluence of around 7.76 J/cm^2.

The relationship between the ppd and fluence was extracted from a picture using the following method. First, the energy and the focused beam spatial distribution were captured in order to obtained fluence. Second, after the background was subtracted, the number of pinpoints was counted from the picture captured by the microscope, using appropriate software. The ppd of the damage region was calculated by the ratio of the number of pinpoints with respect to the volume of the damage region (the product of damage region's cross section containing the pinpoints times the depth through which the damage pinpoints extend).

Single-shot laser pulse tests were performed on the sample, and the results are shown in Fig. 3. As seen in Fig. 3, under the same fluence, the ppd of polarization that parallels the extraordinary axis is definitely less than that of the polarization that parallels the ordinary axis, and the difference is about 1.5 times. Therefore, we can conclude that there is a strong dependence of damage resistance on laser polarization orientation. To account for this observed damage resistance dependence, an absorption model based on a non-spherical absorber is proposed[17,18]. The precursor within the bulk of KDP crystals may be nonspherical and orientated to a special direction, leading to enhanced light absorption in that direction. Therefore, this may be the explanation for the dependence of damage resistance on beam polarization orientation.

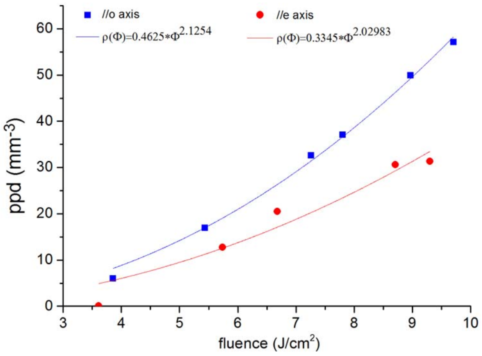

Fig. 3. Ppd versus fluence for doubler KDP crystals under 532 nm pulse irradiation with different polarizations.

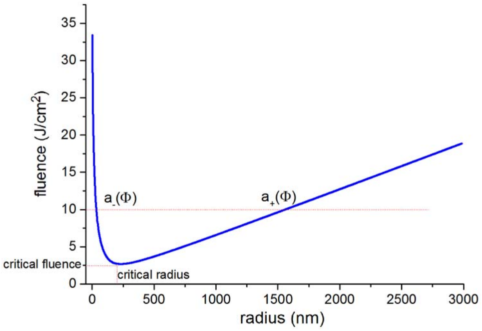

Fig. 4. Relationship between laser-induced damage threshold and the radius of the precursor calculated from the nano absorber model[8,19].

For evaluation of the dependence of ppd on fluence for a doubler KDP crystal, the nanoabsorber model[8,19] was revisited. It is believed in this model that the precursors induce the damage initiation under laser irradiation. As shown in Fig. 4, for a given fluence above the critical fluence, the precursors whose radius is between $a_-(\Phi)$ and $a_+(\Phi)$ may be activated by a laser pulse. $a_-(\Phi)$ and $a_+(\Phi)$ whose values are both determined by fluence limit the range of the absorber activated by a 6.5 ns pulse irradiation. Here the typical values of $a_-(\Phi)$ and $a_+(\Phi)$ are ~50 and ~1500 nm under 532 nm pulse irradiation with fluence 10 J/cm^2, respectively. So the relationship between ppd and fluence can be expressed as

$$\rho(\Phi) = \int_{a_-(\Phi)}^{a_+(\Phi)} n(a)\mathrm{d}a, \tag{1}$$

where $\rho(\Phi)$ is the ppd under irradiation by a 532 nm pulse with fluence of Φ, a is the radius of precursors, and the $n(a)$ is the size distribution of precursors and is strongly dependent on radius, and having the form

$$n(a) = C/a^{p+1}, \tag{2}$$

where c and p are parameters. So

$$\rho(\Phi) \propto \Phi^p \tag{3}$$

can be obtained. According to Eq. (3), the relationship between ppd and fluence can be obtained. Next, as shown in Fig. 3, each $\rho(\Phi)$ data set is a least squares fit to this equation, and the value of p was found to be 2.0, which was found to be the same within 5% for two different polarization orientations. So we can draw the conclusion that the relationship between the ppd and fluence is polarization dependent. This value contrasts with previously reported results for 3ω pulse irradiation, where the value of p is approximately 3[20]. This difference suggests that the ppd initiated by 2ω light is much less sensitive to fluence than in the case for 3ω light. For shorter wavelengths, the absorption efficiency factor of the precursors in bulk KDP crystals is obviously higher due to higher photon energy, which leads to more precursors participating in bulk damage initiation. So the value of p in the case of 532 nm pulse irradiation is smaller than that in the case of 355 nm.

One of the detriments of bulk damage that consists of pinpoints is of enhanced beam contrast, which is the result

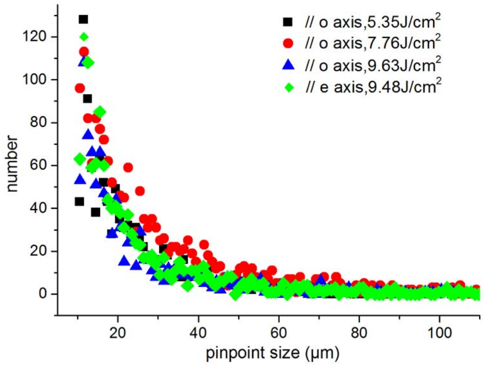

Fig. 5. Size distribution of pinpoints induced by a 532 nm, 6.5 ns pulse with different fluences and polarization orientations.

of both ppd and pps. So pps is another concern of KDP bulk damage[11,18,21]. In this Letter, the pps distribution was extracted from the picture captured by microscope, and the result is shown in Fig. 5. The pps distribution below 10 μm is absent due to the resolution limit. As seen in Fig. 5, the pps distribution induced by the 532 nm pulse is almost same, except that the number under 7.76 J/cm^2 seems to be a little more than that in the other three cases, maybe due to crystal inhomogeneity[22]. So we can conclude that the pps distribution is both fluence and polarization independent, although ppd is both fluence and polarization dependent. For nanosecond laser pulse-induced bulk damage in a KDP/DKDP crystal, the damage process can be roughly depicted by seven stages[23]. The pps and its distribution are determined by both pressure and shock waves (the last two stages of damage processes), and the polarization and fluence play key roles in the damage initiation (the second stage of damage processes).

In conclusion, damage characteristics of the influence of polarization orientation on the damage performance of a doubler KDP grown by the conventional growth method are observed; polarization has an influence on ppd, while it has no influence on pps distribution. The former results are consistent with the result of Ref. [17].

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