

Experimental investigation of the athermal orientation in Yb:KGW

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Abstract: A comparative, experimental study between b-cut Yb:KGW and Yb:KGW cut along a proposed athermal direction is presented. The athermal direction gives a significantly weaker thermal lens, lower astigmatism and higher beam quality under lasing conditions.

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1. Introduction

During the last years, a lot of research has been committed to Yb³⁺-doped double tungstate crystals like KGd(WO₄)₂ (KGW) and KY(WO₄)₂ (KYW). The reason for this attention is the crystals' numerous advantages as diode-pumped laser materials. One major advantage is the extremely low quantum defect that, together with the absence of upconversion and excited state absorption, gives high slope efficiencies [1]. Another important advantage is the broad emission band that enables both a significant tuning range [2] and mode-locked femtosecond pulses [3,4].

The structure of the double tungstate crystals is anisotropic and the three orthogonal crystalloptical axes: N_m , N_p and N_g all show different optical parameters such as refractive index, dn/dT and absorption/emission spectra. Also the axes of thermal expansion: X_1' , X_2' and X_3' are anisotropic [5]. Hence, the orientation of the laser crystals is a major issue of optimization in these systems. Though there are exceptions such as in Ref. 4, many of the Yb:KGW crystals in laser systems have been cut for propagation along the **b** crystallographic direction (b-cut), which is parallel with N_p . This is due to the high absorption and emission cross sections of light polarized along N_m . Recently, Biswal et al. [6,7] proposed an athermal propagation direction where the refractive index change and thermal expansion approximately cancel. Based on calculations and thermo-optic measurements of homogeneously heated Yb:KGW samples they proposed a propagation direction 15°-17° clockwise from N_m for the pump and laser radiation polarized parallel to N_p .

The exact athermal direction for the laser operation is difficult to establish due to strongly inhomogeneous heating of the laser medium by a laser diode in the end-pumped configuration. Moreover, KGW is characterized by strong asymmetries in pump absorption cross-sections, thermal expansion and thermo-optic coefficients. In this work we compare laser performance, thermal lensing and mode quality in b-cut and athermally-cut Yb:KGW laser crystals using high-power laser diode end-pumping.

2. Experimental results and discussion

Two 5 at.% doped Yb:KGW crystals were used in the experiments and cut in $3 \times 3 \times 3$ mm³ cubes with AR-coated end faces in the respective propagation directions. The first (b-cut) crystal was cut with the crystallographic direction **b** as the propagation direction. The second (athermally cut) crystal was cut with the propagation direction in an angle of 17° clockwise from the crystalloptic direction N_m as in Fig. 1.

The pump laser used was a diode laser from LIMO GmbH, which produced a maximum output power of 23.4 W at 978 nm providing 95% linearly polarized output. The laser output was focused to a spot of 200×150 μm ($1/e^2$) in the laser crystal. The input coupler was a plane mirror coated for HR @ 1020–1200 nm and AR @ 810–980 nm. The pump optics transmitted a maximum power of 19.3 W into the crystal that was placed in a water-cooled heat sink.

The b-cut crystal was pumped with the pump polarized along the crystalloptic direction N_m , which has the highest absorption cross-section. At the maximum pump power, the absorbed power was 18.1 W (94% absorption). The athermally cut crystal was pumped with the light polarized along N_p , which gave a maximum absorbed power of 10.4 W (55% absorption).

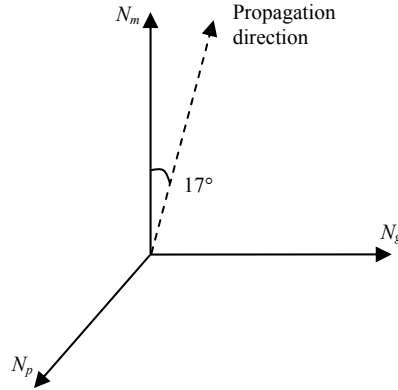


Fig. 1. The direction of propagation in the athermally cut crystal.

The highest output powers were achieved with the shortest radius of curvature (roc) of the output couplers that were available: 50 mm. The laser experiments were performed with a 17 mm long cavity.

The output power versus absorbed pump power for different output-coupler reflectivities is depicted in Fig. 2. The threshold was about the same in both crystals. In both cases the laser polarization coincided with that of the pump. Close to the threshold the lasers exhibit superlinear output power dependence, characteristic for quasi-three level systems with substantial reabsorption. The superlinearity and the higher slope efficiency in the b-cut crystal was stronger and can be attributed to improving laser mode overlap with the pump beam due to the influence of a substantially stronger thermal lens. Indeed the M^2 measurements of the laser mode revealed that at the maximum absorbed power the athermally-cut crystal showed rather stigmatic beam with $M^2=1.5$, while the b-cut crystal generated astigmatic beam with $M_x^2 \times M_y^2=4.5 \times 3.5$.

CCD-camera pictures of the far-field mode profiles for the two laser crystals is shown in Fig.3, where the measurement was performed for the same absorbed pump power of 10W. The most pronounced astigmatism develops in the laser containing b-cut crystal as should be expected. In the case of b-cut Yb:KGW, the ellipse was twisted about 32° from the crystalloptic axes. For the athermally-cut crystal the ellipticity is much less pronounced and is primarily a result of the astigmatism in the pump beam. The pump beam is wider and has a top-hat intensity distribution in the direction which is vertical in Fig.3, giving a weaker thermal lens along this direction. In the other direction, the horizontal in Fig. 3, the pump beam is narrower and has a Gaussian intensity distribution, which would contribute stronger to the thermal lens. The long axis of the laser far-field beam ellipse corresponds to the thermal expansion axis of the crystal that is closest to the horizontal direction in Fig.3. In the athermally cut crystal it is the thermal expansion axis X_2' which is parallel with N_p and horizontal in Fig. 3. In the case of b-cut crystal, it is the X_1' axis positioned at an angle of 31° from N_m . For the b-cut crystal, N_m is oriented horizontally in Fig. 3. This explains the observed twist of the ellipse. At least in the b-cut crystal, thermal bulging should be the dominant effect over dn/dT since the thermal expansion coefficient is larger.

The thermal lens was measured directly by use of a probe beam at 532 nm with the same polarization as the laser emission. The probe beam passed through a lens system that gave a $150 \mu\text{m}$ beam radius inside the crystal in order to overlap the pump focus. The laser was operated using a $\text{ROC}=50 \text{ mm}$, $R = 95\%$ output coupler. The measurements revealed that both crystals gave thermal lenses, which was most astigmatic for the b-cut crystal, as expected. In the strong thermal lens direction the radius of the probe beam was reduced, while in the weak direction it was not affected enough for a reliable measurement. In the athermally cut crystal, the strong thermal lens direction was parallel to N_p , which is also parallel to the thermal expansion direction X_2' . In the b-cut crystal, the strong thermal lens direction was oriented at an angle of 32° from N_m , and should coincide with the thermal expansion axis X_1' . The results of the thermal lens measurements are summarized in Fig. 4. It is evident that the thermal lens of the athermally cut crystal is significantly weaker for the same pump powers which makes this particular configuration promising for high power end-pumped lasers.

3. Conclusions

The novel propagation direction of Yb:KGW proposed by Biswal et al. following thermo-optic studies has been tested under lasing conditions. The tests confirmed that the thermal lens is lower than in conventional b-cut Yb:KGW. Under the specific pumping circumstances used here and 10 W of absorbed power, the optical power of

the thermal lens is approximately two times lower for the athermally cut crystal. Moreover, the laser beam for the athermal cut is characterized by much lower astigmatism which eventually results in better output beam quality.

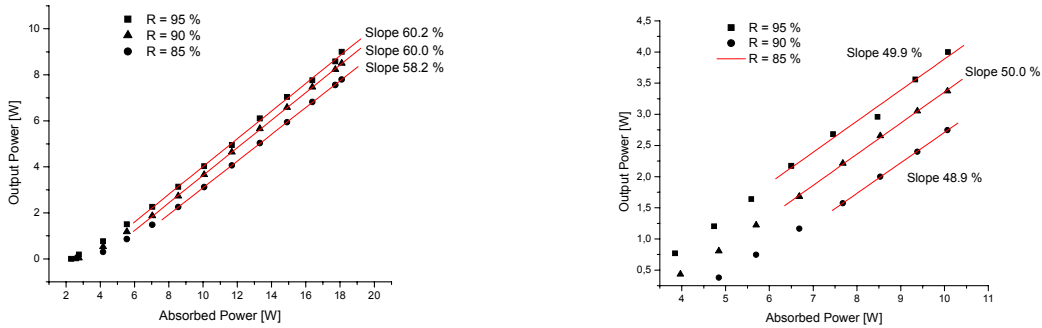


Fig. 2. Output power vs. absorbed power for the b-cut crystal (left) and the athermally cut crystal (right) for different out-coupling reflectivity.

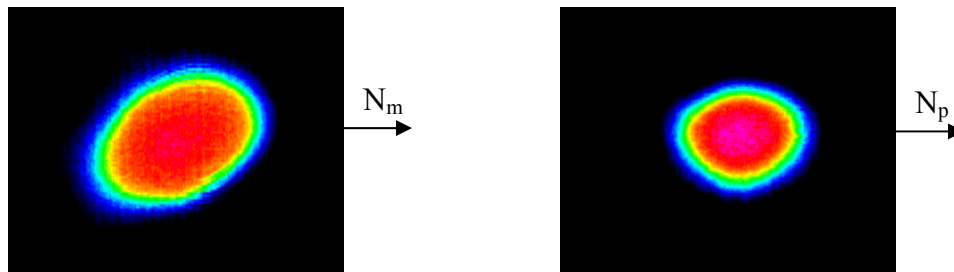


Fig. 3. Record of the far-field of the beam at 10.1 W of absorbed power for b-cut crystal (left) and athermally cut crystal (right).

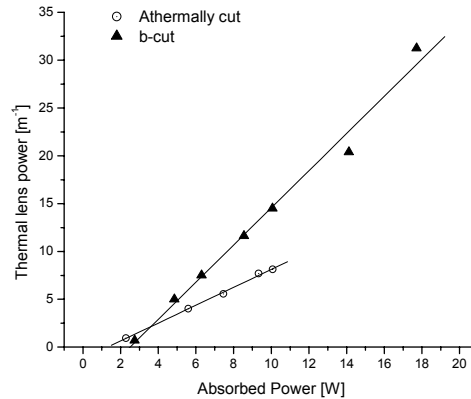


Fig. 4. Thermal lens power vs. absorbed power for the two crystals.

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