Evaluation of Transverse Raman Scattering in KDP and DKDP in Geometries Suitable for Beam Polarization Control

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KDP and DKDP are particularly suitable materials for polarization control due to their ability to grow in large sizes and their inherent birefringence. However, their performance in large-aperture, high-fluence systems at 351 nm is hindered by the generation of transverse stimulated Raman scattering (TSRS)[1,2] seeded by the strong symmetric A_1 Raman mode. This process transfers energy to parasitic transverse beams and thereby limits the maximum power output in order to avoid damage to the optic and its mount. The intensity of the TSRS signal is governed by the propagation length (optic size) L; the laser intensity I_{pump}; and the Raman-gain coefficient g, where the latter is directly proportional to the spontaneous Raman-scattering cross section, $d\sigma/d\Omega$:

$$I_{\text{TSRS}} \sim \exp\left(gI_{\text{pump}}L\right), \text{ where } g = \left(8\pi cM \big/ \hbar\omega_{\text{s}}^3 n^2 \Delta\bar{\nu}\right)\cdot\left(\text{d}\sigma \big/ \text{d}\Omega\right).$$

The strength of the Raman-scattering cross section in a given orientation is related to the mode's Raman polarizability tensor which was only recently ascertained with high accuracy (due to the presence of numerous measurement artifacts mainly arising from depolarization of the pump beam and Raman signal during propagation in these birefringent materials) for both KDP and 70% DKDP.[3]

The goal of this work is to develop a modeling capability to evaluate the TSRS risk and its directional dependence in geometries relevant to polarization control. This ability, in turn, will enable optimization of the design (such as the crystal-cut orientation) of KDP or DKDP polarization control optics and guide the design of future laser systems. To support this modeling effort, a detailed experimental study of the transverse Raman scattering was conducted to validate the model accuracy. Experiments were performed using a novel setup detailed in Ref. 4 that utilized spherical samples to enable accurate measurements at relevant excitation geometries. A complete set of data was acquired by varying three parameters: (1) the angular position θ of the optic axis (OA) with respect to the vertical pump beam between 0° and 90°, (2) the angular alignment α of the pump-laser polarization relative to the vertical plane containing the OA, and (3) the transmission axis of the signal analyzer (parallel and orthogonal with respect to the beam-propagation direction). The data shown in Fig. 1 were obtained for an excitation and signal collection geometry suitable for polarization control (angle between OA projection on transverse plane and laser polarization $\alpha = 45°$). The signal intensity is normalized to the signal corresponding to the orientation that produces the maximum spontaneous Raman-scattering cross section in each material. The signal detected using the parallel analyzer arises mainly from polarization artifacts, which also cause the complex peak and valley features detected when using the orthogonal analyzer. As Fig. 1(c) demonstrates, the model is capable of reproducing the experimental results fairly accurately when considering the experimental conditions (a 32-mm-diam sphere, an ~0.5° incident half-angle, and a 5.7° collection half-angle).

The ray-tracing model tracks the spontaneous Raman emission using geometrical optics. Rays are generated from each point source (with initial intensity determined according to the relevant tensor products) and propagate in all directions as either ordinary (o) or extraordinary (e) components acquiring different phases. In the cross-section simulations, the source volume contains a large number of such source points and the collected Raman o and e photons are considered mutually incoherent. The corresponding experimental results (with the analyzer parallel and perpendicular to the pump laser) are estimated as the sums of the projections of the o and e components.

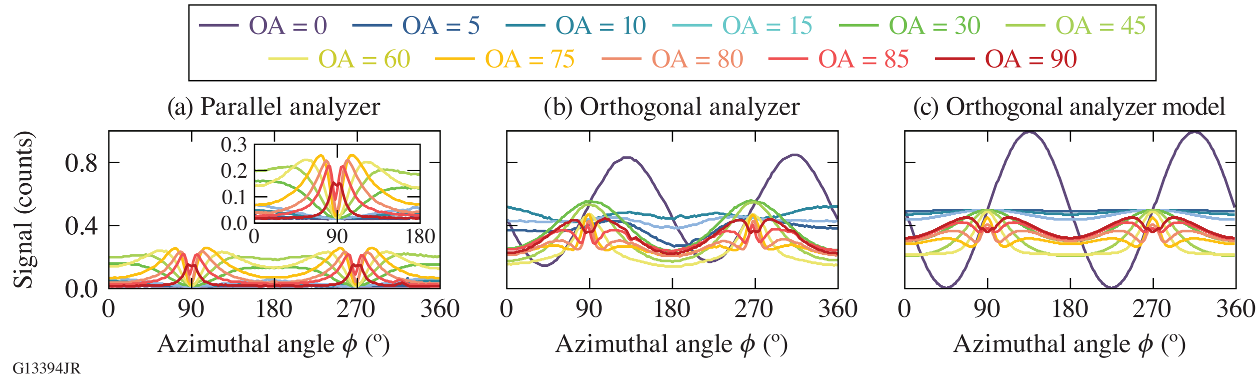

Figure 1
Data acquired using the KDP spherical sample with the Raman signal analyzer aligned (a) parallel and (b) perpendicular to the pump laser. (c) Ray-trace modeling reproduced experimental data, including polarization rotation artifacts. The pump polarization was set at $\alpha = 45°$ with respect to the vertical plane containing the crystal OA, whose position is varied between 0° and 90° with respect to the beam-propagation direction.

The ray-trace modeling also confirmed that the polarization rotation artifacts decrease as the collection aperture size is reduced. If we assume a collimated beam propagating though the crystal and the Raman scattering detected over an infinitely small collection angle, the signal with the analyzer perpendicular to the pump beam will converge the shape of the total signal (sum of the two analyzer positions). This behavior is shown in Fig. 2, which includes the (a) experimental and (b) modeling results.

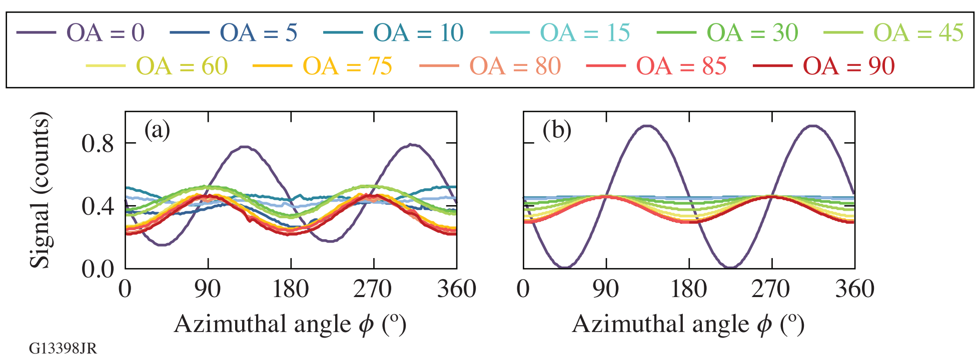

Figure 2
The sum of the parallel and perpendicular polarizations is shown as the total Raman signal for (a) experimental data and (b) the model. The polar angle varied between 0° and 90°, and the profile color coding is the same as in Fig. 1.

The results discussed above can be directly applied for the assessment of the TSRS risk in large-aperture laser systems. The validation of the model and methodology by the experimental results provides confidence on its use to guide crystal-cut optimization needed to minimize TSRS gain, to predict maximum operational fluence, or to help develop novel designs with complex polarization control properties in large-aperture optics. Future work will consider the design of specialized optics and include the ray paths contained by total internal reflection or retroreflected conditions that introduce longer gain paths.

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