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ABSTRACT

Optical components of large-aperture, high irradiance and high fluence lasers can experience significant levels of stimulated scattering along their transverse dimensions. We have observed transverse stimulated Raman scattering in large aperture KDP crystals, and have measured the stimulated gain coefficient.

Keywords: stimulated Raman scattering, nonlinear optics

1. INTRODUCTION

As high irradiance, high fluence laser light propagates through large aperture optics, spontaneously scattered light can experience high gain across the transverse dimensions of those optical components. The scattering geometry is shown schematically in Figure 1. With sufficiently high gain, transverse stimulated scattering can lead to energy loss from the main beam and, more importantly, optical damage in the components in which this scattering occurs. Thus transverse stimulated scattering is of concern in large aperture fusion lasers such as Nova¹ and Beamlet, which is a single-aperture, full-scale scientific prototype of the laser driver for the proposed National Ignition Facility.

Transverse stimulated Brillouin scattering (SBS) has been observed in large aperture fused silica components on the Nova laser.¹ Because SBS spectral peaks are typically quite narrow due to long phonon lifetimes, transverse SBS can usually be suppressed by the addition of modest bandwidths to the main laser beam.¹ The Beamlet laser is operated with 30 GHz of bandwidth applied to the main beam by phase modulation of the master oscillator output pulse.^{2,3} On the other hand, the optical phonons associated with Raman scattering typically have much shorter lifetimes, which leads to significantly broader peaks in the scattered light spectrum than those of Brillouin scattered light. Consequently, the use of bandwidth to suppress transverse stimulated Raman scattering (SRS) requires bandwidths that are too large to propagate through the laser system and frequency-convert efficiently without major changes to the laser system. Thus transverse SRS can limit laser design and performance.

Figure 1. Transverse stimulated scattering geometry in a third harmonic generation crystal. Transverse SRS experiences high gain as it propagates in a direction orthogonal to the third harmonic pump polarization.

Because of the wavelength scaling of the SRS gain coefficient,⁴ transverse SRS driven by the third harmonic laser output is of particular concern in the large aperture potassium dihydrogen phosphate (KDP) third harmonic generation crystals used on fusion laser systems.⁵ The spontaneous Raman scattering spectrum of KDP is shown in the plot in Figure 2. The measurement of this spectrum was made with a KDP crystal cut for type II third harmonic generation from a fundamental wavelength of 1.053 μm . The very strong peak at 913 cm^{-1} , which is due to the totally symmetric "breathing mode" of the PO_4 group, is the principle SRS threat. For a KDP type II third harmonic generation crystal, Smith, Hennesian, and Milanovich⁵ have determined that the third-harmonic-pumped transverse SRS has a stimulated gain coefficient of 0.23 cm/GW . With an

Figure 2. Spontaneous Raman scattering spectrum of KDP. The KDP crystal was cut for type II third harmonic generation, and the Raman scattered light was observed along a direction orthogonal to the pump direction and polarization.

Figure 3. Spontaneous Raman scattering spectrum of KDP as a function of deuteration level. Each crystal was cut as a type II tripler, and the Raman scattering signal was observed along a direction orthogonal to the pump direction and polarization.

aperture size of 30 cm and a third harmonic pump irradiance of 3 GW/cm^2 , transverse SRS will experience a gain of nearly 21 Np in a single pass across the tripling crystal. Since Beamlet and NIF will operate at aperture sizes greater than 30 cm and with pulse lengths long enough to allow gain-path-lengths greater than a single traverse of the crystal, we need to reduce the level of SRS in the tripling crystal.

2. TRANSVERSE SRS REDUCTION IN KDP CRYSTALS

We have reduced transverse SRS in large aperture KDP frequency tripling crystals by reducing the SRS gain coefficient and by limiting the path length over which scattered light can experience high gain. Previous spontaneous Raman scattering experiments indicated that deuteration of KDP crystals can significantly alter the Raman spectrum.⁶⁻⁹ The plot in Figure 3 shows the spontaneous Raman scattering spectra we measured for several KDP crystals of various levels of deuteration for the spectral region between 800 cm^{-1} and 1050 cm^{-1} . Since the SRS gain coefficient is proportional to the spontaneous scattering cross section,⁴ we see from the plot that deuteration levels above 50% lead to nearly a factor of two reduction in the SRS gain coefficient. Consequently, we chose to use 80% deuterated KDP for the Beamlet tripling crystal.

Figure 4. The edges of the tripling crystal are beveled to reduce the high-gain path length available to transverse SRS.

With aperture sizes of 30 cm or more, and laser pulse durations of 1.5 ns or more, it is also important to limit the high-gain path length to a single traverse of the tripler. This is accomplished by beveling the edges of the tripling crystal, as shown in Figure 4. Significant levels of third harmonic light exist only through the last half of the tripler thickness. Consequently, the edge bevels extend only halfway through the tripler, from its center plane to the output face. Furthermore, these

bevels are cut along the two edges that are parallel to the polarization direction of the third harmonic, since the high-gain scattering direction is orthogonal to the third harmonic pump polarization.⁵ The sol-gel dip coating process that is used to apply anti-reflection coatings to the input and output faces also leaves a good anti-reflection coating on the diamond-turned surfaces of the edge bevels. Thus, most of the light striking the edge is transmitted out of the crystal. The light reflected from the 30° bevels then rattles back and forth through the crystal, seeing only a small gain path length between encounters with the AR-coated faces of the crystal. An identical set of bevels are cut along the other two edges extending halfway into the crystal from the input face to reduce the level of second-harmonic-pumped SRS, which has a gain nearly equal to that of the third-harmonic-pumped SRS.⁵

3. TRANSVERSE SRS MEASUREMENTS

Our initial transverse SRS experiments were performed on the Nova laser. We instrumented one of the Nova KDP harmonic generation arrays with optical fibers that carried side-scattered light from the tripling crystals to a spectrograph equipped with an optical multichannel analyzer (OMA). The spectrograph was set up to allow observation of the spectral region from 350 cm^{-1} to 1100 cm^{-1} on every laser shot. The plot in Figure 5 shows the nonlinear growth of the scattered light at 913 cm^{-1} relative to that scattered at 359 cm^{-1} , which linearly tracks the laser pulse energy. Although the Nova tripling crystals are undeuterated KDP, they are operated at lower irradiances and the single-pass gain length is limited by crystal size and beam obscurations to 27 cm or less.

The third harmonic generation crystals for Beamlet are operated at third harmonic irradiances approaching 3 GW/cm^2 and have single-pass gain lengths up to 34 cm. When the third harmonic generator was installed on the Beamlet laser, its KDP doubler and 80% KD*P tripler were also outfitted with optical fibers positioned along the crystal edges to collect side-scattered light. As in the Nova experiments, this light was transported to a spectrograph with an OMA detection system. The plot in Figure 6 illustrates the nonlinear growth we observed for the light scattered by the strong Raman mode at 881 cm^{-1} in the 80% deuterated KDP tripler.

We performed three series of shots on Beamlet with increasing third harmonic irradiances at pulse lengths of 1 ns, 1.7 ns, and 3 ns with a 34 cm aperture beam. At 1 ns and 1.7 ns the SRS gain path length across the crystal is pump-duration-limited to 20 cm and 34 cm, respectively. The 3 ns duration shots allow the SRS gain path to include reflections from the crystal edges. The natural log of the SRS peak height at 881 cm^{-1} is plotted against third harmonic irradiance for 1 ns pulse length in Figure 7, and for 1.7 ns

Figure 5. Transverse Raman scattering at 913 cm^{-1} in the Nova KDP tripling crystal shows nonlinear growth with increasing third harmonic pump irradiance, which is proportional to the Raman scattering at 359 cm^{-1} .

Figure 6. Transverse Raman scattering at 881 cm^{-1} in the Beamlet 80% deuterated KDP tripling crystal shows nonlinear growth with increasing third harmonic pump irradiance.

Figure 7. Natural logarithm of the 881 cm⁻¹ SRS peak height versus third harmonic pump irradiance measured in the Beamlet KD*P tripler. Data were recorded with 1 ns pulses, which limits gain path to 20 cm. The SRS gain coefficient is determined by a linear fit.

Figure 8. Natural logarithm of the 881 cm⁻¹ SRS peak height versus third harmonic pump irradiance measured in the Beamlet KD*P tripler. Data were recorded with 1.7 ns pulses, which limits gain path to 34 cm. The SRS gain coefficient is determined by a linear fit.

Figure 9. Natural log of the 881 cm⁻¹ SRS peak height vs. third harmonic pump irradiance in the Beamlet KD*P tripler. Data were recorded with 3 ns pulses. The data are fit to a two exponential model (to account for edge reflection) using the SRS gain value from the 1 ns data in Fig. 7.

pulse length in Figure 8. Fitting these data with a single exponential gain model, we find an SRS gain coefficient of 0.098 ± 0.007 cm/GW for the 1 ns data, and 0.090 ± 0.005 cm/GW for the 1.7 ns data. Both of these values are in very good agreement with the value of approximately 0.11 cm/GW that we anticipated from our spontaneous scattering measurements and the work of Smith et al.⁵ In Figure 9 we plot the natural log of the SRS peak height versus third harmonic irradiance at 3 ns pulse length. When we fit this data with a two-exponential model that includes an edge reflection and the SRS gain coefficient value determined from the 1 ns data, we find an edge reflectivity of approximately 0.2%.

4. SUMMARY

We have observed third-harmonic-pumped transverse SRS in the Nova and Beamlet tripling crystals. We have measured the third-harmonic-pumped transverse SRS gain coefficient at a frequency shift of 881 cm⁻¹ in the Beamlet 80% deuterated KDP tripler. The use of 80% deuterated KDP with beveled edges for the Beamlet tripler has reduced the transverse stimulated Raman scattered light at 34 cm aperture to easily managed levels.

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