Diamond Raman Lasers

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Abstract: We summarize our recent research in Raman lasers based on undoped single crystal diamond. Highly efficient visible external cavity lasers operating in nanosecond and picosecond regimes are reported.

OCIS codes: (140.3550) Lasers, Raman; (140.3580) Lasers, solid-state; (160.3380) Laser materials; (160.4330) Nonlinear optical materials; (190.2640) Stimulated scattering, modulation, etc.

1. Introduction

Diamond is a highly attractive laser material due to its many of its characteristic properties such as its exceptionally high thermal conductivity and wide band gap. Considerable efforts in doping of diamond over the last two decades to realize semiconductor lasers [1], color centre lasers [2] and rare-earth doped lasers [3] have not yet led to practical devices. On the other hand, progress in the growth of large and pure synthetic single crystals by chemical vapour deposition (CVD) [4] has enabled development of Raman lasers [5].

It has been our aim to demonstrate efficient diamond Raman lasers and exploit the extreme properties of diamond to demonstrate enhanced capability. In particular, the high thermal conductivity, high Raman gain (typically 1.5-3x higher than other high gain Raman crystals) and wide transparency are highly attractive for enabling Raman lasers to be further miniaturized, with high power handling capability, and with increased output wavelength range.

We first studied a diamond Raman laser in 2008 using a 5mm long CVD-grown sample [5]. It was pumped at the second harmonic of Nd:YAG to take advantage of the higher gain coefficient, which scales inversely with the wavelength. Linearly polarized pump and Stokes beam ensured both low losses at the Brewster orientated crystal and maximum Raman gain. The highest conversion efficiency measured was 13%, and slope efficiency 22%, which was well below that for other materials such as barium nitrate, barium tungstate and potassium gadolinium tungstate that all have seen external cavity Raman laser efficiencies exceed 50% and as high as 65%. We identified that serious depolarization in the crystal due to the sample's inherent birefringence was a major cause limiting efficiency. Low birefringence is crucial for efficient operation when using Brewster cut crystals, and important for achieving low Raman laser thresholds and generating the polarized output required for many applications.

Methods have been recently developed that enable growth of large single crystals with birefringence orders much lower than attained previously [4]. We report here external cavity Raman lasers based on a Brewster cut low birefringence diamond with conversion efficiency almost five times higher than demonstrated previously and commensurate with the highest conversion efficiencies reported for other materials. We also report a synchronously pumped diamond Raman laser that provides efficient conversion of 30 ps pump pulses to the yellow at 80 MHz repetition rate.

2. Experiments and Results

The diamond used in the work described here was low birefringence single crystal (Element Six UK) and had dimensions 6.7 mm long, 3.0 mm wide and 1.2 mm thick. The Raman lasers investigated were both external cavity Raman lasers pumped by Q-switched and modelocked frequency-doubled Nd systems respectively at 532 nm.

Nanosecond diamond Raman laser

The Raman laser cavity consisted of an input coupler (94.2% transmitting at 532 nm and highly reflecting HR 560-650 nm) and output coupler (HR 532 nm, 25%T at 573 nm and 80%T at 620 nm), both having radius of curvature 20cm. The output coupler retro-reflects the pump to provide a second pass of the Raman crystal (see Figure below). The mirrors are placed as close as practicable to the crystal so the overall cavity length was 10-12 mm long.

Performance was investigated for input pump powers up to 2.2 W corresponding to pulse energies up to 400 mJ. The following figure shows the output energy as a function of the pulse energy incident on the crystal (ie., factoring in the 5.8% input coupler reflection loss). The Raman laser threshold is approximately 0.1 mJ beyond which output increases linearly with slope efficiency 74.9% up to the maximum pulse energy of 0.24 mJ. The conversion efficiency at maximum energy is 63.5%. The output largely (>090%) consists of first Stokes output at 573 nm. In terms of output power the maximum combined first and second Stokes power was 1.18 W.

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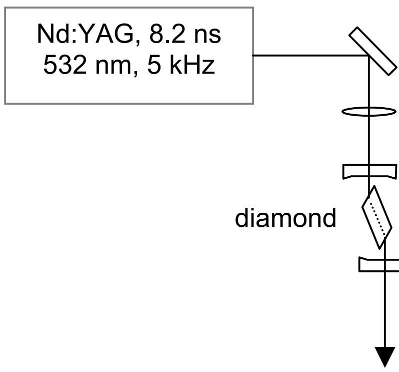
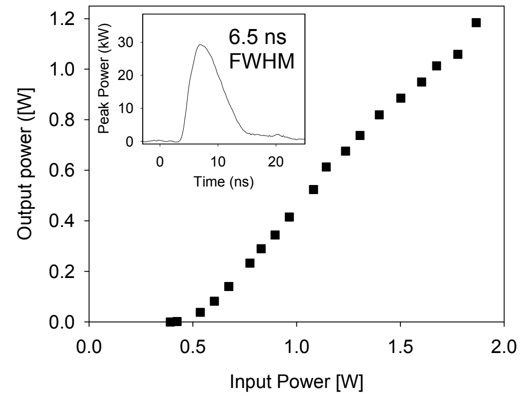
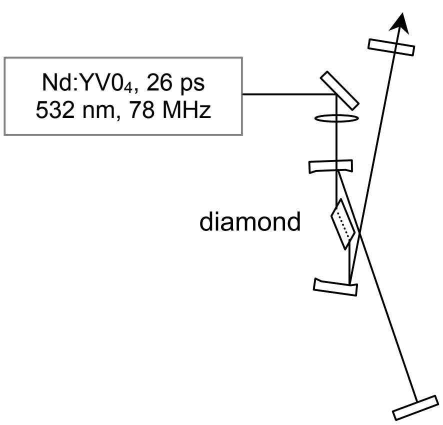
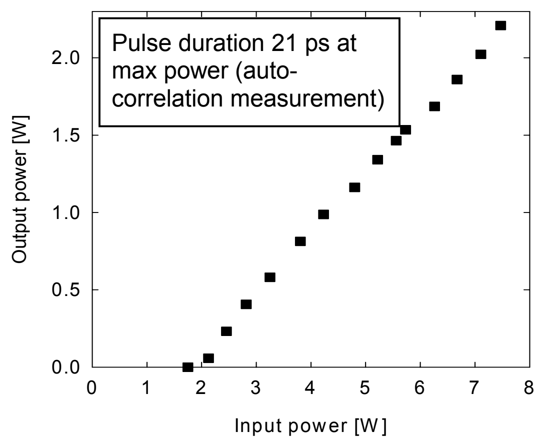




Picosecond diamond Raman laser

In the picosecond regime it is important to consider the transient nature of the Raman process and also the short period of gain compared to the cavity round trip time. We used a synchronously pumped design to enable efficient generation of the Stokes pulses and with excellent output beam quality [6]. The diamond laser cavity was a z-fold configuration comprised of two curved mirrors (concave radii of 200 mm) and two plane mirrors as shown. The pump laser was focused through the input coupler into the diamond crystal. Up to 7.5 W was incident on the diamond crystal, with the pulse train composed of 26 ps pulses at a repetition rate of 78 MHz. All resonator mirrors were highly reflecting at the first-Stokes wavelength of 573 nm except the output coupler which had a transmission of 12%.





The maximum output power was 2.21 W. The laser threshold was approximately 2 W, leading to a slope efficiency of 41% and an absolute efficiency of 29%. The conversion efficiency is slightly higher than that obtained for potassium gadolinium tungstate (25.6%) [6], and our model suggests higher efficiencies are likely to obtained with optimized resonator mirrors. The position of the output coupler is crucial to gaining efficient output and also strongly effects the output pulse duration.

3. Conclusions

We have demonstrated efficient diamond Raman lasers operating at nanosecond and picosecond pulse durations in the 1-2 W regime. The conversion efficiencies are as good, or higher, compared to external cavity Raman lasers operating with other crystals. These results are promising for advancing diamond Raman lasers to achieve performance that leverages its key properties such as compact high average power Raman lasers and output at wavelengths not possible using other Raman materials.

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