All-solid-state, multi-kilohertz, 1.5μm intracavity Raman laser based on Nd:YVO_4 and $KGd(WO_4)_2$

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Abstract: Multi-kilohertz operation at both 1497nm and 1528nm has been demonstrated with an Nd:YVO4 laser operating on the 1342nm transition using intracavity Stimulated Raman Scattering in $KGd(WO_4)_2$. Average powers at 1497nm and 1528nm were 200mW and 100mW respectively.

OCIS codes: 140.3550 Lasers, Raman; 140.3580 Lasers, solid-state.

1. Introduction

Non-linear frequency conversion using Stimulated Raman Scattering (SRS) is an efficient and practical method of extending the current spectral coverage of existing laser technology. SRS in crystalline materials, such as $LiIO_3$, $Ba(NO_3)_2$ and various tungstates has previously demonstrated multiwatt average powers in the near IR [1], and >1W (frequency-doubled) in the visible [2]. Although there are several methods of obtaining frequency conversion using SRS, intracavity configurations are particularly attractive due to high fundamental peak powers inside the laser resonator. Theory, development and comparison of various Raman laser configurations and materials can be found in a recent review of the field [3].

Recent advances in high power operation of diode pumped Nd:YVO_4 on the 1342nm transition [4, 5] have made possible the generation of significant output in the 1.5μm region using SRS in various crystalline materials. This has previously been demonstrated with flashlamp pumped Nd:YAG at low repetition rates using $Ba(NO_3)_2$ [6], although to our knowledge this is the first report of an all-solid-state, high repetition rate 1.5μm Raman laser. We have demonstrated laser operation at 1497nm and 1528nm with the insertion of a $KGd(WO_4)_2$ crystal into an acousto-optically q-switched Nd:YVO_4 laser operating on the 1342nm transition. Multiwatt, high beam quality output is expected with optimised resonator mirror and crystal coatings.

2. Experimental arrangement

The laser pump and resonator configuration is illustrated in figure 1. The double-end-pumping design used two 15W 808nm Optopower diodes coupled into 1mm fibre bundles with a measured NA=0.11. Following the approach of Taira et al [7], the outputs from the fibre bundles were collimated and focussed through the dichroic mirrors M1 and M2 into either end of the crystal with 0.4 magnification giving a pump mode radius of ~200μm. This system was previously optimised for 1342nm generation, where it produced as much as ~8W cw in a TEM_{00} beam (>40% slope efficiency and >30% optical conversion efficiency) [5].

The a-cut Nd:YVO_4 crystal had 0.3at.% Nd^{3+} concentration and 3x3x12mm dimensions. Both crystal faces were AR coated for 808, 1064 and 1342nm (note the crystal was not coated for 1500nm). The crystal was wrapped in indium foil and placed inside a water-cooled copper mount, which was held at ~15°.

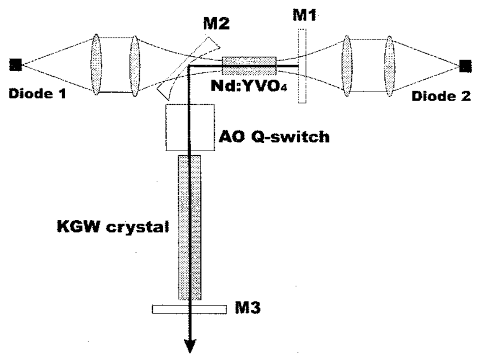

Figure 1: Laser configuration

The $KGd(WO_4)_2$ crystal (supplied by Eksma) was located close to M3 near a resonator beam waist. It had dimensions 5x5x50mm and was AR coated for 1064-1170nm. The crystal coating was designed for 1064nm raman laser operation, which resulted in a 7% single pass loss at 1342nm, this was thought to be a major contributor to reduction in performance of the laser. The acousto-optic q-switch (NEOS type 33027-25-2-1) was AR coated for 1342nm and approximately 40mm in length, giving a total cavity length of ~150mm. This cavity length was longer than optimal given the two flat end mirrors M1 and M3, and the strong $Nd:YVO_4$ thermal lens (~12cm). A summary of the mirror characteristics is displayed in table 1.

TABLE 1 – Selected Mirror Characteristics

	Transmission (%)					
	808nm	1064nm	1342nm	1497nm	1528nm	Curvature
M1	85	85	0.14	0.26	0.53	Flat
M2	67	34	0.54	0.75	1.07	25cm CC
M3	-	5.8	0.07	8.23	7.89	Flat

*Note M2 transmissions are for 45° incidence, vertical polarisation, except for 808nm where the quoted transmission is for unpolarised light.

4. Results and discussion

Either 1497nm or 1528nm output could be selected by rotating the orientation of the $KGd(WO_4)_2$ crystal to match the vanadate polarisation. The maximum achievable output powers for 1497 and 1528nm were 200mW and 100mW respectively (both at 15kHz). The reduced performance of the 1528nm output was partially due to the increased first stokes transmission losses of M1 and M2, although additional issues may have been caused by laser crystal, q-switch and $KGd(WO_4)_2$ crystal coatings at the longer wavelength. The Raman gain for the $900cm^{-1}$ shift is also slightly lower than the $768cm^{-1}$ shift [8], which would also contribute to a higher threshold for the longer wavelength. A laser characteristic for both wavelengths is shown in figure 2.

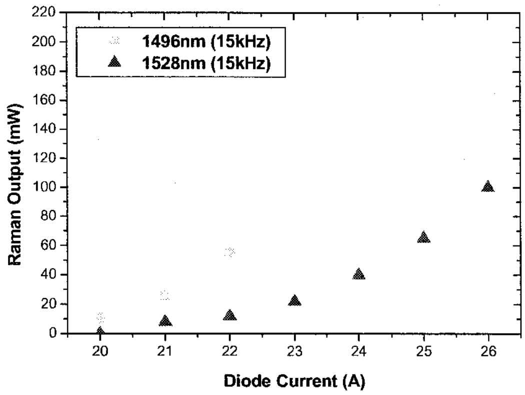

Figure 2: Raman laser output characteristics

The fundamental laser pulse at 1342nm was around 100nsec FWHM, which was notably longer than for 1064nm q-switched operation (this is commonly observed with the lower gain transition). Temporal analysis of the Raman output was also investigated. At 15kHz, the Raman output pulse width was around 25nsec FWHM (the pulse shown in figure 3 was at 1497nm, although 1528nm results were very similar). When viewed with a 2Ghz oscilloscope and 5Ghz detector, the Raman output consisted of multiple short pulses (<250psec FWHM) separated by the cavity round trip time. The two Raman wavelengths were centred at 1497.3 and 1527.8nm, both were less than 0.2nm FHWM in width (instrument limited).

Along with the widely available Neodymium and Ytterbium doped tungstates [9, 10], it should be noted that YVO_4 and $GdVO_4$ have also been previously identified as Raman active materials [11], which presents the possibility of a single crystal Nd:YVO_4 Raman laser capable of operation at either 1175 or 1524nm. Both of the vanadates have strong shifts around 890cm^{-1}, with raman gain at least as great as $KGd(WO_4)_2$. Despite the initial attractiveness of a single crystal Raman laser, a self-Raman shifting laser crystal significantly increases the complexity of optimising fundamental and first stokes mode overlap (for efficient conversion, optimal Raman mode size is usually much smaller than the fundamental laser mode size). They also have the added disadvantage of additional thermal loading from the SRS process.

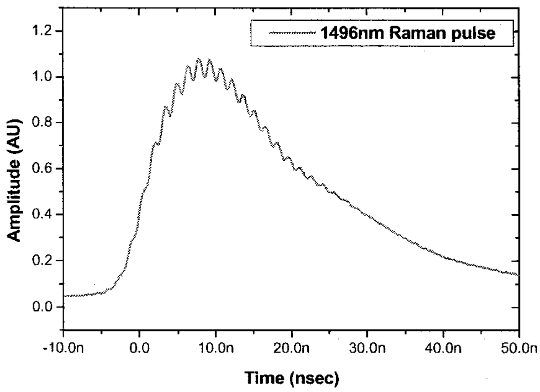

Figure 3: Laser pulse characteristics for the Raman output at 1497nm.

Limitations of the current system were mainly due to non-optimal coatings and resonator design issues, along with vanadate crystal coating damage. Single pass loss through the $KGd(WO_4)_2$ crystal alone was approximately equivalent to the first stokes output coupling, indicating much greater slope efficiencies are attainable with increased crystal coating transmission. The turning mirror M2 also presented a 0.54% loss at the fundamental 1342nm, which corresponded to a round trip loss exceeding 1%, the subsequent reduction in fundamental peak power would also have reduced the SRS conversion efficiency. For the results in this report, using 5% output coupling at 1342nm, the fundamental laser was producing ~2.5W at 15kHz repetition rate, which was considerably less than its pre-damage capability. Overall conversion efficiency from fundamental to first stokes output was therefore ~8% and 4% for 1497nm and 1528nm respectively. Previous intracavity raman laser results have demonstrated fundamental to first stokes conversion efficiencies exceeding 50% [12], suggesting that if damage issues can be addressed, crystal coatings improved and resonator configuration optimised for the current system, multi-watt, high beam quality 1.5μm output is attainable.

5. Conclusion

Intra-cavity SRS is a convenient way to extend current high beam quality laser technology into the 1.5μm eye-safe spectral region, where there are numerous applications. 200mW and 100mW of output was obtained at 1497 and 1528nm respectively using intracavity SRS in $KGd(WO_4)_2$. The fundamental laser was acousto-optically q-switched $Nd:YVO_4$ operating on the 1342nm transition. Based on previous intra-cavity Raman laser results, optimization of the system should increase the output of the laser into the multiwatt region.

6. References

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