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Diode End-Pumped Passively Q-Switched Nd^{3+}:$GdVO_4$ Self-Raman Laser at 1176 nm

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A compact diode-end-pumped passively Q-switched Nd^{3+}:$GdVO_4$/Cr^{4+}:YAG self-Raman laser at 1176 nm is demonstrated. When the $T_0 = 80\%$ Cr^{4+}:YAG saturable absorber is inserted into the cavity, the maximum Raman laser output reaches 175 mW with 3.8 W incident pump power. The optical conversion from incident to the Raman laser is 4.6% and the slope efficiency is 6.5%. The pulse energy, duration, and repetition frequency of the first stokes laser are 4.5 μJ, 1.8 ns, and 38.5 kHz, respectively. There is strong blue emission (about 350–400 nm) can be observed in the Nd^{3+}:$GdVO_4$ crystal when the process of stimulated Raman scattering occurs, which is induced by the upconversion of the Nd^{3+} ions.

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As an important method for frequency conversion, stimulated Raman scattering (SRS) in Raman crystals has undergone resurgence recently. Combined with the diode-pumped solid-state lasers, it is an effective way to obtain the yellow or orange lasers by the technology of second harmonic generation (SHG) of the first stokes lasers,[1] which have special applications in coastal bathymetry and laser display system.

The Raman crystals which were used widely include $Ba(NO_3)_2$,[2] $LiIO_3$, KGW and so on. For the purpose of achieving compact, steady and robust Raman lasers, the self-Raman lasers (such as the Nd^{3+}:KGW self-Raman laser[3]) which use only one crystal served both as laser and Raman crystal have special attraction. As is well known, the Nd^{3+}:$GdVO_4$ crystal is a kind of perfect laser crystal for its high thermal conductivity and large emission cross section and is used widely in the solid state lasers.[4] Fortunately, the $GdVO_4$ crystal is also the Raman active crystal with the most intense mode 883 cm^{-1} and high Raman gain coefficient ($g_R > 5$ cm/GW).[5,6] Thus the self-Raman lasers using Nd^{3+}:$GdVO_4$ crystal must be very interesting and useful.[7,8]

The SRS process belongs to the third order nonlinear effect and the efficient Raman conversion needs the pump laser with high power density, usually Q-switched lasers. Based on the Q-switched theory,[9] the smaller stimulated cross section is more favourable for energy storage and higher pulse peak power output. For the line of 1.06 μm, there is different stimulated cross section in the Nd^{3+}:$GdVO_4$ crystal, the scattering cross section is 7.6×10^{-19} cm^{-2} for an a-cut crystal and 1.2×10^{-19} cm^{-2} for a c-cut crystal.[10] Now that the Nd^{3+}:$GdVO_4$ crystal is used both as laser and Raman crystal, we cut it along the c-axis to decrease the SRS threshold. Although there is a little difference in the Raman scattering cross section between the a-cut and c-cut Nd^{3+}:$GdVO_4$ crystals,[6] we believe that it is not the critical factor compared with the high pulse peak power especially for the low-level pump source. In fact, there is no SRS phenomena occurring when the a-cut Nd^{3+}:$GdVO_4$ crystal is used in our experiment.

In this study, we demonstrate a compact, passively Q-switched Nd^{3+}:$GdVO_4$ self-Raman laser. The maximum Raman laser output is 175 mW with 3.8 W incident pump power. The pulse energy, duration and repetition frequency of the Raman laser is 4.5 μJ, 1.8 ns and 38.5 kHz, respectively. There is strong blue emission in the crystal when the SRS occurs. The reason may be related to the upconversion of the Nd^{3+} ions in the Nd^{3+}:$GdVO_4$ crystal.

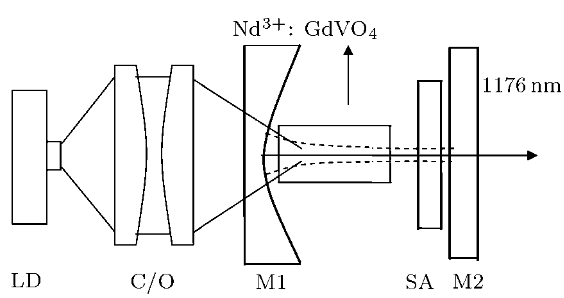

Fig. 1. Experimental setup of the diode end-pumped passively Q-switched Nd^{3+}:$GdVO_4$/Cr^{4+}:YAG self-Raman laser. C/O, coupling optics; SA, the saturable absorber Cr^{4+}:YAG; M1 and M2, input and output mirrors.

Figure 1 schematically shows the experimental setup. The pump source is a single-pipe laser diode

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with the maximum output power of 5 W, and its emitting wavelength is 807.8 nm at room temperature. The multi-element lens, which has the transmission 98% at 808 nm, is used to collimate and focus the pump power into the crystal with the spot size of 200 μm in diameter. The c-cut 5-mm-long Nd^{3+}:$GdVO_4$ crystal with 0.5 at.% doping concentration was coated antireflection (AR) at 1064/1176 nm ($R < 0.2\%$) on both the facets. The cavity length remains only 15 mm long, which is composed of two mirrors, M1 and M2. The input concave mirror M1 with the radius of 50 mm has high reflectivity (HR) at 1064 nm and 1176 nm ($R > 99.8\%$) on the concave facet. The output coupler M2 is a plate mirror with HR at 1064 nm ($R > 99.8\%$) and partial transmission at 1176 nm ($T = 40\%$). In our experiment, two anti-reflection coated at 1064 nm Cr^{4+}:YAG crystal with initial transmission of 90% and 80% are used, respectively. The Raman laser pulse is monitored by a high speed InGaAs photodiode and registered by a digital oscilloscope (LeCroy) with bandwidth of 300 MHz.

From the analysis of the coupled rate equations, the criteria for good passive Q-switched is given by[11]

$$\frac{\ln\left(\frac{1}{T_0^2}\right)}{\ln\left(\frac{1}{T_0^2}\right)+\ln\left(\frac{1}{R}\right)+L}\frac{\sigma_s}{\sigma_g}\frac{A_g}{A_s} > \frac{\gamma}{1-\beta},$$

where T_0 is the initial transmission of the saturable absorber, A_g/A_s is the ratio of the effective area in the gain medium to that in the saturable absorber, R is the reflectivity of the output coupler, L is the nonsaturable intracavity roundtrip dissipative optical loss, σ_s is the ground-state absorption cross section of the saturable absorber, σ_g is the stimulated emission cross section of the gain medium, γ is the inversion reduction factor with a value between 0 and 2, and β is the ratio of the excited-state absorption cross section to that of the ground-state absorption in the saturable absorber. The concave-plate cavity configuration and the c-cut Nd^{3+}:$GdVO_4$ crystal in our experiment ensured the efficient Raman laser conversion from the criteria equation mentioned above. We also changed the cavity to the plate-concave configuration, using a concave output mirror with the same reflectivity as M2 and the input mirror with the same reflectivity as M1. We even did not find the Raman laser when the pump power increases to 3.8 W. Thus the passive Q-switched criterion is quite important for the good pulse output such as high peak power, high pulse energy and also critical for the efficient Raman conversion.

For the comparison of the conversion efficiency from the fundamental, we firstly study the passively Q-switched fundamental laser operation. The output mirror M2 is replaced by a plate mirror with partial transmission ($R = 80\%$) at 1064 nm. Because the single pipe 5 W LD can be easily damaged by the large heat sink, we drive the maximum current to 4.2 A, which corresponds to 3.83 W laser output. The average output power of the fundamental laser with respect to the incident pump power is shown in Fig. 2.

When the initial transmission $T_0 = 90\%$ Cr^{4+}:YAG saturable absorber is insert into the cavity, the maximum fundamental laser output is 576 mW and the corresponding optical conversion efficiency is 15%. When the $T_0 = 80\%$ Cr^{4+}:YAG saturable absorber is used, we can obtain 530 mW fundamental laser output.

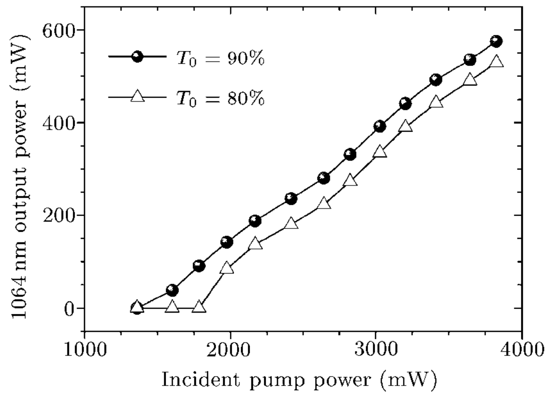

Fig. 2. Q-switched fundamental laser output power versus incident pump power.

The Raman laser operation is studied with different initial transmission ($T_0 = 90\%$ and 80%). Cr^{4+}:YAG saturable absorber is inserted into the cavity. Figure 3 shows the average Raman laser output power versus the incident pump power.

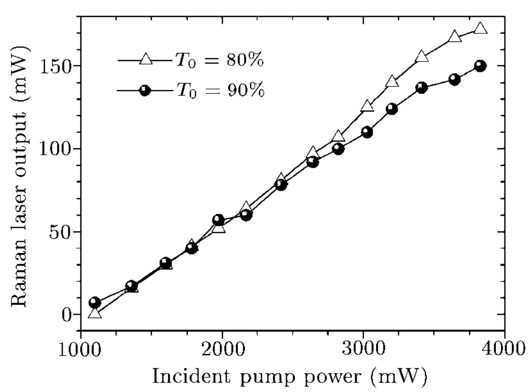

Fig. 3. Raman laser output versus incident pump power.

The maximum Raman laser output is 175 mW with 3.8 W incident pump power when the $T_0 = 80\%$ Cr^{4+}:YAG saturable absorber is inserted into the cavity. The threshold is 1100 mW and the slope efficiency is 6.48%, respectively. When the $T_0 = 90\%$ Cr^{4+}:YAG saturable absorber is used, the threshold is about 1000 mW and the slope efficiency is smaller than that one. There is strong blue emission which can be observed by naked eyes from the Nd^{3+}:$GdVO_4$

crystal when the SRS occurs. When it is operated at fundamental laser (1064 nm), only the yellow radiation can be observed. The blue emission spectrum may be located about 350–400 nm, which corresponds to the transition from the $^4D_{3/2}$ and $^4D_{5/2}$ levels to the lower levels $^4I_{9/2}$, $^4I_{11/2}$ and $^4I_{13/2}$ of the Nd^{3+} ions in the Nd^{3+}:$GdVO_4$ crystal.[12–14] There are two important processes which contribute to the upconversion in the Nd^{3+}:$GdVO_4$ crystal, the excited-state absorption (ESA) and energy transfer upconversion (ETU), and the upconversion macroparameter in the Nd^{3+}:$GdVO_4$ crystal is quite large relatively. Both the high doping concentrations (0.5 at.%) of the Nd^{3+}:$GdVO_4$ crystal in this experiment and the higher power intensity of the fundamental laser in the cavity may be the reasons which strengthen the upconversion process and result in the blue emission. Obviously, it is harmful not only for decreasing the conversion efficiency from the fundamental laser to the Raman laser but also for increasing the thermal lens effect in the crystal.

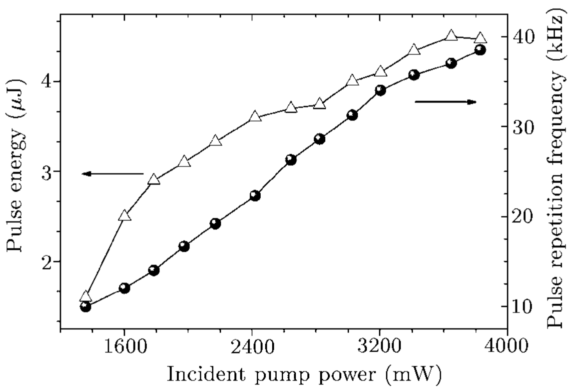

Fig. 4. Pulse repetition frequency and pulse energy of the Raman laser vs incident pump power ($T_0 = 80\%$).

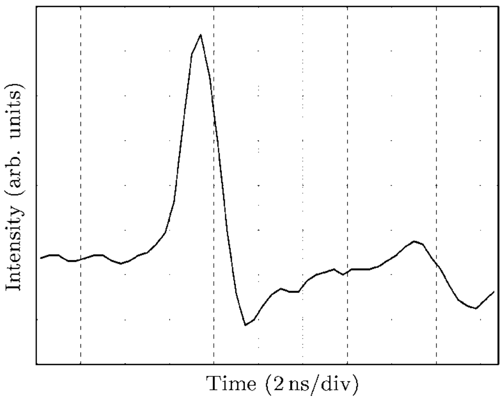

Fig. 5. Pulse shape of the Raman laser at the maximum output ($T_0 = 80\%$).

The pulse repetition frequency and the pulse energy of the Raman laser ($T_0 = 80\%$) is shown in Fig. 4. Both of them increase with the incident pump power, the maximum pulse repetition frequency is 38.5 kHz and pulse energy is 4.5 μJ with 3.8 W incident pump power.

Figure 5 shows that the pulse shape of the Raman laser is about 1.8 ns at the 3.5 W incident pump power ($T_0 = 80\%$). We believe that the practical pulse duration is slightly smaller than that for the reason of the response bandwidth limitation of our oscilloscope (300 MHz). The pulse-to-pulse fluctuation is found within about 10%.

In summary, we demonstrated a compact, diode end-pumped passively Q-switched Nd^{3+}:$GdVO_4$/Cr^{4+}:YAG self-Raman laser. When the $T_0 = 80\%$ Cr^{4+}:YAG saturable absorber is inserted into the cavity, the maximum Raman laser output reaches 175 mW with the optical conversion of 4.6% from incident pump power to the Raman laser. The strong blue emission is also observed in the Nd^{3+}:$GdVO_4$ crystal when the SRS occurs, which is harmful for the conversion efficiency from the fundamental to the Raman laser. By the method of decreasing the Nd^{3+} ions doping or lengthening the Nd^{3+}:$GdVO_4$ crystal, the conversion efficiency can be improved effectively.

References

[1] Simons J, Pask H, Dekker P and Piper J 2004 *Opt. Commun.* **229** 305
[2] Murray J T, Powell R C, Peyghambarian N, Smith D, Austin W and Stolzenberger R A 1995 *Opt. Lett.* **20** 1017
[3] Omatsu T, Ojima Y, Pask H M, Piper J A and Dekker P 2004 *Opt. Commun.* **232** 327
[4] Liu J, Jia Y L, Yang J M, Du J and He J L 2002 *Chin. Phys. Lett.* **19** 1808
[5] Kaminskii A A, Ueda K I, Eichler H J, Kuwano Y, Kouta H, Bagaev S N, Chyba T H, Barnes J C, Gad G A, Murai T and Lu J 2001 *Opt. Commun.* **194** 201
[6] Basiev T T, Zverev P G, Karasik A Y A, Vassiliev S V, Sobol A A, Chunaev D S, Konjushkin V A, Zagumennyi A I, Zavartsev Y D, Kutovoi S A, Osiko V V and Shcherbakov I A 2004 *OSA Trends in Optics and Photonics, Advanced Solid-State Photonics* **94** 1
[7] Chen Y F 2004 *Appl. Phys.* B **78** 685
[8] Basiev T T, Vassiliev S V, Konjushkin V A, Osiko V V, Zagumennyi A I, Zavartsev Y D, Kutovoi S A and Shcherbakov I V 2004 *Laser Phys. Lett.* **5** 237
[9] Degnan J J 1989 *IEEE. J. Quantum Electron.* **25** 214
[10] Liu J, Yang J M and He J L 2003 *Opt. Commun.* **219** 317
[11] Morris J A and Pollock C R 1990 *Opt. Lett.* **15** 440
[12] Ostroumov V, Jensen T, Meyn J P, Huber G and Noginov M A 1998 *J. Opt. Soc. Am.* B **15** 1052
[13] Fornasiero L, Kück S, Jensen T, Huber G and Chai B H T 1998 *Appl. Phys.* B **67** 549
[14] Macfarlane R M, Tong F, Silversmith A J and Lenth W 1988 *Appl. Phys. Lett.* **52** 1300