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Stimulated Raman scattering in Nd:KGW laser with diode pumping

A.S. Grabtchikov[a,*], A.N. Kuzmin[a], V.A. Lisinetskii[a], G.I. Ryabtsev[a], V.A. Orlovich[a], A.A. Demidovich[b]

[a]B.I. Stepanov Institute of Physics NASB, F. Scaryna ave. 68, Minsk 220072, Belarus, Byelorussia
[b]Institute of Molecular and Atomic Physics NASB, F. Scaryna ave. 70, Minsk 220072, Belarus, Byelorussia

Abstract

Operation of an all solid-state compact pulsed Nd:KGW Raman laser pumped by a cw laser diode is demonstrated. The Stokes and anti-Stokes radiations of stimulated Raman scattering at the 1.181 μm and 0.973 μm wavelengths, respectively, are generated as a result of self-frequency conversion of the 1.067 μm laser radiation in a Nd:KGW crystal. With Q-switched operation the Raman laser threshold corresponds to 230 mW of a laser diode light power. The output power of 8.9 mW is achieved at the Stokes wavelength with a kilohertz repetition rate. Blue luminescence trace in Nd:KGW crystal under simultaneous 1.067 μm laser action and Raman generation is observed. A possible mechanism of this up-conversion process is proposed.

Keywords: Stimulated Raman scattering; Nd:KGW Raman laser; diode pumping

1. Introduction

Neodimium-doped potassium gadolinium tungstate Nd^{3+}:$KGd(WO_4)_2$ or Nd:KGW is known as one of the efficient Nd^{3+}-containing laser media. In comparison with the conventionally used Nd:YAG, the main features of the anisotropic Nd:KGW are the large emission cross-section and wide absorption spectrum at 0.810 μm. Besides, it can be also doped with high Nd^{3+} concentrations (up to 8 at%) with no appreciable concentration quenching and crystal quality deterioration. With the laser diode pump the last feature allows a high absorption of pump radiation in a small crystal region, a low threshold and high efficiency can be attained. The 1.067 μm Nd:KGW laser radiation is polarized which is important for further polarization-sensitive nonlinear conversions. A laser oscillation in Nd:KGW crystal with the diode pump has been already shown in the continuous-wave, Q-switched and mode-locked operation modes [1–3].

Besides, KGW host has a high nonlinear susceptibility of the third order: this crystal is one of the most promising Raman-active media. There are several lines of spontaneous Raman scattering whose emergence depends on the orientation of the pump beam direction and polarization towards the crystal indicatrix axes [4]. The most intensive Stokes lines have frequency shifts 767.5 cm^{-1} and 901.5 cm^{-1}. The Raman gain coefficient for both lines is 6 cm/GW, with the linewidths (HWHM) being 7.8 cm^{-1} and 5.9 cm^{-1}, respectively [4].

Raman self-frequency conversion in Nd:KGW crystals was realized at flashlamp pump more than 10 years ago [5]. Over the last years a family of solid-state mediums that allow Raman self-frequency conversion has been substantially enlarged [6–13]. A high value of the Raman gain coefficient in solid state mediums [14,15] and partially in Nd:KGW [4], and recent observation of an extremely low Raman threshold in the high fineness cavity Raman laser [16] open perspectives for efficient Raman conversion in these media using the laser diode pump.

In this report the operation of an all solid-state compact diode pumped Raman laser with self-conversion on KGW crystal is described. A diode laser at 0.8 μm was used to pump Nd:KGW which lased at 1.067 μm. This 1.067 μm laser was then Raman shifted by the KGW to 1.181 and 0.973 μm by Stokes and anti-Stokes stimulated Raman scattering in the same cavity.

2. Experiments and discussion

An experimental setup is shown in Fig. 1. The multimode Polaroid POL-4100 laser diode with an output power up to 1 W with a thermoelectric cooler was used as a pump source. The wavelength tuning range provided by the temperature adjustment was from 0.806 to 0.812 μm.

*Corresponding author.

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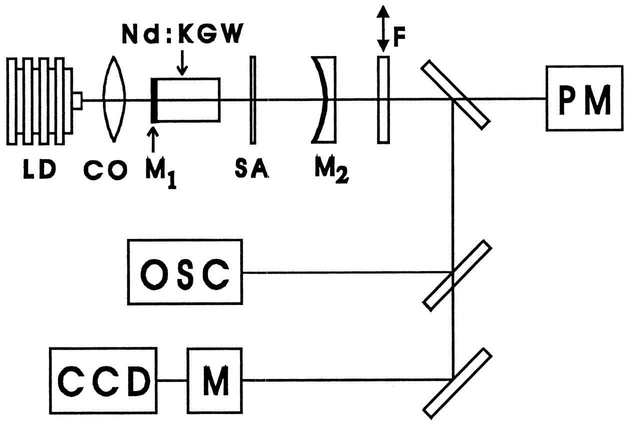

Fig. 1. Experimental setup. LD is laser diode, CO is coupling optics, M_1 and M_2 are cavity mirrors, F are spectral filters, CCD is CCD-array, M is monochromator, PM is power meter, OSC is digital or fast oscilloscope.

The optical pump system was composed of a triplet collimator with the 0.5 numerical aperture, 4.5^x two cylindrical lenses: a telescope for compensation of astigmatism and a spherical lens ($f=10$ mm) for focusing the pump beam to a circular spot with a diameter of about 100 μm. After the focusing system, the pump power was measured to be up to 800 mW. The laser cavity was configured to be semi-spherical, and was formed by the flat mirror M_1 and the 50 mm curvature radius mirror M_2. Mirror M_1 was deposited on the input facet of the Nd:KGW crystal for high reflectivity at 1.067 μm (99.9%) and at 1.181 μm (99.5%), and high transmission at 0.81 μm (95%). The reflectivity of the mirror M_2 was similar to that of M_1. The output facet of the 10-mm Nd:KGW rod with Nd^{3+} concentration of 4% and oriented along the (010) crystallographic axis was antireflection-coated at 1.067 μm and 1.181 μm wavelengths.

The Cr^{4+}:YAG saturable absorber with the 90% initial transmission at 1.067 μm was placed in the cavity to obtain Q-switching. This provided a train of pulses at 1.067 μm with a duration decreasing from 60 to 25 ns and a repetition rate increasing from 8 to 29 kHz as the pump level was increased. The 1.067 μm intracavity power in the Q-switched operation mode was found to be high enough to initiate SRS. Fig. 2 presents the spectral lines observed in the Raman laser output. Spectral lines shifted from the 1.067 μm line by the Raman shift frequency 901 cm^{-1} are indicative of SRS generation at the Stokes and anti-Stokes wavelengths. The Stokes and pump spectral lines, measured by an average over more than 100 pulses, had approximately the same bandwidths. The Raman threshold corresponded to the 230 mW incident laser diode power thus allowing the low-threshold operation. The maximum Stokes power was 9.8 mW, when the 1.067 μm output power was 4.8 mW (Fig. 3). This yields a value of about 0.7% for the conversion of the incident laser diode power to the Stokes power. The duration of Stokes pulses at the 1.181 μm wavelength was changed from 40 to 23 ns

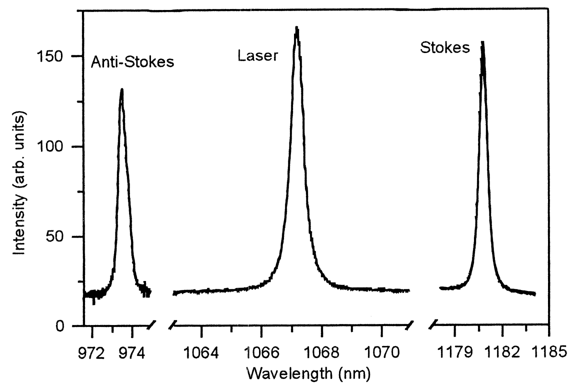

Fig. 2. The output radiation spectrum.

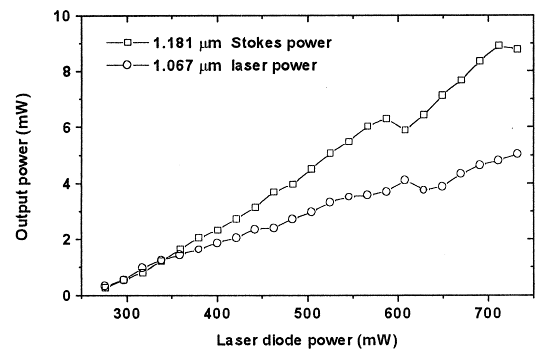

Fig. 3. The output power of the 1.181 μm Stokes radiation and the 1.067 μm laser radiation vs. the 0.81 μm laser diode power.

with increasing pump power. The spectral filters were used to separate either the 1.067 μm or 1.181 μm radiation.

When the Raman laser was under operation a blue luminescence (Fig. 4) in the space channel of laser generation was observed by the naked eye. This blue light may be associated with up-conversion processes shown in Fig. 5. The starting level for up-conversion is the metastable $^4F_{3/2}$ level. The neodymium ions are excited to $^4F_{5/2}$ level by the 810 nm cw laser diode pump radiation with following non-radiative decay to the $^4F_{3/2}$ level. Further, the transition to $^4F_{5/2}$ level takes place under resonance interaction with phonons (901 cm^{-1}) generated

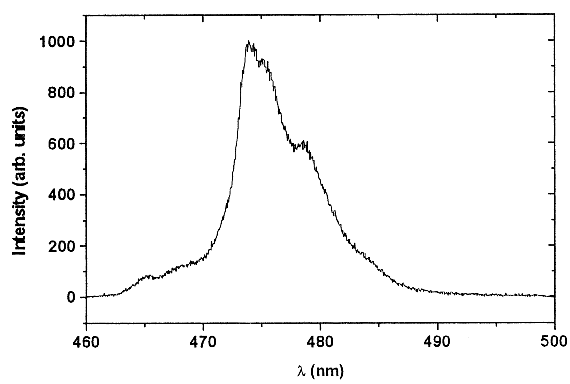

Fig. 4. The blue fluorescence spectrum.

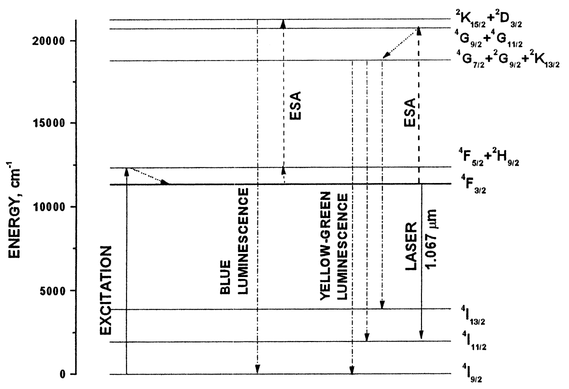

Fig. 5. The partial energy level diagram of Nd:KGW laser crystal with the blue and green-yellow up-conversion schemes.

in crystal during stimulated Raman process. The ESA transition $^4F_{5/2} \rightarrow ^2K_{15/2} + ^2D_{3/2}$ is realized due to 1.067 μm photon absorption. Blue luminescence in the range of 460–490 nm is due to the $^2K_{15/2} + ^2D_{3/2} \rightarrow ^4I_{9/2}$ transition. In the condition where Raman laser action was absent the up-conversion yellow-green luminescence in Nd:KGW crystal took place [17].

3. Conclusions

In conclusion, the operation of an all solid-state diode pumped Raman laser with self-frequency conversion has been demonstrated. This system is compact and efficient. The conversion efficiency and output Stokes power can be increased through the optimization of the Raman laser cavity. Blue up-conversion luminescence in Nd:KGW crystal under simultaneous 1.067 μm laser action and Raman generation is observed.

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