$Nd:GdVO_4$ self-Raman Laser emitting at 994 nm

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Abstract: 1st Stokes laser emission is demonstrated at 994 nm by shifting the Neodymium 914 nm quasi-three level laser emission using a $Nd:GdVO_4$ crystal in a self-Raman configuration. In addition, another laser line was observed at 961 nm which competes with the 914 nm fundamental laser oscillation. This other line is apparently originated by another rare-earth found as impurity in the crystal.
OCIS codes: (140.3550) Lasers, Raman; (140.3580) Lasers, solid-state; (140.3530) Lasers, neodymium.

1. Introduction

Solid-state crystalline Raman lasers have been developed for the past 10 years. Since then, the main venue for this development was focused on the 1 μm Neodymium transition ($^4F_{3/2}\rightarrow^4I_{11/2}$), which is shifted to the 1.1 μm spectral region, using different combination of Raman and laser crystals. Multi-Watt level output powers were obtained at different wavelengths, such as 1147 nm (KGW) [1], 1173 nm ($GdVO_4$) [2], 1180nm ($BaWO_4$) [3] and 1217 nm (diamond) [4]. The major interest in this type of lasers is due their frequency doubled version that creates yellow-orange lasers [2], which have important applications in ophthalmology and astronomy.

In recent years, this technology has migrated to other laser transitions, and there are research groups investigating Raman lasers operating at 1.5 μm using the 1.3 μm Nd^{3+} transition ($^4F_{3/2}\rightarrow^4I_{13/2}$) [5]. Furthermore, Raman lasers based on Yb^{3+} transitions have been shown [6], which might be the next high power solid-state Raman laser generation.

However, Neodymium has another interesting transition not explored in Raman lasers, which is at 0.9 μm ($^4F_{3/2}\rightarrow^4I_{9/2}$). This transition has already demonstrated its potential, reaching CW output powers of up to 15 W [7]. When frequency doubling this line, blue lasers can be obtained such as $Nd:GdVO_4$ (456 nm), Nd:YAG (473 nm), Nd:YLF (454 nm). In addition, for Raman lasers the gain increases linearly for shorter wavelengths [8] which is one more reason to explore this transition combined with Raman technology.

Given the fact that the $Nd:GdVO_4$ crystal demonstrated very good performance for the 0.9 mm transition when compared to other crystals in the literature (slope efficiency of 67% [9]), and given that it is Raman active (g_R> 4.5 cm/GW) [8], it presents an excellent choice for shifting the 914 nm emission to its 1st Stokes at 994 nm.

This wavelength can be used for spectroscopic applications where very specific laser lines are required. If frequency doubled, this laser is going to operate at 497 nm in the blue-green visible range where there are few available lasers sources and therefore it would represent a welcome substitute for the bulky and cumbersome ion-Argon lasers which has very low efficiency (~0.1% at its main line, 514 nm) and expensive maintenance.

In this work, we demonstrate a $Nd:GdVO_4$ self-Raman laser operating at 994 nm, which is for the best of our knowledge the first time a Raman laser is demonstrated using the 0.9 μm Nd^{3+} transition.

2. Experimental setup

A linear laser cavity with a longitudinal pump configuration was used to obtain laser action of the 1st Stokes at 994 nm. The pump system is composed of a 50 W fiber-coupled diode laser (Apollo Inc.) emitting at 808 nm with a 100 μm core diameter fiber (N.A. of 0.22), a 35 mm focal length collimating lens and a 80 mm focal length focusing lens. This system delivered a pump waist (radius) of 135 μm at the crystal position. The optical resonator setup employs a pump mirror with a radius of curvature (ROC) of 350 mm, a 3x3x4.8 mm^3 $Nd:GdVO_4$ crystal with Nd^{3+} doping concentration of 0.1at% and an output mirror that was directly coated on one of the Laser facets of the crystal (O.C.). All coatings specifications of the mirrors and the crystal are shown in Table 1. The resonator was 10 mm long (240 μm mode size-diameter), and the complete laser setup is shown in Figure 1.

Spectroscopic measurements were performed to characterize the emission profile of the crystal under lasing and non lasing conditionsusing two different fiber coupled spectrometers: one for the infrared range (Ocean Optics, model HR4000) and one for the visible range (Ocean Optics, model HR2000).

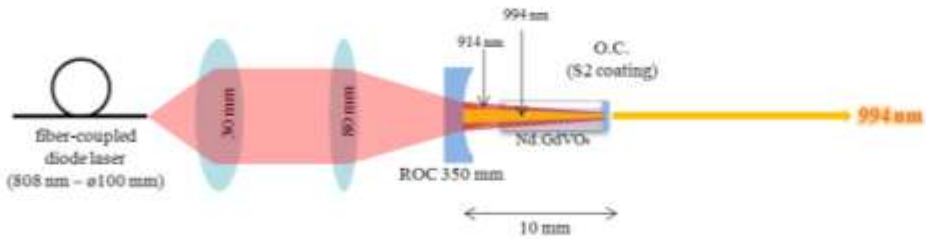

Fig. 1. 994 nm Raman laser setup.

Table. 1. Mirror and crystal coatings.

Reflectivity – R%		
Input mirror	**S1 crystal face coating**	**S2 crystal face coating**
R>99.9% at 914-995nm R<10% at 808nm+1064nm R<30% at 1311nm-1340nm	**R<99.9% at 914-995nm** R<1% at 808nm+1064nm R<1% at 1311nm-1340nm	**R=99.6% at 994nm** **R>99.9% at 914nm** R<20% at 1064nm R<5% at 1311nm-1340nm

3. Results

CW laser action was obtained at 994 nm with very low output powers (few μW). Figure 2 shows the measured spectrum of the residual laser emission at 914 nm together with the 1st Stokes laser emission at 994 nm.

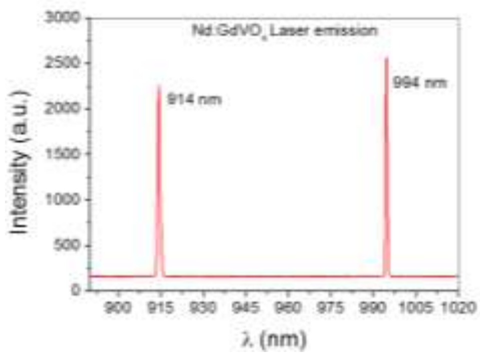

Fig. 2. Fundamental laser and 1st Stokes laser lines.

Due to the very low power, no output power curve was collected at this time. While the optimizing process was being performed, another laser line was observed at 961 nm. This emission line is not expected to be seen amongst the Nd^{3+} ion transitions. We suppose that it is an impurity, probably some other rare earth ion (e.g. Er^{3+}, Yb^{3+}, Tm^{3+}), which was introduced during the growth process contaminating thereby the crystal.

In order to find the origin of this emission, spectral characterization under lasing and non lasing conditions were made in the near infrared and visible ranges. The results are shown in Figure 3(a) for the near infrared and Figure 3(b) for the visible range.

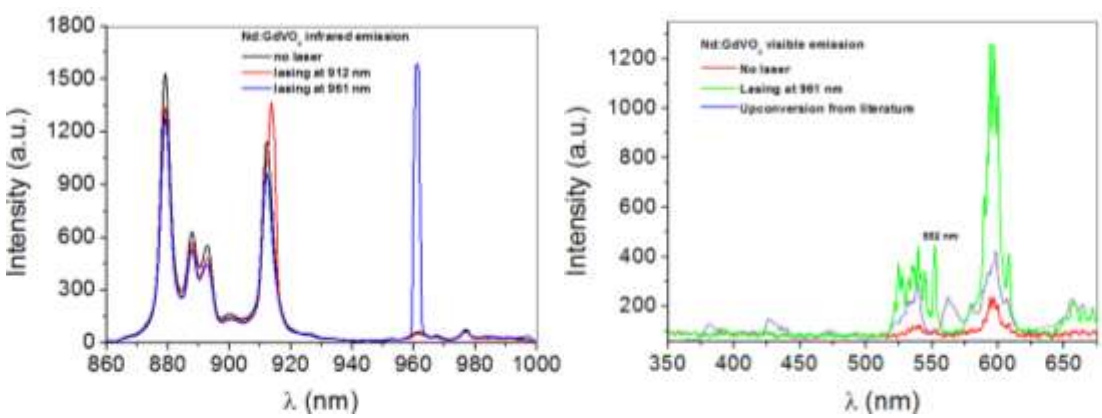

Fig. 3. Emission spectra of the $Nd:GdVO_4$ crystal (a) in the near infrared and (b) in the visible.

The emission characteristics during three different operating conditions were registered: one with no lasing at all, one with laser action solely at 914 nm and another with laser action solely at 961 nm (see Fig. 3a). In all three curves it is possible to observe an emission band at 960-990 nm. Based on this result, a search for rare-earths with similar emission bands has to be made. Er^{3+} and Yb^{3+} are strong candidates. For the visible spectra two curves were recorded, one with no laser and another with 961 nm laser action. In this case, an emission line at 552 nm is observed, which is not observed in the upconversion spectra of the Nd:$GdVO_4$ crystal collected in Ref. [10]. On the other hand, this is corresponds exactly the position of a green emission line of Er:$GdVO_4$ measured in Ref. [11]. These are observations that support the presence of Er^{3+} impurities in the crystal, which is further corroborated by the fact that Er^{3+} ions are very small and therefore may easily contaminate laser crystals.

More measurements need to be carried out to fully determine the origin of this laser emission, such as lifetime and emission characterization in between 1 μm and 2 μm, where Er ions have very specific emission bands.

Another interesting observation is with respect to the polarization of the laser emissions at 914 nm and at 961 nm. The first one is π-polarized, while the 961 nm is σ- polarized. This means that if an intracavity polarizer is introduced, it is possible to select 961 nm or 914 nm oscillation.

Finally, the laser oscillation at 961 nm was probably only observed in this work, and not in other similar reported lasers that might contain the same impurities, because of the very low resonator losses used here. The very high reflectivity band of the mirrors and very low reflectivity crystal AR-coatings that extend from 912 nm to 995 nm enhance any possible lasing transition within this range.

4. Conclusion

Raman laser action was demonstrated at 994 nm using a Nd:$GdVO_4$ self-Raman laser operating at the 914 nm quasi-three level transition. Optimization of the laser is still in progress in order to get measurable output power. During the Raman laser action, another laser oscillation at 961 nm was observed and competed for the gain with the 914 nm fundamental laser, which is one of the reasons of the low output power of the 1st Stokes laser. A first characterization showed the emission might be originating from Er^{3+} impurities. At last, one first approach to avoid the competition between the laser lines is the use an intracavity polarizing optics (e.g. Brewster window), since these laser transitions presented orthogonally oriented polarizations.

5. References

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