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Comparative laser study of Nd:KGW and Nd:YAG near 1.3 μm

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Abstract. A comparative study of Nd:KGW and Nd:YAG laser crystals pumped by flashlamp has been conducted near 1.3 μm with output energy up to 1 J and at a repetition rate up to 50 Hz. An average power of 23 W for KGW in free-running mode was achieved with a total efficiency better than 2.8 % for the Nd:KGW and 1.8 % for the Nd:YAG.

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Laser emission has been observed in a variety of Nd host crystals such as garnet or yttrium composite. Up to now, the best material (considering efficiency, average power, divergence and thermal lensing) under flashlamp pumping has always been Nd:YAG despite the rather low value of Nd dopant concentration (about 1 at·%). The problem with YAG is that a high concentration of Nd causes local distorsion of the host crystal due to the mismatch in size of the ionic radius of Y3+ and Nd3+. This difference between the two ions may be minimized by replacing Y3+ by Gd3+ . Nd concentration as high as 3–7 at·% have been obtained in a neodynium doped gadolinium tungstate KGd(WO4)2 or KGW. This crystal was tested for the first time under flashlamp-pumping by Kaminskii and al.[1]. Better results were more recently obtained in both free-running and Q-switched mode [2–4]. A maximum average output power of 61 W and 22 W, with an efficiency as high as 6% and 3%, respectively in free-running and Q-switching mode, have been obtained in our laboratory [5–6]. All these results were measured at the usual emission wavelength of 1.06 μm. Some experiments at a wavelength of 1.35 μm were recently presented but only under diode-pumping [7] and then a comparison with a Nd-YAG crystal under similar pumping conditions has shown that the KGW crystal gave sligthly better results than YAG at this wavelength, while there was no evident difference of efficiency between KGW and YAG at 1.06 μm, except for the threshold which was lower for KGW [8]. Today there is a big interest from medical device manufacturers for a high effeciency 1.3 μm laser source, preferably pulsed. For this purpose, flashlamp pumping schemes have been used to produce the 1.3 μm laser radiation in Nd:YAG, Nd:YLF and Nd:YALO crystals [9–11]. We decided to test also the laser emission at 1.35 μm of the Nd ion in KGW (see Table 1). In Fig. 1 we display the fluorescence spectra of the and Nd:KGW around 1.06 and 1.3 μm. By comparison with a similar curve given for Nd:YAG [8], it is clear that the emission feature in the Nd:KGW is much wider than in Nd:YAG. We note too that the relative intensity of this radiation is much higher than that in Nd:YAG. So we can expect a better laser efficiency from KGW and we tested the two crystals ; the results from the Nd:KGW have been compared with those of Nd:YAG under identical experimental conditions. In each cases, the laser efficiency from Nd:KGW was found to

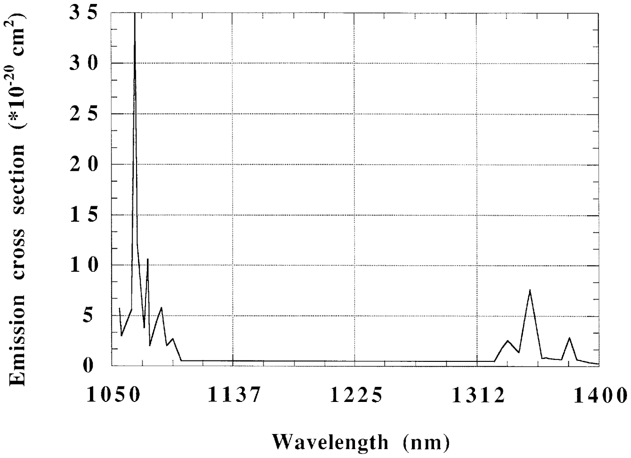

Fig. 1. Fluorescence spectra of ND:KGW around 1.06 and 1.3 μm

Table 1. Comparative properties of Nd: doped YAG and KGW

	Nd:YAG	Nd:KGW
Fluorescence lifetime (10^{-6} s)	230	120
Transition wavelength (nm)	1064 1320	1067 1350
Emission cross-section (10^{-19} cm^2)	3.5 at 1.06 μm 0.9 at 1.3 μm	3.3 at 1.06 μm 0.76 at 1.3 μm
Thermal conductivity (W m^{-1} °K^{-1})	9.76	3.8
Thermal lensing (δ/kW)	0.5	-1.5

be much higher than that from Nd:YAG to the difference of diode-pumping.

Experimental setup

In our experiment, we use two laser rods (Nd:KGW and Nd:YAG) of 6.35 mm in diameter and 75 mm in length. They have flat and parallel end faces which are anti-reflection coated at 1.06 μm. The neodymium concentration is respectively around 3% for the Nd:KGW rod and 1% for the Nd:YAG rod (as indicated by the manufacturers). The suppliers are Marenna Co (Bremen, GERMANY) for the KGW and Crismatec (Grenoble FRANCE) for the YAG. As noted before, the crystals are AR coated for 1.06 μm and we have no estimation of their reflectivity at 1.34 μm.

The two laser rods are pumped in the same conditions with a single flashlamp close- coupled laser head with a diffuse reflector.This laser head is a commercial model from KIGRE Inc (FE354KK) with an internal samarium-doped UV filter and cerium-doped flashlamp to avoid any solarization. The laser resonator consists of a high reflectivity concave mirror (99.9% at 1.3 μm) with a radius of curvature of 1 m and a flat or curved output coupler with a reflectivity of 70%.

To initiate the flashlamp we use a specially designed multiple-mesh network made of 8 identical L-C cells for a total capacitance of 32 μF and a total inductance of 112 μH. These cells can be connected in series or in parallel to obtain the desired discharge pulse duration. We can choose a pulse duration between 60 and 120 μs and in these experiments we use a pulse duration of 120 μs, close to the fluorescence lifetime of Nd:KGW (110–120 μs). To increase the flashlamp lifetime and to improve both laser energy stability and efficiency we use a low current (50 mA) cw simmer supply. We test the laser emission with up to 40 J of pumping energy and up to 50 Hz for the repetition rate.The pumping energy and repetition rate are in fact limited by our 1500 J/s capacitor-charging power supply.

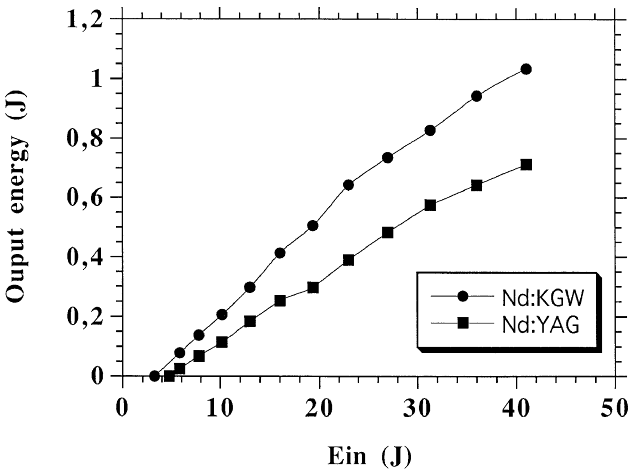

Fig. 2. Output energies of Nd:KGW and Nd:YAG near 1.3 μm vs. pump energy

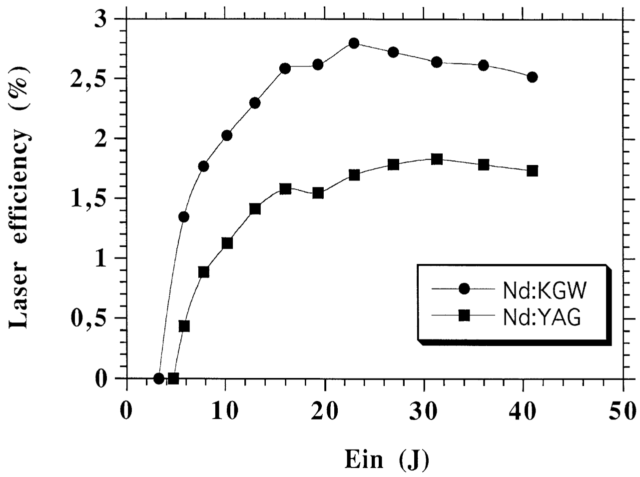

Fig. 3. Electrical to optical laser efficiencies for Nd:KGW and ND:YAG near 1.3 μm vs. pump energy

Results

Our first goal was to compare the laser performance of the Nd:YAG and the Nd:KGW crystal rods under identical experimental conditions, except the neodymium concentration, near 1.3 μm. By using the experimental elements described before, we obtained laser emission at 1.35 and 1.32 μm: on Fig. 2, we display the output energy of the laser for the Nd:KGW and the Nd:YAG . It is clear from this figure that the Nd:KGW is much more efficient than the Nd:YAG. The slope efficiencies are 2.8% for the KGW and 1.8% for the YAG. The thresholds for the laser emission are respectively 3.2 J and 4.7 J for each material. In other terms, the slope efficiency is 55% higher and the threshold 32% lower for the KGW as compared to YAG. The maximum output energies we have obtained are superior to 1 J with 41 J of pump energy for the Nd:KGW and 0.7 J with the same input energy for the Nd:YAG. The Fig. 3 presents the laser efficiency versus the pump energy for the two rods. The highest efficiency is obtained with an input energy of 23 J for the KGW and 31 J for the YAG, the values of the total efficiency are also 2.8% and 1.8% for each rod.

Due to the very high gain of Nd:KGW on the 1.06 μm line, it is important to verify if the laser power is not the sum of the emissions at 1.06 and 1.34 μm. For that we have set before our detector a calibrated $R_{\max}$ mirror at 1.06 μm. We noted a drop of only 8% in the transmitted power due partly to the Fresnel reflection on the rear face of the mirror which was not AR coated, the remaining value (about 4%) being certainly due to the reflectivity of this mirror at 1.34 μm. We have also measured the reflectivity of our 1.34 μm mirrors at 1.06 μm and we have obtained a reflectivity of 6% for the $R_{\max}$ mirror and 12% for the output coupler. Here again a part of these values is given by the Fresnel reflection on the rear faces of the mirrors which are not AR coated for 1.06 μm. This proves that all the output of our laser is made of the 1.34 μm line only.

As a comparison we can give the results we have obtained with the same crystals with similar experimental conditions but at 1.06 μm [6]. At that wavelength, the slope efficiencies are respectively 6% for KGW and 4% for Nd:YAG in free-running mode. We can note that the advantage of KGW over

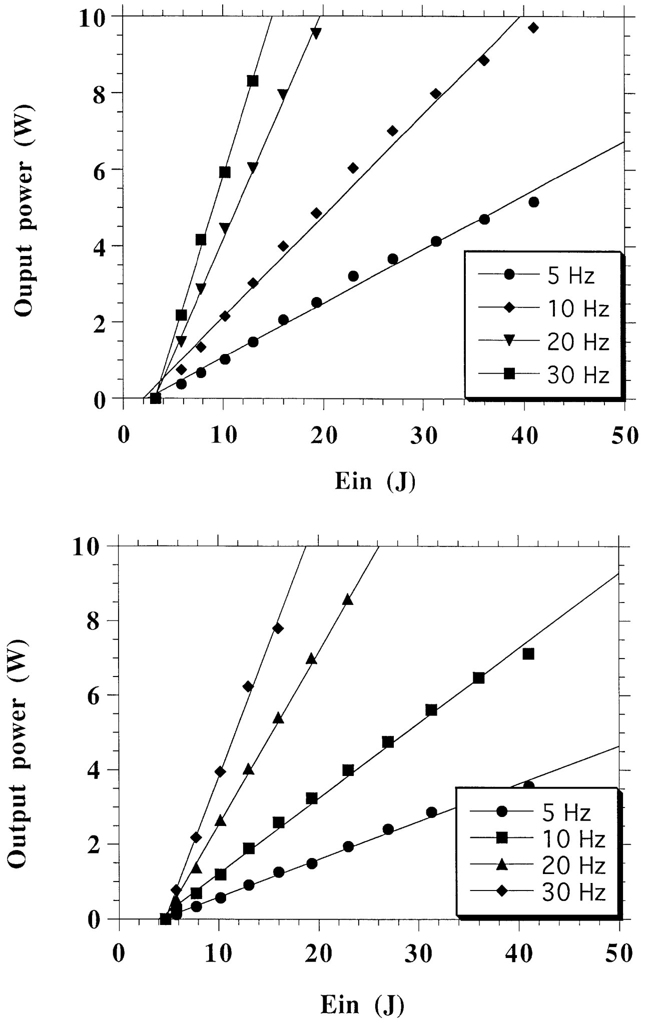

Fig. 4. Output power vs. pump energy at various repetition rates for **a** Nd:KGW; **b** Nd:YAG

YAG is quite the same at the two wavelengths and that the efficiency at 1.35 μm is not far from the half of the corresponding one at 1.06 μm, a higher value than the expected one by considering the relative cross-sections at these two wavelengths, as presented in Table 1.

Our second goal was to test the stability of the laser emission at different repetition rates from 5 to 50 Hz in order to see the effects of thermal effects under strong pumping. The Figs. 4 a) and b) present the results for the two neodymium doped materials. For the Nd:KGW we obtain a maximum average output power of 10 W at 10, 20 and 30 Hz with respectively, 40, 20 and 15 J of pump energy which corresponds to an average pump power of 450 W. In the case of the Nd:YAG we obtain at the same repetition rate and the same input energy around 7 W of average output power. We observe a lower beam divergence for the Nd:YAG laser due to the much higher thermal conductivity of YAG . In Table 1 we notice a dioptric power three times higher for the KGW that for the YAG as obtained from [6]. This strong difference between the two laser crystals leads to the high divergence of the KGW laser beam. To compensate for this thermal effect we use a convex output mirror with a 58 cm radius of curvature replacing the plane mirror. The best results in efficiency and stability are obtained with this configuration at high pumping power. The maximum average output power is 23 W at a 30 Hz repetition rate; above this value, the resonator becomes unstable and we note instabilities and a drop of output power.With this mirror, a large improvement of the beam quality without losses in ouput power was observed and the stability of the laser cavity was enhanced. On Fig. 5 we presents the results obtained at repetition rates up to 50 Hz and a maximum pump power of 1200 W. We have then obtained an average output power of 23 W. We have tested two similar Nd:KGW rods and the results are exactly the same. Further experiments will be conducted with different output mirrors with other radii of curvature and reflectivity.

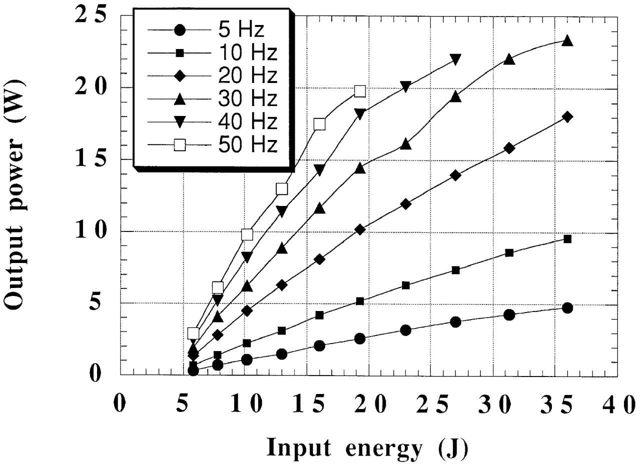

Fig. 5. Output power vs. pump energy for Nd:KGW with pump powers up to 1200 W

In conclusion, we have studied the laser emission of the Nd:KGW at 1.35 μm in free-running mode under flashlamp-pumping. The results from the Nd:KGW have been compared with the Nd:YAG at similar experimental conditions. The electrical to optical and slope efficiencies were determined to be around 2.8% and 1.8% for the Nd:KGW and the Nd:YAG respectively. The loss in efficiency between 1.35 and 1.06 μm is not as high as expected since we obtain at 1.35 μm almost 50% of the corresponding value at 1.06 μm. Some significant increase in the efficiency and output power can moreover be expected by using laser rods with suitable AR coatings. The Fresnel losses on the crystal faces are very high, about 11% per face, due to the high value of Nd:KGW index of refraction (about 2). We have observed that is easy to compensate the low thermal coefficients in the KGW to obtain a beam quality as high as in the Nd:YAG. We have obtained output power in the range of the 20 W while maintaining a good beam quality. Future experiments will be made in Q-switched mode in order to test different frequency doublers with high conversion efficiency to dispose of a performing laser source either in the infra-red or in the visible spectrum.

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