Self-Q-switched diode-end-pumped Cr,Nd:YAG laser with polarized output

Shiqun Li, Shouhuan Zhou, Pei Wang, and Y. C. Chen

Department of Physics and Astronomy, Hunter College, City University of New York, 695 Park Avenue, New York, New York 10021

K. K. Lee

Department of Electrical and Computer Engineering, University of Colorado, Colorado Springs, Colorado 80933

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We report self-Q-switching operation of a miniature diode-end-pumped Cr,Nd:YAG laser in which the chromium ions act as a saturable absorber for the Nd^{3+} laser emission at 1064 nm. The laser output is highly polarized, with an extinction ratio of 600:1. The use of laser host crystal doped with saturable absorber can lead to the development of monolithic Q-switched solid-state lasers.

Passive Q switching of solid-state lasers is usually accomplished with organic dyes or color centers as the saturable absorber. Dyes, however, have poor thermal stability and tend to degrade rapidly. To operate in cw-pumped lasers, dyes require a circulation system. Color centers, such as the color-center LiF crystal,[1–3] exhibit a fading phenomenon that may limit the period of reliable operation. Recently, the chromium-doped host crystals, such as yttrium aluminum garnet (YAG), gadolinium scandium gallium garnet (GSGG), and forsterite, are reported to exhibit color-center-like saturable absorption at the Nd^{3+} laser wavelength at 1064 nm.[4–7] The absorption now is believed to be associated with Cr^{4+}.[7,8] Chromium-doped forsterite has been used to realize passive Q switching and mode locking in a Nd:YAG laser.[6] Passive Q switching in flash-lamp-pumped Cr–Nd-codoped YAG and GSGG lasers has also been demonstrated.[4,5]

In this Letter we report a self-Q-switching operation in a miniature diode-end-pumped Cr,Nd:YAG laser. By using the laser host crystal codoped with saturable absorbers, the functions of the gain medium and the saturable absorber are combined into one. This can lead to the development of monolithic Q-switched solid-state lasers. We have also observed a highly polarized output with an extinction ratio of 600:1.

The room-temperature absorption spectrum of Cr,Nd:YAG is shown in Fig. 1. The absorption feature in the visible region is similar to those of Cr^{3+},Nd:YAG[9] and chromium-doped YAG.[10] The sharp lines at 0.53, 0.59, 0.75, 0.81, and 0.88 μm are attributed to Nd^{3+} ions. The broad absorption bands centered at 0.43 and 0.59 μm are attributed to the ${}^4A_2$–${}^4T_1$ and ${}^4A_2$–${}^4T_2$ transitions of Cr^{3+}.[9] The band from 900 to 1200 nm is believed to be caused by Cr^{4+} ions.[7,8] The absorption coefficient is 5.25 cm^{-1} at the pumping wavelength of 808 nm and is 0.32 cm^{-1} at 1064 nm. With the pump and probe method, the saturation intensity at 1064 nm is 3.6 MW/cm^2. Thus, this absorption loss can be easily saturated with an intracavity power of 100 W in a diode-end-pumped Nd:YAG laser if the spot diameter at the absorber is 50 μm. We have no data on the recovery time of the saturable absorber. Because laser action at 1.4 μm, pumped by 1.06 μm, has been demonstrated in Cr^{4+}:YAG,[10] the saturable absorber is believed to be long lived. The lifetime of the luminescence at 1.4 μm, emitted by the absorber, is 8 μs.

To demonstrate the effect of saturation, we performed a test by replacing the total reflector of a Quantronix 114 cw flash-lamp-pumped Nd:YAG laser with a 1-mm-thick Cr,Nd:YAG mirror with antireflection coating in the front and high reflectivity in the back. The cw laser generates a train of Q-switched 400-ns-long pulses with a repetition rate of 10 kHz and an average power of 2 W. This YAG mirror has been subjected to continuous passively Q-switched operation at an intracavity power density of 10 MW/cm^2 for the possible fading phenomenon commonly observed in the color-center materials. After 6 h of operation, no apparent degradation of performance is detected.

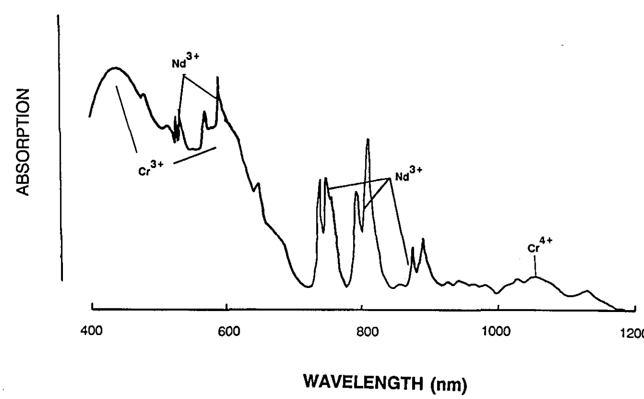

Fig. 1. Room-temperature absorption spectrum of Cr,Nd:YAG.

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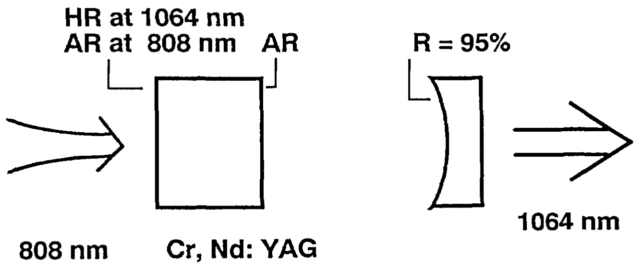

Fig. 2. Experimental setup of self-Q-switched diode-end-pumped Cr,Nd:YAG laser. HR, highly reflecting; AR, antireflecting.

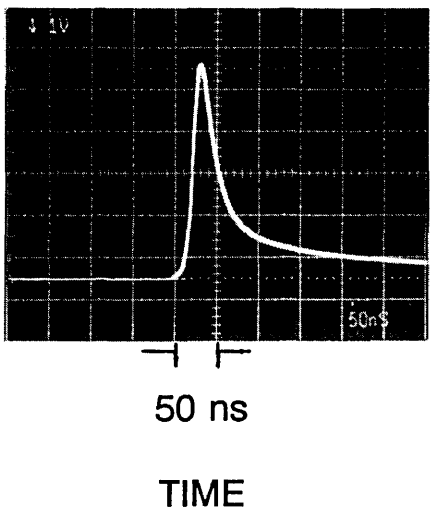

Fig. 3. Self-Q-switched laser pulses with a pulse energy of 3 μJ and a FWHM duration of 30 ns. Traces are taken with 200 shots.

Figure 2 is a schematic of the diode-end-pumped laser cavity. The pump source is an AlGaAs/GaAs single-quantum-well laser with a 60-μm stripe width emitting at 810 nm. The end surface of the YAG rod facing the diode laser is coated for high reflection at 1.06 μm and high transmission at 809 nm. A spherical concave mirror with 95% reflection and 5-cm radius of curvature is used as the output coupler. The overall cavity length is 4.7 cm. The diode-laser output, after beam shaping with a pair of cylindrical lenses, is focused onto a spot with a diameter of 50 μm. The diode laser is operated in the quasi-cw mode, with 300-μs pulse duration at a repetition rate of 100 Hz to avoid the degradation of the diode laser.

With a regular Nd:YAG gain medium, the threshold pumping power is 40 mW. The slope efficiency is 40%. With Cr,Nd:YAG as the active medium, the laser Q switches. The threshold pumping power is raised to 300 mW. Figure 3 shows a typical Q-switched pulse shape with a single-transverse-mode energy of 3 μJ and a FWHM duration of 30 ns. The peak power is estimated to be ~100 W. The clean oscilloscope traces in Fig. 3, taken with 200 shots, show that the shot-to-shot intensity fluctuation is quite small.

In contrast to conventional Nd:YAG lasers whose output is unpolarized, the Cr,Nd:YAG laser output is polarized with an extinction ratio of 600:1. However, we detected no measurable anisotropy in the absorption coefficient at 1064 nm. The mechanism of the polarized output is still under investigation.

In this study, we made no attempt to increase the pulse energy or to shorten the pulse duration. Because the dopant concentration and crystal thickness can alter Q-switching characteristics, substantially higher pulse energy and shorter pulse duration can be achieved by using thicker absorber crystal and/or higher doping concentration.

From the absorption spectrum, it is important to note that there are many more absorption bands in the visible and UV for the chromium-doped material than for the Nd:YAG alone. Thus the codoped material is most suitable for diode pumping. In fact, diode pumping of the codoped material has the advantage of the saturable absorber to induce Q switching and possibly mode locking, while avoiding the problem of additional thermal loading if pumped by flash lamp.[4]

In conclusion, we have demonstrated a self-Q-switched diode-pumped Cr,Nd:YAG laser with polarized output. A compact monolithic self-Q-switched diode-end-pumped Cr,Nd:YAG is also under investigation.

Shiqun Li is on leave from Tsinghua University, Beijing, China.

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