Monolithic self-Q-switched Cr,Nd:YAG laser

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We report the operation of a diode-pumped monolithic self-Q-switched Cr,Nd:YAG laser in which the codoped ions create saturable absorption for Nd^{3+} laser emission at 1064 nm. With a 70-μm beam diameter in the gain medium, the Q-switched pulse has a duration of 3.5 ns and a peak power of 2 kW. The output is linearly polarized with an extinction ratio of 600:1. The pulse-to-pulse intensity fluctuation is less than the instrument resolution of 0.25%. A 5-mm-long KTP crystal butted against the monolithic cavity produces 2-ns-long pulses at 532 nm with a peak power-conversion efficiency of 30%.

Recently, chromium-doped host crystals, such as gadolinium scandium gallium garnet, forsterite, and yttrium aluminum garnet (YAG) were found to exhibit saturable absorption in the 900–1200-nm range.[1–3] The absorption has color-centerlike characteristics and is believed to be associated with the Cr^{4+} ions.[4,5] Cr-doped forsterite has been used to realize passive Q switching and mode locking in Nd:YAG lasers.[2] When YAG and gadolinium scandium gallium garnet host crystals are codoped with Nd and Cr, the functions of the gain medium and the saturable absorber are combined. This result has led to self-Q-switched operation.[1,3] The output of the Cr,Nd:YAG crystal is linearly polarized without any polarizing optics in the cavity.[3]

In this Letter we report the operation of a diode-pumped monolithic self-Q-switched solid-state laser that is based on Cr,Nd:YAG. Our purpose is to demonstrate a compact, efficient, highly polarized, and highly stable Q-switched laser. The applications of Q-switched lasers are well known: lidars, remote sensing, pollution detection, nonlinear-optical processes, and material processing. Pulse-to-pulse stability is also important for measurement accuracy.

The device configuration is illustrated in Fig. 1. A Cr,Nd:YAG crystal is polished to a planar–concave geometry. The concave mirror has a radius of curvature of 80 mm and is coated for high transmission at 808 nm and total reflection at 1064 nm. The planar surface is coated for 95% reflection as the output coupler. The misalignment of the axes of the two mirrors is measured to be less than 0.3°. The absorption coefficient is measured to be 5.25 cm^{-1} at the pumping wavelength of 808 nm, which is typical of a 1 wt.% Nd:YAG. Because both Cr^{3+} and Cr^{4+} are present in the absorption spectrum,[3] the concentration of the absorbers is not known, although absorption loss at 1064 nm is 0.32 cm^{-1} at low power. The saturation power density at 1064 nm was measured previously to be 3.6 MW/cm^2.[3] Thus this absorption can easily be 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. With end pumping, the pumping power is mostly depleted within the 3-mm length in the front end of the crystal facing the pump source, and the saturable loss is evenly distributed throughout the length. A longer crystal is expected to result in shorter pulses and higher threshold. As a compromise between the available pumping power and high peak power, we chose the cavity length to be 6 mm. The pump source is an AlGaAs/GaAs single-quantum-well laser emitting at 808 nm.[6] The diode laser output, after beam shaping, is focused onto a 50-μm spot at the gain medium. With this configuration, the threshold pumping energy is measured to be 270 μJ (=900 mW × 300 μs). Approximately 95% of the pumping energy is absorbed in the gain medium. To extend the lifetime of the diode laser, we took all measurements reported in this Letter with 300-μs square pulses at a repetition rate of 100 Hz.

Figure 2 is a photograph of the traces of 200 Q-switched pulses with a single transverse-mode energy of 7 μJ and a FWHM duration of 3.5 ns. The input energy at 808 nm is 270 μJ. To the best of our knowledge, this pulse is the shortest passively Q-switched laser pulse ever generated in a Nd:YAG laser. The corresponding peak power is 2 kW.

The Q-switched laser pulse is linearly polarized along either of the two mutually orthogonal axes with an extinction ratio of 600:1. By rotating the polarization of the pumping beam, we can switch the laser's polarization between the two axes. The crystal used in this experiment exhibits neither birefringence nor anisotropic transmission for low levels of light intensity. The polarized laser output is probably caused by the anisotropy in the saturation power of the absorber. This effect is still under investigation.

Because the dopant concentration, crystal length, and cavity Q value can alter the Q-switching char-

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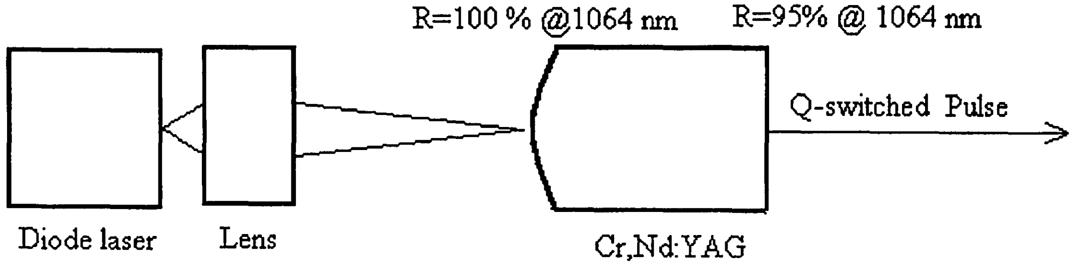

Fig. 1. Schematic of a diode-pumped monolithic self-Q-switched Cr,Nd:YAG laser.

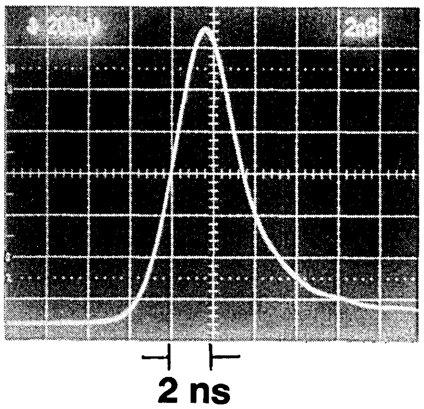

Fig. 2. Self-Q-switched laser pulses with a pulse energy of 7 μJ and a FWHM duration of 3.5 ns. The trace is the superposition of 200 pulses.

acteristics, substantially higher pulse energy can be obtained by use of a longer crystal, higher concentration of saturable absorber, and larger beam cross section.

Although Q-switched lasers generally have larger intensity fluctuations, we have found that the Q-switched pulse amplitude is extremely stable. The pulse-to-pulse intensity fluctuation is less than the instrument resolution of 0.25%, which merely reflects the small fluctuation of the baseline of the oscilloscope traces. This unprecedented stability is attributed to the stable pump beam and the cavity that is free from mechanical vibrations. No deterioration in intensity stability was detected over a continuous 4-h testing period.

The power density of 54 MW/cm^2 at the output mirror is high enough for efficient second-harmonic generation without any focusing lens. Using a 5-mm-long KTP crystal proximity-coupled against the monolithic cavity, we have generated 2-ns-long linearly polarized pulses at 532 nm with a peak conversion efficiency of 30% for 7-μJ, 3.5-ns Q-switched pulses.

In conclusion, we have demonstrated the operation of a monolithic self-Q-switched diode-pumped Cr,Nd:YAG laser with polarized output. A diode-pumped monolithic laser has the following virtues: it is compact, rugged, efficient, and stable. The device is expected to find wide applications in lidar, remote sensing, nonlinear-optical processes, and material processing.

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