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Picosecond laser pulse generation in a monolithic self-Q-switched solid-state laser

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Abstract

We report the generation of laser pulses of 290-ps duration with 8-μJ pulse energy in single longitudinal mode and single transverse mode in a diode-end-pumped monolithic self-Q-switched Cr,Nd:YAG laser.

The most commonly used method of generating picosecond laser pulses is the mode-locking technique. Mode-locking generally requires a light modulator such as an intracavity acousto-optical modulator, dye cell, or external cavity. Proper operation of a mode-locked laser also requires critical alignment or precision timing. In semiconductor lasers with high-frequency relaxation oscillations, picosecond pulses can be easily obtained by selecting the first peak of the relaxation oscillation by gain switching [1]. In solid-state lasers with short cavity length, pulses of 270 ps duration have been produced using electro-optical Q-switching in a microchip laser [2]. The actively Q-switched laser requires the use of high-speed modulator and high-voltage electronics.

Recently, the development of miniature self-Q-switched solid-state lasers [3,4] points to a new way of generating short pulses using a much simpler approach. In these self-Q-switched lasers, the functions of the gain medium and saturable absorber are combined into one [3,4]. This eliminates the need of the external modulator. By using a 5-mm-long monolithic cavity consisting of a Nd:YAG laser crystal co-doped with chromium as saturable absorber, we have demonstrated the operation of a monolithic self-Q-switched laser that generates laser pulses of several nanosecond duration. Using properly designed cavity parameters for shorter photon lifetime, it is possible to reduce the pulse duration by one order of magnitude. The pulses are expected to have high spectral purity due to the presence of the self-induced loss grating in the cavity containing distributed saturable absorber [4].

In this paper, we report the generation of picosecond pulses in a diode-pumped monolithic self-Q-switched laser. In a Q-switched laser, the duration of the laser pulse is determined by the ratio, r, of the threshold population inversion levels before and after the saturation of the absorber and by the photon lifetime, τ_p, of the laser cavity. These parameters are defined as

$$r = \frac{N_i}{N_{th}} = \frac{\alpha_s + \alpha_u + \alpha_m}{\alpha_u + \alpha_m}, \quad (1)$$

$$\tau_p^{-1} = (c/n)(\alpha_u + \alpha_m), \quad (2)$$

where α_s is the saturable part of the absorption loss, α_u is the unsaturable part of the absorption loss, α_m is the mirror loss giving by $(1/2L)\ln(R_1R_2)$ where L is the cavity length, and R_1 and R_2 are the reflectiv-

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ity of the end mirrors. Although the saturation of the cavity loss from the initial level $(\alpha_s+\alpha_u+\alpha_m)$ to the saturated level $(\alpha_u+\alpha_m)$ is expected to take finite time, for the cavity design purpose, we use the approximation that the saturation takes place instantaneously so that the result of previous rate-equation analysis can be applied [6]. The pulse duration can be obtained by solving the rate equations:

$$\tau=\frac{r\eta(r)}{r-1-\ln(r)}\tau_p\,, \tag{3}$$

where η satisfies the relation $1-\eta(r)=\exp[-r\eta(r)]$. The value of η *in*creases with increasing r and, for $r\gg 1$; η approaches 1 and τ approaches τ_p. In the present experiment, our approach is to shorten the photon lifetime by increasing both the absorption loss and the mirror loss of the laser cavity. The laser material is a Cr,Nd:YAG crystal containing 1 wt% Nd^{3+}. The absorption coefficient at 1064 nm caused by Cr-related absorption center is 1.6 cm^{-1} at low fluence. The absorption saturates at high fluence. The residual absorption coefficient at high fluence, determined by measuring the transmittivity of intense 1064-nm laser pulses at various fluence levels, is about 20% of the low-fluence value. Using $\alpha_s=1.28$ cm^{-1} and $\alpha_u=0.32$ cm^{-1}, $\alpha_m=0.5$ cm^{-1} for a mirror reflectivity of 90%, we have $N_i/N_{th}=2.5$ and $\tau_p=72$ ps, the pulse duration is predicted to be about 3.7 τ_p or 270 ps. The pulse duration can be further shortened by increasing α_u and α_m.

The schematic of the experimental setup is shown in Fig. 1. The plane-parallel cavity is formed by a 1-mm-thick Cr,Nd:YAG crystal. The end surface facing the pumping beam is coated for high transmission at 808 nm and total reflection at 1064 nm. The output coupler is coated for 90% reflection at 1064 nm. The pump laser is an AlInGaAs single quantum well laser with 75 μm stripe width. The output of the diode laser is focused into a 70 μm × 100 μm square spot in the gain medium by using beam shaping optics. The laser is operated in the quasi-CW mode with 350 μs duration and 10 Hz repetition rates. The transmission of the output coupler is nearly 90% at 808 nm. About 30% of the pumping energy is absorbed by the gain medium.

The laser reaches threshold at a pumping energy of 350 μJ. The output pulse energy is 8 μJ, corresponding to an energy conversion efficiency of about 8% of the absorbed pump energy. The laser operates in single transverse with a Gaussian-like intensity distribution. The full-width-half-maxima diameter of the lasing mode is 100 μm. The lasing spectrum consists of a single longitudinal mode without pulse-to-pulse mode hopping. The pulse-to-pulse intensity fluctuation is less than 1%. Fig. 2 shows the slow-scan autocorrelation trace of the self-*Q*-switched pulses. The duration of the autocorrelation trace is 400 ps. Since our detection system can not resolve the actual pulse shape, to estimate the pulse duration, we assume a Gaussian pulse shape with a convolution factor of 1.4. The deconvoluted pulse duration is 290 ps.

The simple short-pulse, high-peak-power, high spectral purity and spatial coherence light source is expected to find wide applications in remote sensing, nonlinear frequency conversion, and as the seed for high power lasers and regenerative amplifiers.

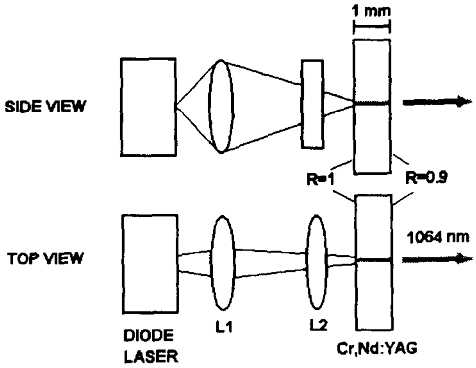

Fig. 1. Schematic of the laser device. The output of the diode laser is focused into a 100 μm spot in the Cr,Nd:YAG crystal by a collimating lens (L1) and cylindrical lens (L2). The laser crystal is 1-mm thick with the end surfaces coated with 100% and 90% reflectivity at the laser oscillating wavelength.

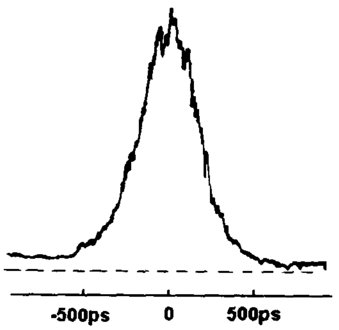

Fig. 2. Autocorrelation trace of the self-*Q*-switched laser pulse. The background level is indicated by the dashed line.

The shot-to-shot temporal jitter of the laser pulse referenced to the beginning of the laser pump excitation pulse is on the order of several microseconds. In applications, such as LIDAR, that require precision timing, the detection system could be synchronized by an electrical pulse generated by a high-speed photodiode triggered by the laser pulse.

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