2.4-ns Pulse Generation in a Solid-State, Passively Q-Switched, Laser-Diode-Pumped Nd:YAG Laser

Y. Isyanova and D. Welford

Schwartz Electro-Optics Inc., 45 Winthrop Street, Concord, Massachusetts 01742

Abstract

We report generation of 5-mJ, 2.4-ns Q-switched pulses from a single-frequency, TEM_{00}-mode, laser-diode-pumped Nd:YAG laser using F_2^- color centers in LiF.

Introduction

In the present work, we report the passive Q-switching of a laser-diode-pumped solid-state laser using a solid-state saturable absorber. Earlier work reported 12-ns duration, microjoule energy pulses [1] and 20-ns duration millijoule energy pulses [2]. Our work concentrated on the generation of much shorter (2.4 ns) pulses at millijoule energies for altimetry.

The saturable absorber material of choice for 1064-nm operation is LiF in which has been gamma-irradiated with a total dose of 5.5×10^8 rads. The active absorber site is the F_2^- color center [3]. The only addition to a conventional two-mirror linear resonator is the insertion of a window-like piece of AR-coated F_2^-:LiF material. The simplicity and small size of such a Q-switch is ideally suited for use in compact laser-diode-pumped laser designs. The use of a short resonator, high output coupling, and low unsaturated absorber transmission leads to short pulse generation and increased longitudinal mode selection.

In the past, F_2^- color centers have been observed to degrade rapidly [1,2,3]. The degradation is seen as an increase in saturated loss with a corresponding reduction in laser output energy. This is due to the presence of non-radiative F_3^- centers in the LiF crystal [3]. We have observed no drop in laser energy for $>10^7$ shots (138 hours) at 20 Hz operation, generating 5 mJ pulses of 2.4 ns duration.

Experimental Results

The resonator used in this work is shown in Figure 1. TEM_{00}-mode operation was obtained by the use of a novel side-pumping geometry, reported previously [4], that achieves near-Gaussian pump energy deposition in the laser rods. A pair of opposing Brewster-angled, 12-mm long, semicircular-cross-section (3-mm diameter) Nd:YAG laser rods were each side-pumped by a 5-bar stack of quasi-cw laser diodes (SDL 3230 devices). The resonator TEM_{00}-mode size matches that of the deposited energy in the laser rods, thereby ensuring efficient TEM_{00}-mode operation (see Figure 2).

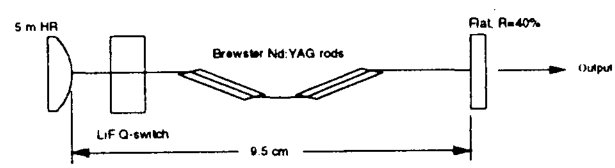

Figure 1. *Passively Q-switched laser resonator.*

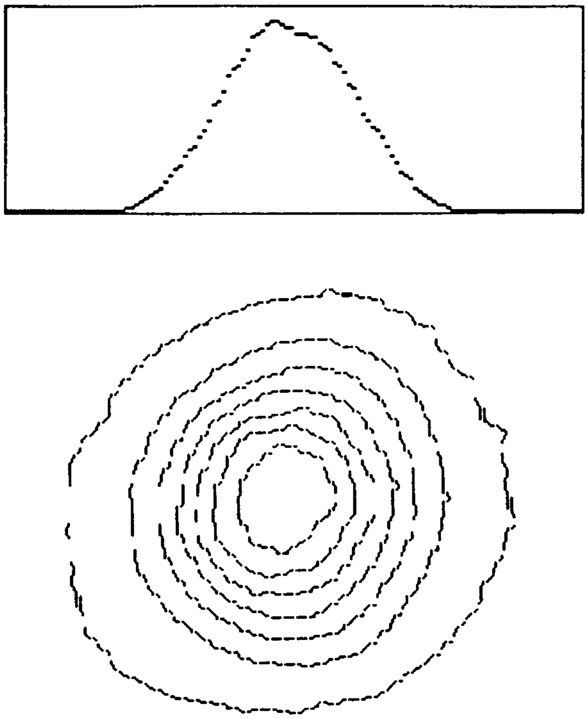

Figure 2. *TEM_{00}-mode beam profile.*

The laser was operated at a 20-Hz pulse repetition rate with 200-μs duration pump pulses. In normal-mode operation, the laser generated pulses at 19.5 mJ energy with 16% conversion efficiency and 22.6% slope efficiency. In Q-switched operation, 2.4-ns duration pulses were obtained at 5 mJ energies with 5.2% conversion efficiency. Figure 3 shows the output energy data.

Table 1 summarizes the Q-switched performance obtained using different length (from 6 mm to 30 mm) F_2^-:LiF crystals, which are characterized by their unsaturated single-pass transmissions, T_0. The diode-laser pump energy was equal to the threshold energy for single-pulse generation in each case. Further increasing the pump energy leads to multiple-pulse generation with the same energy in each pulse [2]. Note, that the data for the 12% transmission F_2^-:LiF material shows an improved pulse duration of 2 ns. However, the pulse energies were reduced to 4 mJ by the onset of damage to one of the Nd:YAG laser rods.

After replacing the damaged laser rod, we were able to generate 2.4-ns duration, 5 mJ pulses at a 20 Hz for $>10^7$ shots with no damage to laser rods or saturable absorber.

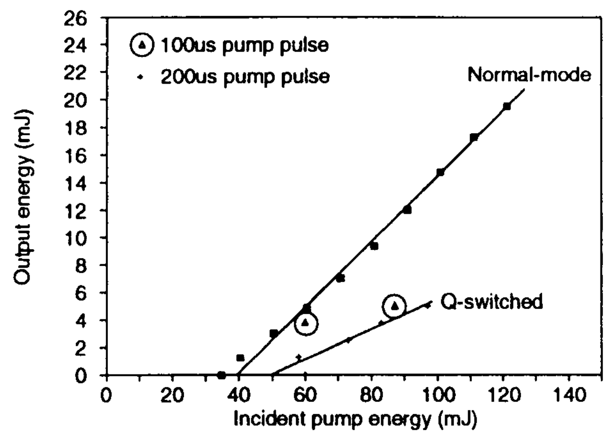

Figure 3. *Normal-mode and Q-switched output data.*

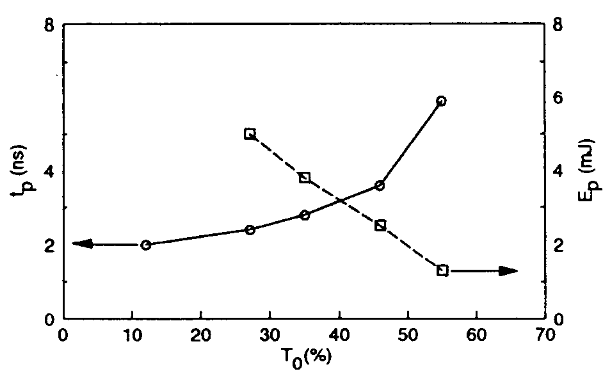

Figure 4. *Pulse energy, E_p, and pulse duration, t_p, as a function of unsaturated Q-switch transmission, T_0.*

Table 2 shows that shorter pump pulses improve the conversion efficiency in Q-switched operation. Pumping harder to reduce the build-up time reduces spontaneous emission losses from the excited level of the laser medium prior to energy extraction in the Q-switched pulse. Approximately 60% of the normal-mode energy could be extracted in a Q-switched pulse using 100-μs pump pulses. This represents an increase of 10% of the normal-mode energy extracted compared to the 200-μs pump pulse.

Table 1. *Passive Q-switched laser performance.*

T_0 (%)	E_{pump} (mJ)	E_p (mJ)	t_p (ns)
55	58	1.3	5.9
46	73	2.5	3.6
35	83	3.8	2.8
27	97	5.0	2.4
12	121	4.0	2.0

Table 2. *Q-switched energy extraction.*

T_0 (%)	E_{pump} (mJ)	t_{pump} (μs)	Normal-mode E_{out}(mJ)	Q-switched E_p(mJ)	NM to QSW Conversion (%)
35	83	200	8.2	3.8	46
35	60	100	6.5	3.8	58
27	97	200	10.2	5.0	49
27	87	116	8.3	5.0	60

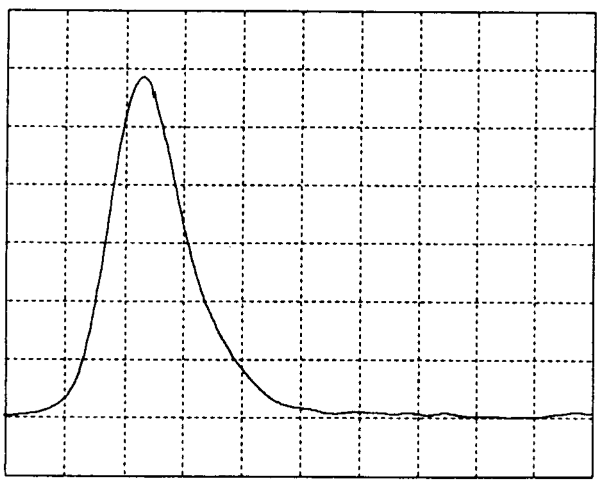

Figure 5. *2.4-ns duration Q-switched laser pulse. (2 ns/div timescale).*

A 2.4-ns duration pulse is shown in Figure 5. The lack of longitudinal mode-beating is a characteristic of single-frequency operation. This is a direct result of using the F_2^-:LiF material as our saturable absorber. The specific property of the solid-state saturable absorber (compared to dyes) which leads to better mode selectivity is the larger saturation fluence (typically a factor of 20). This leads to a longer pulse build-up time in the Q-switched laser. During the longer build-up time the difference in gain between adjacent longitudinal modes will produce a difference in build-up time between modes. Hence, the highest gain mode will Q-switch first and extract all the stored energy. *If the difference in build-up times, Δt_s, between adjacent modes is longer than the Q-switched pulse duration, t_p, the laser pulse will contain a single longitudinal mode.* This constitutes a temporal criterion for single-frequency Q-switched laser operation.

$$\Delta t_s > t_p$$

We have derived an expression for Δt_s [5]:

$$\Delta t_s = \frac{G t_l (1+k)}{2k^2 \sigma_n l_a N_{th}} \left(\frac{\sigma_n - \sigma_m}{\sigma_n} \right)$$

The reader is referred to [5] for a complete description of the parameters and their typical values. Estimates of Δt_s from this expression are plotted in Figure 6 with measured pulse durations for each sample of saturable absorber tested. Δt_s is always greater than tp and the laser was observed to be single-frequency as confirmed by the absence of mode-beating in the temporal pulse profile.

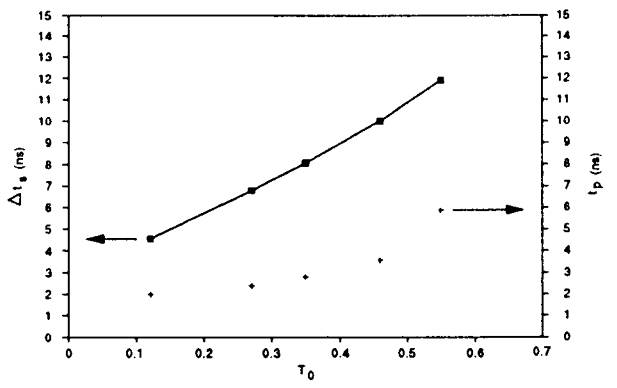

Figure 6. *Pulse build-up time difference, Δt_s, and pulse duration, t_p, as a function of unsaturated Q-switch transmission, T_0.*

Summary

In summary, we have demonstrated an all solid-state passively Q-switched laser that generates 5-mJ, 2.4-ns, single-frequency pulses with a TEM_{00} beam profile. The major advantages for this approach compared to electro-optic Q-switch technology are the elimination of drive electronics and simplified resonator configurations. This technology is ideally suited to space-based and commercial applications. Greater than 10^7 shots have been demonstrated at 20 Hz with no noticable performance degradation.

Acknowledgments

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