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Q-SWITCHED LASER WITH CONTROLLABLE PULSE LENGTH*

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Experimental results of a recently proposed technique for obtaining Q-switched laser pulses of controllable length are presented. A lithium iodate doubling crystal inside the cavity of a Nd : YAG laser running at 0.946μ is used to provide both output coupling and an easily adjustable, nonlinear loss mechanism. Controllable pulse lengths in the range of 200 nsec to 1 μ at 0.473μ have been achieved at nominally constant energy.

This letter describes experimental results on a recently proposed technique[1] for obtaining Q-switched laser pulses of controllable length. The basis of this technique is to use a nonlinear doubling crystal inside the laser cavity, where it acts as both the output coupler for the laser and as a nonlinearly increasing loss mechanism. A number of other techniques have been proposed and demonstrated for lengthening Q-switched pulses.[2-7] The present technique has two advantages. First, the internal loss can be conveniently adjusted by simply varying the angle, and thus the $\tilde{k}$ vector matching condition, of the internal doubling crystal. Second, the technique is conservative in the sense that the loss applied at the fundamental laser frequency is also the output coupling of the laser, and comparable output pulse energies are obtained independent of pulse length. Using a Nd : YAG laser running at 0.946μ with an internal $LiIO_3$ crystal, we have achieved controllable pulse lengths in the range of 200 nsec to 1 μsec at 0.473μ with approximately 0.25 mJ per pulse.

A nonlinearly increasing loss mechanism inside a laser cavity acts essentially as a power limiter. As the laser field builds up, the loss seen by the laser cavity increases as the square of the internal field. Once gain equals loss, the remainder of the atomic inversion no longer increases the peak power of the pulse, but acts only to increase its length. A key parameter describing this process is β, the ratio of the second harmonic conversion efficiency per unit of fundamental power to the single pass gain per unit of stored energy in the inversion. This parameter is a function of the laser transition, the nonlinear crystal, and focusing. In a system with a large β, the output coupling will increase rapidly as the pulse builds up and the internal fundamental power will be limited at a relatively low value, leaving a large inversion to supply energy for a long pulse. This internal power limiting has the additional benefit of protecting laser components from burning, even with high-energy pulses. For a fixed cavity length, cavity optics, and $LiIO_3$ crystal length, β is about 14 times as large for the 0.946-μ line of Nd : YAG as it is for the 1.06-μ line.[1] Thus, substantially longer pulses may be obtained using the 0.946-μ line.

In the present experiment we have employed a refrigerated Nd : YAG laser capable of operating at a number of different infrared wavelengths.[8] As shown in Fig. 1, wavelength selection is obtained via a fixed prism and movable back mirror. The laser is Q switched with an acousto-optic Q switch and is frequency doubled with an internal crystal of lithium iodate. The output mirror of the laser is highly reflecting at the fundamental wavelength and highly transmitting at the second

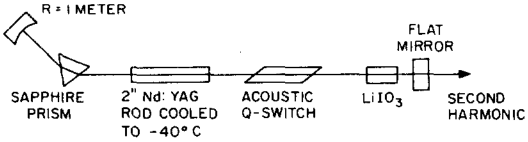

FIG. 1. Schematic of internally-doubled Nd : YAG laser.

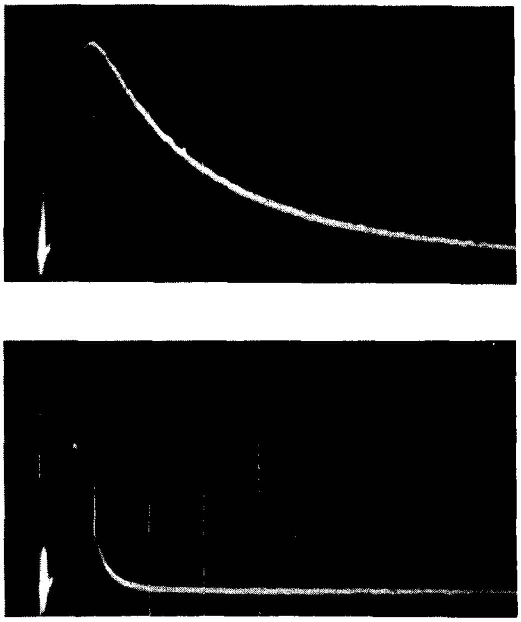

FIG. 2. Laser output pulse at 0.473μ: (a) maximum coupling, (b) optimum coupling, horizontal scale: 500 nsec/ division, vertical sensitivity in (b) reduced by a factor of 4 from (a).

harmonic, and thus the entire output coupling of the laser is obtained via the lithium iodate crystal. By rotating the crystal a few degrees, the output coupling of the laser, at peak fundamental power, can be varied from about 0 to about 20%. This adjustment can be made easily while the laser is running without additional realignment.

Figure 2 shows the second harmonic output pulse obtained with a 1.4-cm-long crystal of lithium iodate with cavity optics such that the beam size inside the lithium iodate crystal was about 0.6-mm in diameter. Figure 2(a) shows the 0.473-μ output with the crystal tuned to exact phase matching. For this condition, the laser is substantially overcoupled and pulses of about 1 μsec and 0.25 mJ are produced. In Fig. 2(b) the lithium iodate crystal has been adjusted for maximum peak power or "optimum" output coupling. The pulse width is reduced to about 200 nsec while the pulse energy is roughly comparable. Further misalignment of the lithium iodate crystal reduces the output energy with relatively little change in pulse shape.

This internally doubled, overcoupled laser has proven very useful as a pump for optical parametric oscillators. For these devices only moderate peak powers are required, while long pulse lengths are necessary to permit the oscillation to build up from the noise and to reach steady state. By adjusting the system for short, high-peak power pulses, it has also been used very successfully to pump dye lasers.

The lithium iodate was grown by R. S. Fiegelson of the Stanford Center for Materials Research and fabricated by R. Griffin. The authors also acknowledge B. Yoshizumi for his technical assistance in building the laser. We note that similar experiments have been performed by R. W. Wallace of Chromatix.

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SINGLE-MODE OPERATION AND MODE LOCKING OF HIGH-PRESSURE CO$_2$ LASERS BY MEANS OF SATURABLE ABSORBERS*

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Single-longitudinal-mode operation of pulsed, high-pressure, transversely excited CO$_2$ lasers has been obtained by means of a saturable absorber (SF$_6$) cell placed inside the laser cavity. Eighty percent of the multimode ouput power is obtained in the single-mode output. Single-mode operation has been verified by means of a scanning Fabry-Perot interferometer. Pressure broadening of the saturable absorber by a buffer gas has been found to cause multimode mode-locked operation of the laser.

Pulsed atmospheric-pressure CO$_2$ lasers[1] possess a strongly collision-broadened gain bandwidth of the order of 4 MHz/Torr.[2] Since in a typical case the longitudinal modes of the laser cavity are separated by perhaps 50 MHz, the device tends to oscillate simultaneously on many longitudinal modes. This tendency reduces the spectral purity of the output and gives rise to random power fluctuations (beats). We have found that a cell of SF$_6$ gas placed within the laser cavity can act as a mode selector, producing single-longitudinal-mode operation. This provides a simple and convenient method for obtaining single-frequency pulses with peak power in the megawatt range. Single-mode peak output power in our experiment was approximately 80% of the multimode power obtained with no absorber in the cavity.

When helium buffer gas is added to the SF$_6$, a transition to mode-locked multimode operation is found to occur. Thus in the pulsed CO$_2$-SF$_6$ system, the saturable absorber can, under different conditions, force the laser into either single-mode or mode-locked multimode operation. Similar dual effects of saturable absorbers have previously been noted in ruby[3,4] and helium-neon[5,6] laser systems.

Two different laser tubes were used in the experiments. Tube A is 2 m long and contains 168