A SIMPLE, HIGH POWER, NANOSECOND PULSE Nd:YAG LASER

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Received 28 March 1984

A relatively simple, Q-switched and self-injected oscillator is described which employs a passive pulse forming network to produce single, one nanosecond duration laser pulses with nanosecond jitter times. Peak powers of 50 MW were obtained from the Nd:YAG system with 5% amplitude stability at 10 Hz repetition rate.

1. Introduction

In several applications of nonlinear optics and laser spectroscopy there is a need for a high power pulse of radiation with a duration of about 1 ns. Conventional Q-switched laser pulses are in the range 10 to 30 ns. Mode-locked lasers normally operate in picosecond regime although acousto-optically driven systems can produce 1 ns pulses. These, however, have small energy content and thus require amplification together with complex and expensive single pulse selection devices. An alternative scheme was devised a few years ago based on "self-injection" of a short duration seed pulse, followed by regenerative amplification. The seed pulse is produced by pulsed modulation of the cavity Q after the initial Q-switched operation and just prior to the emergence of the giant pulse. The principle of this technique was first demonstrated by Liu [1] in a Nd:YAG laser and independently by Ewart [2] in a flashlamp-pumped dye laser. The technique has been developed extensively by Brito Cruz, Mataloni and de Martini with others [3] to generate single nanosecond and sub-nanosecond pulses from flashlamp-pumped dye, Nd:YAG and Nd:glass lasers. These workers have also shown that with saturable absorbers in the cavity the method can be used to generate picosecond duration pulses in a temporally controlled manner [4]. With the exception of the scheme of ref. [2] all these methods rely on half-wave voltage switching by intracavity Pockels cells to modulate the cavity flux. The elegant schemes of refs. [3] and [4] employ a tailored sequence of voltage steps applied to a single intracavity Pockels cell to achieve Q-switching, seed pulse generation and finally single pulse extraction. The voltage step sequence is generated electronically by a circuit with five Krytron valvės triggered by a series of appropriately timed pulses. We report here a relatively simple scheme based on quarter-wave voltage switching and which uses a minimum number of Krytron valves which are expensive to replace repeatedly in long term operation.

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2. The electro-optical system

The scheme uses an optical cavity defined by two 100% reflecting mirrors. The arrangement is shown schematically in fig. 1. The cavity contains a normal

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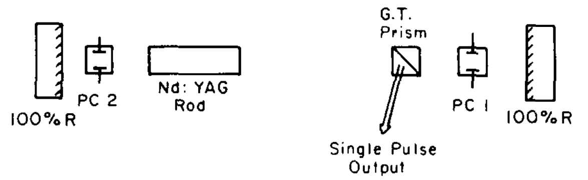

Fig. 1. Cavity configuration.

Q-switch comprised of a Glan-Thompson polarizing prism, G.T., and a Pockels cell, PC1. A second Pockels cell, PC2, is placed close to one end mirror. The operation of the device may be understood by referring to fig. 2 which shows the sequence of electrical pulses applied to both Pockels cells and the development of the flux inside and that ejected from the cavity. The system works as follows:

(1) At a suitable time in the flashlamp pumping pulse the voltage on PC1 is switched off to initiate laser oscillation in the usual Q-switched manner, fig. 2(a).

(2) After a delay, T_1, a "top hat" voltage pulse is applied to PC2 with an amplitude equal to the quarter-wave voltage, $V_{\lambda/4}$, fig. 2(b). The duration of this pulse, T_2, is less than the cavity round trip time for a photon, T_R. The flux which makes a double pass through PC2 during this time, T_2, has its plane of polarization rotated by 90° and is thus ejected from the cavity by the G.T. prism. A seed pulse of duration

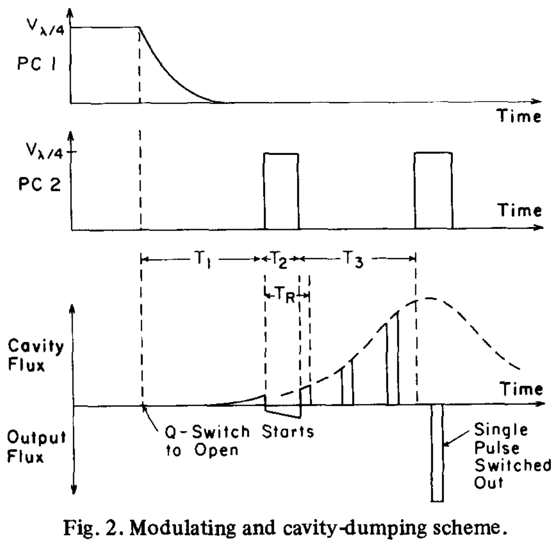

Fig. 2. Modulating and cavity-dumping scheme.

$(T_R - T_2)$ remains in the cavity and is of sufficient intensity to saturate the gain in the amplifier rod after only a few round trips, fig. 2(c). The timing of the final output pulse is thus determined by the timing of this modulation pulse. The output is then easily synchronized with external events.

(3) When the seed pulse has grown to its peak intensity a second top hat, $V_{\lambda/4}$ pulse is applied to PC2. The delay on this pulse, T_3, is arranged so that the light pulse makes a double pass through PC2 when the voltage, $V_{\lambda/4}$, is on. The high intensity, short pulse is then dumped from the cavity by the G.T. prism, fig. 2(c). So most of the energy available to the normal 20 to 30 ns Q-switched pulse is swept out in a pulse whose width is determined mainly by the initial seed pulse duration $(T_R - T_2)$.

If a fast Q-switching step is applied to PC1 such that the fall time of the voltage is much less than T_R, a nonuniformity is induced in the intracavity flux. This initial modulation is maintained during the development of the giant pulse, and dominates the form of the output from the system. This required that the modulating pulse on PC2 by synchronized with the existing modulation. To eliminate this effect the fall time of the voltage on PC1 was increased by a resistive load to about 50 ns. The fast Krytron circuit (fall time ~1 ns) originally used to drive PC1 was then replaced by a much cheaper transistor stack circuit. (Without the resistive load this circuit had a fall time of 3 to 4 ns). With this slower Q-switching the timing and subsequent development of the seed pulse was totally determined by the timing of the modulating pulse on PC2, and this timing was not critical. This feature allows the output to be readily synchronized *by* an external trigger. A pulse derived from the transistor stack switching was delayed electronically by T_1 and used to trigger the circuit producing the modulating pulse. A similar, undelayed, pulse is available for synchronizing *of* external circuitry.

The duration of the modulating pulse, T_2, is determined by a passive pulse forming network, PFN, driven by a fast voltage step from a Kryton (E.G. and G., KN22). The fall time of this step was $\lesssim 1$ ns. The modulating pulse is reflected in the PFN and applied a second time to PC2 after a delay, T_3. This timing interval, T_3, is the most critical aspect of the scheme. Fortunately, since the pulse builds up to its peak intensity in only 3 or 4 round trips this delay can be generated in the PFN. The passive nature of the pulse length and delay generation in the PFN distinguishes the scheme from other schemes which require electronically generated delays. Such delays on high voltage pulses are difficult to produce reliably with a jitter time of ~1 ns required for efficient pulse extraction. The passive PFN employed here has inherently zero jitter.

The system used only one Krytron and so reduces the running costs associated with replacing these devices. It does use an extra Pockels cell and so the initial cost is that much higher. However, the simplicity and reliability of the system, and its lower operating voltage, which reduces wear on components, may give it some advantages.

The cavity length, which was not critical, was chosen for convenience; the only constraint is that $T_R > T_2$ and T_2 is limited by the rise and fall times of the modulating pulses from the PFN. The usual resonator comprised of one curved mirror (2m radius) and one plane parallel mirror spaced by 1.1 m (T_R = 7.3 ns). The Nd:YAG rod was 75 mm long and 6.3 mm in diameter. The build up time of the output pulse after the initial Q-switch was just over 100 ns. Typical values for the times in the pulse sequence on PC2 were: T_1 = 85 ns, T_2 = 6.5 ns, T_3 = 19.5 ns.

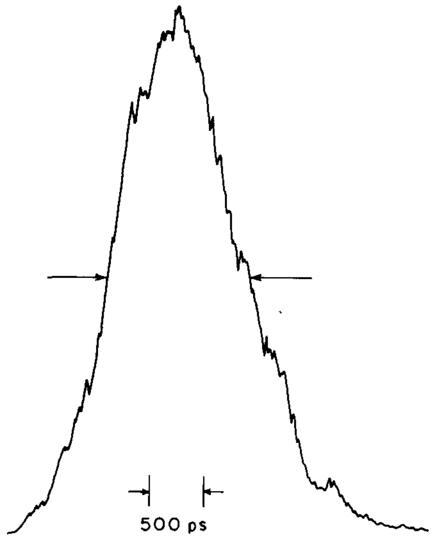

Fig. 3. Output pulse recorded by sampling system (effective response time ~200 ps). Recorded pulse duration (FWHM) is 1.3 ns.

3. System performance

The timings quoted above optimized the output in respect of minimizing the output pulse duration. The pulses were recorded by a fast photodiode (10 ps response time). The pulse duration was measured by processing the photodiode's output with a Boxcar Averager using a Tektronix sampling head (PARC Model 163). The detection system's bandwidth is approximately 200 ps. Fig. 3 shows a typical pulse form recorded by averaging approximately 10^4 pulses. The deconvolved pulse duration is then ~1 ns. Recording the pulse in this manner illustrates the excellent stability and low jitter of the system. The jitter relative to the synchronization pulse from the Q-switch is <1 ns. With a pumping energy of 16 J the output pulse has an energy of typically 45 mJ, or a power of 45 to 50 MW. Under similar conditions the normal Q-switched output is 50 mJ. The system is thus very efficient in compressing the available energy into the short pulse. The energy is restricted to these values to avoid damage to optical coatings in the cavity. The shot-to-shot amplitude variation is 5% and no feedback circuits were found necessary to achieve this stability. The system operated at 10 Hz repetition rate.

The pulse duration is approximately $(T_R - T_2)$ and can be varied from 1 to 4 ns by altering T_2. The minimum pulse width is determined by the rise and fall times of the modulating pulse on PC2. Since the combined rise and fall times is greater than the minimum pulse width of the output, gain saturation must play some part in compressing the pulse. An interesting feature of the system is its ability to produce long pulses i.e. normal Q-switched pulses of ~30 ns duration. These pulses are obtained by omitting the modulating and dumping pulses from PC2 and misaligning this crystal slightly. The misalignment introduces some birefringence and in effect provides a variable output coupler via the G.T. polarizer. The high power output leads to very efficient harmonic conversion for dye laser pumping, and so high power, tunable, subnanosecond pulses may be easily generated. For most such applications there is sufficient power from the oscillator alone and a Nd:YAG amplifier is not needed. The harmonic pulses (<1 ns) will be used in our laboratory to amplify a c.w. dye laser either in single mode (<2 MHz bandwidth) or mode-locked operation. Since the amplifying pulses have no perceptible high frequency amplitude modulation the resulting dye laser pulses should be transform limited (or very close to it). The technique could conceivably be allied to single longitudinal mode Nd:YAG systems [5] to guarantee absence of mode beating noise. The nanosecond pulse from our system have distinct advantages over those from normal Q-switched oscillators for amplifying picosecond dye laser pulses. Since the energy storage time is limited to a few nanoseconds by the radiative lifetime of the excited states in most dyes, most of the energy from a 20 to 30 ns pumping pulse is wasted, or lost by amplified spontaneous emission, A.S.E. As a picosecond pulse travels through the dye amplifier only the energy deposited in the preceding few nanoseconds is available for amplifying the pulse. Also, if a series of dye amplifiers is used, saturable absorber cells must usually be placed between them to prevent loss by A.S.E. during a long pumping pulse. The ~1 ns pumping pulses for dye amplifiers should greatly increase the efficiency of such systems by reducing losses due to short energy storage times, A.S.E. and losses in saturable absorbers which would no longer be necessary. Synchronization to a particular pulse in a mode-locked train should also be facilitated by our system due to its very small timing jitter. Timing tolerances could be relaxed by using a slightly longer pulse in the 1 to 4 ns range.

4. Conclusion

We have demonstrated a relatively simple self-injected laser system to produce reliably and reproducibly single 1 nanosecond pulses at 1.06 μm. The pulses have powers of typically 50 MW, with 5% amplitude stability at 10 Hz repetition rate, and are emitted with <1 ns jitter relative to an electrical synchronization pulse emitted ~100 ns earlier. The pulse may also be timed with ≲2 ns jitter relative to an external trigger making it suitable for synchronization to other experimental events. These characteristics may be useful in a variety of applications requiring high power and temporal resolution on a nanosecond timescale.

Acknowledgements

We are grateful to the Nuffield Foundation for a grant to support this work. It is a pleasure also to acknowledge useful consultations with Dr. C.L.M. Ireland (J.K. Lasers) and to thank J.K. Lasers for providing some equipment. One of us (A.C.) was supported by a S.E.R.C. CASE studentship with J.K. Lasers.

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