Optical chopper Q-switching for flashlamp-pumped Er,Cr:YSGG lasers

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Abstract

We present a novel way of Q-switching a flashlamp-pumped, $\lambda = 2.8 \mu\text{m}$ Er,Cr:YSGG laser, wherein a rotating polygon is used as an optical chopper. Single pulse energies of $\sim 3.8 \text{ mJ}$ were achieved with pulsewidths of $\sim 305 \text{ ns}$. The scheme benefits from the simplicity of design, and, compared with other Q-switching methods, a reduction in losses and laser damage problems from intracavity components. We also investigate the optimisation of the laser output through purging of the laser with nitrogen, and find a 29% increase in peak output energy.

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(Some figures may appear in colour only in the online journal)

1. Introduction

The $\lambda \approx 3 \mu\text{m}$ erbium laser has gained much attention in recent years, mainly thanks to the presence of strong water absorption at this wavelength allowing them to be used in the ablation of human tissue [1]. These lasers are used for cosmetic skin treatment [2], dentistry [3], ophthalmic surgery, for the removal of cataracts [4] and have even been considered for corneal ablation in photorefractive surgery [5, 6]. For high-precision medical applications, single, short pulses are preferred, since CW and long-pulse-duration lasers lead to increased collateral damage of the peripheral tissue due to excess thermal loading and the generation of pressure waves.

A number of methods for shortening the beam pulsewidths through Q-switching the erbium laser have been reported. These include electro-optic Q-switching [7], rotating mirror Q-switching [8], acousto-optic Q-switching [9], and Q-switching through piezoelectric-modulated prism-halves [10]. These methods can be categorized further according to the speed of the Q-switch. “Fast” Q-switches, such as the electro-optic Q-switch, switch from low to high Q quasi-instantaneously, i.e. on a timescale short compared to the pulse

build-up time of the laser (the time from the threshold condition being fulfilled to the time of pulse emission). “Slow” Q-switches, on the other hand, such as the rotating mirror Q-switch, switch on time scales comparable to the pulse build-up time of the laser [11].

Here we demonstrate a simple “slow” Q-switch for the Er,Cr:YSGG laser which is itself not susceptible to laser-induced damage, and is based on well-developed, inexpensive, and readily available mechanical components. Longevity is a particularly desirable feature of medical lasers, as are minimal maintenance costs, and so we suggest this Q-switch design as a potential candidate for this application. We also present properties of the laser pulse in free-running mode, and the results of purging the laser atmosphere to remove intra-cavity moisture.

2. Self-termination of free-running, flashlamp-pumped Er,Cr:YSGG

Whilst Yttrium Aluminium Garnet (YAG) is commonly used as a host for $\lambda \approx 3 \mu\text{m}$ erbium lasers, Yttrium Scandium Gallium Garnet (YSGG) is a potentially superior candidate for Q-switching [12] because of its longer upper laser level lifetime (1.3 ms in YSGG

compared to 0.12 ms in YAG [13]) This longer upper laser-level lifetime also makes the YSGG based lasers more suited to “slow” methods of Q-switching. With the YSGG host, the primary laser wavelength is $\lambda = 2.794 \mu\text{m}$, and when flashlamp-pumped, the erbium ions are co-doped with chromium to increase pump energy absorption, giving Er,Cr:YSGG [14]. Figure 1 shows a pulse trace of our laser in free-running mode, measured with a Molelectron P3-01 pyroelectric detector, used in two modes corresponding to rise-times of 10 μs and 10 ns. The output pulse in fact consists of a pulse-train of ~ 20 pulses, each of ~ 400 ns duration, separated by 10 μs . This is indicative of self-termination of laser action, caused by the fact that, for $\lambda \approx 3 \mu\text{m}$ erbium, the lower laser level is longer-lived than the upper laser level (for example, 3.4 ms compared to 1.3 ms in Er,Cr:YSGG [13]).

Figure 1. Experimental pulse trace of the free-running, flashlamp-pumped Er,Cr:YSGG laser, as detected with a Molelectron P3-01 pyroelectric detector. The left hand side, with a detector rise-time of 10 μs , shows the output to be a pulse train of ~ 20 pulses. The right hand side, with a detector rise-time of 10 ns, shows the individual pulses of the pulse train are of ~ 400 ns duration, in $\sim 10 \mu\text{s}$ intervals. This pulse train occurs because of self-termination effects that arise because the upper laser level is shorter-lived than the lower one.

Perhaps surprisingly, despite this fact, other researchers have demonstrated CW operation from the $\lambda \approx 3 \mu\text{m}$ erbium laser, although this requires a discrete-wavelength pump laser rather than flashlamp-pumping [13, 15]. CW

operation occurs via inter-ionic up-conversion processes which together act as an aid to population inversion [12].

3. Polygon chopper Q-switching of Er,Cr:YSGG laser

3.1 Q-switching method and cavity configuration

The method of Q-switching presented here, the “polygon chopper Q-switch” (PCQS), utilizes a rotating polygon configured to act as an optical chopper (figure 2). The polygon is adjusted so that, as it rotates, its vertices move in and out of the intra-cavity beam path, thus constituting a chopper. In this instance the polygon was a Lincoln Laser decagon, model SOS-SA24C.

The laser cavity was in flat-flat configuration, with an $R = 60\%$ output coupler and high-reflectivity back mirror. The laser rod was 90 mm long and Brewster-cut to select the horizontal polarisation in the cavity. The cavity had lengths from rod-end to cavity mirrors of 190 and 220 mm, giving a total cavity length of 500 mm. Note that at this length, there is little theoretical difference between the output characteristics of a “fast” and “slow” Q-switch for the erbium system [16].

This cavity length was chosen to suit the Er,Cr:YSGG rod thermal lens and produce fundamental mode output at high output energy. From our own measurements, the thermal lens strength was found to scale with input power as $\frac{1}{f}/P_{in} = 0.035 \pm 0.003 \text{ m}^{-1} \text{ W}^{-1}$.

The pulse repetition rate was limited to below ~ 12 Hz by the thermal lens and cavity configuration, the input power being limited to $P_{in} < 700 \text{ W}$.

Figure 2. The polygon chopper Q-switch (PCQS) set-up. The spinning polygon acted as a chopper for the cavity mode: when its vertices blocked the mode, the cavity had low Q; when the polygon edge was parallel to the mode, the cavity was in high Q.

3.2 PCQS Q-switching time and laser performance

The PCQS was set to rotate at 400 rps, with a laser pulse triggered to be emitted every 64 rotations, corresponding to a 6.25 Hz repetition rate. To measure the effective Q-switching time at this rotation rate, the laser cavity mode was substituted with an external HeNe laser beam, whose beam waist was matched to that of the erbium laser cavity mode, and a silicon detector, positioned on the opposite side of the PCQS, was used to measure how quickly the HeNe signal changed between maximum and minimum values. Figure 3 shows the signal of the HeNe as the PCQS rotated, with the minima corresponding to the PCQS vertex fully obscuring the laser mode (resulting in low Q), and vice versa. The laser pulse emission was found to coincide with the chopper being fully retracted from the path of the cavity mode, corresponding to the laser pulse being emitted about 300 μ s after the flashlamp onset. With the PCQS rotating at 400 rps, the effective Q-switching time for the PCQS, i.e. the time for the signal to be switched from maximum to minimum, was ~ 30 μ s. This confirmed that the PCQS constituted a “slow” Q switch, since the build-up time of Er,Cr:YSGG was ~ 2.2 μ s, as measured from a similar cavity equipped with a “fast” electro-optic Q-switch.

Figure 3. The variation of HeNe signal (representing cavity Q) with time as PCQS rotates: the PCQS switched from low Q (minimum) to high Q (maximum) in ~ 30 μ s. The PCQS was rotating at 400 rps, so the loss period was 250 μ s. The flashlamp pulse and the laser pulse are superimposed with the laser output pulse occurring approximately 250 μ s after the triggering of the flashlamp.

Rotating the PCQS much slower than 400 rps led to an output consisting of multiple pulses. Therefore, 30 μ s represented the approximate

limit of the Q-switching time for the Er,Cr:YSGG system. At the moment it is uncertain how well the PCQS would work for Er:YAG lasers with their shorter upper laser level lifetimes. It would be possible to increase the rotation rate of the PCQS, though in that case it would be important to change the number of sides of the polygon. This is because, if the PCQS is rotated too rapidly, it will cause a high Q instance that is too early, thus interrupting population inversion growth before optimum emission time, thereby giving a pulse below the maximum possible energy. This could be remedied by using a polygon with fewer sides.

Shown in figure 4 is the trace of the laser pulse, with pulse width of ~ 305 ns. This is shorter than the individual pulses of the pulse train when in free-running mode, and compares favourably with other established Q-switching methods for this system, of 100-300 ns pulse widths [7, 8, 17]. The inset of figure 4 shows the energy in versus energy out for the PCQS laser. Maximum energy output was ~ 3.8 mJ at 60 J flashlamp input and the slope efficiency was $\eta_{\text{slope}} = 0.014\%$.

Figure 4. The pulse width of the Q-switched pulse, as measured with a Moletron P3-01 on the fast response mode (10 ns rise-time). Inset is the energy in versus energy out of the laser, showing a 0.014% slope efficiency.

3.3 Nitrogen purging of laser

To remove water vapour, a strong absorber at $\lambda \approx 3$ μ m, from the laser cavity, we encased the laser in an air-tight box, which could be purged with gaseous nitrogen. Purging increased the slope efficiency to $\eta_{\text{slope}} \approx 0.016\%$ and the maximum energy output to 4.9 mJ, a 29% increase compared to before purging. In this case, the atmosphere had a 41% relative humidity before purging, and relative humidity was $< 0.1\%$ after purging.

On more humid days, the improvement in efficiency was greater still.

4. Conclusion

We have demonstrated a simple and robust Q-switch method based on the optical chopper Q switch concept. Here, the vertex of a rotating polygon acted as a chopper, as it passed into and out of the path of the intracavity mode of an Er,Cr:YSGG laser. The PCQS represents a simple Q-switch to implement in this laser system, based on off-the-shelf components with little exposure to laser-induced optical damage to the Q-switch itself, and minimal maintenance needs. The simplicity of the concept means that the same Q-switching assembly can be potentially used with a wide range of pulsed lasers operating at different wavelengths. Furthermore, nitrogen purging of the laser was shown to increase the output pulse energy by ~29%, the exact improvement being dependent on the ambient humidity before purging. We recommend this method of Q-switching as a simple solution for creating short $\lambda \approx 3 \mu\text{m}$ pulses for medical applications.

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References

- [1] Jean B and Bende T 2003 *Solid-State Mid-infrared Laser Sources* ed Sorokina I and Vodopyanov K (Springer: Berlin / Heidelberg) pp 511–544
- [2] Kaufmann R and Hibst R 1990 *Clin. Exp. Dermatol.* **15** 389–393
- [3] Hoke J A, Burkes E J, Gomes E D and Wolbarsht M L 1990 *J. Laser Appl.* **2** 61–65
- [4] Ross B S and Puliafito C A 1994 *Laser Surg. Med.* **15** 74–82
- [5] Jean B, Kriegerowski M, Matallana M and Bende T 1995 *J. Refr. Surg.* **11** 392–396
- [6] Telfair W, Hoffman H, Norquist R and Eiferman R A 1998 *Proc. SPIE* vol 3246 pp 97–108
- [7] Jelinkovss H, Nemec M, Sulc J, Cech M and Ozolinsh M 2002 *Proc. SPIE* vol 4903 pp 227–232
- [8] Skorczakowski M, Pichola W, Swiderski J, Nyga P, Galecki L, Maciejewska M, Zajac A, Gross S, Heinrich A, Bragagna T and Kasprzak J 2011 *Opto-Electron. Rev.* **19** 206–210
- [9] Schnell S, Ostroumov V, Breguet J, Luthy W, Weber H and Shcherbakov I 1990 *IEEE J. Quantum Elect.* **26** 1111 – 1114
- [10] Högele A, Ziolek C, Lubatschowski H, Lohmann S, Welling H, Olmes A and Ertmer W 1997 *Laser und Optoelektronik* **29** 45–51
- [11] Svelto O 2010 *Principles of Lasers* (Springer: New York) pp 319–321
- [12] Arbabzadah E, Chard S, Amrania H, Phillips C C and Damzen M J 2011 *Opt. Express* **19** 25860–25865
- [13] Dinerman B J and Moulton P F 1994 *Opt. Lett.* **19** 1143–1145
- [14] Moulton P, Manni J and Rines G 1998 *IEEE J. Quantum Elect.* **24** 960–973
- [15] Bagdasarov K S, Zhekov V, Lobachev V, Murina T M and Prokhorov A M 1983 *Kvantovaya Elektronika* **10** 452–454
- [16] Högele A, Horbe G, Lubatschowski H, Welling H and Ertmer W 1996 *Opt. Commun.* **125** 90–94
- [17] Vodopyanov K L, Ganikhanov F, Maffetone J P, Zwieback I and Ruderman W 2000 *Opt. Lett.* **25** 841–843