SHEAUMANN

Quasi-Continuous Operation of 2.94-µm Er:YAG MIR-Pac Lasers

Sheaumann's diode laser pumped 2.94-µm Er:YAG MIR-Pac laser product [1, 2] may be operated in the quasi-continuous-wave (QCW) pulsed mode of operation, often referred to as long-pulse or normal-mode operation, wherein the laser is operated with pulse durations that are long enough for the laser to reach its steady-state operating condition. This technical note describes the characteristics of this mode of operation.

In the continuously operating mode the MIR-Pac laser is specified for operation at 0.75 W of output power in a TEM_{00} mode beam (M^2<1.2) with a typical beam divergence of 17 mrad. Although specified at 0.75 W of output power, the laser is typically capable of operation at output powers on the order of 1 W (see Figure 1) at the maximum pump laser continuous drive current rating of 6 A.

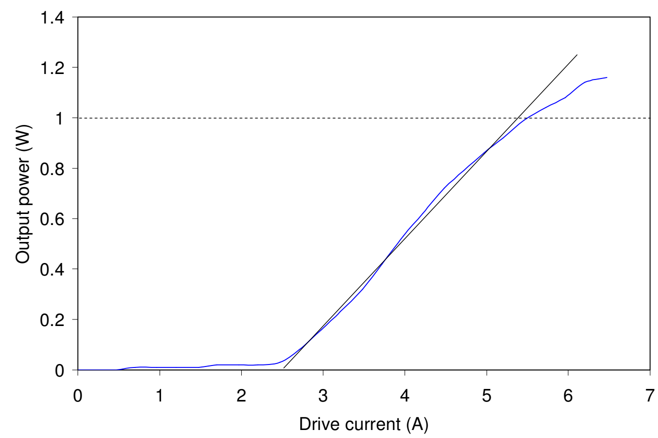

Figure 1. Output power versus drive current performance of a 2.94-µm MIR-Pac laser.

The MIR-Pac laser is optically pumped using a diode laser that may be operated continuously, or pulsed, by using the appropriate drive current waveform. By driving the diode laser with a rectangular current pulse with rise times <10 µs the corresponding optical pump pulse can efficiently create a population inversion that exceeds the lasing threshold.

The finite build up time required to reach the lasing threshold means that the population inversion density is initially larger than the threshold inversion density by the time lasing begins. The excess gain results in the generation of a short laser pulse that depletes the population inversion and this process repeats itself several times. The initial laser pulses are often referred to as being gain switched. The generation of gain switched pulses quickly gives way to damped intensity oscillations known as relaxation oscillations, which in turn cease as the intensity reaches a steady-state value (see Figures 2 & 3).

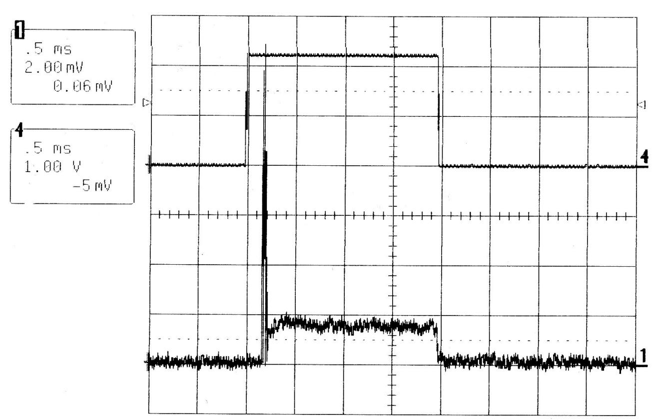

Figure 2. QCW MIR-Pac laser output (lower trace) and drive current waveform (upper trace) for a 0 A to 10 A, 2-ms duration current pulse at a 100 Hz repetition rate.

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At the end of the optical pump pulse most lasers turn off with a monotonic decrease in intensity. The MIR-Pac laser is not as well behaved and turns off by emitting a series of decaying relaxation oscillations (see Figure 4) of the same type as those at the beginning of the QCW laser pulse and they arise because of the unique pumping dynamics of the gain medium, Er:YAG [3, 4].

Referring to the pumping dynamics illustrated in Figure 5, the 6.4 ms lifetime of the lower laser level, $^4I_{13/2}$, is much longer than the 0.1 ms lifetime of the upper laser level, $^4I_{11/2}$, which would lead to self-saturation except that strong upconversion from the lower laser level depletes its population and at the same time provides greater than unity quantum efficiency.

An artifact of the upconversion process is that when the laser turns off the $^4I_{11/2}$ level continues to be populated after termination of the pump pulse, which leads to the generation of a series of decaying relaxation oscillations in a manner analogous to those at the beginning of the laser pulse. The energy level dynamics in Er:YAG are illustrated in Figure 5.

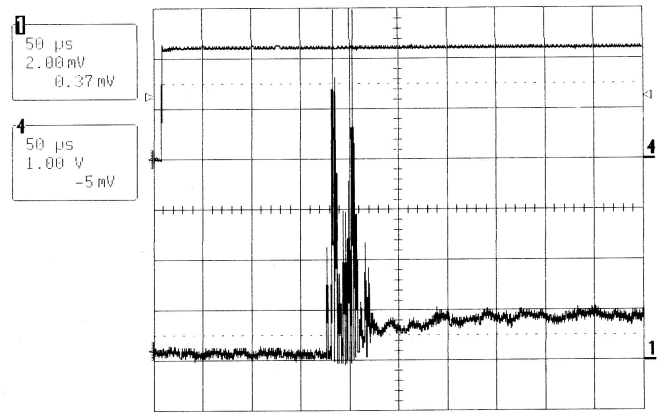

Figure 3. QCW MIR-Pac laser output (lower trace) and drive current waveform (upper trace) corresponding to the first 0.5 ms of Figure 2.

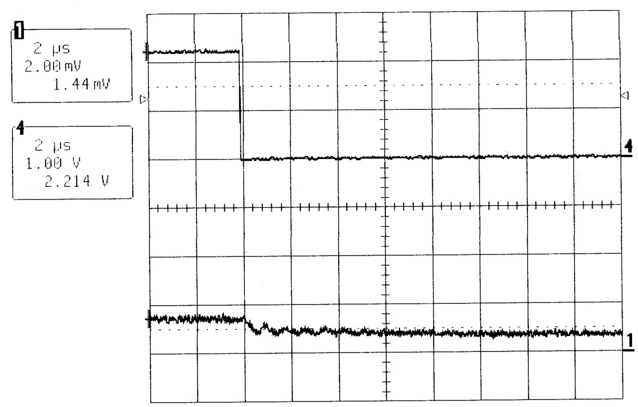

Figure 4. QCW MIR-Pac laser output (lower trace) and drive current waveform (upper trace) showing the relaxation oscillation decay at the end of the laser pulse.

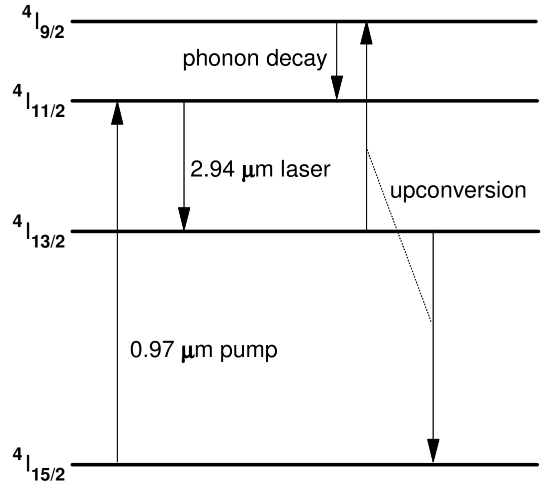

Figure 5. The energy level diagram for Er:YAG showing the pump absorption and laser transitions. Upconversion from the lower laser level, $^4I_{13/2}$, provides greater than unity quantum efficiency.

The relaxation oscillation damping time, τ_0, of an ideal four level laser [5] is given by

$$\tau_0 = \frac{2\tau\left(1 - N_{th}/N_t\right)}{W_p/W_{p,th}}$$

where the characteristic lifetime of the upper laser level, τ, is modified by the ratio of the population inversion density at threshold to the total number of active ion sites in the pumped region of the gain medium, N_{th}/N_t , and the number of times the optical pumping rate exceeds the lasing threshold, $W_p/W_{p,th}$. It is clear that pumping harder shortens the relaxation oscillation damping time and this fact applies to the MIR-Pac 2.94-µm Er:YAG laser even though its energy level dynamics are not exactly the same as those of the ideal four level laser.

Pumping the MIR-Pac laser close to, but below, its lasing threshold prior to the main pumping pulse shortens the relaxation damping time and almost eliminates the build up time delay (see Figure 6). The ideal pulsed drive current for QCW operation of the MIR-Pac laser consists of a continuous bias current set to 80% of the continuous lasing threshold value (typically 2 A) with a larger pulsed drive current. The peak drive current may be as high as the 15 A maximum permissible drive current of the diode pump laser, with the additional constraint that the duty cycle corrected average MIR-Pac laser output power does not exceed the specified maximum operating power in the device test data sheet.

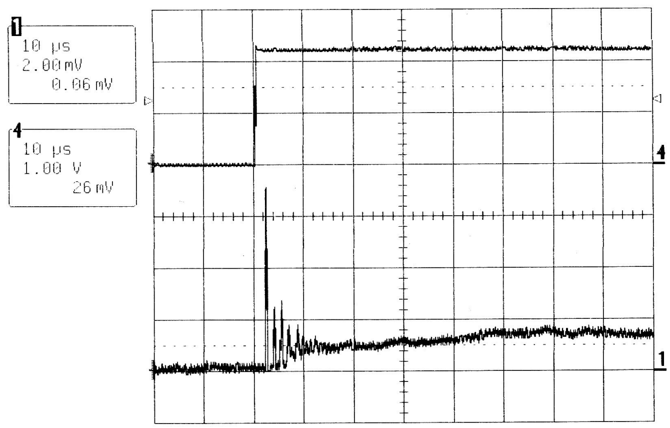

Figure 6. QCW MIR-Pac laser output (lower trace) and drive current waveform (upper trace) for a 2 A to 10 A, 2-ms duration current pulse at a 100 Hz repetition rate.

The pulsed peak power capability of the MIR-Pac laser is ultimately limited by the same thermal fracture mechanism as in continuous operation, which for the current product is specified at 0.75 W with typical maximum operating powers as high as 1 W (see Figure 1). The corresponding recommended peak power limit for quasi-continuous operation at a duty cycle of 10%, i.e. 1 ms pulses at a repetition rate of 100 Hz, would therefore be specified at 7.5 W. In practice, the pump diode laser in the standard MIR-Pac laser product is limited to a maximum drive current of 15A, which corresponds to peak powers approaching 4 W at 2.94 µm.

The data in Figures 7 and 8 demonstrate the generation of up to 2.5 W peak powers in QCW operation at 10A peak drive current when generating millisecond regime pulses at pulse repetition rates up to 600 Hz, with corresponding pulse energies up to ~5 mJ (2 ms pulses at 200 Hz). The average power limit is only reached at duty cycles approaching 50% and pulse peak powers as high as 2W; with corresponding pulse energies of 1 mJ at 1 kHz.

Care must be taken to ensure that the electronics used to deliver continuous or pulsed drive currents to the MIR-Pac laser do not include positive or negative switching transients that exceed the safe operating limits of its internal pump diode laser. No negative voltage, pulsed or continuous, may be safely applied to the laser. Positive drive currents, pulsed or continuous, must not exceed 15 A.

The average heat loads of the MIR-Pac laser under QCW operation may be significantly less than for continuous operation depending on the duty cycle of the pulse modulation format and as a result the pump diode laser operating wavelength will drift from the optimum pumping wavelength. Hence, under QCW operation, the user may have to adjust the temperature set point of the pump diode laser of the MIR-Pac laser to obtain the maximum peak and average output powers for their pulse modulation format.

Although the first gain switched laser pulse present at the beginning of the relaxation oscillations can be isolated by use of a short duration pump pulse, this practice is not recommended as a reliable means for the generation of a short duration output pulse. The build up times of the first gain switched laser pulse and the next pulse are very sensitive to the spontaneous emission conditions that drive the lasing process and as a result the timing jitter of the first and second gain switched laser pulses are on the order of the time interval between them. The net result is the generation of one and sometimes two pulses with timing jitter of several hundred nanoseconds.

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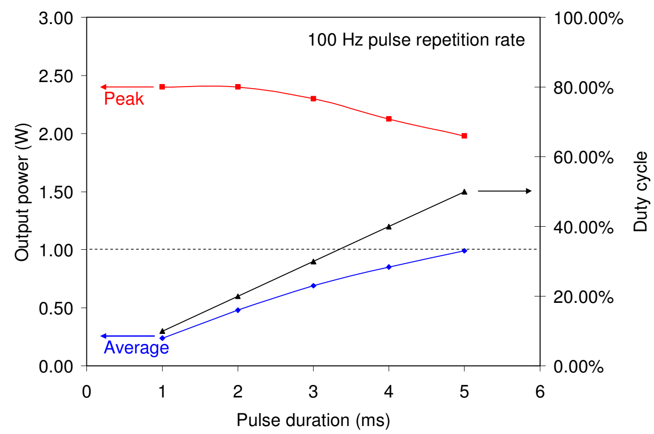

Figure 7. QCW laser performance at a fixed pulse repetition rate of 100 Hz for 8 A drive current pulses superimposed on a 2 A continuous bias current.

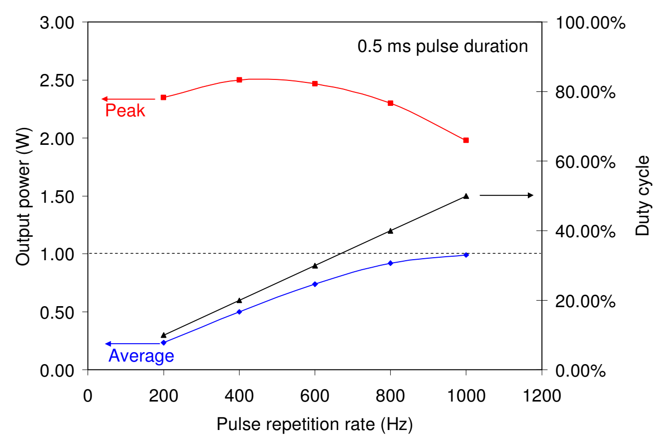

Figure 8. QCW laser performance at a fixed pulse duration of 0.5 ms for 8 A drive current pulses superimposed on a 2 A continuous bias current.

References

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[3] R.C. Stoneman and L. Estrowitz, "Efficient resonantly pumped 2.8-μm Er^{3+}:GSGG laser," Opt. Lett., **17**, 816, (1992).

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[5] J.J. Zayhowski, D. Welford and J. Harrison, "*Miniature Solid-State Lasers*," Chapter 10, *The Handbook of Photonics*, second edition, CRC Press, 2007.