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Sub-nanosecond microchip oscillator for a MOPA system tailored for tattoo removal

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***Abstract*— In this work we study a microchip laser designed to function as an oscillator in a Master-Oscillator Power-Amplifier (MOPA) system targeted for laser tattoo removal. Different configurations of the Nd:YAG resonator were used by changing the output coupler mirror reflectivities and the initial transmission of the Q-switch. The quasi-CW resonator provided 55.4 W of output with 51.31% and 78.2% optical and slope efficiencies, respectively. For Q-switched operation, the best configuration resulted in a peak output power of 3.6 MW with 588 ps pulse width.**

***Keywords*— Nd:YAG, Q-switched laser, tattoo removal, microchip laser, solid-state laser.**

I. INTRODUCTION

The removal of tattoos using Q-switched lasers with nanosecond pulse widths has been the gold standard since the 90s. The treatments are mainly done with solid-state lasers, mostly with the active medium being either Nd:YAG, alexandrite or ruby. Picoseconds pulse width technology has been commercially available since 2012. Picoseconds pulse lasers offer some advantages for tattoo removal when compared to nanosecond lasers. One of these advantages is the selective removal of dye particles since tattoo pigments are in the range of 10-100 µm, which implies in a thermal relaxation time in the picoseconds range [1,2]. Another clear advantage for picoseconds lasers is in terms of pain, as a study [3] has classified the pain for nanosecond lasers as a 7.9, on a scale from 0 to 10 where 0 means no pain and 10 means extreme pain, while picoseconds lasers were classified as 3.8. This can be attributed to both, lower photon fluency and thermal relaxation time.

Aiming to develop a high energy (>700 mJ) picosecond laser, a master-oscillator power-amplifier (MOPA) system was proposed based on previous experience of our group [4,5]. The system comprises a Q-switched microchip laser as an oscillator that is expected to produce > 3 mJ level pulses in the sub-nanosecond range (< 0.7 ns). These pulses will be further amplified in order to reach the energies necessary to be used in laser tattoo removal. A schematic of the system is shown in Figure 1, where a double- pass amplification scheme in the lamp pumped Nd:YAG rods is expected to increase the energy to close to the 1 J level without the need for pulse pickers. In this study we focus on the laser oscillator.

The oscillator is based on works from the literature [6] but with the additional condition that shorter pulse durations with < 200 ps should be feasible in the future by decreasing the cavity length and with the use of a shorter active medium. With these shorter pulse durations, we expect to be able to see greater beneficial effects during tattoo removal.

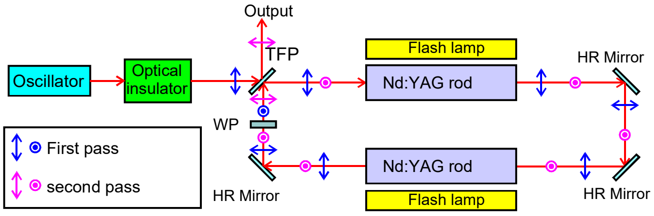

Figure 1 – Scheme of the proposed MOPA laser system. TFP:thin-film polarizer; WP: half wave plate

II. EXPERIMENTAL SETUP

A Nd:YAG crystal measuring Ø10 mm x 4 mm was longitudinally pumped by a 140W diode (CW) at 808 nm coupled to a 600 µm fiber. The active medium was doped with 1.1 at. % Nd. In order to obtain a QCW output, two synchronized choppers were employed: the first determined the pump pulse width and the second selected one pulse out of every ten, so that a low repetition rate was attainable. The beam from the fiber was focused onto the crystal by a telescope composed of a plano-convex lens L1 (f = 30 mm) and a biconvex lens L2 (f = 50 mm). The pump repetition rate to which the crystal is subjected is 9 Hz with a pulse width of 390 µs. The pump surface (S1) of the active medium has a high reflectivity coating for 1064 nm and the second surface (S2) has a high reflectivity for 808 nm, enabling double pump pass through the crystal. S1 acts as the first mirror of the cavity, eliminating the need for an additional component. Figure 2 shows the experimental setup used throughout this article, where Cpp1 and Cpp2 are the first and second choppers, respectively, L1 and L2 are the pump focusing lenses and OC is the output coupler. A Cr^{4+}:YAG was inserted in the laser cavity as a passive Q-switch. Pump waist at the crystal was approximately 1 mm and was optimized for each cavity configuration based on pulse energy considerations. The OCs (plain mirrors) employed had 50% or 75% reflectivity at 1064 nm, and the initial transmission (T_0) of the saturable absorber varied from 10% to 41.7%.

III. RESULTS

First the laser was tested in the quasi-continuous (QCW) mode. The input-output curve for the R=75% OC is shown in Figure 3. The optical and slope efficiencies were 51.31% and 78.2%, respectively. This very high slope efficiency can

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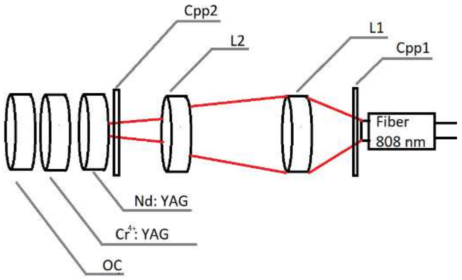

Figure 2 - Laser cavity scheme, were: Cpp1 and Cpp2 are the choppers, L1 and L2 are plano-convex leans, OC is output coupler, Cr^{4+}:YAG is the passive Q-switch and Nd:YAG is the active medium.

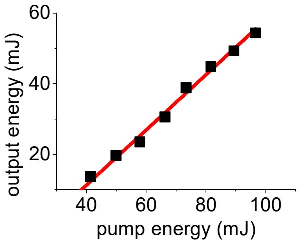

Figure 3 – Input output curve for the quasi-CW resonator.

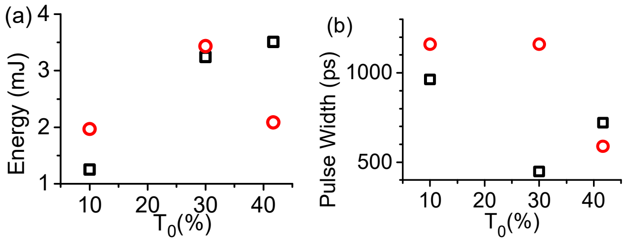

Figure 4 – Energy (a) and pulse width (b) measured for different initial transmission of the saturable absorber (T_0), obtained with T = 50% O.C (circles) and T=75% O.C (squares).

be compared to the best results in the literature for neodymium doped materials [7-11]. Next, the Q-switches were inserted into the cavity and the energy and pulse width were measured for each OC as T_0 varies. For single pulse operation, 2.1 mJ pulses with 588 ns was the best result obtained with R=50% O.C. and the 20% T_0 saturable absorber, as shown in Figure 4a. Next, the resonator was configured for bulse burst of up to 5 pulses. The results are summarized in figure 5. Up to 5.5 mJ output was obtained for five pulses with energy per pulse reduced to 1.1 mJ, shown in figure 5. For the cavity with the 75% output coupler, the best initial transmission value was 30% with energy of x 1.7mJ and the shortest measured pulse width of 448 ps (figure 4b), and for the 50% output coupler, the best initial transmission was 20% with 2.07 mJ e 588 ps.

IV. CONCLUSIONS

Considering higher energy per pulse and lower pulse width, we can conclude that the most suitable configuration to apply to a MOPA system is the cavity with 50% reflective OC and a Q-switch with T_0 = 20%. Under these conditions the microchip laser oscillator reached 2.1 mJ pulses with 588 ps pulse width at 9 Hz repetition rate.

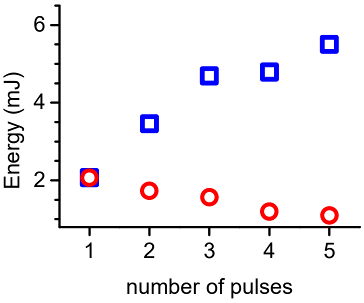

Figure 6 – Total energy (squares) and energy per pulse (circles) obtained with T=50% O.C and T_0=20 % saturable absorber.

Further improvement in pulse width will be obtained in reducing the active medium to a 2 mm thick Nd:YAG crystal thus allowing the resonator to assume lengths as low as 4-5 mm. The next step will be to amplify the output pulses.

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