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A passively Q-switched Yb:YAG microchip laser

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Abstract. We present a diode-pumped passively Q-switched Yb:YAG microchip laser, using a semiconductor saturable absorber mirror. We obtained pulses with 1.1-μJ energy, 530-ps duration, 1.9-kW peak power, and a repetition rate of 12 kHz. The laser is oscillating in a single longitudinal mode.

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Simple, compact sources of single-frequency sub-nanosecond pulses with high pulse energies and peak powers, together with a diffraction-limited output beam, are of interest for applications in the fields of range finding and non-linear frequency conversion. Diode-pumped passively Q-switched microchip lasers are ideal sources for these requirements. Most of the work on passively Q-switched microchip lasers has been done with neodymium-doped crystals as gain medium and Cr^{4+}:YAG as saturable absorbers [1, 2]. Exceptions are Er:Yb:glass microchip lasers, Q-switched with Co:LMA [3], $Nd:YVO_4$ microchip lasers, Q-switched with a V:YAG crystal [4], Yb:KGW microchip lasers, Q-switched with a Cr^{4+}:YAG crystal [5] and our prior work on microchip lasers, where we used semiconductor saturable absorber mirrors (SESAMs) [6–8] for Q-switching. Microchip lasers passively Q-switched with a SESAM typically generate much shorter pulses compared to those using bulk crystal absorbers because the cavity length is essentially not increased by the SESAM [9]. However, the pulse energy of our microchip lasers using neodymium-doped crystals at 1 μm was typically around 100 nJ [9, 10]. With an Er:Yb:glass microchip laser we obtained pulse energies of up to 4 μJ [11]. The low laser cross-section of Er:Yb:glass leads to a large gain saturation energy and therefore to high Q-switched pulse energies and a low repetition rate [9]. Here, we also demonstrate pulse energies around 1 μJ in the 1-μm wavelength domain, using Yb:YAG.

1 Materials and experimental procedure

As a gain medium, Yb:YAG is particularly interesting for several reasons. Figure 1 shows the measured emission and absorption cross-sections. We used small splinters of the gain medium surrounded by index matching fluid in order to avoid undesired effects such as reabsorption and radiation trapping [12]. In order to obtain the emission cross-section, the measured fluorescence spectrum was multiplied by λ^5 and an absolute scaling was done using the measured fluorescence lifetime, assuming a purely radiative decay. We measured σ_{em} to be $2.5 \times 10^{-20}\,cm^2$ at 1030 nm. The upper state lifetime was determined to be 950 μs. As already mentioned, the relatively low laser cross-sections of Yb:YAG led to larger pulse energies compared with those of neodymium-doped crystals. Additionally, YAG has excellent thermal properties and is well established as a microchip host material [2]. Yb:YAG has a small quantum defect and a simple electronic structure, which prevents loss mechanisms like up-conversion and excited state absorption. This results in a small heat load and a potential for high efficiency.

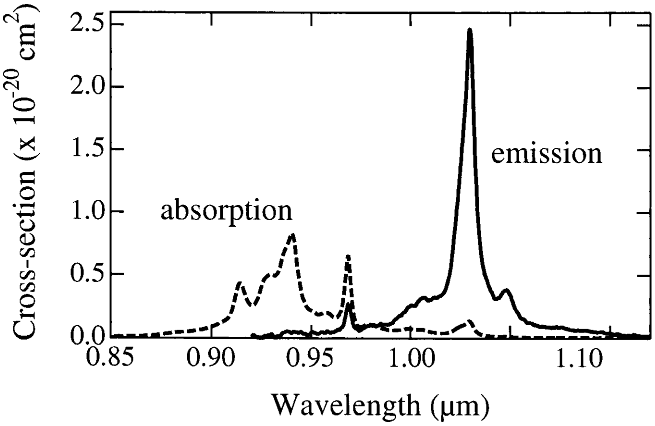

Fig. 1. Measured emission and absorption cross-sections for 20% doped Yb:YAG

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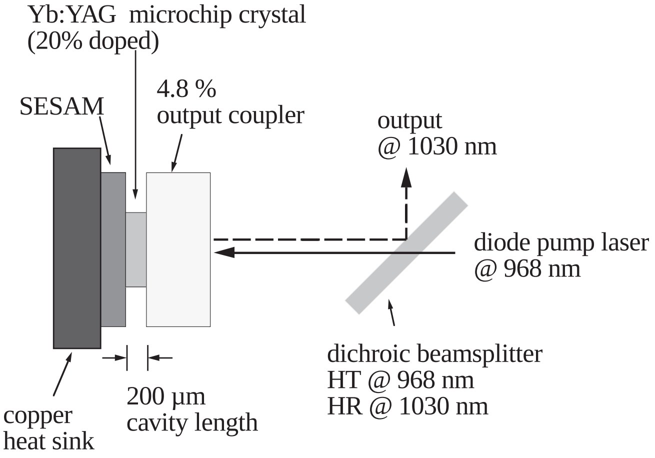

Fig. 2. Cavity set-up of the Yb:YAG microchip laser. HR, highly reflecting; HT, highly transmitting

The microchip cavity was very simple and compact, consisting of a thin Yb:YAG disk sandwiched between the cavity mirrors [13]. The stability of the resonator and two flat mirrors was provided by the pump-induced thermal lens, thermal expansion, and gain guiding [13, 14]. The extremely short cavity length of typically several hundred microns forced the laser to oscillate in a single longitudinal mode and allowed for pulse widths well below 1 ns during Q-switched operation.

Figure 2 shows a schematic of our experimental set-up. The uncoated gain plate of 200 μm thickness was sandwiched between a 4.8% output coupler and a SESAM, which acted as a Q-switch. The laser was pumped using a 30-μm-stripe size single emitter laser diode at 968 nm, which was focused to a pump spot of 27 μm × 56 μm radius in the crystal. The laser was pumped through a dichroic beam splitter, in order to separate the laser beam from the pump beam. The gain plate used was only 200 μm thick, in order to obtain single longitudinal mode operation in spite of the relatively wide emission band of Yb:YAG. This also led to short pulses because the pulse width was directly proportional to the cavity round-trip time [9]. The short cavity length required a large doping level in order to maximize the absorption of the pump in a single pass. For our pump diode at 968 nm, the absorption length of the 20% doped Yb:YAG was approximately 550 μm.

The SESAM used for this experiment was grown by metal-organic chemical vapor deposition. It consisted of 9 strained InGaAs/GaAs quantum wells grown on an AlAs/GaAs high reflector with 25 quarter wave layer pairs, covered by a 75% dielectric top reflector. The top reflector reduced the laser field inside the antiresonant Fabry–Perot cavity of the SESAM, and thereby raised the damage threshold. This is important, because the fixed mode size (on the SESAM) results in fluences around 100 mJ/cm^2. For this SESAM, we measured a modulation depth of 3.8%, a lifetime of 78 ps, and a saturation fluence of $\approx 210\ \mu\text{J/cm}^2$ using 6 ps pulses.

2 Results and discussion

With the Yb:YAG microchip laser, we obtained 1.1-μJ pulses with a duration of 530 ps (Fig. 3). The peak power was 1.9 kW and the repetition rate 12 kHz. The measured optical spectrum clearly showed that the laser oscillates in a single longitudinal mode at 1030 nm. Theoretically [9], one would expect 200-ps pulses with about 3 μJ energy, taking into account the given modulation depth and assuming a laser mode area of a third of the pumped area. The reduction in pulse energy and the longer pulses can be explained by the etalon effect of the air gap between the gain plate and the SESAM. For the given set-up, a change in the thickness of the air gap by half a wavelength (i.e. changing from etalon antiresonance to resonance) can change the coupling into the SESAM by a factor of three. This changes the modulation depth (and the saturation fluence) of the SESAM by a factor of three.

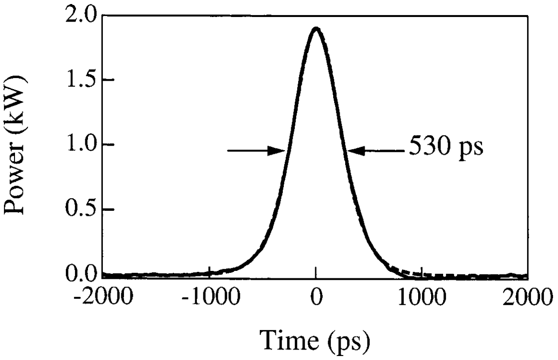

Fig. 3. *Solid*: 25-GHz sampling oscilloscope trace of the single-frequency 530-ps pulses with 1.1-μJ pulse energy and a repetition rate of 12 kHz. *Dashed*: Ideal 530-ps sech^2 fit

The moderate efficiency (incident pump power 485 mW, average output power 13 mW) originated from the non-optimized parts used for the laser: The output coupler, through which the laser was pumped, had no special coating for high transmission at 968 nm. Thus, 64% of the pump light was reflected. For diode pumping, it would have been preferable to have used the absorption band of Yb:YAG around 940 nm, as it is stronger and wider than the one at 968 nm. A pump diode at 940 nm would have at least doubled the fraction of absorbed pump power because of the reduced absorption length and the wider absorption band. A high reflectivity coating on the SESAM at the pump wavelength would have allowed for a double pass through the pump, and additionally it would have reduced the heat load on the SESAM. In total, a five to ten times better efficiency should be easily possible by using optimized components.

3 Conclusion

In conclusion, we have presented an Yb:YAG microchip laser passively Q-switched using a SESAM. The simple, compact laser yields microjoule sub-nanosecond pulses in a single longitudinal mode output.

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