Passive mode locking of an Yb:YAB laser with a low modulation depth SESAM

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A passive mode-locked diode-pumped self-frequency-doubling Yb:YAB laser with a low modulation depth semiconductor saturable absorber mirror operating at 374 MHz is demonstrated. The measured pulse duration is 1.98 ps at the wavelength of 1044 nm. The maximum average power reaches 45 mW.

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Yb^{3+}-doped solid-state lasers have received much attention recently. Their simple energy level scheme minimizes undesirable effects such as up-conversion, excited-state absorption, and concentration quenching. Also, the small quantum defect (< 0.1) and high quantum efficiency reduce the thermal load and associated problems. An important advantage of Yb^{3+}-doped laser crystals over Nd^{3+}-doped counterparts is their broadband fluorescence, which allows tunability or sub-picosecond pulse generation at wavelength near 1 μm. For example, 340-fs pulses have been achieved in a semiconductor saturable absorber mirror (SESAM) mode-locked Yb:YAG laser with an average output power of 110 mW[1]; the 40-mW, 90-fs pulses were obtained from an Yb^{3+}:$Ca_4GdO(BO_3)_3$ laser[2]; and the 200-mW, 112-fs pulses were got from an Yb^{3+}:$KGd(WO_4)_2$ laser[3].

Efforts to develop new crystal hosts for the Yb^{3+} ion have led to successful doping of $YAl_3(BO_3)_4$ (YAB)[4]. Apart from its favorable laser properties[5], Yb:YAB has a sizable second-order nonlinearity ($d_{\text{eff}} > 1.4$ pm/V) and has so far been used in miniaturized continuous wave (CW) and Q-switched lasers in the infrared (IR) region and been highly efficiently self-doubled[6]. Because of its fluorescence bandwidth of 20 nm (centered at 1040 nm), Yb:YAB is ideal for femtosecond pulse generation in the IR and green light ranges.

In this paper, we report, to our knowledge, the first passive mode-locked diode-pumped Yb:YAB laser with a low modulation depth SESAM, by which CW mode-locked Yb:YAB laser with pulse width of 1.98 ps and average power of 45 mW was achieved. A few degrees off phase matching, the IR output was accompanied by as much as 6.5 mW of green light pulse.

The structure of the cavity is shown in Fig. 1. The cavity contains a 4-mm-long, 10-at.%-doped, anti-reflection-coated Yb:YAB crystal. In experiments, the crystal-mount temperature was held at 19 °C. The laser diode was imaged inside the crystal through a lens (F) and a dichroic mirror (M_1). An other mirror M_3 with a smaller focal length was used to obtain tight focus on the SESAM. The laser is pumped by an InGaAs laser diode (Apollo, F15-940-11) with a 15-W output at 940 nm. A glass sheet was placed in the cavity to get about 4% output of the laser.

It is well known that solid-state laser media with a long upper-state lifetime (τ_{u}) and a small emission cross section (σ_{e}) tend to Q switch or Q-switch mode lock in the presence of intracavity saturable absorption[7]. With $\tau_{\text{u}} = 0.68$ ms and $\sigma_{\text{e}} = 0.8\times10^{-20}$ cm^2, Yb:YAB is comparable to other Yb^{3+}-doped laser materials that operate on a quasi-three-level energy model and require high brightness pumping.

In the Yb:YAB laser we used a low modulation depth SESAM to reduce loss and overcome Q-switching operation. The SESAM structure is shown in Fig. 2. It has a high reflection film on the surface to get high reflectivity at the wavelength of 1064 nm and at the same time reduce the modulation depth to approximately 0.22%. With this kind of SESAM the laser achieved CW mode-locking operation, as shown in Fig. 3. The digital real-time oscilloscope (TDS.380, Tektronix, USA)

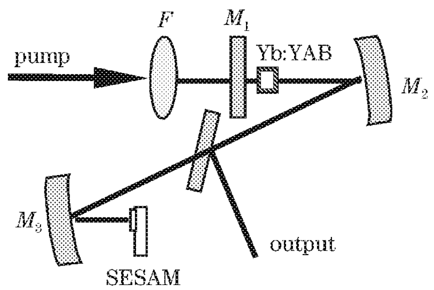

Fig. 1. Structure of the cavity. F (f = 50 mm): focus lens; M_1: dichroic mirror; M_2 (R=100 mm): concavo-convex lens; M_3 (R=30 mm): concave mirror. The distance between M_2 and M_3 is 325 mm.

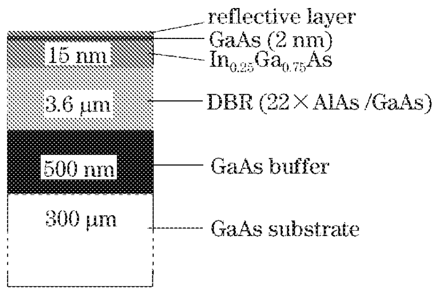

Fig. 2. Schematic structure of SESAM.

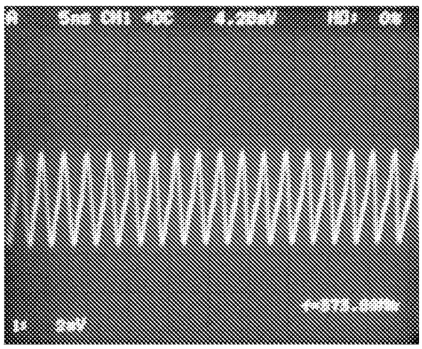

Fig. 3. CW mode-locking train of the Yb:YAB laser by the SESAM.

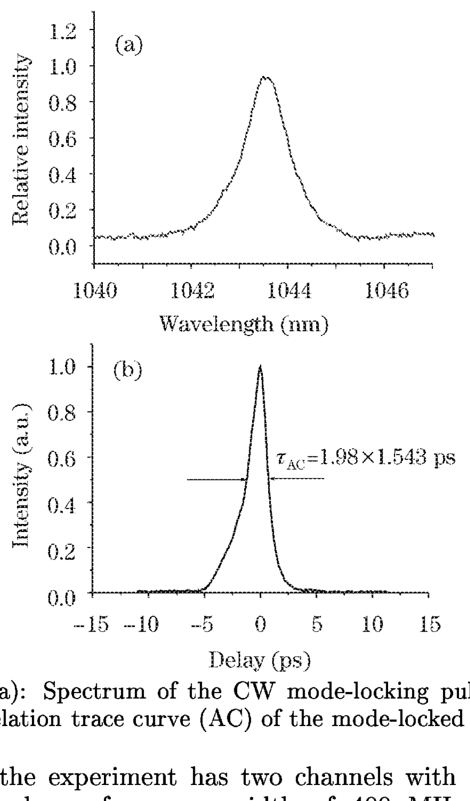

Fig. 4. (a): Spectrum of the CW mode-locking pulse; (b): autocorrelation trace curve (AC) of the mode-locked pulses.

used in the experiment has two channels with a maximum analogue frequency width of 400 MHz and a maximum sampling rate of 2×10^9 samples/s. The measured spectrum and the intensity autocorrelation curve were depicted in Fig. 4. The full-width at half-maximum (FWHM) of the spectrum is 2 nm. Assuming sech^2 pulses, we deduce a pulse width of 1.98 ps. The time bandwidth product $\Delta\nu\tau_{\mathrm{FWHM}} = 1.089$ is much greater than that of the transform limited pulses.

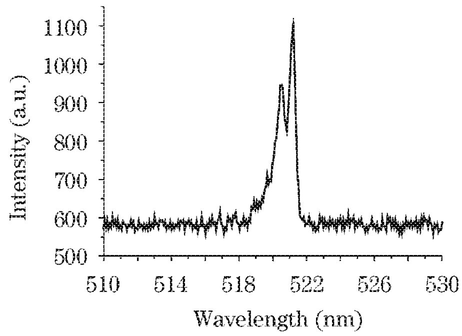

Fig. 5. Spectrum of the green light pulses.

There may be two reasons responsible for this deviation: the large residual chirp and the non-sech^2 pulse profile. Extracavity compensation may be needed to compress the pulse to transform limited (600 fs).

With careful alignment, the output power was about 23 mW for one direction and the total output power (bidirectional) was greater than 45 mW. The repetition rate of the CW mode-locked laser was 374 MHz. Simultaneously, we also measured 6.5-mW output at the wavelength of 521 nm, which was the frequency-doubling of the IR laser emission. The spectrum of the green light was shown in Fig. 5. Because the coatings for this wavelength on M_1, M_2, and the laser crystal are nonideal, the power could be increased by improving coating.

In conclusion, we have demonstrated passive mode locking of a self-doubling Yb:YAB laser. The diode-pumped laser was passively mode-locked by the low modulation depth SESAM. The laser produced CW mode-locked IR pulses with pulse width of 1.98 ps. Simultaneously, green light pulses with a total output power of 6.5 mW were generated. Further work to compress the pulse is under progress.

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