Stable mode-locking in an Yb:YAG laser with a fast SESAM

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Stable mode-locking in a diode-pumped Yb:YAG laser was obtained with a very fast semiconductor saturable absorber mirror (SESAM). The pulse width was measured to be 4 ps at the central wavelength of 1047 nm. The average power was 200 mW and the repetition rate was 200 MHz.

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Yb-doped materials attract much interest as promising active media for all-solid-state ultrashort pulse lasers emitting in the 1-μm region, since the emergence of powerful InGaAs diode lasers[1,2]. Owing to its very simple electronic structure (consisting only two states), the Yb^{3+} ion used as a dopant in crystalline or glass hosts has numerous advantages over the widely used neodymium ion: the smaller Stokes shift between the involved absorption and emission energy levels increases the laser efficiency and reduces heating and concentration quenching. The lack of relevant higher-lying excited states eliminates undesired effects such as excited state absorption or up-conversion. Furthermore, a broad emission spectrum makes it suitable for both tunable and ultrashort pulse lasers[2].

However, the quasi-three-level nature of Yb can lead to re-absorption loss and cause the laser performance to be very dependant on temperature. Furthermore, a long upper level lifetime results in self Q-switching easily when a semiconductor saturable absorber mirror (SESAM) is introduced to the cavity[2].

In this paper, we present the results of a CW mode-locked Yb:YAG laser by a surface state SESAM. To our knowledge, this is the first time Yb:YAG was CW mode-locked by surface state quantum well (QW).

The major problem in passive mode-locking of solid-state lasers is that the SESAM introduces a tendency of the laser toward Q-switched mode-locking (QML)[3]. This tendency increases with the increase of the laser mode area in the gain medium. This area could be quite large in diode-pumped lasers because of the unfocusable beam of diode laser. This problem is more severe in Yb:YAG lasers, in which the crystal has small emission cross section and thus a high gain-saturation fluence. The condition for CW mode-locking is derived as[4]

$$\left|\frac{\mathrm{d}R}{\mathrm{d}I}\right| I < \frac{g_0}{l}\frac{T_R}{\tau_l}, \qquad (1)$$

where R is SESAM reflectivity, I is the CW intensity, T_R is the cavity round trip time, τ_l is the upper level lifetime of the gain medium, g_0 is the small-signal gain, and l is the cavity loss. From Eq. (1) we can see that to suppress QML, we should increase the small signal gain g_0 and round trip time T_R (or equivalently, to reduce saturation recovery time).

In this experiment, a number of measures were taken to suppress QML. First, the laser mode area was kept as small as possible to increase the gain. Second, a small modulation depth, short recovery time SESAM was designed and grown. Third, a low transmission output coupler (OC) (1%) was employed. Finally, a mirror with a smaller focal length was used to obtain tight focus on the SESAM to operate the laser well above the saturation fluence of the SESAM.

The SESAM structure used in this work is shown in Fig. 1. The absorption layer is a 15-nm $In_{0.25}Ga_{0.75}As$ QW, grown on the top of AlAs/GaAs Bragg mirror. The Bragg mirror contains 22 pairs of quarter-wave layers. By placing the QW close to the air interface, the carrier recombination is accelerated through tunneling to the surface states[5], thus the absorption recovery time is reduced to ~ 1 ps. A very thin (2 nm) GaAs was added on the top of the QW as a protection layer. The growth of SESAM was made with metal-organic-chemical-vapor deposition (MOCVD) at a temperature of 700°C.

The laser crystal is 3 mm long, Brewster-cut, 10 at.-% Yb^{3+} doped, and is mounted on a copper heat sink which is cooled by 19°C circulate water. The cavity (Fig. 2) consists of two dichroic plane-concave mirrors (M_1, M_2), a concave mirror (M_3), a SESAM and a 1% OC. The dichroic mirrors have high transmission at 940 nm and high reflectivity over 1020 – 1100 nm. The radius of

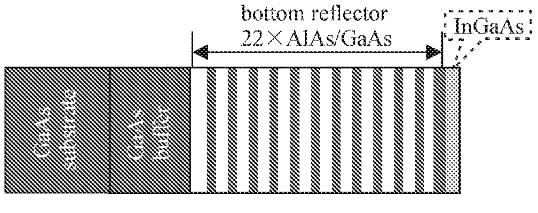

Fig. 1. Schematic structure of SESAM.

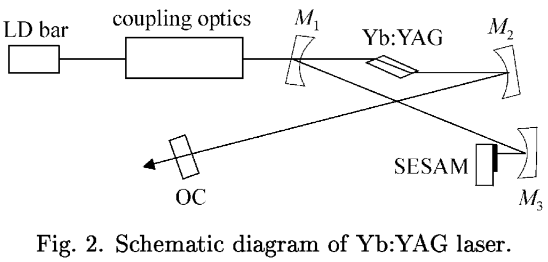

Fig. 2. Schematic diagram of Yb:YAG laser.

curvature is 75 mm. The radius of curvature of M_3 is chosen to be 30 mm, allowing tight focusing on the SESAM. The folding angle of M_1 and M_2 is 9°, for astigmatism compensation. The folding angle of M_3 is kept as small as possible to reduce astigmatism. The cavity is 75 cm long corresponding to 5-ns round-trip-time. The laser was pumped by a 10-W diode bar at a wavelength of 940 nm (F15-940-1, Apollo Instruments, Inc.). The pump beam is collimated and focused onto the Yb:YAG crystal with a single lens ($f = 60$ mm).

The laser is very easy to work at QML mode (Fig. 3). With careful alignment, the laser turn to work at CW mode-locking state (Fig. 4), the average output power is 200 mW at the repetition rate of 200 MHz. The spectra of the laser and the intensity autocorrelation trace are shown in Figs. 5 and 6, respectively.

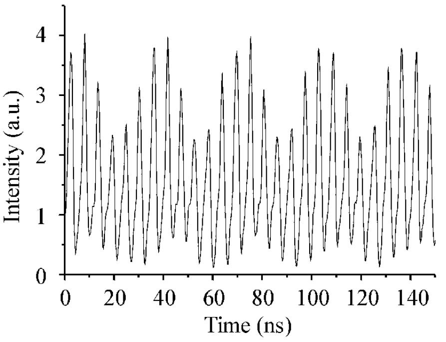

Fig. 3. Q-switched mode-locking pulses array of Yb:YAG laser.

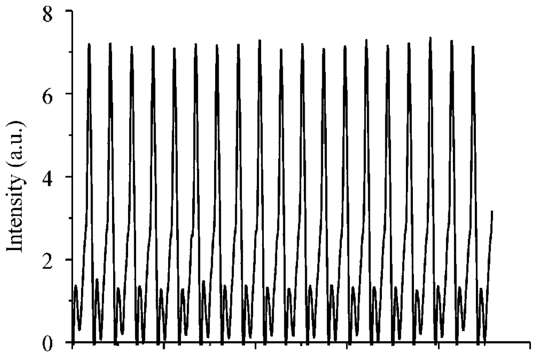

Fig. 4. Mode-locking pulses array of Yb:YAG laser.

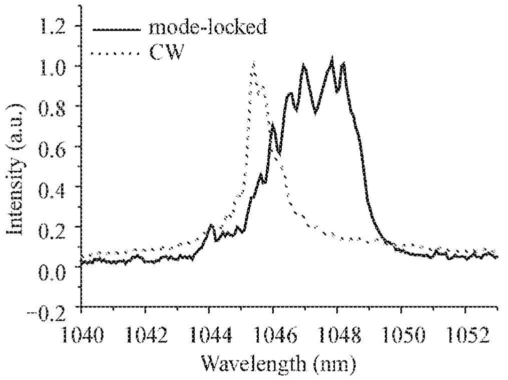

Fig. 5. The spectra of Yb:YAG laser.

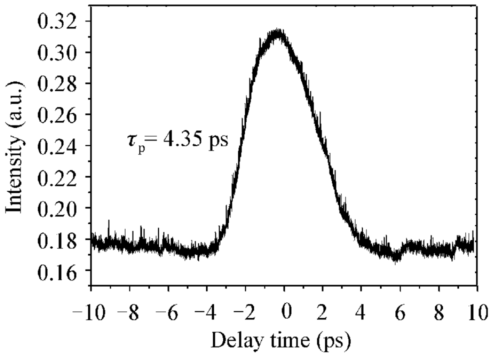

Fig. 6. Intensity autocorrelation trace of Yb:YAG laser.

When the laser is not mode-locked, the spectrum is 1 nm at 1046 nm. For the mode-locking state, the spectrum is expanded to 3 nm, and the central wavelength is 1047 nm. The autocorrelation width is measured as 6.71 ps. By assumed sech^2 pulse profile, the pulse width is estimated to be 4.35 ps. The resulted time-bandwidth product is 3.57. This value is 10 times of that of transform limited sech^2 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 ($\sim$ 0.4 ps).

In conclusion, we have developed a diode-pumped, mode-locked Yb:YAG laser. With a SESAM of very short recovery time, stable CW mode-locking of Yb:YAG was achieved. At an incident power of 10 W, the average output power of 200 mW was achieved. The pulse width is 4.35 ps, which is not transform limited. Further work to compress the pulse is under progress.

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