Simple repetition rate tunable picosecond pulse-generating 10 GHz laser

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A compact, passively fundamental-mode-locked, optically pumped Er:Yb:glass laser where the pulse repetition rate is continuously tunable in the range 8.8–13.3 GHz is demonstrated. The average output power exceeds 20 mW, and the pulse duration is between 1.7 and 1.9 ps over the whole tuning range. Tuning is turnkey and the main laser parameters remain unchanged during tuning.

Introduction: As data transmission rates continue to increase, pulsed lasers are becoming increasingly important for telecomms applications. Transmission systems at 10 GHz and higher often use return-to-zero (RZ) formats and soliton dispersion techniques, which both rely on clean optical pulses. The repetition rate of these pulses for a 10 Gbit/s connection is defined by the applied standard. For example, SONET (synchronous optical NET) STS-192 requires a repetition rate of 9.95328 GHz. However, in practice there are a number of different data rates possible. If forward error correction (FEC) is applied, the required pulse repetition rate has to be adjusted to 10.667 GHz, or even higher with more sophisticated FEC coding. A pulse source with continuously tunable repetition rate increases the flexibility of a network and allows for later upgrades to different transmission standards. Continuous-wave (CW) lasers with external modulators allow the adjustment of the pulse repetition rate to the different standards by modifying the electronics. However, their limited pulse quality can be detrimental for transmission. Directly pulse generating lasers, such as passively mode-locked solid-state lasers [1], harmonically mode-locked fibre ring lasers [2], or hybrid mode-locked semiconductor lasers [3, 4] typically give better transmission performance at high bit rates due to their significantly better pulse quality. Yet, in terms of repetition rate tunability, there have been limitations for these pulse sources. The complex setup of a harmonically mode-locked fibre ring laser requires readjustment of several other parameters when adjusting the repetition rate. This might be simpler for hybrid mode-locked semiconductor lasers, but this type of laser suffers from limited average output power and higher timing jitter. In this Letter, we present an extension of the simple passively mode-locked Er:Yb:glass laser, allowing for turnkey tuning operation without significant changes in the laser output and other important laser parameters. The obtained tuning range allows the laser to be used for all the different RZ transmission standards at 10 Gbit/s as well as a multi-wavelength source for the ITU channel spacing of 12.5 GHz. Also applications in the test and measurement area could benefit from this new versatile tool.

Results: Recently, we have demonstrated a passively mode-locked Er:Yb:glass laser tailored for telecomms applications around 10 Gbit/s [1]. With one set of optics, its repetition rate can be set between 9.2 and 12.7 GHz. However, due to the three-mirror-cavity design with a curved output coupler [1], continuous tuning is not possible. If the curved output coupler is not moved exactly along the resonator axis, lateral readjustment is required after changing the repetition rate. In addition, the position of the gain medium and the saturable absorber have to be readjusted to exploit the whole repetition rate range. Finally, the changes of the cavity length affect the mode sizes in the gain medium and in the saturable absorber, thus affecting parameters like output power and pulse duration.

Here, we refined the three-mirror-cavity setup from [1] by using a four-mirror-design (see Fig. 1). By the addition of a flat mirror the cavity can be arranged in such a way that a large laser mode is obtained on the flat mirror M4. This allows tuning of the repetition rate simply by moving this end mirror along the beam axis. Due to the large laser mode on the flat end mirror M4, the beam divergence is very small. Thus the stability region with respect to the position of mirror M4 is very wide, and movement of M4 only weakly affects the mode sizes in the gain medium and on the saturable absorber. Therefore, the main laser parameters (pulse duration, output power and optical bandwidth) hardly change, and the tuning range is mainly limited by geometric factors (i.e. achievable travel range of M4, see Fig. 2*a*). Also the output beam size is nearly constant over the tuning range (Fig. 2*b*), ensuring a constant efficiency of coupling into a single-mode fibre. Unlike the three-mirror-cavity in [1], this cavity design is insensitive to lateral offsets of the tuning mirror, so that no sophisticated mechanical setup is required to ensure movement exactly along the beam axis, and tuning of the repetition rate is possible without realignment of the resonator. Additionally, this setup significantly reduces the dependence of the laser mode size in the gain, on the SESAM and in the output beam on repetition rate (Fig. 2*b*), thus avoiding problems like changing output power, beam quality or pulse duration.

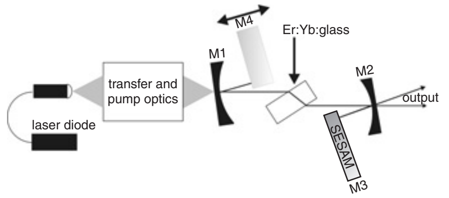

Fig. 1 *Setup of laser. Flat end mirror M4 is used for tuning pulse repetition rate*

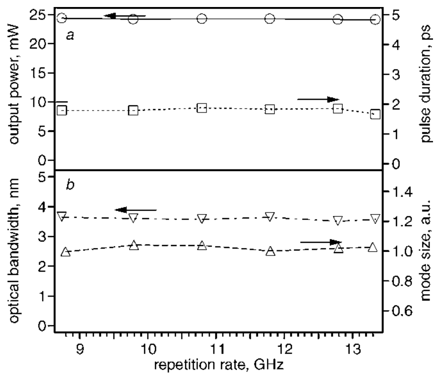

Fig. 2 *Measured output power, pulse duration and optical bandwidth as functions of repetition rate*

a Measured output power and pulse duration
b Measured relative radius of output beam and optical bandwidth

With this setup we could demonstrate a continuously repetition rate tunable 10 GHz Er:Yb:glass laser oscillator with a tuning range from 8.8 to 13.3 GHz, a centre-wavelength of 1534 nm, and an output power of 24.3 mW (combined power of two output beams). We obtained a pulse duration of 1.8 ps (assuming a Gaussian pulse shape) and a time-bandwidth product of <0.85. These pulses are obtained with passive mode locking using a semiconductor saturable absorber mirror (SESAM) [5, 6], i.e. the laser does not require any microwave drive signal to achieve stable mode locking. Since this laser is fundamentally mode-locked, there is one single pulse oscillating in the cavity and the emitted pulses have a fixed phase relation, allowing promising new coding formats like return-to-zero differential phase shift keying (RZ-DPSK) coding technique [7].

We used Er:Yb:glass as gain element because it is well suited for telecomms applications. Its gain bandwidth covers the entire C-band, it can be pumped with standard 980 nm diodes used in EDFAs, and it is robust and low-cost. Q-switched mode-locking is suppressed by the use of a cavity design with small mode areas in the gain and on the saturable absorber, and a SESAM with low saturation fluence and modulation depth [8, 9]. The laser gain element is pumped by a standard 250 mW fibre-coupled 980 nm laser diode with polarisation-maintaining single-mode fibre. For lack of appropriate mirrors, we used fold mirror M2 as the output coupler. The specified output power is the combined power of both output beams (see Fig. 1); a single output beam could be obtained by output coupling through the end mirror M4. Fig. 2 shows the measured output power, pulse duration and optical bandwidth as functions of the repetition rate. This shows only minor changes of pulse duration (between 1.7 and 1.9 ps), optical bandwidth (<3.7 nm) and power (>24 mW) over the full tuning range of 8.8–13.3 GHz. Tuning is achieved with a manual translation stage, which could easily be replaced with a motorised miniature translation stage. The obtained pulse duration is suitable for optical time domain multiplexing (OTDM) at 160 Gbit/s [10].

Since this laser is tunable between 8.8 and 13.3 GHz, it is not only suitable for telecommunication applications that work in the time domain, e.g. in transmitters or demultiplexers for OTDM systems [10], but also as a multi-wavelength source in dense wavelength division multiplexing (DWDM) with 12.5 GHz channel spacing [11]. By insertion of an appropriate solid etalon into the cavity, this laser should be wavelength-tunable over the full C-band (similar to [1]). Additionally, combining this turn-key repetition rate tunable cavity with an active cavity length stabilisation to an external clock [12], a very versatile, simple, and powerful source with low timing jitter should be obtained. Possible applications go beyond telecommunications into the test and measurement area.

Conclusions: We have demonstrated a simple passively mode-locked Er:Yb:glass laser with turnkey repetition rate tunability in the range from 8.8 to 13.3 GHz. The average output power of 24 mW as well as the pulse duration of 1.8 ps do not significantly depend on the pulse repetition rate. The tuning range covers all required data rates for SONET-based STS-192 and applicable forward error correction schemes, as well as the requirements on a multi-wavelength source for 12.5 GHz channel spacing. The pulse parameters of this laser make it suitable for use in 40 and 160 Gbit/s transmission systems.

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