Passively modelocked 77 GHz Er:Yb:glass laser

S.C. Zeller, T. Südmeyer, K.J. Weingarten and U. Keller

A compact diode-pumped passively modelocked 1.5 μm Er:Yb:glass laser with 77 GHz repetition rate and 3.0 ps pulse duration is demonstrated. The laser could serve as a pulse generator in future high-speed return-to-zero data transmission systems.

Introduction: With steadily increasing data transmission rates and the number of WDM transmission channels, pulsed lasers with high repetition rate such as passively modelocked solid-state lasers [1], harmonically modelocked fibre ring lasers [2], or hybrid modelocked semiconductor lasers [3] are becoming increasingly important. Data streams are encoded on the pulse train with a modulator, which then only has to change its state between two successive pulses. This approach avoids extremely stringent demands on the modulator, as the pulse shaping is already done in the laser source itself. Passively modelocked solid-state lasers generate a pulse train with high extinction ratio and low timing jitter close to the quantum limit [4]. Furthermore, system complexity can be reduced significantly, as all the multi-GHz drive electronics are eliminated. In current state-of-the-art high bit rate data transmission systems running, i.e. at 80 Gbit/s, the pulsed laser source usually runs at much lower repetition rate and therefore needs to be time multiplexed to 80 GHz. Generating a pulse train with a repetition rate of 80 GHz with high average output power directly from the laser greatly simplifies system design, since the multiplexing device as well as the amplifiers can be omitted. Therefore, passively modelocked lasers running at high repetition rates are interesting for high bit rate return-to-zero (RZ) transmission systems.

The Er:Yb:glass laser material has many advantages for applications in the 1.5 μm telecom region. Its can be pumped with reliable standard 980 nm laser diodes, and its emission bandwidth covers the entire C-band. Previously, the maximum repetition rate of passively modelocked 1.5 μm diode-pumped solid-state lasers was 50 GHz [5]. Higher repetition rates directly generated by a fundamentally modelocked laser were only achieved in the 1 μm region because of the larger emission cross-section of $Nd:YVO_4$ [6] which strongly reduces the tendency for Q-switching instabilities [7]. In this Letter, we report on a new Er:Yb:glass laser concept for overcoming this limitation, achieving record high repetition rate for passively modelocked diode-pumped solid-state lasers in the 1.5 μm region.

Experimental setup: Operation at tens of GHz repetition rates puts stringent demands on the design of the laser cavity. Er:Yb:glass has a relatively weak emission cross-section, requiring very tight focusing in the gain medium to suppress Q-switched modelocking [8]. Furthermore, at such high repetition rates, the intracavity pulse energies become very low (around 10 pJ in the laser described here). Therefore a tight focus of few micron radius on the semiconductor saturable absorber mirror (SESAM) [9, 10] is needed for sufficient saturation of the absorber. Our former approach to realise such tight foci in a bulk cavity was based on a folded geometry with a SESAM at one cavity end and a curved output coupler at the other cavity end. The folding mirror was also curved, and a thin Er:Yb:glass plate was mounted under the Brewster's angle between the output coupler and the folding mirror. Optimisation of all components resulted in a minimum optical cavity length of 3 mm for a linear standing-wave cavity, corresponding to 50 GHz repetition rate [5].

For 77 GHz, fundamental modelocking leads to an extremely small optical cavity length of 1.9 mm, which cannot be realised with the former cavity design. To ease the mechanical constraints at these very high repetition rates, we developed an improved cavity design which uses gain at the end and a flat output coupler (Fig. 1). The gain medium is cut in a flat-Brewster geometry. Such an approach is normally avoided because of the astigmatism introduced by the gain element. However, by varying the folding angle we can compensate the astigmatism. The cavity then has a round output beam, which can be easily coupled into a standard singlemode fibre. The optimal folding angle is 32°, which is almost the internal Brewster's angle. The beam in the SESAM arm is therefore almost parallel to the surface of the gain element, which greatly simplifies the mechanical mounting. The mode radius in the gain medium is 15 and 4 μm on the SESAM, using a radius of curvature of 0.5 mm at the folding mirror. The SESAM consists of an InGaAs quantum well embedded in a low finesse design, resulting in low saturation fluence and a modulation depth below 1% [11]. The output coupler has a transmission of 1.3%. Note that the small air gap between the output coupler and the gain element acts as an air-spaced Fabry-Perot filter and therefore can be used to tune the wavelength of the laser. If tuning is not needed, the output coupler coating can be directly applied to the gain medium, thereby reducing the number of cavity elements to three.

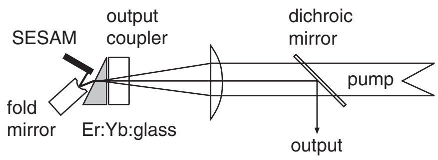

Fig. 1 *Setup of 77 GHz cavity*

Results: We obtained pulses of 3 ps duration at 77 GHz (Fig. 2) with good extinction ratio. The repetition rate was determined by measuring the pulse-to-pulse distance with an FR-103MN autocorrelator from Femtochrome Research, Inc. This autocorrelator has a nonlinear movement of the varying delay arm, which needs to be taken into account. To calibrate the autocorrelator, we measured the temporal shift of the pulse peak position while changing the length of the fixed delay arm. This dependence was fitted with a second-order polynomial. Using just a linear fit would have resulted in an error of 10% over a scan length of 40 ps. Third-order or higher polynomial fitting did not improve accuracy. Fig. 3 shows a high dynamic range optical spectrum recorded with an Ando 6319B spectrum analyser (0.01 nm resolution). The displayed optical signal-to-noise ratio (OSNR) is 56 dB, is measurement system limited (i.e. photodetector and spectrometer). The spectrum is centred at 1535.8 nm with a full width at half maximum of 1 nm. This results in a time bandwidth product (TBP) of 0.37, which is nearly transform limited for $sech^2$ pulses. The wavelength difference between the optical modes is 0.605 nm, which corresponds to a repetition rate of 77.03 GHz. This independent measurement is in very good agreement with the repetition rate determined with the autocorrelator. The Q-switching threshold is at 5.5 mW output power. Above this power level, the pulse train is stable, which can be observed with a slow photodiode. The maximum average output power was 10.7 mW.

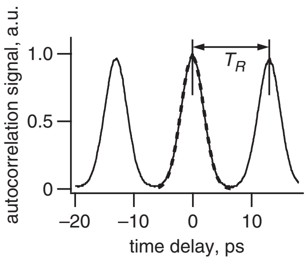

Fig. 2 *Autocorrelation trace of 77 GHz pulse train (solid) together with fit (dotted) for 3 ps $sech^2$ pulse train (cavity round trip time: $T_R = 13.0$ ps)*

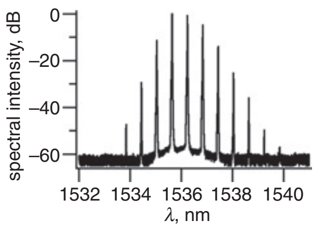

Fig. 3 *Optical spectrum taken with resolution bandwidth 0.01 nm*

Full width at half maximum 1.0 nm; mode separation 0.605 nm

Polishing defects are difficult to avoid for mirrors with strong curvature, thereby introducing additional losses into the cavity. The replacement of the curved output coupler of the former design with a flat output coupler in the here-described system is advantageous for loss reduction. Despite the higher repetition rate of 77 GHz, the output power could be improved by 30% compared to the previous 50 GHz version.

Conclusions and outlook: We have demonstrated a passively fundamentally modelocked diode-pumped Er:Yb:glass laser operating at an extremely high repetition rate of 77 GHz at 1535.8 nm, which is the highest repetition rate obtained directly from a solid-state laser oscillator operating in the 1.5 µm telecom window. The pulse duration was 3 ps with an output power of 10.7 mW. The modelocking is self-starting and stable. The combination of high output power and good pulse quality with a compact and simple setup makes this laser very competitive against actively harmonically modelocked fibre lasers, semiconductor lasers and DFB lasers used in future high-speed OTDM and DWDM telecom applications. The repetition rate was limited by constraints in the mechanics holding the optics. With an improved mechanical design even higher repetition rates are feasible, pushing the performance into the 100 GHz regime. This repetition rate would also allow for wavelength division multiplexed (WDM) applications matching the 100 GHz-grid defined by the International Telecommunication Union (ITU).

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