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Rapid communication

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Passively mode-locked 40-GHz Er:Yb:glass laser

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ABSTRACT A diode-pumped Er:Yb:glass miniature laser has been passively mode-locked to generate transform-limited 4.3-ps pulses with a 40-GHz repetition rate and 18-mW average power.

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1 Introduction

Future data transmission systems will operate at 40 Gbit per second. Current systems operating at, for example, 2.5 Gbit/s are normally based on a continuous-wave laser source in combination with a modulator, whereas much higher data rates will greatly benefit from a pulse-generating laser with a pulse repetition rate of, for example, 40 GHz. This approach avoids extremely stringent demands on the modulator, which then only has to change its state between the pulses. Particularly with a passively mode-locked laser, one can also significantly reduce the complexity of the system architecture, as all of the multi-GHz drive electronics are eliminated. The 40-GHz laser should generate transform-limited pulses with a good extinction ratio and high average power, apart from having a compact and stable setup. Here we demonstrate a passively mode-locked Er:Yb:glass laser fulfilling these criteria. Previously, the maximum repetition rate of passively mode-locked 1.5-mm lasers was 10 GHz [1] and more recently 25 GHz [2], while high-quality pulses with 77-GHz repetition rate have been generated at a 1064-nm wavelength with Nd:YVO_4 [3].

2 Experimental setup

Our approach is not harmonic mode locking (for which stable operation requires sophisticated means) but fundamental mode locking, i.e., with a single pulse circulating in the laser cavity. For 40 GHz, this leads to an extremely short optical cavity length of 3.75 mm for a linear standing-wave cavity. By using very small and strongly curved mirrors, we realized such a cavity (Fig. 1) in a folded geometry, analogous to an earlier 10-GHz cavity [1]. The output coupler has 1% transmission at the laser wavelength and 86% transmission for the pump wave at 976 nm.

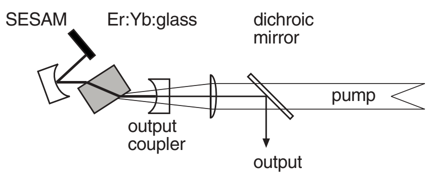

FIGURE 1 Cavity setup of the 40-GHz miniature Er:Yb:glass laser (SESAM: semiconductor saturable absorber mirror)

The pump light with up to 230-mW power is generated with a fiber-coupled (single-mode, polarization maintaining) telecom-grade laser diode. A dielectric mirror is used to separate the output pulses from the beam. The gain medium is a thin Er:Yb:glass plate (QX/Er from Kigre), mounted under Brewster's angle. Passive mode locking is achieved with a semiconductor saturable absorber mirror (SESAM, [4, 5]), having a modulation depth below 1%. The mode radii on the SESAM and in the gain medium are optimized to achieve a low Q-switched mode-locking threshold.

3 Results

The autocorrelation (Fig. 2) for the maximum average output power of 18 mW shows that the laser generates clean Gaussian-shaped pulses with 4.3-ps duration and a good extinction ratio. The optical spectrum (Fig. 3), recorded with an Ando AQ3617C spec-

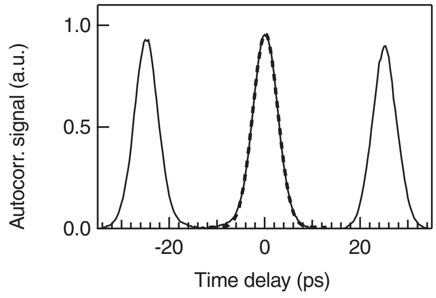

FIGURE 2 Autocorrelation trace of the 40-GHz pulse train at full average output power (18 mW), together with a fit (*dotted*) for 4.3-ps Gaussian pulses

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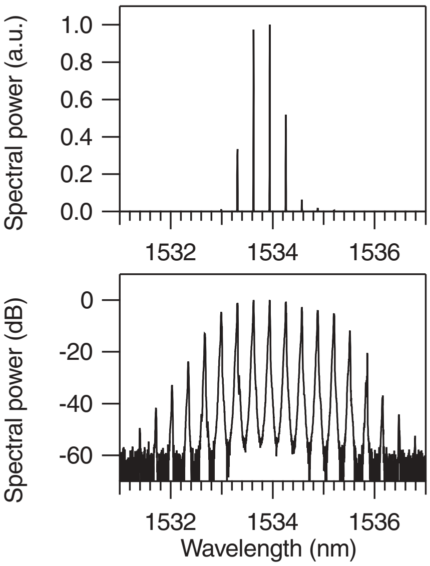

FIGURE 3 Optical spectrum of the pulse train at full average output power (18 mW), taken with a resolution bandwidth of 0.01 nm and displayed with a linear scale (*upper graph*) and a logarithmic scale (*lower graph*). The full width at half maximum is 0.8 nm (determined for a Gaussian envelope), and the time–bandwidth product is 0.44

trum analyzer (0.01-nm resolution), has a Gaussian shape with a full width at half maximum of 0.8 nm. This re-

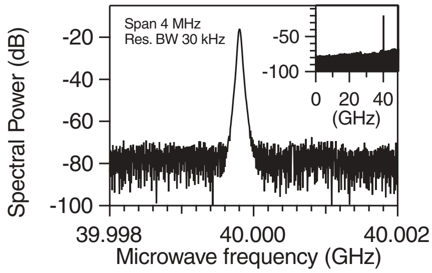

FIGURE 4 The microwave spectrum, demonstrating the absence of Q-switching instabilities and higher order transverse modes. The width of the peak at 39.9998 GHz is limited by the resolution bandwidth

sults in a time–bandwidth product of 0.44, which is exactly as expected for transform-limited Gaussian pulses. The microwave spectrum (Fig. 4), recorded with a 45-GHz photodiode and an Agilent 8565EC frequency analyzer, shows a single peak at 39.9998 GHz and no side peaks. At a lower pump power (below 16 mW of output power), for which Q-switched mode locking occurs, such peaks are observed (but not shown here) with a 766-kHz spacing. The repetition rate can be tuned from 38.5 to 40.8 GHz. The operation is stable over hours.

4 Conclusions

We have demonstrated a passively fundamentally mode-locked Er:Yb:glass laser operating at the extremely high repetition rate of 40 GHz. The combination of its high output power and good pulse quality with the compactness and simplicity of the setup makes it very competitive against actively harmonically mode-locked fiber lasers [6] and semiconductor lasers [7].

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