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50-GHz, ultrastable, polarization-maintaining semiconductor fiber ring laser

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Abstract. We demonstrate a highly stable, all-polarization-maintaining fiber semiconductor ring laser source. It uses a semiconductor optical amplifier (SOA) to provide both gain and gain modulation from an external 5-GHz optical pulse train. The laser source generates 3.5-ps pulses up to a 50-GHz repetition rate with negligible amplitude pattern. [DOI: 10.1117/1.1926867]

Subject terms: fiber lasers; gain modulation; semiconductor optical amplifier; polarization-maintaining ring laser.

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1 Introduction

Short-pulse and high-repetition-rate lasers are essential for high-speed time-division multiplexing (TDM) networks. With the advent of wavelength-division multiplexing (WDM), progress in transmission speeds is lagged behind the deployment of large number of wavelength channels. Key component for a further increase in line rates is the development of robust, highly stable laser sources, capable of generating picosecond optical pulse trains at ultrahigh speeds. Active mode-locking is one of the most promising techniques applied in ring cavities that demonstrate such features. The majority of these sources use erbium-doped fiber amplifiers (EDFAs) for signal amplification and amplitude modulators to achieve mode-locking. Furthermore, by applying rational harmonic mode-locking,[1] the frequency of the generated pulse train can be multiplied to higher rates. With this technique, rates up to 40 and 200 GHz, respectively, have been obtained.[2,3] However, loss modulation in these experimental setups results in optical pulses with unequal pulse amplitudes. On the other hand, a beneficial, alternative technique for rational harmonic mode-locking that exploits the fast time-dependent saturation of an intracavity semiconductor optical amplifier (SOA) by an externally introduced optical signal has been used for optical pulse train generation[4] up to 40 GHz.

Nevertheless, for practical system use, stability in all these laser setups must be significantly improved as Li:NbO$_3$-based, non-polarization-maintaining (non-PM) cavities tend to display sensitivity to polarization fluctuation of the oscillating signal. Similarly, the use of erbium fiber for gain results in long cavities, which make these lasers sensitive to small environmental perturbations, such as thermal fluctuations and acoustic vibrations. In terms of this, numerous research groups have worked on the stabilization of the aforementioned circuits, building all-PM fiber lasers,[5,6] complex feedback stabilizations schemes,[7] or by incorporating high-finesse Fabry-Pérot (FP) filters.[8,9]

In this paper, we present an ultrastable semiconductor fiber ring laser that is constructed using exclusively PM fiber pigtailed components. This laser source is capable of generating 3.5-ps pulses at repetition rates up to 50 GHz.

2 Experimental Setup

Figure 1 shows the experimental setup. The ring cavity consisted of a fiber beam expander, in which a half-wave plate and a 5-nm tunable optical filter were inserted for polarization control and wavelength selection, respectively. In addition, optical isolators were employed in the cavity to ensure unidirectional oscillation and to stop the externally introduced signal from circulating in the loop. Finally, a polarization beamsplitter (PBS) was used for the insertion of the external, orthogonally polarized, optical signal. Moreover, the PBS was also employed to force the cavity to oscillate in a single polarization state, exploiting its polarization filtering function. Gain was provided in the cavity from a 500-μm, bulk InGaAsP/InP ridge waveguide SOA with 100 angled and antireflection-coated facets. The SOA had small signal gain of 21 dB at 1538 nm and a recovery time 400 ps, when driven with a 250-mA dc current. The SOA exhibited negligible polarization gain dependence, as the PM fiber pigtails were carefully aligned to the semiconductor to compensate its original polarization sensitivity. The end-to-end cavity loss was 3 dB and the cavity length was 7 m, corresponding to a 28.57-MHz fundamental frequency. The externally introduced pulses were provided by a gain-switched distributed feedback (DFB) laser emitting light at 1548.5 nm. These pulses were linearly compressed down to 7 ps using a dispersion-compensating

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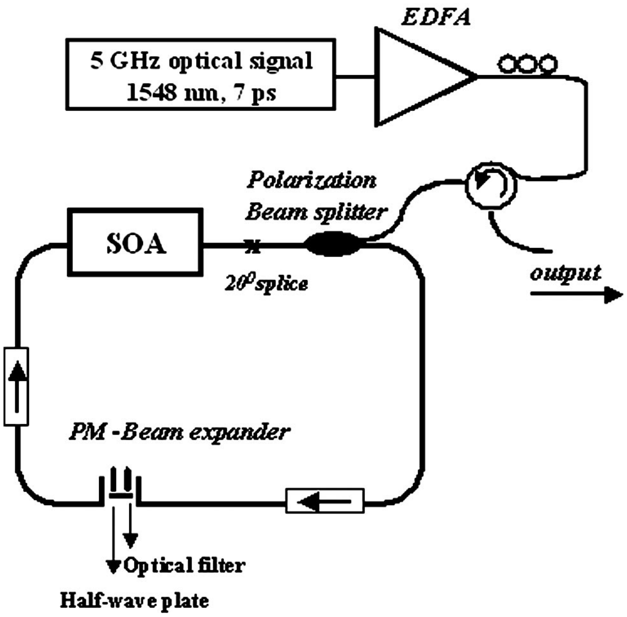

Fig. 1 Experimental setup.

fiber (DCF) of total dispersion −44 ps/nm, amplified, and were then inserted into the cavity. A polarization controller (PC) was employed in the path to maximize the power entering the cavity through the PBS. Output from the source was obtained by adjusting the polarization state of the cavity signal with the half-wave plate and forcing part of it to drop out via the PBS.

3 Results and Discussion

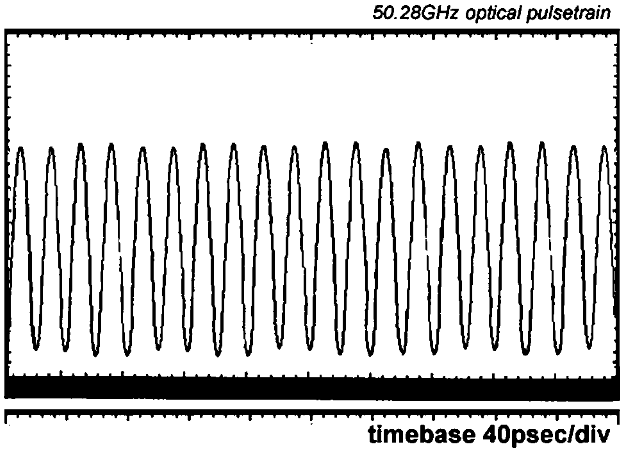

Fig. 2 Oscilloscope trace of the 50.28-GHz pulse train. The time base in the oscilloscope is 40 ps/div.

With the frequency of the externally introduced signal tuned to a harmonic of the cavity and the EDFA adjusted to provide 1.5 mW, the ring laser breaks into stable mode-locked operation at 5.028 GHz, generating 6-ps pulses. The 5-nm intracavity filter was tuned for optimum operation at 1546.8 nm. Detuning the frequency of the external optical signal by 1/10 away from the fundamental frequency of the cavity, 10-times repetition rate multiplication was achieved. Further, by detuning the optical filter, the output wavelength could be selected at will across a 20-nm range around 1546.8. Figure 2 displays the 50.28 GHz pulsetrain monitored on a 50-GHz oscilloscope at 1557 nm. The obtained pulses were not transformed limited due to the extra chirp induced by the gain saturation of the SOA. To this end, 3.5 ps pulse duration was obtained after linear compression, using a DCF of total dispersion −3 ps/nm. Figure 3(a) displays the second-harmonic autocorrelation trace, indicating a pulse of 3.5-ps duration, assuming a squared hyperbolic secant profile, while Fig. 3(b) shows the corresponding optical spectrum, indicating a spectral FWHM of 0.8 nm again at 1557 nm. The pulsewidth-bandwidth product is 0.35, i.e., very close to the transform limited value. For optimum operation, the half-wave plate in the beam expander was set so as to compensate the nonlinear polarization rotation in the SOA and to drop part of the recirculating power at the output. This angle was found to be around 5 deg away from the fast axis of the PM fiber. With this arrangement, the output power of the laser was 300 μW.

Note here that optical pulse trains at repetition rates up to 80 GHz were obtained at the expense of a degraded extinction ratio due to pulse overlapping. However, the use

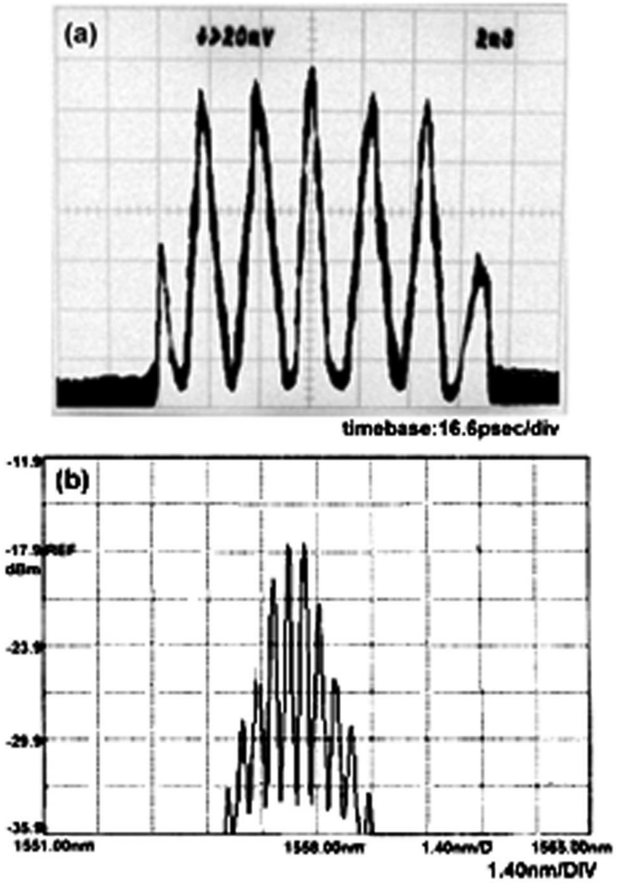

Fig. 3 (a) Second-harmonic autocorrelation trace of the 50.28-GHz pulses for time base 16.6 ps/div and (b) optical spectrum analyzer trace.

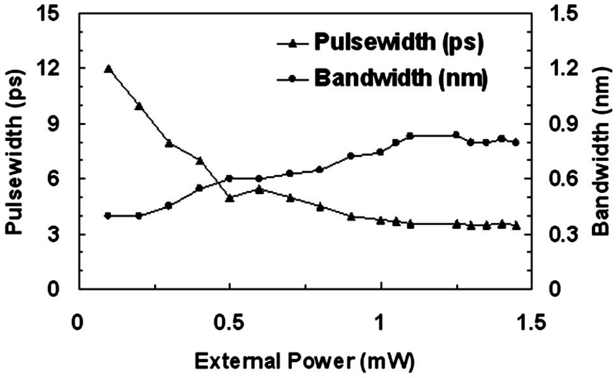

Fig. 4 Pulsewidth-bandwidth product of the mode-locked pulses versus the external pulse power.

of an SOA with a higher gain in combination with an external signal of higher power[4] could narrow the width of the circulating pulses and generate an output signal of higher quality at the aforementioned rates. Figure 4 shows the variation of the temporal and the spectral FWHM of the mode-locked pulses versus the power of the externally introduced signal. This figure indicates that for external pulses with an average power higher than 1 mW, the pulsewidth of the generated pulses was 3.5 ps, while their bandwidth remained almost constant and was 0.8 nm. Thus, the pulsewidth-bandwidth product was calculated to be 0.35, very close to the transform-limited value.

Finally, the laser source exhibited stable operation over hours. This is primarily due to the short cavity length in combination with the PM-fiber pigtailed components employed. In addition, the use of an SOA for gain amplification in the cavity improves the stability of the laser source by removing the supermode noise.[2]

4 Conclusion

We demonstrated an ultrastable, actively mode-locked ring laser, constructed entirely from PM-fiber pigtailed compo-nents. The laser source generates 3.5-ps transform-limited pulses at repetition rates up 50 GHz.

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