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An 18.6 MHz Wavelength-Swept Laser Source Based on Stretched-Pulse Mode-Locking at 1290 nm

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Abstract: We present a stretched-pulse mode-locked (SPML) wavelength-swept laser source at 1290 nm. The lasing bandwidth of the source was 80 nm at a sweep rate of ~18.6 MHz.

1. Introduction

Fourier-Domain Optical Coherence Tomography (FD-OCT) imaging modality offers rapid imaging with high sensitivity [1, 2]. FD-OCT enables radical and profound changes in many medical practices, such as intraoperative [3] or endoscopic OCT techniques and applications [4]. Researchers have proposed various wavelength-swept laser source designs and OCT systems, providing rapid imaging [5].

In this report, we present a stretched-pulse mode-locked (SPML) wavelength-swept laser based on intracavity stretching and compression of a pulse generated by an electro-optic intensity modulator. The lasing bandwidth was 80 nm at a center wavelength of 1290 nm. The laser produces a variable repetition rate up to 18.6-MHz, an order of magnitude faster than our previously demonstrated SPML lasers operating at 1.55 μm [6] and 1.275 μm [7].

2. Methods

Figure 1 shows a block diagram of the laser source operating based on stretched-pulse mode-locking described in detail in Reference [6]. The laser cavity constituted of the 1247-nm central wavelength semiconductor optical amplifier (SOA1250, Innolume, Germany) and the 1289-nm booster optical amplifier (BOA1130P, Thorlabs, USA) as gain components. As a critical point of design, we used two highly matched continuously chirped fiber Bragg gratings (CFBGs) within the cavity. Gratings provided chromatic dispersion of 454 ps/nm and -454 ps/nm dispersion at 1290 nm, respectively. We incorporated the CFBGs into the cavity via wide-band polarization-maintaining circulators (Precision Micro-Optics, USA). Two amplifiers were cascaded to filter out the intensity noises and non-uniform insertion losses of the CFBGs along with the optical band [8]. A high extinction ratio $LiNbO_3$ electro-optic intensity modulator (MX1300-LN, iXblue, France) generated a train of optical pulses. We locked a DC bias controller to the modulator to suppress any voltage drift because of any environmental distortion effects such as temperature or stress. Also, the DC bias controller ensured that the stability of the optical pulses in time. A bit pattern generator (PAT5000, Sympuls, Germany), clocked by an RF signal generator (SG386, Stanford Research Systems, USA), provided a 210-ps electrical pulse to drive the electro-optic modulator through a driver module (DR-PL-10-MO, iXblue, France).

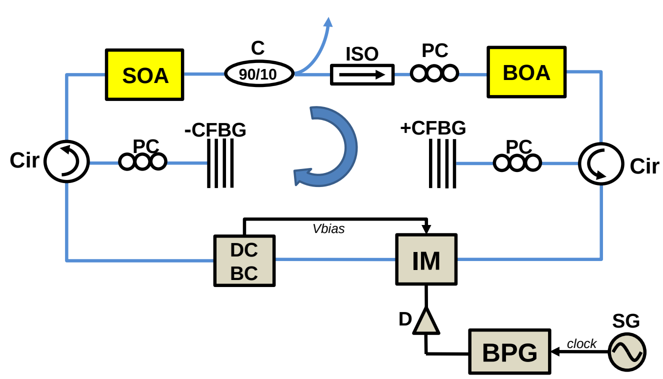

Fig. 1. A schematic illustration of the proposed SPML laser. SOA: Semiconductor optical amplifier, BOA: booster optical amplifier, ISO: optical isolator, Circ: circulator, SG: signal generator, BPG: bit pattern generator, IM: electro-optic intensity modulator, DCBC: DC bias controller, D: modulator driver, CFBG: chirped fiber Bragg grating, C: coupler, PC: polarization controller pedal.

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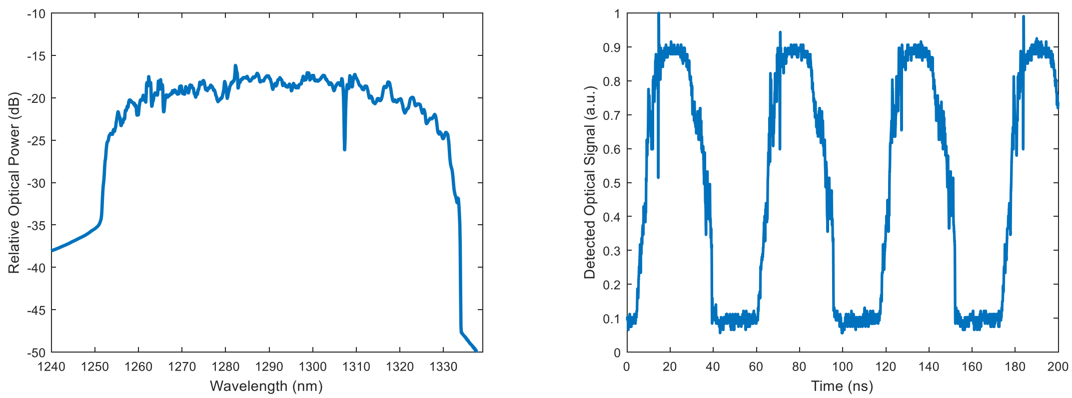
Overall, the generated optical pulses were stretched, amplified, and compressed within the ring cavity, and the modulator pulsing was synchronized to a harmonic of the cavity round trip time. An optical isolator forced unidirectional oscillation in the ring cavity. A 10/90 optical coupler was used with a tap output port of 10%.

3. Results

Figure 2(a) shows a representative spectral output produced by the laser. The measured lasing bandwidth was 80 nm (1250 to 1330 nm). The time-domain laser output (source operated at ~70% duty cycle) was detected with an amplified photodetector (9.5 GHz, PDA8GS, Thorlabs, USA) and digitized by a high-speed oscilloscope (40 GS/s, 3.5 GHz, DPO7354C, Tektronix, USA), shown in Fig. 2(b). The SPML laser was run at an 18.56 MHz repetition rate. The measured output power of the laser was ~12.3 mW.



(a) (b)

Fig. 2. The proposed SPML laser outputs. (a) The lasing spectrum of the laser >80 nm. (b) The laser output pulses at the time domain at an 18.56 MHz repetition rate.

To further examine the performance, the laser was applied to a fiber-based Michelson interferometer, as shown in Figure 3. The interferometer consisted of a fiber coupler at a ratio of 50/50 and a circulator. A neutral density filter (ND_1) with a 2.0 optical density was placed in the sample arm to mimic the loss of the biological tissues. Another filter (ND_2) was placed in the reference arm for dispersion compensation. A balanced photodetector (1.6 GHz, PDB480C-AC, Thorlabs, USA) used in combination with the 3.5 GHz bandwidth oscilloscope acquired fringe signals as a function of the interferometer delay. Therefore, we investigated the coherence length of the laser source by measuring the fringe amplitude (i.e., fringe visibility) as a function of optical path difference.

Figure 4(a) shows a typical raw interference signal generated by the system, and Figure 4(b) shows the estimated point spread functions for multiple different mirror distances in the sample arm. The double pass coherence length was >0.6 mm (limited by the bandwidth of the photodetector). The calculated axial resolution in the air was <15 μm at a distance of 0.3 mm in a double-pass sample arm variable-delay interferometer (Fig. 4(b)). Relative intensity noise was measured in the 1 GHz spectral range and was -123.8 dB at 507 MHz.

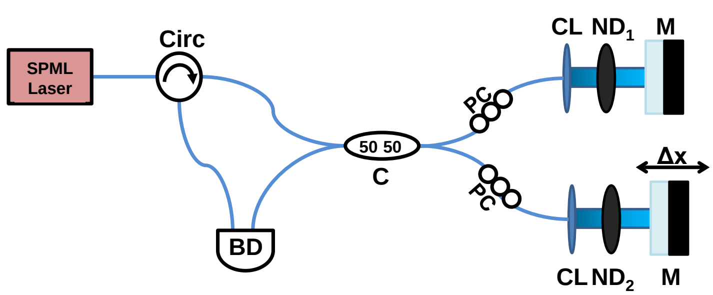
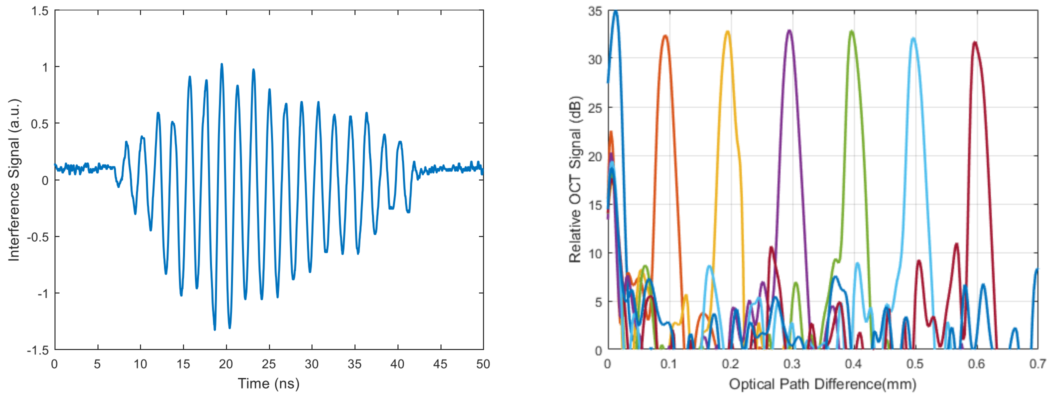


Fig. 3. Fiber-based Michelson interferometer scheme. Circ: circulator, C: coupler, PC: polarization controller pedal, CL: collimating lens, ND_1: neutral density filter with 2.0 OD, ND_2: neutral density filter with 0.2 OD, M: gold coated flat mirror, BD: balanced photodetector



(a) (b)

Fig. 4. (a) An interference signal of the proposed laser, (b) Estimated Point Spread Functions for different mirror distances.

4. Conclusion

In this report, we present an SPML laser source that sweeps a range of 80 nm at the center wavelength of 1290 nm. By the studied laser design, we achieved ~18.6 MHz A-line rate. Besides, the estimated axial resolution was <15 µm. With its rapid A-line combined high phase stability, the laser may have potential in OCT angiography applications.

Acknowledgment

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