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A stretched-pulse mode-locked laser source at a central wavelength of 1275 nm

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ABSTRACT

This study presents a time-stretched wavelength-swept laser source based on stretched-pulse mode-locking. A broadband semiconductor optical amplifier (SOA) technology is used as an optical gain element. The laser comprises a unidirectional ring cavity with matched positive and negative continuously chirped fiber Bragg gratings (FBG's). One FBG generates a total positive dispersion of 454 ps/nm at 1275 nm and the other chirped FBG generates a total negative dispersion of -454 ps/nm at 1275 nm. A high-extension lithium-niobate intensity modulator (>30dB extinction at 1275 nm, 4.9 dB loss at maximum transmission) is driven with short pulses by a bit pattern generator providing approximately 0.235 ns full-width at half-maximum pulse profiles. These pulses are stretched, amplified, and compressed within the ring cavity, and the modulator pulsing is synchronized to a harmonic of the cavity round trip time. The laser output is provided from the cavity by a 25% coupler. The output light is amplified by another SOA. The laser source provides a sweeping range of approximately 90 nm centered at around 1275 nm at a repetition rate of ~5 MHz. This yields an estimated axial resolution of 8 μm in air.

Keywords: Mode-locking, pulse stretching, wavelength-swept laser source, chromatic dispersion

1. INTRODUCTION

Optical Coherence Tomography[1,2], a new imaging model that has been extensively studied by hundreds of scientists in dozens of research centers for over twenty-five years, demonstrates the potential to contribute positively to the medical diagnostic practice of disciplines such as cardiology and ophthalmology[3]. This three-dimensional (3D) optical imaging technique is divided into two: Time-domain OCT and Fourier-domain OCT. The recently developed swept-source OCT (i.e., a subcategory of Fourier-domain OCT) can provide relatively high (MHz) acquisition speed with highly sensitive imaging[4-6]. In this new generation technique, the critical parameters of the imaging device such as axial resolution, A-line scanning speed, coherence length, and sensitivity are largely characterized by the wavelength-swept laser source. Recent studies have introduced many different laser designs and technologies for swept-source OCT[7-15]. Therefore, rational innovations in wavelength-swept laser sources can pave the way for further advances in this imaging model, particularly in the fields of cardiology, flow and perfusion, ophthalmology, and elastography.

In this study, we present a stretched-pulse mode-locking based wavelength-swept laser source at 1275 nm that comprises a unidirectional ring cavity with matched positive and negative continuously chirped fiber Bragg gratings as dispersive elements.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic of the unidirectional ring cavity laser design. The operating principle of stretched-pulse mode-locked (SPML) laser source was described in detail in Reference [16]. A semiconductor optical amplifier (SOA) was used as a gain element in the laser (Thorlabs, USA). Continuously chirped fiber Bragg gratings (Proximion Fiber Systems, Sweden) generated highly matched positive (454 ps/nm) and negative (-454 ps/nm) dispersion at the center of 1275 nm.

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A lithium-niobate intensity modulator (MX1300-LN-10, iXblue, France), having 4.9 dB loss at maximum transmission was driven with short electrical pulses. A bias controller, which was locked to the modulator to compensate the drift and maintain a very high optical pulse contrast value and stability, was used. A bit pattern generator (PAT 5000, Sympuls, Germany) provided approximately 0.235 ns full-width at half-maximum optical pulse profiles. Besides, a RF signal generator (SG386, Stanford Research System, USA) externally clocked the pattern generator. These 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. A 25% tap coupler provided the laser output.

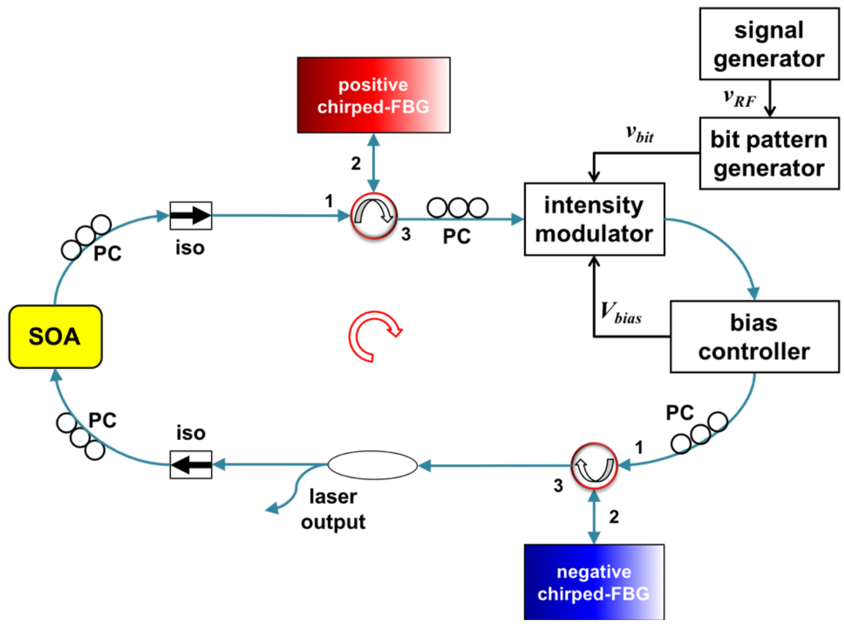

Figure 1. A schematic of the stretched-pulse mode-locked laser. PC: polarization controller; SOA: semiconductor optical amplifier; iso: isolator; FBG: fiber Bragg grating (±454 ps/nm at 1275 nm).

3. RESULTS

Figure 2(A) demonstrates the output of the bit pattern generator. The lasing bandwidth of the SPML laser measured to be 1275 nm at a repetition rate of around 5 MHz. This corresponded to the first-order harmonic of the laser cavity (i.e., the cavity length was 44.5 m). The laser output in the time-domain (source was 25% duty cycle) was detected with 25 GHz bandwidth photodetector (UPD-15-IR2-FC, Alphalas, Germany) and digitized with 3.5 GHz bandwidth and 40 GS/s oscilloscope (DPO7354C, Tektronix, USA), shown in Figure 2(b). The measured average output power of the laser was 1 dBm. The calculated axial resolution in air was determined to be 8 µm.

4. DISCUSSION AND CONCLUSIONS

One of the emerging imaging approaches is the swept-source Optical Coherence Tomography imaging modality. Research studies on wavelength-swept laser sources can contribute to the enhancement of this imaging model, including rapid data acquisition and high sensitivity. From this motivation perspective, scientific studies on wavelength-swept laser sources remain an interesting topic. In this context, we presented a new laser design (i.e., a stretched-pulse mode-locking laser at 1550 nm) in a previous study that also describes the laser operating principles[16]. In this study, we presented a stretched-pulse mode-locking (SPML) based wavelength-swept laser source operating at the center wavelength of 1275 nm. The cavity comprises a unidirectional ring cavity with matched positive and negative continuously chirped fiber Bragg gratings as dispersive elements. One dispersing element produced 454 ps/nm at 1275 nm, while the other produces -454 ps/nm. The laser provided a sweeping range of approximately 90 nm centered at a repetition rate of ~5 MHz (at 25% duty cycle). When the laser is operated at 100% duty cycle, the wavelength sweeping rate can increase up to 20 MHz.

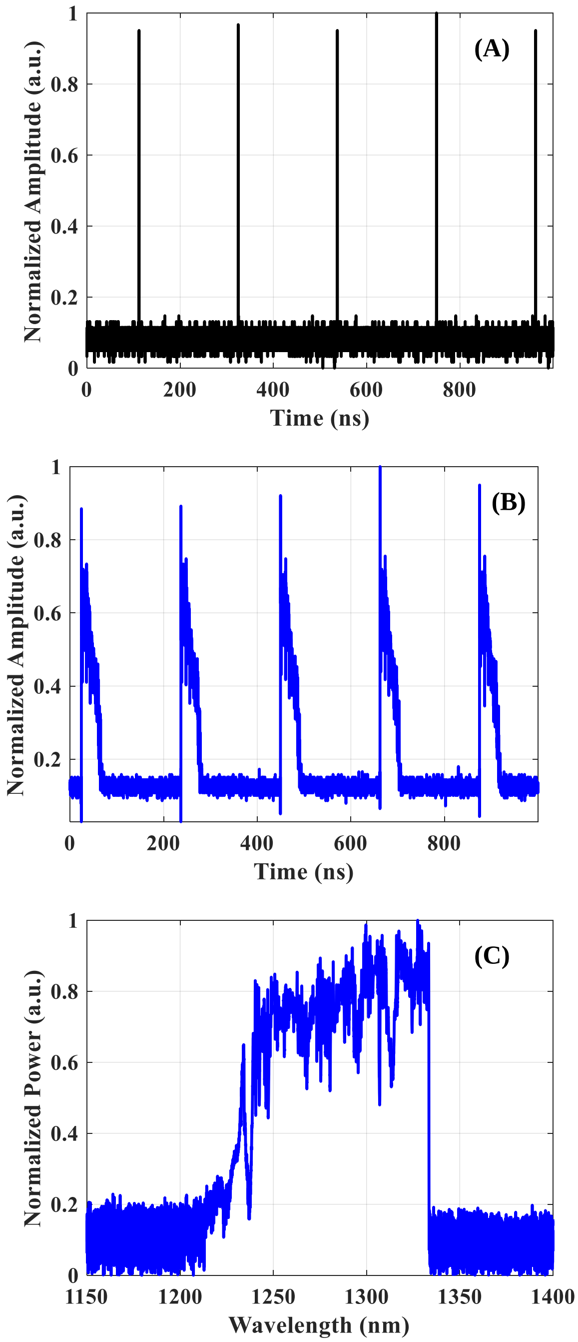

Fig. 2. (A) The output of the bit pattern generator. (B) Laser output in the time domain at a repetition rate of around 5 MHz. The generation of temporally separated optical pulses is shown with 3.5 GHz receiver bandwidth limitation. (C) The lasing spectrum of the stretched-pulse mode-locked laser is approximately 90 nm centered at 1275 nm

However, some aspects need to be completed. First, to increase the lasing optical bandwidth, it is necessary to carry out careful studies to reduce the polarization-dependent optical loss in the cavity. Second, a point spread function is a critical measure of source performance, especially for optical coherence tomography. Third, rigorous noise characterization studies involving the relative intensity noise and the dynamic range of the point spread function should be performed.

Overall, with further improvement in effective control of the polarization dependent loss in the cavity, the laser may have the potential to be used for swept-source optical coherence tomography.

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