

Tunable Wide Dissipative Soliton Resonance Generation by Figure-of-Eight Nonlinear Amplifying Loop Mirror

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Abstract

We demonstrate dissipative soliton resonance (DSR) mode-locking using a nonlinear amplifying loop mirror (NALM) in a C-band erbium-doped fiber (EDF) laser. The mode-locked laser achieved 3-dB spectral bandwidth of 24.56 nm centered at 1562.7 nm, with an output power of 5.0 mW and a pulse energy of 16.81 nJ. The DSR pulse tunability was optimized, where the pulse width was extended from 20 ns to 140 ns, demonstrating enhanced performance with a repetition rate of 297.3 KHz. The optimization was achieved through figure-of-eight NALM cavity design, precise polarization control, and progressive pump power tuning under net anomalous dispersion.

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1. Introduction

The dissipative soliton resonance (DSR) phenomenon is a novel formation of a single wave-breaking free rectangular pulse, first proposed in 2008 [1]. According to the theory of DSR, as the pump power increases, both energy and the pulse width increase infinitely and linearly while the pulse peak power remains constant [2]. The reverse saturable absorption behavior of the saturable absorber (SA) facilitates DSR generation via a peak power clamping effect [3]. In the 1.5-micron regime, the DSR is generated by passive mode-locking through a real SA, such as using germanium telluride (GeTe) [4]. However, the real SAs have a low damage threshold, limiting the DSR pulse width to 35.5 ns. Moreover, fabricating real SA is complex and time-consuming. Alternatively, an artificial SA, such nonlinear amplifying loop mirror (NALM), has been used for DSR generation [5]. Compared to the real SAs, artificial SAs have a higher damage threshold, enabling the generation of a wider tunable DSR pulse width. Only a few studies have reported DSR generation in C-band erbium-doped fiber (EDF) lasers using NALM configurations under the anomalous dispersion regime [5], [6], [7]. However, the DSR pulse width was limited, where it changed from 43.1 ns to 72.2 ns [5] and from 1.35 ns to 14.95 ns [6]. Meanwhile, in [7] it was reported that the DSR pulse width increased from 0.97 ps to 100.63 ns. Therefore, in this paper, we report the widening of the DSR pulse width from 20 ns to 140 ns using a figure-of-eight NALM EDF laser.

2. Experimental setup

Figure 1 shows the proposed NALM with a single-pump power laser diode. The figure-of-eight's bi-directional loop consists of 14 m of EDF Lucent Technologies HP980 with a dispersion coefficient, β_2

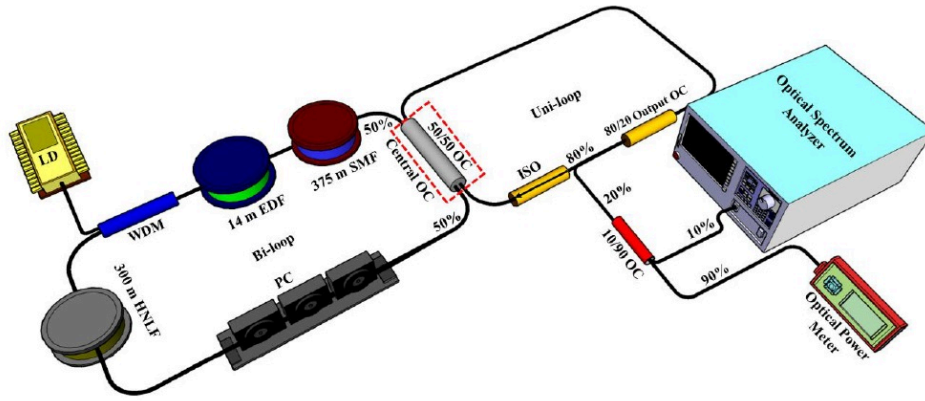


Figure 1: Experimental setup of figure-of-eight NALM.

of 23 ps²/km as a gain fiber and an absorption coefficient of 3.5 dB/m at 1530 nm center wavelength. The EDF was pumped at a maximum power of 344.7 mW using a 980 nm laser diode through a wavelength division multiplexer (WDM), with a dispersion of -7 ps²/km of Hi-1060 fiber. A 300 m high nonlinear fiber (HNLF) with β_2 of -0.04 ps²/km was spliced to the WDM, followed by three paddles of polarization controller (PC). A spool of 375 m of single-mode fiber (SMF) with β_2 of -22 ps²/km was spliced directly to the EDF. A symmetrical 50/50 central optical coupler (OC) is used to form the figure-of-eight cavity. The counter-propagation fields in the bi-directional accumulate high nonlinear phase shifts, resulting in a low saturation power of the cavity. Therefore, reverse saturable absorption was activated at a low pumping threshold, leading to a strong peak power camping effect, enabling the DSR generations [8]. The uni-directional loop consists of an optical isolator (ISO) and a 20/80 output OC, where 80 % of the power is spliced back to the 50% arm of the central OC. The other 20 % was used for the laser pulse measurement. The 20% output arm is spliced to a 10/90 OC to allow simultaneous measurement of the output spectrum and power. The total NALM cavity length is 712.28 m, with an anomalous net cavity of -8.42 ps². The output power of the figure-of-eight laser cavity was analyzed by using an optical spectrum analyzer (OSA; Yokogawa, AQ6375), an oscilloscope (Tektronix, TDS 3012C), a radio frequency (RF) spectrum analyzer (GwINSTEK GSP-830), an autocorrelator (APE, PluseCheck 150) and an optical power meter (OPM; Thorlabs, PM100D).

3. Results and Discussion

DSR mode-locking was achieved by increasing the pump power and adjusting the polarization states of the NALM cavity using the PC. The laser performance of the DSR was analyzed in optical, time, and frequency domains. Figure 2(a) shows the DSR optical spectra with respect to the supplied pump power. The DSR was obtained at the threshold pump power of 50.1 mW (black color). At the maximum pump power of 344.7 mW, the measured 3-dB bandwidth and the central wavelength were 24.56 nm and 1562.7 nm (red color). Figure 2(b) shows the temporal evolution of the DSR as a function of pump power. The pulse width was broadened significantly from 20 ns to 140 ns with the increase of the pump power. This linear increment of the DSR pulse width is due to the peak power clamping effect, which is a unique characteristic of the DSR. Figure 3(a) presents the RF spectrum over 50 MHz at 344.7 mW with a resolution bandwidth of 30 kHz. The RF spectrum exhibited a periodic frequency modulation of 7.14 MHz with respect to the pulse width of 140 ns. This demonstrates the typical feature of the DSR pulse. As shown in Figure 3(b), the signal-to-noise ratio (SNR) was measured to be 40.37 dB, indicating a well-defined generated pulse compared to the background noise and the stability of the DSR laser performance.

Figure 4 shows the pulse width, pulse energy, output power, and peak power of the DSR, with respect to the supplied pump power. Figure 4(a) shows that DSR pulse width and energy increase

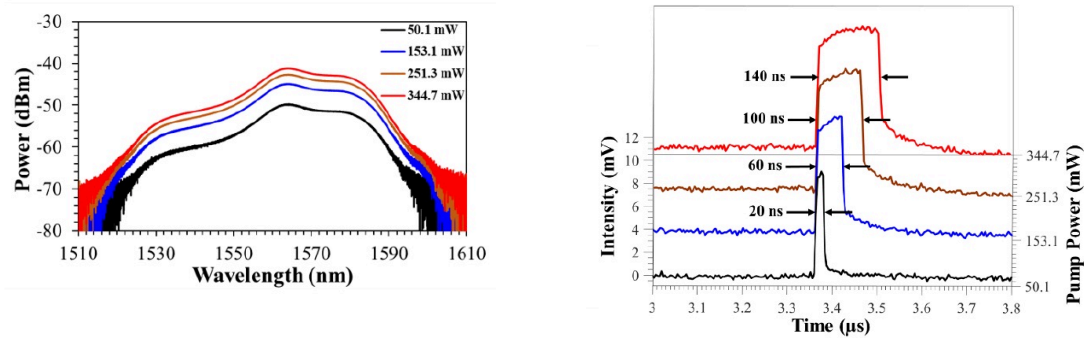


Figure 2: DSR pulse evolution in (a) optical domain and (b) time domain with respect to the pump power.

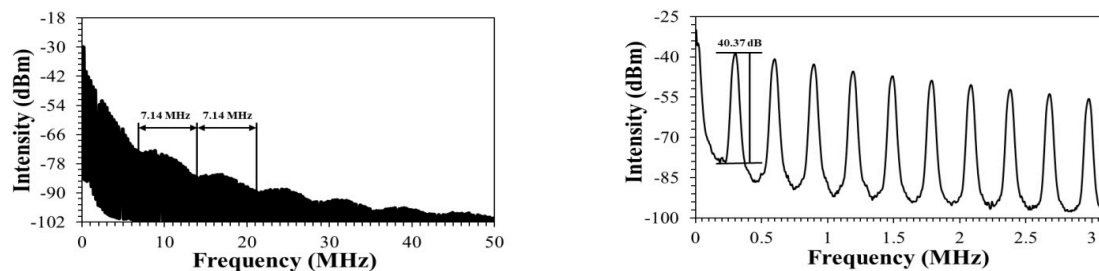


Figure 3: DSR RF spectrum at a maximum pump power over (a) 50 MHz and (b) 3.1 MHz.

linearly with the pump power, with a correlation coefficient of 0.9995 and 0.9996, indicating that the linear fitting is in good agreement with the experimental data. The DSR pulse widths were tuned from 20 ns to 60 ns, 100 ns, and 140 ns as the pump power increased from 50.1 mW to 153.1 mW, 251.3 mW, and 344.7 mW. At the maximum pump power of 344.7 mW, the calculated pulse energy was 16.81 nJ. In Figure 4(b), the maximum output power was 5.0 mW at 344.7 mW of pump power. The error bar in both figures also indicating the reproducibility of the generated pulse. On the other hand, the peak power was clamped around 120 mW due to the linear increase of both pulse width and pulse energy.

4. Conclusion

We have demonstrated the generation of DSR pulses in a figure-of-eight NALM EDF laser operating in the C-band with net anomalous dispersion. At a maximum pump power of 344.7 mW, the laser produced DSR pulses with a 3-dB bandwidth of 24.56 nm centered at 1562.7 nm, a pulse width of 140 ns, and a repetition rate of 297.3 kHz. The maximum output power and pulse energy were 5.0 mW and 16.81 nJ, respectively, with peak power clamped at approximately 120 mW. The DSR pulse width tunability of 20 ns and 140 ns exceeds previously reported values. Further broadening of the DSR range may be achieved by enhancing the cavity nonlinearity and pump power.

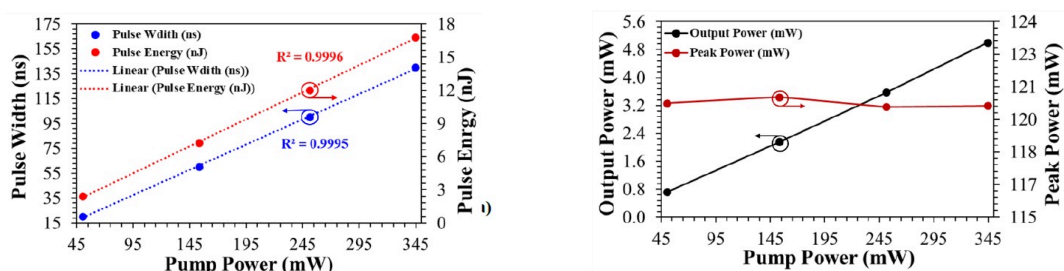


Figure 4: The variation of (a) pulse width and pulse energy, (b) output power and peak power with respect to pump power.

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