Efficient regenerative self-pulsating sources

Thibault North and Martin Rochette
Department of Electrical and Computer Engineering, McGill University, Montral, QC, H3A 2A7, Canada
thibault.north@mail.mcgill.ca

Abstract: We present an improved design of regenerative self-pulsating sources including large filter bandwidths. Pico- and sub-picosecond pulses of energies 20× higher than previously reported are observed in a setup increasing the source efficiency.

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Cascaded reshaping and reamplification regenerators in closed-loop offer an alternative to well-known pulsed fiber lasers based on additive-pulse mode-locking, semiconductor saturable absorbers, or Kerr-lens mode-locking [1, 2]. Distinctive features of regenerative sources include aperiodicity, low polarization sensitivity, and built-in spectral broadening, which enables the generation of femtosecond pulses via nonlinear compression [3]. The properties of the pulses sustained in the cavity are directly determined by the spectral profiles of the band-pass filters (BPFs), and the nonlinear transfer function of these sources naturally provides a high stability [4, 5], forming eigenpulses which are close to being chirp-free when the BPFs have a bandwidth < 1 nm. Previous reports of such sources are limited to an operation with filters bandwidths of 0.9 nm or less. In Ref. [3], the shortest pulses observed without nonlinear compression were at their transform limit, with a duration of 3 ps and an energy of 0.17 pJ. Recently, we reported numerical simulations suggesting that large filter bandwidths were not an obstacle to self-pulsation [6]. On the contrary, less energy is wasted during the regeneration stage because the BPFs transmit a larger amount of spectral components contributing to the pulses in comparison to the use of smaller bandwidth filters [7].

In this paper, we report the observation of ultrashort pulses in cavity configurations featuring large filter bandwidths, and hence providing high power efficiency. In this work, near chirp-free pulses as short as 2 ps and with energies increased 20× with respect to previous reports are observed without compression or chirp compensation when the filter bandwidth attains 3.5 nm. After propagation in single-mode fiber and amplification, the pulses are compressed down to a duration < 0.5 ps. We also present a simplified setup, composed of a low- and a high-pass filter, and demonstrate that this configuration enables self-pulsating and minimizes the number of discarded spectral components. The self-pulsating cavity under study is depicted in Fig. 1(a), and resembles the design of Ref. [3]. Instead of using BPFs

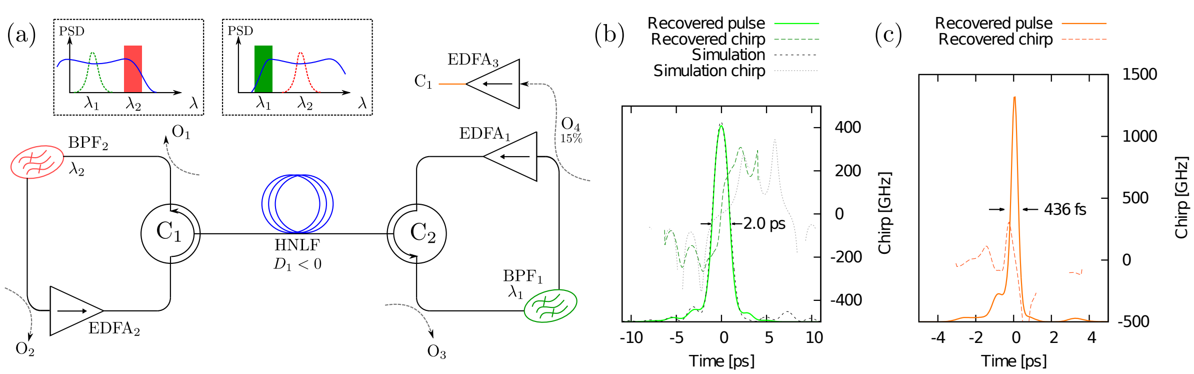

Fig. 1. (a) Experimental setup of the self-pulsating source. Insets: Spectral overview of the source operation, including spectral broadening by SPM and offset filtering at wavelengths λ_1 and λ_2. (b) Pulse observed at O_4, recovered with a FROG. (c) Pulse observed at C_1, recovered with a FROG.

tunable in wavelength only, filters that are adjustable in bandwidth and tunable in wavelength are used. Such filters offer flexibility, but with the downside that their spectral shapes deviate strongly from Gaussian. As a consequence of that, the temporal profile of the output pulses is expected to exhibit a pedestal. Fig. 1(b) indicates that the pulses generated at a filter bandwidth of 3.5 nm exhibit a near-Gaussian shape with a pedestal. Pulses of 436 fs are generated at C_1 with additional dispersion compensation, as depicted in Fig. 1(c). In Fig. 2(a), the output spectra of the source observed at O_1 are shown for two different filter offsets, and compared with the pulsed operation of Ref. [3]. The

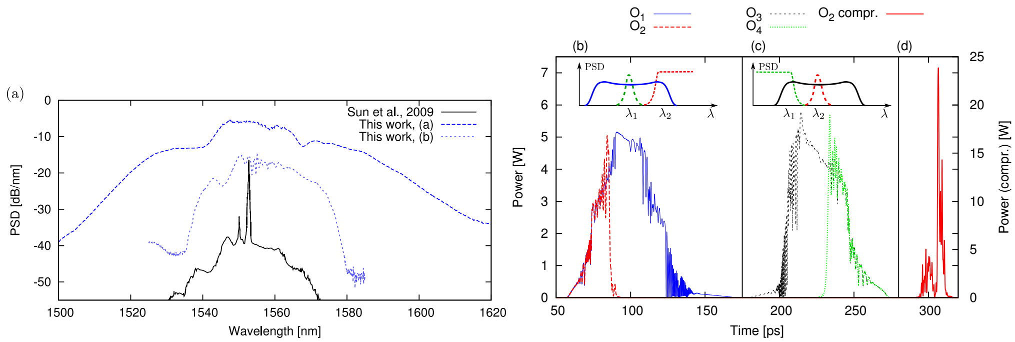

Fig. 2. (a) Comparison of the output spectra originating from this work and previous work by Sun et al. In [3] (solid line), the filter bandwidth was of 0.9 nm, and the filter offset was of 2.6 nm. In this work, the filter bandwidth is of 3.5 nm. In line (a), with a filter offset of 4.2 nm, and in line (b) with a filter offset of 5 nm. (b) and (c): Simulated pulse profiles at outputs O_{1-4} when a pair of low and high pass filters are used. (d) Pulse of (c) compressed by compensation of the residual dispersion.

amount of spectral broadening induced by SPM in the setup of Sun et al. is such that $< 2\%$ of the power is transferred from λ_2 to λ_1. In the dash and dotted lines (a) and (b) of this work, the amount of transferred power is of 13% and 15%, respectively. The spectral width of the BPFs are maximized in the limiting case. At such bandwidths, the filters BPF_1 and BPF_2 can be considered as high- and low-pass filters, respectively, as their leftmost and rightmost cutoff edges are outside of the gain window of the erbium-doped fiber amplifiers (EDFAs). Therefore, the pulse bandwidth is limited by the gain window on one side, and by a filter edge on the other, thereby enabling pulsed operation as when a pair of BPFs is used. Fig. 2(b) and (c) show the simulated pulses profiles in the time domain, before and after filtering at BPF_1 and BPF_2. The spectral components of the pulses spread in time during propagation in a dispersive HNLF. Only the short wavelengths corresponding to the tail of the pulse are selected after BPF_1, while it is the opposite at BPF_2. Therefore, no single eigenpulse is sustained in the cavity, but rather the alternation of two symmetrical pulses of complex profiles. As depicted in Fig. 2(d), such pulses do not converge towards Gaussians after dispersion compensation. Because of SRS, large pulse-to-pulse fluctuations occur, and the autocorrelation trace of such pulses resembles the one of noise inside a Gaussian envelope.

Despite the non-optimal filter shapes, pulses of 2 ps as well as pulses shorter than 0.5 ps are observed at the output of the cavity. Regenerative sources therefore operate at large filter bandwidths and are robust to non-optimal filter shapes.

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