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Sub-picosecond ultra-low frequency passively mode-locked fiber laser

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Abstract We developed a nonlinear polarization rotation all-fiber mode-locked erbium-doped fiber laser, with the purpose to reach a sub-picosecond and sub-megahertz light pulse emission. In the process, we observed three different emission regimes as the net birefringence is changed, namely high-power dissipative soliton resonance, low-power soliton regime, and a mixed combination of both. In the pure solitonic regime, a 0.961 MHz train of chirp-free Gaussian pulses was obtained, with a time width of 0.919 ps at 1564.3 nm.

1 Introduction

Ultra-low frequency train of ultrashort light pulses—typically <1 MHz and <1 ps, respectively—is demanded for many applications such as micromachining, biomedicine, and lidar systems. As an example, in ophthalmic surgery, the repetition rate of light pulses is constrained to the multi-kHz region in order to avoid detrimental secondary effects or to take advantage of high gain regenerative amplifiers [1]. Further, for applications involving materials or tissue removal, laser-induced damage studies show that the damage threshold fluence has a material-dependent optimum in the range 0.1–10 ps [2]. Indeed, conventional mode-locked fiber lasers can provide ultrashort light pulses, but with frequencies well in the ten of MHz and beyond. Solutions encompassing acousto-optic modulators or pocket cells used as pulse pickers to reduce the repetition rate are energetically inefficient. Not to mention that they increase the energy losses impairing the signal-to-noise ratio while simultaneously increasing system's complexity. On the other hand, *Q*-switched lasers fulfill the ultralow frequency requirement, but their pulses widths are well in the nanosecond regime and beyond. Thus, the study of ultrashort and ultralow frequency light pulses is a highly demanded challenging topic.

In fiber lasers, the repetition rate can be easily reduced just by lengthening the cavity, since both are inversely related. In this regard, the advantages of an optical fiber cavity are self-evident, because in solid-state lasers it would be necessary a critical alignment, which can be very cumbersome and time-consuming for long propagation distances. Different results on passively mode-locked fiber lasers with long and ultra-long cavities have been reported. However, lengthening of the fiber cavity increases dispersion; therefore, the temporal width of light pulses obtained is well in the nanosecond regime [3–5]. The waveforms obtained from these lasers are typically Gaussian or hyperbolic secant. In all- and net-normal long dispersion cavities, noise-like or double (temporal)-scale pulses have been also reported [6–8]. Recently, square-shaped pulses were also reported in long-cavity fiber lasers. This phenomenon, known as dissipative soliton resonance (DSR), is governed by the cubic–quintic Ginzburg–Landau equation [9]. By

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