Ultrahigh-repetition-rate pulse-train generation in a passive optical fiber cavity

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We use the modulational instability regime of a passive optical fiber cavity to generate trains of pulses. The repetition rate of such trains is inversely proportional to the group velocity dispersion (GVD) of the fiber cavity. Using a dispersion shifted fiber (DSF), it was possible to work with a GVD coefficient as low as $-0.02\,ps^2/km$. This allowed for the measurement of a pulse train with a 1.5 THz repetition rate. The characterization of this train was performed in the spectral and in the temporal domains. This clearly demonstrates that optical passive fiber cavities can be used as sources of pulse-trains at a repetition rate above 1 THz.

Introduction

Modulational instability (MI) is a passive physical process through which a high-repetition-rate train of solitons can be generated in an optical fiber. This instability process comes from the interplay between dispersion and Kerr nonlinearity. In optical fibers, the Kerr nonlinear effect results from the excitation of the electronic cloud surrounding the atoms. As a consequence, the Kerr response is very fast, with a typical response time of a few femtoseconds. This duration is compatible with ultrahigh bit rates ranging from a few tens of GBits/s to TBits/s. Such ultrahigh bit rates are required to increase data transfer in future telecommunication networks.

The first generation of pulses using modulational instability was reported in the eighties by Hasegawa [1], and Tai [2]. They generated pulse trains in a single pass configuration by using strong quasi-cw pump pulses. Even if these first results were very promising the use of a strong and pulsed pump is not compatible with the telecommunication requirements. A few years ago, Coen *et al.* [3] generated optical trains of pulses in a fiber ring cavity, at lower pump power. By taking advantage of the increased power level in the cavity, these authors demonstrated the generation of a pulse train at a repetition rate of 50 GHz, with a continous pump beam.

In this letter we report on the same kind of pulse train generation, with a strong enhancement of the bit rate. This was realized by designing a very low dispersion fiber ring cavity. Our experimental results, namely spectra and autocorrelation traces, are in very good agreement with numerical simulations.

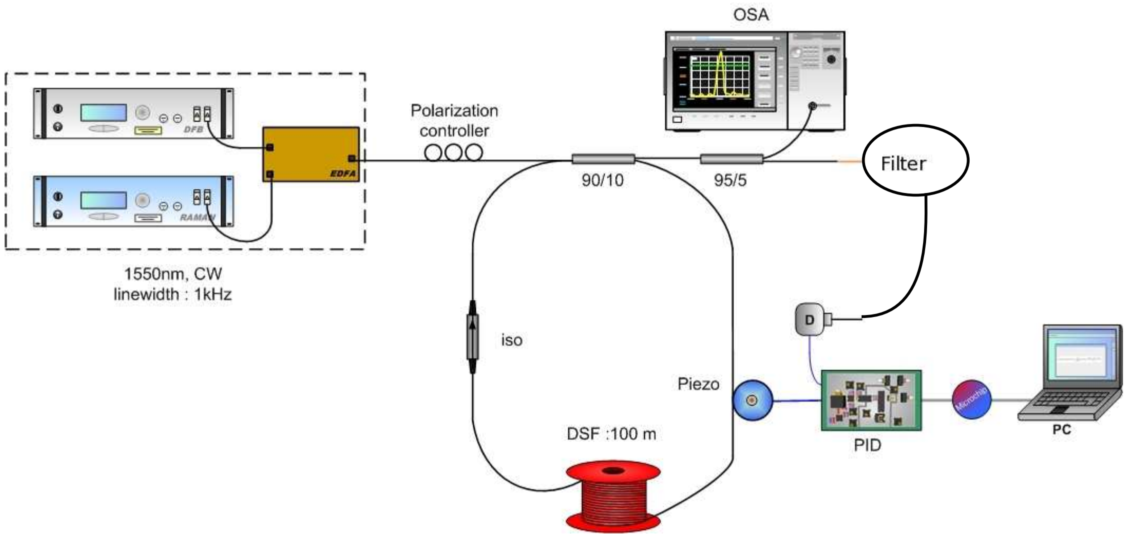

Figure 1: Experimental setup. DSF length 100 m, SMF28 length 0.8 m (inside coupler and isolator). The zero dispersion wavelength of the DSF was measured at 1550.6 nm.

Experimental setup

We used the experimental setup described in Fig. 1. The pump is an extremely stable cw laser (1 kHz linewidth). The pump field is launched inside the cavity via a 90/10-coupler. The cavity is made of 80 cm of SMF28 and 100 m of dispersion shifted fiber (DSF). The overall group velocity dispersion inside the cavity was estimated to $-0.02\,\mathrm{ps}^2/\mathrm{km}$ at the pump wavelength (1549.8 nm). The average dispersion in the cavity could be slightly adjusted either by controlling the temperature of the pump (small spectral tuning over 1 nm) or by tailoring the length of the SMF28. Because we were working close to the zero dispersion wavelength, even a small modification of the SMF28 length, in the range of 10 cm, was inducing a significant change in the average cavity dispersion. As a result, it was possible to finely control the repetition rate of the output train by tuning these parameters.

We stabilized the cavity length by using a piezoelectric stretcher inside the cavity, driven via a servo control system. The feedback loop was designed to increase as much as possible the growth of a side lobe induced by the modulational instability. The frequency detuning between the pump beam and the control side lobe was selected around the natural repetition-rate of the system, i.e., the frequency appearing in a free running configuration (without feedback loop). This setup allowed for a very accurate stabilization of the cavity over a few seconds, which was enough to perform the measurements.

Results

The results are depicted on Fig. 2. The red continuous curve on Fig. 2(a) corresponds to the experimental output spectrum with a pump power of 73 mW. This value is just above the threshold of the cavity. The blue dashed curve on the same figure corresponds to the numerics. Both experimentally and in the numerical simulations, we observed the generation of side lobes on each side of the pump with a frequency detuning of 1.8 THz and the rise up of an harmonic on the Stokes side of the pump.

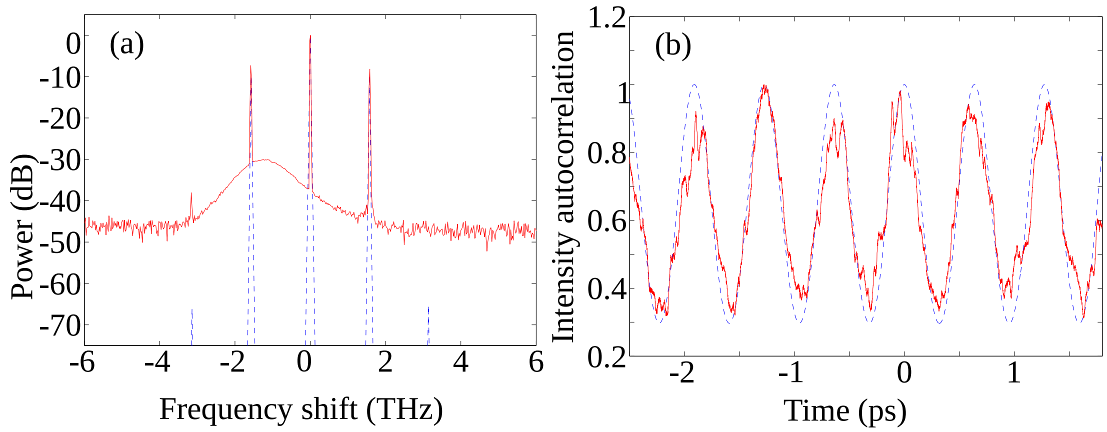

Figure 2: (a) Output spectrum. (b) Autocorrelation trace. The experimental results (red continuous line) are compared with the numerical simulations (blue dashed line).

These spectral features correspond to an important periodic modulation of the field in the time domain. In order to confirm this prediction, we recorded the autocorrelation trace at the output of the cavity. The experimental result is presented on Fig. 2(b) (red continuous line). The periodic feature as well as the strong depth of this trace confirm that a periodic train of pulses is generated in the time domain. In order to compare theses experimental results with the theory, we integrated numerically the Lugiato-Lefever model with the classical split-step method.

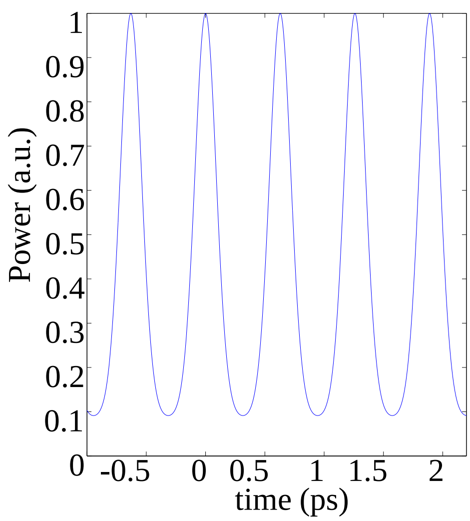

Figure 3: Pulse train generated at the output of the cavity (numerical results).

The numerical results correspond to the blue dashed line on Fig. 2(a) and (b). We had to slightly tune the dispersion value of the DSF to achieve such a good agreement between numerical simulations and the experiment. However, the tuning range of the dispersion parameter in the numerical simulation was lower than the uncertainty resulting from the measurement of the dispersion parameter of the DSF. The spectral features as well as the autocorrelation trace are reproduced by the simulations with a very good agreement. From the numerical simulations, we computed the intensity profile in the time domain (see Fig. 3) corresponding to the experimental spectrum and autocorrelation traces presented on Fig. 2. The resulting pulse train is characterized by a repetition rate of 1.6 THz, and a low background.

Conclusion

We have demonstrated experimentally that an optical train of pulses at a repetition rate above one THz can be achieved in a passive optical fiber cavity, by using the modulational instability. These results are of primary interest for future ultra-high bit rate telecommunication systems.

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