Spectral and Temporal Behavior of a Mode-Locked Er-doped Frequency Shifted Feedback Fiber Laser

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Abstract

We present new experimental and numerical studies of the behavior of the optical spectrum, and pulse shape of an Er-doped FSF fiber laser as functions of the frequency shift and cavity optical bandwidth.

1. Introduction

Frequency Shifted Feedback (FSF) lasers have generated a lot of interests as light sources for applications ranging from tunable broadband CW lasers to mode-locked (MD) lasers [1]. Mode-locking (MD) of a FSF laser cavity is achieved through the interaction among the bandwidth-limited gain medium, the frequency shifting of the laser modes and the Kerr-type nonlinearity generated in the laser cavity [2],[3]. So far, most of the experimental works carried out with FSF lasers (in the MD regime) have focused on achieving shorter pulses without paying much attention to the relation between the asymmetry of the optical spectrum and pulse shape as functions of the frequency shift mechanism and the intra-cavity filter bandwidth. In this work, we carry out both experimental and numerical analyses of a MD Er-doped FSF fiber laser in a ring configuration, in order to comprehensively understand the behavior of the optical spectrum for different values of frequency shifts and optical bandwidths. The simulations presented in this work agree well with the experimental results and allow us to do a better analysis of the characteristics of the pulses in terms of its width, shape and stability.

2. Experimental Setup

The setup of the FSF laser is shown in Fig. 1. The laser consists of 2-m of Er-doped fiber pumped by a laser diode (total power of ~ 160 mW) through a WDM coupler (1480/1550 nm). Two sets of polarization controllers, PC 1 and PC 2, are spliced between a fiberized polarization beam splitter (PBS) to introduce the necessary phase bias to lock the longitudinal modes of the ring cavity and to adjust the output coupling of the cavity. The intra-cavity signal is monitored with a 95%:5 % tap coupler. The frequency shifting mechanism inside the cavity is obtained through three different fiber-coupled, downshifted AOMs (Δf: 80, 110 and 200 MHz) driven by a tunable rf signal generator. Finally, a compact optical tunable bandpass filter (BPF) ($\Delta\lambda$ = 1.3 nm) is spliced into the cavity after the AOM together with a fiberized isolator to ensure unidirectional lasing. The length of the cavity is ~ 10 m and have an average GVD parameter $\beta_2 = -0.132\ \mathrm{ps}^2$.

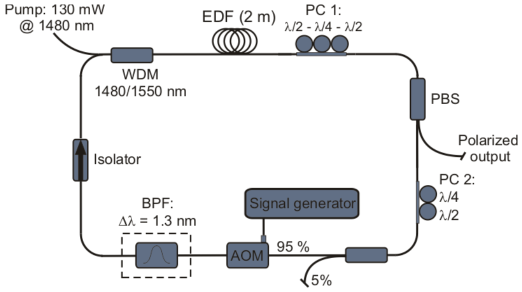

Fig. 1. Schematic diagram of the Er-doped FSF fiber ring laser.

3. Experimental and numerical results

MD of the laser cavity was achieved, in all cases, for the fundamental repetition rate of the ring cavity, and for pump powers $P_{pump} > 35$ mW. A main feature observed in the output signal of the lasers was the dual wavelength formation of the optical spectrum (see Fig. 2(a)). Note that the dual wavelength formation we mention here is different from the typical asymmetric shape of the optical spectrum observed with this type of lasers [2],[3]. The shoulder formed on the longer wavelength side of the spectra is due to the frequency downshift mechanism of the AOMs, and its position and level with respect to the main peak will depend on the frequency shift mechanism and the frequency-dependent losses of the cavity. The experiments carried out with different AOMs agree well with the data presented in [2] where shorter pulse widths are expected for higher frequency shifts (see Fig. 2(b)).

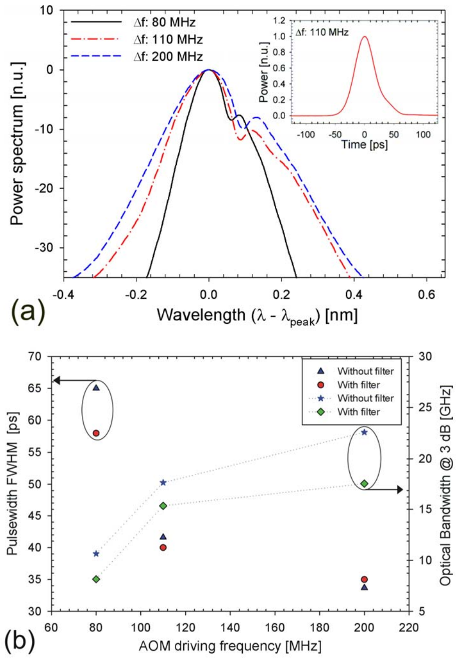

Fig. 2. (a) Optical spectrum for different AOM driving frequencies (*Δf*). Upper inset shows the asymmetric pulse shape of the output pulses (*Δf*: 100MHz). (b) Experimental measurements of the pulsewidth FWHM and optical bandwidth Δf_{3dB} as a function of the AOM driving frequency.

In order to have a better understanding on the formation of the shoulder at the longer wavelength side of the optical spectrum, we carried out numerical simulation of the laser described in Fig.1. We modified different parameters of the laser cavity like the AOM frequency shift, optical filter bandwidth and cavity coupling factor, and compared the results with our experimental data. The steady-state regime of the simulations agrees well with the experimental results. Here, we highlight the fact that the numerical simulations also show the formation of the second shoulder for broader optical bandwidths. Therefore, the formation of the shoulder is determined in first instance by the bandwidth of the optical filter (see for example Fig.3). In the time domain, the formation of the dual wavelength spectrum accentuates the asymmetry of the pulse shape, making the leading edge of the pulse steeper than the trailing edge (see inset of Fig.3). In fact, by optically filtering the optical spectrum, we show that this asymmetry correspond to the superposition of two pulses traveling together inside the cavity. More detailed outcomes from our experimental work and numerical simulations will be discussed at the conference.

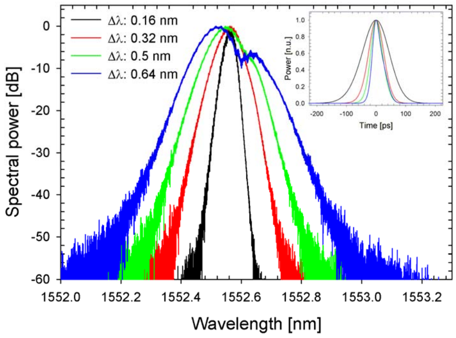

Fig. 3. Steady state regime of the optical spectrum for different optical filter bandwidths. Inset shows the corresponding pulse shape for the different optical spectra shown in the graphic.

4. Conclusion

We carried out an experimental and numerical study of the behavior of the optical spectrum and pulse shapes for various operating conditions, varying the amount of frequency shift and bandwidth of the optical filter in a MD FSF laser. We believe that our study will provide more comprehensive understanding of the evolution of the optical spectrum and pulse shape of MD FSF lasers that has not been clarified in the literature so far..

5. Reference

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