Modelling of Polarization Effects in Fourier Domain

Mode-Locked (FDML) Lasers

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Fourier domain mode-locked (FDML) lasers are rapidly wavelength-swept continuous-wave (cw) light sources, providing a large wavelength sweep range (>100 nm) with narrow instantaneous linewidths (<0.1 nm) at sweep repetition rates of up to 5 MHz [1]. In biomedical imaging, these lasers have become the light source of choice for high speed optical coherence tomography (OCT) [1]. Furthermore, picosecond pulses have been generated by temporal compression of the cw FDML output, constituting a fundamentally new approach of ultrafast optical pulse generation with many potential applications [2].

For a systematic design and improvement of FDML lasers, careful modelling is essential. The existing FDML models neglect the polarization dynamics [3,4], restricting their validity to polarization maintaining (PM) FDML setups [3]. However, FDML lasers commonly use non-PM optical components, making them cheaper and easier to build as well as avoiding problems with spectral ripple. We demonstrate that for these lasers, good agreement with experiment can only be obtained by including polarization effects due to polarization mode dispersion, fiber bending birefringence, and cross-phase modulation. For this purpose, we extend our theoretical model [3] by adding the corresponding polarization sensitive terms to the nonlinear Schrödinger equation, which describes the optical propagation in fibers [5].



**Fig. 1**. (a) Investigated experimental setup. (b) Comparison of experimental and simulated optical pulse duration as a function of frequency detuning. (c) Simulated instantaneous lineshape and sweep filter transmission curve.

Fig. 1(a) shows a schematic illustration of the investigated experimental setup, consisting of an FDML laser and a temporal compressor for the generation of picosecond pulses from the FDML output [2]. The wavelength sweep is generated by driving a narrowband optical bandpass filter resonantly to the roundtrip time of the light in the fiber cavity. A polarization insensitive semiconductor optical amplifier (SOA) is used as a gain medium. Furthermore, standard non-PM single mode fiber (SMF) is employed, along with dispersion compensating fiber (DCF) for dispersion compensation and optical compression. In Fig. 1(b), the experimental full with at half-maximum (FWHM) pulse duration as a function of the detuning between the cavity roundtrip rate and sweep filter drive frequency is compared to simulation results. Only for the extended simulation including the polarization effects, good agreement with experiment is obtained, while the conventional model [3] shows significant deviations, especially for small and negative detuning. Notably, as shown in Fig. 1(c), the extended model also predicts that the polarization dynamics in non-PM FDML setups with polarization insensitive SOA even has a beneficial effect on the optical linewidth and thus the coherence length.

**References**

[1] W. Wieser, B. R. Biedermann, T. Klein, C. M. Eigenwillig, and R. Huber, "Multi-Megahertz OCT: High quality 3D imaging at 20 million A-scans and 4.5 GVoxels per second," Opt. Express **18**, 14685 (2010).

[2] C. M. Eigenwillig, W. Wieser, S. Todor, B. R. Biedermann, T. Klein, C. Jirauschek, and R. Huber, "Picosecond pulses from wavelength-swept continuous-wave Fourier domain mode-locked lasers," Nat. Commun. **4**, 1848 (2013).

[3] C. Jirauschek, B. Biedermann, and R. Huber, "A theoretical description of Fourier domain mode locked lasers," Opt. Express **17**, 24013 (2009).

[4] S. Slepneva, B. Kelleher, B. OShaughnessy, S. P. Hegarty, A. G. Vladimirov, and G. Huyet, "Dynamics of Fourier domain mode-locked lasers," Opt. Express **21**, 19240 (2013).

[5] G. P. Agrawal, *Nonlinear Fiber Optics*, 3rd. ed., (Academic Press, Boston, 2001).