Dispersion-managed Monolithic All Polarization-Maintaining Ultrafast Thulium-doped Fiber Oscillator

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Abstract. We report on our first results of a dispersion-managed monolithic polarization-maintaining ultrafast Thulium-doped fiber oscillator. The design incorporates only commercially available polarization-maintaining components and emits linearly polarized light with a polarization extinction ratio of over 17 dB . The observed optical pulse spectra with up to 10 nm width centered at 1961.5 nm beyond the water absorption lines support sub-1 ps pulse duration. The simple linear configuration and the wide spread availability of the used low cost polarization-maintaining fiber components makes the presented oscillator a valuable concept for an environmental stable seed source.

1 Introduction

Ongoing efforts on developing ultrafast Thulium-doped fiber lasers are driven by applications like nonlinear microscopy, driving of frequency conversion stages and material processing. For generating suitable output parameters in terms of average power, pulse energy and pulse duration, advanced chirped pulse amplification (CPA) schemes with multi-GW peak power have been developed [1]. Those systems require a stable seed source to avoid catastrophic damage and guarantee a reliable long term operation. As potential seed source for a CPA, various mode-locked oscillators scheme based on real saturable absorbers [2–5] or different types of artificial saturable absorbers [6–8] have been presented in the past.

Even though various configurations of mode-locked oscillator schemes have been proposed, only a small number of oscillators incorporated a polarization-maintaining (PM) architecture, which is highly desirable for environmental stable pulsed operation. Owing to the anomalous material dispersion, using only standard silica PM single mode step-index fibers is limiting oscillators to the soliton regime, which deliver rather long pulses and show the characteristic Kelly sidebands. Those sidebands corresponds to the interference of the soliton with a longer dispersive pedestal [9]. The present pedestal hinders a good contrast between main pulse and background during the amplification and at the application. Furthermore, the efficiency of the amplification can be reduced by a double-digit percentage, owing to undesired amplification of the Kelly sidebands [10]. This is mainly due to the lack of a proper PM fiber-based dispersion management, which is necessary to operate in the stretched pulse [11] or dissipative dispersion-managed soliton [3] regime without Kelly sidebands and shorter pulse durations. Michalska addressed this issue by reporting on a hybrid system of polarization-maintaining fibers and a non-PM fiber for dispersion-management, mode-locked by a nonlinear optical loop mirror [7]. The environmental stability and the polarization extinction ratio (PER) with about 7 dB remained limited. Another report on a monolithic PM Thulium-doped fiber oscillator with dispersion-management by Sotor et. al. included a PM home-built normal dispersive passive fiber and saturable absorber made out of graphene [5]. However, the authors stated no value for the achieved PER and the restrain to special home-built components is still limiting the construction of completely polarization-maintaining ultrafast oscillators with dispersion-management.

Here, we report on a monolithic ultrafast Thulium-doped fiber oscillator, which incorporates only commercially available components. This allows the wide-spread use as seed source and serves as starting point for further developments towards an environmental stable fiber front-end for CPA systems.

2 Experimental Setup and Results

The oscillator was set up in a monolithic all PM linear cavity configuration, as presented in Figure 1a. Pump light at 1550 nm was provided by an Ytterbium-Erbium-doped fiber amplifier (PE) with up to 4 W of power. In order to couple the light into the oscillator, a commercially available fused wavelength-division multiplexer (WDM) optimized for 1970 nm was used. As gain medium, a 16 cm long highly doped fiber (TDF, Nuferm PM-TSF-5/125) was used to enhance the re-absorption inside the oscillator to support operation at longer wavelengths beyond the water absorption lines. A chirped fiber Bragg

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grating (CFBG, Teraxion) provided the wavelength selection, output coupling as well as dispersion-management. It was inscribed into the core of a PM1950 fiber and had a peak reflectivity of about 15 % with a full width at half maximum (FWHM) of 35 nm and a group delay dispersion (GDD) of 1 ps^2 at 1970 nm by design. By adjusting the length of an additional piece of PM1550 fiber, the net cavity GDD was set to 0.01 ps^2. For initiating and sustaining the mode-locked operation, a broadband semiconductor saturable absorber mirror (SAM, Batop) was used. The SAM had a saturation depth of 14 %, a non-saturable loss of 8 % and a saturation fluence of 60 $\mu J/cm^2$ at 2000 nm. For the first experiments, the SAM was butt-coupled, but the same SAM is also commercially available as mechanically stable version, directly glued on to the faced of a PM fiber connector. This glued version will be incorporated in the next steps.

With a pump power of 820 mW, the oscillator emitted mode-locked pulses with a rectangular spectrum centered at 1961.5 nm with a FWHM of about 10 nm, as depicted in Figure 1b, supporting a transform limited pulse duration of about 800 fs. The long wavelength operation beyond 1950 nm was chosen to rule out pulse and beam distortion due to water absorption in the later CPA system [12].

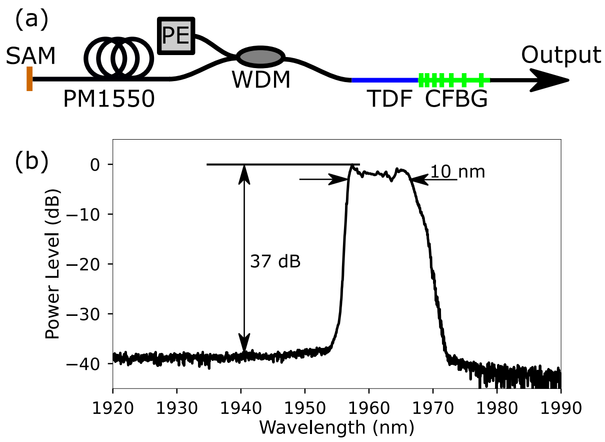

Figure 1. Experimental setup of the linear cavity (a) and output spectrum (b).

Further characterization of the oscillator in the temporal domain allowed to observe a stable pulse train with an average power of 14 mW consisting of single pulses with a temporal spacing of 57 ns, which corresponds to a fundamental repetition rate of 17.4 MHz. Operating the oscillator below 20 MHz is suitable for pulse picking in a later fiber front-end with stretcher unit and fiber-based acousto-optic modulators as pulse picker. A PER of 17.2 dB was determined, even though the cavity does not include any designated polarization selective elements. In order to further improve the PER and to ensure always operating in the slow axis, a fiber-based inline polarizer will be included into the cavity.

3 Conclusion

We presented our first results of a monolithic PM ultrafast Thulium-doped fiber oscillator, which supports sub-1 ps pulse duration. Work in the near future will include the replacement of the current SAM to the mechanically stable glued version and the further integration into an environmental stable fiber front-end with stretcher and pulse picker for use as seed for a high power Thulium-doped fiber CPA system.

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