Polarization-multiplexed thulium-doped fiber laser for free-running dual-comb generation

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ABSTRACT

We demonstrate a polarization-maintaining passively mode-locked thulium-doped fibre laser that can operate at two different repetition rates (dual-comb) simultaneously. Based on the presented approach, we observe beat notes with a free spectral range of 1.97 kHz and aim to realize a free-running dual-comb source in the 2 µm band.

1. INTRODUCTION

Dual frequency combs have evolved into a powerful technology that can be used in a variety of applications, including high-precision laser ranging over long distances and rapid and high-resolution dual-comb-based molecular spectroscopy.[1] A dual frequency comb consists of two stabilized pulse trains with slightly different repetition rates. When both pulse trains are generated by two different laser cavities, their repetition rate and carrier-envelope frequency will drift differently over time and both lasers must therefore be stabilized. However, when both pulse trains are generated in the same laser resonator, they shift together, and no stabilization is required for the aforementioned applications.[2,3] When generating such free-running dual-combs from a single laser cavity, the operation at two repetition rates could be set by wavelength-multiplexing or polarization-multiplexing. However, wavelength-multiplexing necessitates subsequent nonlinear frequency conversion to overlap the two combs,[4] whereas polarization-multiplexed dual-combs are often obtained from free-space laser resonators.[2] Here, we demonstrate the first polarization-multiplexed dual-comb source in the 2 µm regime based on a free-running thulium-doped fibre mode-locked laser. Because atmospheric molecules such as H_2O, CO_2 and NH_3 have strong rotational-vibrational absorption lines in this wavelength range,[5] this source could be effectively used for their molecular detection.

2. EXPERIMENTAL SETUP

The experimental setup shown in Fig. 1 is used to realize the dual-comb laser source. A nonlinear amplifying loop mirror (NALM) on the left side and a semiconductor saturable absorber mirror (SESAM) on the right end form the laser resonator. The NALM comprises a 3 m long polarization-maintaining (PM) thulium-doped fibre (TDF) which is pumped through a wavelength-division multiplexer (WDM) with 2.0 W of pump power at 1565 nm wavelength. The NALM also contains an in-line polarization controller (PC) and a 50/50 fibre optic coupler. Passive mode-locking is achieved by the NALM and the SESAM as saturable absorbers. Except for the PC, all fibres maintain polarization. We extract the laser output from the 50/50 coupler's fourth port and feed it to several measurement systems. We use a fast and a slow photodiode with 21 GHz and 50 kHz bandwidth) to monitor the radio-frequency (RF) spectra at high and low frequencies with two electrical spectrum analyzers (ESA 1 and ESA 2). The optical spectrum was observed using an optical spectrum analyzer (OSA).

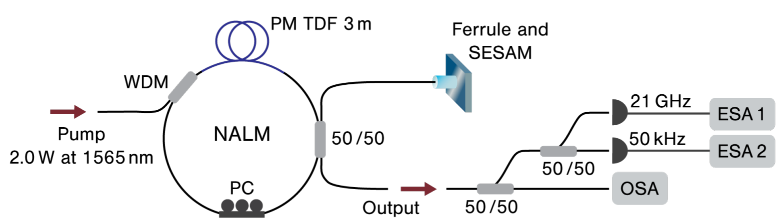

Figure 1. Schematic of the laser cavity monitored by several measurement systems.

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3. RESULTS

Dual-polarization mode-locking is feasible when the pump power exceeds the mode-locking threshold (1.4 W) and the intracavity PC is correctly adjusted. All measurements reported in this manuscript, however, were taken at 2.0 W of pump power for which we obtained an average output power of 11.5 dBm, and the optical spectrum shown in Fig. 2(a) with central wavelength of 1976 nm and a 3 dB bandwidth of 2.2 nm. The observed RF spectrum on ESA 1 (see Fig. 2(b)) indicates a repetition rate of 11.04 MHz, which matches the roundtrip path length of 20 m. As previously stated, the adjustments to the intracavity PC enabled the laser to switch over from continuous-wave mode-locking to dual-polarization mode-locking, i.e. the laser cavity began lasing in the fast and slow axes of the PM fibres at the same time. The pulse trains have slightly different repetition rates due to the birefringence of the PM fibres. This difference in the repetition rate of the dual pulse trains was observed at the 20^{th} harmonic of the comb lines as 39.37 kHz (corresponds to a fundamental frequency line separation of 1.97 kHz) using the fast photodiode and ESA 1, as shown in Fig. 2(c). This line separation of 1.97 kHz matches the free spectral range (FSR) of the beat notes (1.95 kHz) observed with ESA 2 in combination with the slow photodiode (refer Fig. 2(d)).

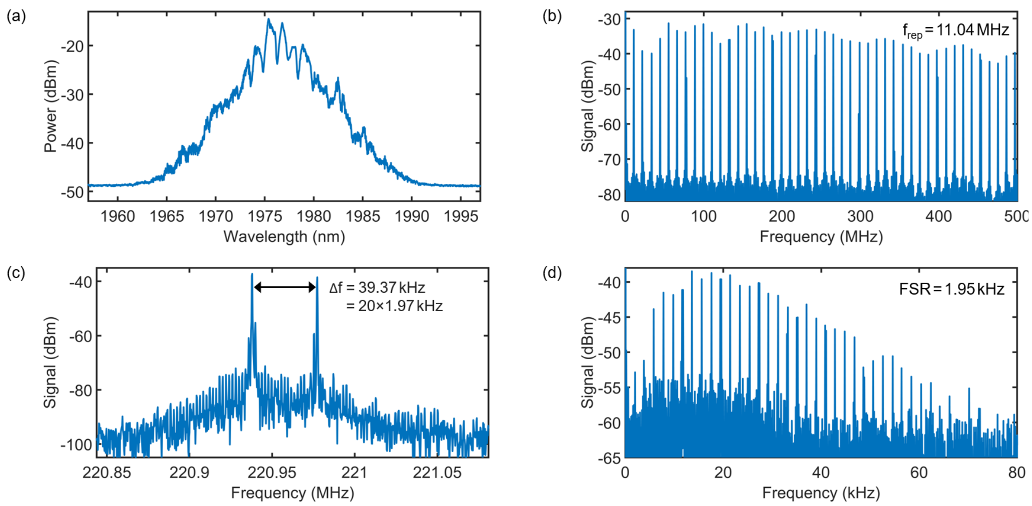

Figure 2. (a) Optical spectrum of the laser output. (b) RF spectrum recorded using a fast photodetector (ESA 1). (c) Zoom on the 20^{th} harmonic of the RF spectrum. (d) Beat notes observed using a slow photodiode (ESA 2).

4. CONCLUSIONS

We report a polarization-multiplexed thulium-doped fibre laser for a free-running dual-comb generation without the use of complicated optical or electronic stabilization schemes. We believe our findings pave the way for dual-comb spectroscopy experiments in the 2 µm band, which could be used to detect various atmospheric molecules.

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