Pulsewidth-stretchable femtosecond erbium fiber lasers using an intracavity short-pass edge filter

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Abstract: We demonstrate pulsewidth-stretchable Er^{3+} -doped femtosecond mode-locked fiber lasers by incorporating a tunable short-pass edge filter into the ring cavity. Pulsewidth stretch ratio of 3.53 (882/250) can be efficiently achieved under a temperature variation of 4°C.

1. INTRODUCTION

Femtosecond mode-locked fiber lasers (FMLLs) have played important roles in optical coherence tomography imaging, supercontinuum generation, precision sensing, micro/nano-machining, micro/nano-surgery and so forth. From the viewpoint of material processing, femtosecond fiber lasers are useful in generating micro-holes with sharp cutting edge due to less thermal-diffusion effect and the shorter lasing wavelength when compared with CO₂ lasers. Moreover, fiber lasers are also featured with high peak power, excellent beam quality, low thermal load, strong power confinement, long interaction length, and ultra-short pulses through the mode-locking effects. The modelocked fiber laser pulses can give rise to a very high peak power when the cavity dispersion and polarization effects are well controlled. In practical applications, the pulse intensity capable of easy, fast, and wide-range tuning is important when a composite material is in a micromachining or in a direct-writing process. An efficient way to quickly change the laser peak intensity is to change the laser pulsewidth instead. In addition to peak intensity tuning, a pulsewidth tunable FMLL is also advantageous for precision sensing system of varying sensing distance and resolution, like optical time-domain reflectometer (OTDR). Since the mode-locked pulses can be stretched or compressed by adjusting the cavity length or by introducing chirped gratings and filters to change the cavity dispersion and Kerr nonlinearity, the laser peak power can thus be tuned to a desired value. However, the FMLL with a widely tunable pulsewidth is difficult to achieve because an extra fiber with a fixed length for cavity dispersion adjustment is usually added into FMLL to acquire a fixed pulsewidth. In this work, we demonstrate an efficient pulsewidth-tunable FMLL by dispersionally stretching the mode-locked pulses. In the beginning, the total cavity dispersion of fiber laser is preset around zero to obtain the shortest pulsewidth of ~ 250fs. When the cutoff wavelength of intracavity short-pass edge filter (SPEF) [1] is thermally tuned to cut the long wavelengths components of mode-locked pulses, the total cavity dispersion is moved to the normal dispersion regime [2] to broaden the pulsewidth. The pulsewidth can be tuned from 250fs to 882fs (total pulsewidth stretching of 632fs) under a temperature variation of 4°C (from 36°C to 32°C) at the SPEF.

2. DEVICE STRUCTURE AND FABRICATION

Fig. 1(a) shows the experimental setup of the FMLL. The operation of the FMLL is based on polarization additive pulse mode-locking. A 3.5-m-long EDF (OFS: R37005) with a positive group velocity dispersion (GVD) parameter β_2 is used as the gain medium. The cavity dispersion is fine tuned by using a section of single-mode fiber (SMF-28) with proper length to make the net cavity dispersion in the anomalous dispersion regime but is quite close to the zero GVD. In order to change the cavity dispersion to achieve pulsewidth stretching, a SPEF is inserted between the output coupler and the waveplates in the cavity to suppress the long-wavelength lights [1], as shown in Fig. 1. The photomultiplier tube and the lock-in amplifier are used to measure the autocorrelation trace of output pulsewidth. To fabricate the SPEF, a SMF-28 fiber is heated and stretched until the diameter of tapered waist is approaching 30µm. The length of uniform waist is about 1.5 cm and the filter is tunable over 1250-1650 nm with the rejection efficiency above 45 dB. The cutoff slope (slope of the line passing through the 10 dB and 30 dB loss) is about -1.0 dB/nm when the tapered fiber is in an optical liquid ($n_D = 1.456$). Typical transmission spectra measured by OSA under the resolution (RES) of 1 nm are shown in Fig. 1(b).



Fig. 1(a). Experimental set-up of our pulse-stretchable Er^{3+} -doped mode-locked fiber laser. OSA: optical spectrum analyzer, RF: RF spectrum analyzer, AC: autocorrelator, SPEF: short-pass edge filter, EDF: erbium-doped fiber, PMT: photomultiplier tube, Lock-in Amp.: lock-in amplifiers. (b) Spectral responses of a SPEF at different heating temperatures. (Res: 1 nm).

3. MEASUREMENTS AND CHARACTERISTICS

In the experiments, the EDF is backward pumped by a 122-mW 980-nm diode laser with a broadband amplified spontaneous emission (ASE) covering C+L band and partial S-band with the gain peak around 1.531 µm. The total cavity length is estimated to be 14 m and the repetition rate of the femtosecond fiber laser is 20 MHz, measured by a radio-frequency (RF) spectrum analyzer. In the beginning, the heating temperature of the liquid in SPEF was tuned to 36°C to obtain the shortest pulsewidth. The temperature is then gradually decreased. When the cutoff wavelength of SPEF is tuned to cut some of the long wavelength portions of the mode-locked pulses, as shown in Fig. 2(a), the net cavity dispersion is tuned to the normal dispersion regime and the pulsewidth is broadened. In Fig. 2(b), the experimental intensity auto-correlation traces show that pulsewidth at 36°C is 250fs (assuming a Gaussian pulse shape) and is gradually stretched to 381fs, 441fs, 529fs, and 882fs at 35°C, 34°C, 33°C, and 32°C, respectively. The temperature variation of 4°C on the SPEF can efficiently stretch the pulsewidth over the amount of 632fs (250-882fs), as shown in Fig. 2(b). The corresponding pulsewidth stretch ratio is 3.53 (882/250). When the temperature is tuned below 32°C, the mode-locking is stopped. The SPEF with a high cutoff slope can provide a large negative dispersion at the wavelengths near the roll-off curve for laser cavity. A SPEF with an inferior (not as sharp) cutoff slope is also employed in FMLL to investigate the pulsewidth stretching but the results are poor. It is obvious that a sharp cutoff slope filtering curve is crucial to an efficient cavity dispersion tuning for a widely tunable pulsewidth stretchable FMLL.



Fig. 2(a). Output spectra of Er^{3+} -doped mode-locked fiber laser with the SPEF operating at different temperatures (Res: 1 nm). (b) Autocorrelation traces of the output pulses at different temperatures.

4. CONCLUSION

We have demonstrated pulsewidth-tunable FMLL by incorporating a tunable SPEF into the laser ring cavity. The SPEF with a steep cutoff slope can introduce a large negative waveguide dispersion to tune the cavity dispersion from anomalous dispersion to normal dispersion. The corresponding pulsewidth of the output pulses can be stretched from 250fs to 882fs under a temperature variation of 4°C. This approach enables the all-fiber femtosecond laser, to be pulsewidth tunable. This all-fiber scheme is simple, cost-effective, and wide-range tuning. The multistage intracavity SPEFs could be promising for achieving efficient pulsewidth stretching to even large values for mode-locked fiber laser applications.

5. REFERENCES

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