

34.3 fs pulse generation in an Er-doped fibre laser at 201 MHz repetition rate

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A 34.3 fs pulse generation dechirped from a nonlinear polarization evolution (NPE)-based modelocked Er-doped fibre laser at a repetition rate of 201 MHz is reported. The output power is 38.5 mW at a pump power of 700 mW.

Introduction: Ultrashort pulse fibre lasers with repetition rates >200 MHz are attractive in numerous applications, such as high-speed optical sampling, frequency comb generation for optical frequency metrology and optical arbitrary waveform generation. Tremendous progress has been made in shortening pulse durations and increasing pulse repetition rates from fibre lasers within the past two decades. Wilken *et al.* reported an Er-doped fibre laser modelocked by NPE and operated in the stretched pulse regime, which has a fundamental repetition rate of 250 MHz. The pulse duration was approximately 70 fs and the full width at half maximum (FWHM) of the optical spectrum was 53 nm [1]. Moreover, with this scheme, Peng *et al.* [2] achieved a fundamental repetition rate of 300 MHz as well as pulse duration of 93 fs. A similar fibre laser in the stretched pulse regime was dechirped with the pulse duration of 37.4 fs and the FWHM of 135 nm at a fundamental repetition rate of 225 MHz [3]. Qi *et al.* [4] demonstrated a 325 MHz fundamental repetition rate with output pulse duration of 123 fs and optical spectrum FWHM of 24 nm by employing two gain fibres with opposite dispersions to shorten the cavity length and free from additional dispersion compensation devices inside the cavity. We recently demonstrated an NPE-based fibre laser, producing 44.6 fs direct output pulses and 148 nm spectrum at a repetition rate up to 200 MHz under effective dispersion and nonlinearity optimisation [5]. In this Letter, we demonstrate that this modelocked fibre laser with an SF10 Brewster prism pair laid externally outside the cavity is capable of generating 34.3 fs ultrashort pulses.

Experimental setup: As shown in Fig. 1, the ultra-short pulse fibre laser investigated in this work is a passively modelocked ring fibre laser based on NPE under dispersion and nonlinearity management [5]. The laser cavity is a counter-clockwise ring cavity, which is composed of a 37 cm long highly Er-doped gain fibre (Liekki ER110-4/125), an OFS-980 fibre pigtail of a 980 nm/1550 nm wavelength division multiplexer (WDM) with the length of 30 cm, two leading fibres (SMF28) of the collimator1 and collimator2 with lengths of 9 cm and 12 cm, respectively, and a set of free-space components. The total free-space length of the cavity is 11.5 cm, and the total cavity length is 99.5 cm. Taking into account the group velocity dispersion (GVD) of free-space bulk components, the laser cavity net GVD is managed to near-zero at 1550 nm wavelength. The output pulse is rejected from the polarisation beam splitter (PBS). The SF10 Brewster prism pair laid outside the cavity is used to dechirp the pulse.

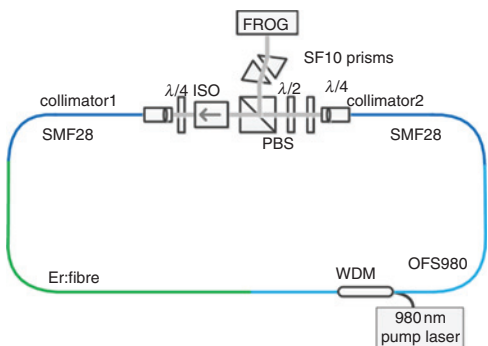


Fig. 1 Experimental configuration of laser with external dechirping

PBS, polarisation beam splitter; ISO, polarisation-dependent isolator; $\lambda/2$, half waveplate; $\lambda/4$, quarter waveplate; WDM, wavelength-division multiplexer

Results and discussion: The modelocking was initialised with the NPE. At the pump power of 700 mW, the maximum average output power of the direct pulse was 50.2 mW and the repetition frequency was measured to be 201.64 MHz. The optical spectrum is flat, smooth and

broad with the FWHM of 148 nm ranging from 1490 to 1640 nm [5], and the cavity net GVD is approximately maintained to be near-zero only at 1550 nm wavelength. It is reasonable to estimate that the direct output pulse still contain some residual dispersion chirp within the whole wavelength range. A commercial frequency-resolved optical gating (FROG) trace of output pulse (Grenouille & Frog15–40). The FROG traces of the output pulse without and with the SF10 Brewster prism pair for external dechirping are compared in Figs. 2a and b, respectively. The recovered time-domain pulse before and after dechirping is compared in Fig. 2c. It shows that the pulse duration is compressed from 49.1 to 34.3 fs. The average output power of the dechirped pulse is 38.5 mW, indicating a compression's energy efficiency of 77% ($=38.5 \text{ mW}/50.2 \text{ mW} \times 100\%$). Note that the dechirped pulse duration is slightly larger than the transform-limited pulse of 23.6 fs, which is estimated by assuming a Gaussian profile of the modelocked pulse and the FWHM of 148 nm. The difference is possibly attributed to some residual chirp induced by the third-order dispersion and non linearity effects in the laser cavity. Further study to eliminate the residual third-order chirp is now in progress.

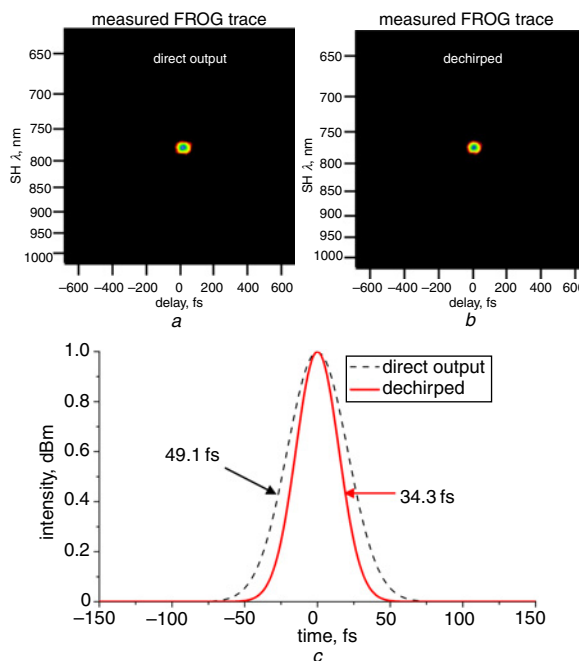


Fig. 2 Measured pulse profile of ultrashort pulse before or after dechirping

a FROG trace of direct output pulse and
b Dechirped pulse
c Pulse intensity in time domain retrieved from (Fig. 2a) (dash trace) and (Fig. 2b) (solid trace)

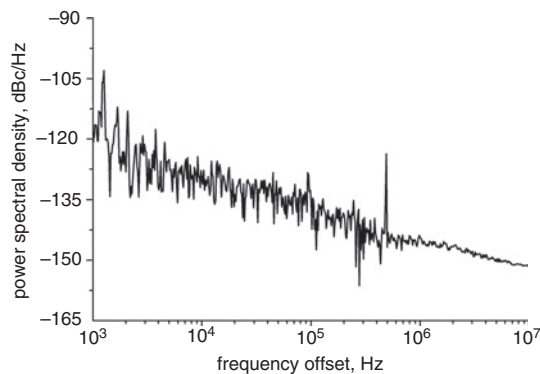


Fig. 3 Measured phase noise spectral density of dechirped pulse at 8th harmonic frequency ($\sim 1.61 \text{ GHz}$) of laser's repetition rate

Fig. 3 shows the single sideband phase noise spectrum density measured at the 8th harmonic frequency ($\sim 1.61 \text{ GHz}$) of the laser's repetition rate. This measurement was carried out by use of a 10 GHz photo detector (EOT, ET-3500F) laid after the dechirping prisms, an electrical

bandpass filter (K&L 5B120-1550/T200, 1.55 GHz, 200 MHz), a low-noise amplifier (Cernex CBL01023805RX, 13.5 dBm output power), and a signal source analyser (Agilent 5052B). The timing jitter integrated starting from 1 kHz progressively up to 10 MHz is ~ 24 fs.

Conclusion: We have demonstrated 34.3 fs pulse generation dechirped from an NPE-based modelocked Er-doped fibre laser at a fundamental repetition frequency of 201 MHz. The dechirped pulse has an average output power of 38.5 mW with a compression's energy efficiency of 77%. The time jitter is measured to be ~ 24 fs. A higher pulse repetition rate and further shorter pulses are now under further study.

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One or more of the Figures in this Letter are available in colour online.

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