Short-cavity, passively modelocked fibre laser oscillator at 1.5 µm with 550 MHz repetition rate and high average power

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A short-cavity fibre laser oscillator emitting 12 ps-long pulses at the fundamental cavity frequency of 550 MHz is reported. The simple, stable and ultra-compact laser cavity consists of a short active fibre section which is spliced to a narrowband fibre Bragg grating, and a butt-coupled semiconductor saturable absorber mirror. Only 8 cm of the heavily Er/Yb co-doped phosphate-glass active fibre is sufficient to produce as much as 775 mW of average output power at 1.5 µm directly from the oscillator.

Introduction: Compact and reliable picosecond lasers with high average power and high repetition rates are indispensable in a variety of high-speed photonics applications. Passively modelocked solid-state laser oscillators are widely used in such areas as laser material processing, spectroscopy and nonlinear frequency conversion [1, 2]. Although the best performance is still delivered by modelocked bulk lasers, the all-fibre format is practically advantageous owing to the design simplicity, robustness, environmental stability and the convenience of the singlemode fibre output delivery. Presently, the conventional active medium used in fibre lasers operating in the telecommunication spectral window around 1.5 µm is the Er/Yb co-doped silica glass. Since the active ion concentration in silica is practically limited by less than 1%, several metres of the active fibre are needed in order to reach the watt-level of average output power. This sets a limitation on the highest pulse repetition rate that can be achieved from a fibre laser source modelocked at the fundamental cavity frequency. Substantially higher repetition rates are possible by using the harmonically modelocked fibre oscillators. However such sources are of limited practical use because of the problems with the locking stability and pulse jitter [3, 4].

Recently developed optical fibres based on the soft phosphate glass can be heavily doped with rare-earth ions without the detrimental clustering effects. The doping concentration in such fibres can be as high as 20% by weight. Using these heavily-doped fibres allows having an abundance of the active lasing material in active fibres as short as several centimetres. The compact laser oscillators based on such fibres can be both end- and side-pumped, and successful applications of these fibres in both continuous-wave and pulsed lasers have been reported [5, 6].

In this Letter, we report an all-fibre, passively modelocked laser oscillator at 1.5 µm that utilises a short piece of the Er/Yb co-doped phosphate fibre. The self-started modelocked operation of the oscillator is initiated by the semiconductor saturable absorber mirror (SESAM) which is butt-coupled to one end of the short, standing-wave laser cavity. The oscillator emits nearly transform-limited 12 ps-long pulses at the fundamental cavity frequency of 550 MHz, and produces as much as 775 mW of average output power directly from the oscillator. To the best of our knowledge, this repetition rate is the highest among the watt-level fundamentally modelocked fibre oscillators reported previously. The simplicity and robustness of our approach suggest that our oscillator can be an ideal candidate for the pulsed seed source in high-power master-oscillator-power-amplifier (MOPA) designs [7].

Experimental setup: The laser oscillator reported here is shown schematically in Fig. 1. An 8 cm-long piece of the heavily Er/Yb co-doped phosphate glass fibre is used as a gain medium. The doping concentrations of Er and Yb ions in the fibre core are 1 and 8 wt%, respectively. The active fibre has the core diameter of 14 µm and the numerical aperture of ~0.08. Thus the V-number of the fibre at the lasing wavelength is equal to 2.26, indicating that the fibre is marginally singlemode. The active fibre is side-pumped with multimode laser diodes operating at 975 nm using the scalable pumping scheme described in detail in [8]. As an output coupler, we use a narrowband (FWHM of 1.5 nm), low-reflectivity (15%) fibre Bragg grating written in a standard telecommunication fibre (SMF-28). The grating is fusion-spliced to one end of the active fibre. The other end is spliced to a short piece of SMF-28 fibre which is cleaved and butt-coupled to the SESAM. This short piece of SMF-28 serves as a spatial mode filter which is essential for the stable modelocked operation of the oscillator as described below.

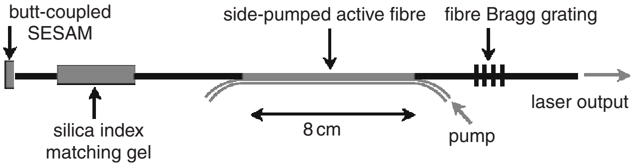

Fig. 1 *Schematic diagram of short passively modelocked fibre laser oscillator*

A considerable difference in refractive indices between the phosphate glass and silica can result in partial reflections off the splice points between the fibres. Such reflections can result in parasitic sub-cavities that tend to destabilise the modelocking. To eliminate the sub-cavity effects, the splices between the phosphate and silica fibres are performed on the fibres cleaved at an angle. The total cavity length in the setup is ~18 cm, corresponding to the fundamental cavity frequency of 550 MHz.

The SESAM that initiates and sustains the modelocked operation of the laser has the saturable loss of 30%, the saturation fluence of 50 µJ/cm^2, and the recovery time constant of 10 ps. Further, owing to a slight mode mismatch between the active fibre and SMF-28 pigtails, several cladding modes are excited in the silica fibre. The cladding modes should be stripped before reaching the SESAM surface, otherwise the nonlinear response of the absorber would distort the beam coupled back into the fibre even further. Such distortion can result in a reduced stability of the modelocked operation. To facilitate the stripping of the cladding modes, a large fraction of the silica fibre which is butt-coupled to the absorber is covered with an index-matching gel.

Results: The modelocked operation starts when the oscillator is pumped with ~9.5 W of pump light at 975 nm and the average output power at 1.5 µm is 370 mW. Even though the energy per pulse at this power level is about 0.7 nJ and the absorber is already over 10 times above saturation, the modelocking is not stable and has a tendency to simultaneous Q-switching [9]. By increasing the pump power we achieved the pure and stable CW modelocked operation which occurred in the range between 500 and 775 mW of the average output power. The highest output power was limited by the ~17 W of total available pump power at 975 nm. The nonlinear intensity autocorrelation trace and the optical spectrum of the laser pulses were recorded throughout the entire operation range. Within the measurement accuracy, the pulse width was found to be independent of the average output power. The optical spectrum and the autocorrelation trace of the pulses at the highest power level are shown in Fig. 2. Assuming the Gaussian pulse shape, the width of the pulses is estimated at 12 ps. The FWHM of the optical spectrum is 0.37 nm, which corresponds to nearly transform-limited Gaussian pulses with the time-bandwidth product of 0.54. At the highest power level, the pulse energy and peak power reach 1.4 nJ and ~110 W, respectively.

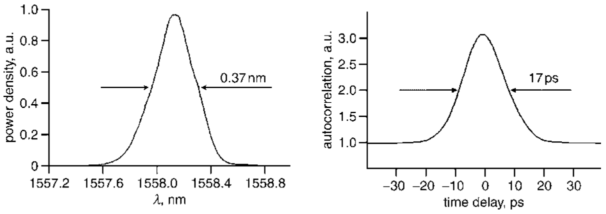

Fig. 2 *Spectrum and nonlinear autocorrelation of laser pulses at maximum output power*

a Spectrum
b Nonlinear autocorrelation

Conclusion: We have reported an ultra-compact, all-fibre picosecond laser oscillator with high average power and high repetition rate. By using a short and heavily-doped active fibre, 775 mW of average output power at 1.5 µm has been generated directly from the modelocked oscillator that was operating at the fundamental pulse repetition rate as high as 550 MHz. We believe that our pulsed source is an ideal candidate for the pulsed master oscillator in high-power MOPA designs.

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