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Millijoule, high-peak power, narrow-linewidth, sub-hundred nanosecond pulsed fibre MOPA at 1.55 μm

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Abstract: A millijoule, high-peak power, sub-hundred nanosecond pulse, fibre master-oscillator power-amplifier (MOPA) source with narrow linewidth output is presented. In addition, fibre MOPA design challenges and system limitations are discussed

Introduction - Narrow-linewidth high power pulsed erbium-ytterbium doped fibre lasers and amplifiers (EYDFAs) in the "eye-safe" 1.5 – 1.6 μm wavelength range are ideal sources for LIDAR systems, nonlinear optical conversion, and remote sensing thanks to their compactness, versatility and efficiency. Fibre-based devices can be made with small foot print and low weight while maintaining the optical performance required in such applications. The recent increase of fibre output power [1, 2] has been rendered possible thanks to advances in diode pump technology such as diode stacks and improved double-clad fibre designs. However a number of challenges remain for the energy scaling of narrow-linewidth pulses at ~ 1550 nm.

Scaling of energy and peak power of pulses has been much slower [3] at 1550 nm than in the 1050-1080 nm wavelength region with Yb-doped fibre sources [4]. Because of the low absorption of erbium, the conventional approach to cladding-pumping of Er-doped fibres is to use ytterbium sensitisation to increase the pump absorption [5]. However, the large pump-signal wavelength difference increases the quantum defect which leads to heat generation in erbium-ytterbium co-doped fibres. In addition, high-quality doped fibres are required to alleviate any potential spurious lasing of the ytterbium emission [6]. Furthermore, in case of narrow linewidths, Stimulated Brillouin scattering (SBS) is the major impediment for high-power "single-frequency" pulses. Although some SBS suppression schemes have been proposed at low power (e.g. [7]), cumbersome and complex arrangements make them unsuitable with the power level of LIDAR applications. In this work, in order to avoid SBS, we use fibres with increased core size and reduced length in a MOPA configuration. The drawbacks are that the large core leads to a transversely multimode output and in addition increases the amplified spontaneous emission (ASE), which limits energy extraction. Nevertheless, such fibres are compatible with widely available components developed for telecom applications, which can provide good spectral and temporal control. Hence, a high-power fibre MOPA consisting of multiple application stages make an attractive combination. For example, in the 1550 nm wavelength range, we have recently demonstrated fibre MOPAs with good beam quality generating cw high power single-frequency single-mode radiation (e.g., [8]), 1 mJ pulses [9], and pico-second pulses with 60 W average power [10]. In this work we present narrow-linewidth high-energy pulses with record peak powers without any SBS in a fibre MOPA.

Experimental set-up - The fibre MOPA consisted of four cascaded fibre amplifiers. Monitoring taps were introduced to monitor spectral and temporal evolution of the pulse along the MOPA. The master source was a directly modulated external-cavity tuneable laser source (TUNICS-Plus) operating at 1535 nm. Though the precise linewidth is unknown, it is sufficiently narrow to generate SBS in the cascade. Direct measurements demonstrated a linewidth of less than 0.05 nm (resolution-limited). The oscillator output was amplified in a core-pumped erbium-doped fibre amplifier (length ~ 3m, core diameter ~12 μm) whose output was time-gated with a synchronized acousto-optic modulator. The signal was then further amplified in a cladding-pumped EYDFA (length ~2.5m, core diameter ~ 18 μm) whose output was spectrally filtered with a narrow-band fibre-Bragg grating (FBG) at the signal wavelength. The final two amplifiers used 50 μm core and 90 μm core double-clad EYDFs, 2.5 m and 2 m long, respectively. Both stages were end-pumped with multimode pumps sources at 915 and 960 nm respectively. The overall length of the MOPA was reduced to a minimum (< 12 m) and the powers from different amplifiers were adjusted to avoid any SBS or ASE saturation. Without proper power adjustment of the amplification stages, SBS arose in the second stage indicating a "single-frequency" nature of at least a part of the energy in the optical pulse.

Results - The performance of MOPAs similar to this one, without the fourth stage, has been reported before [11], so here we concentrate on the behaviour of the fourth-stage amplifier. The average input power of the fourth amplification stage was 233 mW at 1 kHz repetition rate. The pulse energy was measured to be 179 μJ with an energy meter. This was then amplified to 1.011mJ pulse at maximum pump power (fig. 1). This corresponds to a peak power of 6.6 kW for a pulse duration (FWHM) of 88 ns (fig. 1 insets). Pulse compression due to the differential gain between the leading and trailing pulse edges is observed. Despite the high-peak power, no non-linear effects were observed. The average output power (ASE included) was more than 1.5 W. The energy extraction was limited by ASE saturation which represents about 50% of the output power. The ASE can be suppressed, and the average power in the pulses can be improved, at higher repetition rates, however at the expense of pulse energy and peak power. The output optical spectrum is shown in fig. 2. The amplified linewidth remains resolution-limited below 0.05nm (fig. 2 inset). The spectral pedestal is due to ASE generated in the amplifier cascade.

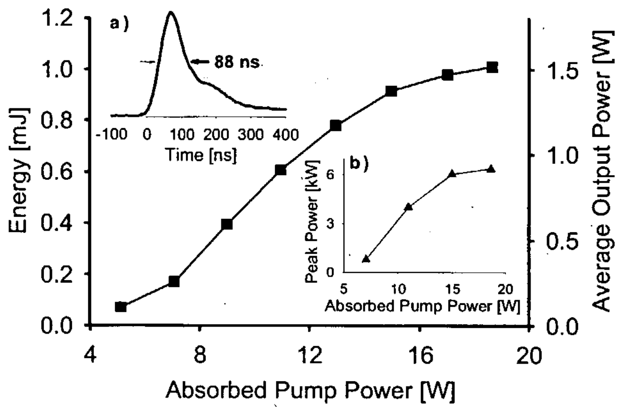

Fig. 1: Output energy and average output power versus absorbed pump power in the final stage. Insets: a) temporal trace of the pulse, b) peak power versus absorbed pump power.

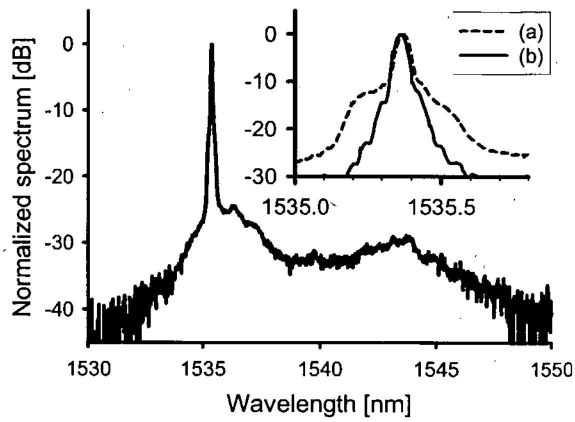

Fig. 2: Normalized output optical spectrum (resolution 0.05 nm). Inset enlarged spectra from: a) output b) diode

Our experience with this fibre suggests that the beam is not diffraction-limited, but may have an M^2-value of 5. Direct measurements of beam-quality of the pulses, is difficult when there is a significant ASE-background. While the launch of the signal pulses can be adjusted for best beam quality, the ASE cannot be controlled in that way and can therefore have a worse beam quality. A more advanced setup that could distinguish the beam quality of the pulses from the ASE was not available.

Conclusion – A high-energy, high-peak power, narrow-linewidth cascaded fibre MOPA is presented. Up to 1mJ and 6.6 kW peak power pulses with a 88 ns FWHM, are obtained at 1 kHz repetition rate. The main limiting factor in this configuration is ASE saturation due to the large-core fibre used. However, no SBS or any other non-linear effects have been observed which indicates that even higher energies are possible with improved fibre design.

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