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1 mJ narrow-linewidth pulsed fiber MOPA source at 1535 nm

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Narrow-linewidth high power pulsed "eye-safe" erbium-ytterbium doped fiber lasers and amplifiers (EYDFA) are ideal source for LIDAR systems, nonlinear optical conversion, and remote sensing thanks to their compactness, versatility and efficiency. However although recent progress has been made [1,2], scaling of the energy and peak power of narrow-linewidth pulses presents many challenges. Stimulated Brillouin scattering (SBS) is the major impediment for "single-frequency" pulses. Here, in order to avoid this nonlinear effect, we use a fiber with increased core size and reduced length, which allows us to reach a pulse energy of over 1 mJ in 88 ns long pulses. The drawbacks are that the core size increase leads to a transverse multimode output and in addition increases the amplified spontaneous emission (ASE) which limits energy extraction.

We used a master-oscillator power amplifier (MOPA) comprising four cascaded fiber amplifiers. The master source was a directly modulated external-cavity tunable laser source (TUNICS-Plus). 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 short erbium-doped fiber amplifier whose output was time-gated with a synchronized acousto-optic modulator. The signal is then further amplified in a cladding-pumped EYDFA whose output was spectrally filtered with a narrow-band fiber-Bragg grating (FBG) at 1535 nm. The final two amplifiers use 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 power from different amplifiers was 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 the optical pulse. In addition, monitoring taps were introduced to monitor spectral and temporal evolution of the pulse along the MOPA.

Performance of MOPAs similar to this one, without the fourth stage, has been reported before [2], so here we concentrate on the behavior of the fourth-stage amplifier. The average input power of the final stage was 233 mW at 1 kHz repetition rate. The pulse energy was measured to 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 kW for a pulse duration (FWHM) of 88 ns (fig.1 insets). The average output power (ASE included) was more than 1.5 W. The energy extraction was limited by ASE saturation. The output optical spectrum is shown in fig.2. The amplified linewidth remains resolution-limited below 0.05nm (fig.2 inset). There is also a continuous-wave spectral pedestal due to ASE

Our experience with this fiber 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. This work was sponsored in part by QinetiQ.

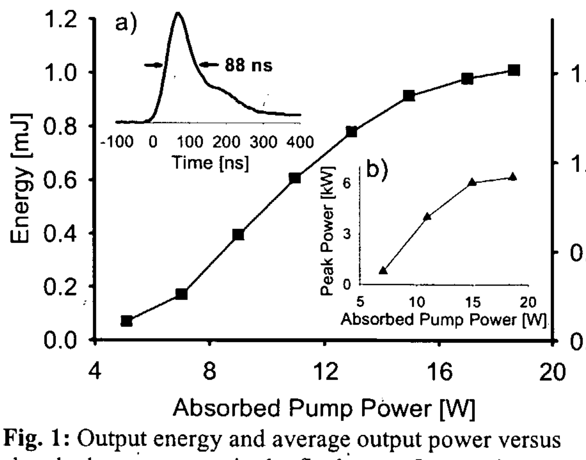

Fig. 1: Output energy and average output power versus absorbed pump power in the final stage. Insets: a) temporal trace of the pulse, b) peak power versus absorbed pump power.

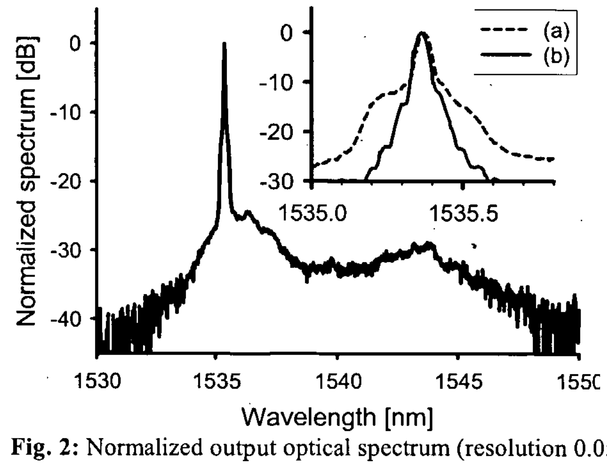

Fig. 2: Normalized output optical spectrum (resolution 0.05 nm). Inset enlarged spectra from: a) output b) diode

[1] V. N. Philippov, J. K. Sahu, C. Codemard, W. A. Clarkson, J.-N. Jang, J. Nilsson, and G. N. Pearson, "All-fiber 1.15 mJ pulsed eye-safe optical source", Proc. SPIE **5335**, 1-5 (2004)

[2] V. N. Philippov, C. Codemard, Y. Jeong, C. Alegria, J.K. Sahu, J. Nilsson, G. N. Pearson, "High-energy in-fiber pulse amplification for coherent lidar applications", Opt. Lett. **29**, 22 (2004)