Low-birefringence 120 W Yb fiber amplifier producing linearly polarized pulses with 69-GHz linewidth at 1083 nm

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Abstract: A low-birefringence 5-m-long fiber amplifier with a highly Yb-doped 40-µm, 0.028-NA phosphosilicate core produces linearly polarized (7.2-dB PER) 20-ns, 0.8-mJ pulses with 69-GHz linewidth, $M^2 = 1.2$, and 120 W of average output power at 1083 nm.

OCIS codes: (140.3510) Laser, fiber; (140.3280) Laser amplifiers; (320.5550) Pulses;

Laser sources based on Yb-doped fiber amplifiers (YDFAs) in master oscillator – power amplifier (MOPA) configuration are excellent at generating high-power light with sophisticated temporal and spectral properties [1-2]. In case of polarized light, high-birefringence polarization-maintaining (PM) fibers can be used. The power is often limited by nonlinearities such as SBS and SRS (stimulated Brillouin and Raman scattering) and self-phase modulation [3-4]. Signal wavelengths at 1030nm - 1040 nm allow for high gain per unit length and thus lower nonlinear degradation in short fibers. Large-mode-area (LMA) core designs also reduce nonlinear degradation. Typically their numerical aperture (NA) is low which, advantageously, also mitigates thermal mode instability. Recently, refined fabrication methods have enabled even lower NAs in fibers with high Yb-concentration [5], which increases the attraction of this approach.

Here, we report a polarized pulsed narrow-line five-stage MOPA at a wavelength of 1083 nm, where the small stimulated-emission cross-section presents additional challenges, in terms of spectral gain control and the length required to reach adequate gain. We overcome these challenges by inter-stage spectral filtering and by using a well-matched cladding-pumped LMA Yb-doped fiber (YDF) in the final 5th stage. The nonlinearities are critical, and we therefore use a short fiber (5 m), which despite a high Yb-concentration (8.78×10^{25} m–3) maintains a core-NA as low as 0.028. The fiber is fabricated by Clemson University with an improved technique which effectively eliminates the NA limit of ~0.06 of conventional approaches and opens up many new possibilities for larger cores and improved mode quality. The fiber has a hexagonal core, 42 µm flat-to-flat and 46 µm corner-to-corner. The inner cladding is also hexagonal, 411 µm flat-to-flat, 431 µm corner-to-corner, with NA 0.46. The peak pump absorption is ~6.1 dB/m at 975 nm. The fiber cross-section is shown in Fig. 1, together with the overall MOPA layout. All YDFAs are cladding-pumped. Furthermore, the first four stages are co-directionally pumped and fully fiberized with PM fibers in the signal path. By contrast, the 5th-stage YDF is non-PM, but still manages to reach a polarization extinction ratio (PER) of 7.2 dB.

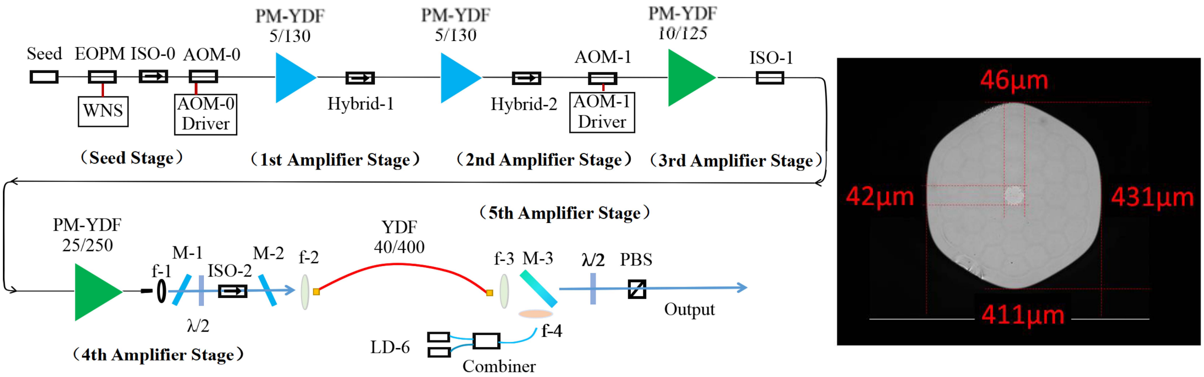

Fig. 1 Setup of the 1083-nm narrow-linewidth pulsed YDF MOPA.

A continuous-wave DFB diode laser with 40-mW output power and linewidth specified to < 2 MHz serves as the master oscillator. Its output is broadened by an electro-optic phase modulator (EOPM, EOSpace, 10 GHz, V_π 3.1 V @ 1 GHz) driven by a 5 V (RMS), 8 GHz white noise source (WNS) to suppress SBS. Then, an acousto-optic modulator (AOM) defines 20-ns pulses at 600-kHz pulse repetition frequency (PRF). The first YDFA boosts the average power to 8 mW, measured at the output of a hybrid of an isolator and a 5-nm bandpass filter to block amplified spontaneous emission (ASE) and optical return. (All quoted powers are after any output isolator.) The second YDFA boosts the power to 130 mW, again at the output of a similar isolator – bandpass hybrid. Both these YDFAs use 6 m of 5-μm core, 130-μm cladding YDF (Nufern PM-YDF-5/130-VIII). A 2nd AOM then down-samples the PRF to 150 kHz, and also helps to suppress ASE within the passband of the hybrids. The 3rd stage (3 m of 10-μm core, 125-μm YDF, Nufern PLMA-YDF-10/125-M) boosts the power to 0.75 W.

The 4th stage comprises 3 m of 25-μm core, 250-μm YDF (Nufern PLMA-YDF-25/250-M), which is terminated at an angle of 8°. A 20-mm focal length aspheric lens collimates the output, which is then passed through a dichroic mirror that deflects the 4th-stage residual pump, and a free-space single-polarization isolator. Here, the power is 8 W and the polarization extinction ratio becomes 21 dB, following the polarizer in the isolator. The 5th stage uses 5 m of Clemson's 40-μm, 0.028-NA core non-PM YDF. Despite its length, the bending is only ~135° (less than half a loop), and very gentle. The signal is launched through a dichroic mirror that deflects any backward pump from the 5th stage and an aspheric lens (focal length 40 mm). The YDF is free-space end-pumped by 975-nm and 950-nm fiber-coupled laser diodes (nLight e18.1350976105, Lumentum ST-915B-100) launched through the signal output end via a pump combiner and aspheric lenses, one of which also collimates the output signal beam.

Fig. 2(a) shows the average output power against pump power absorbed in the 5th stage. The slope efficiency reaches 75% and the output power reaches 120 W. By adjusting the orientation of a half-wave plate we manage to transmit 102 W (84%) of this through a polarizing beam splitter (PBS), for a PER of 7.2 dB. The power in different polarizations is also shown in Fig. 2(a). The high degree of linear polarization did not drift for several days. Fig. 2(b) shows the pulse shape after the PBS at full output power. Here, the AOMs are adjusted to counteract saturation-induced pulse-shaping and realize a symmetric pulse. The peak power and pulse energy were calculated to be 40 kW and 0.8 mJ before the PBS and 34 kW and 0.68 mJ after the PBS. The spectrum measured with an optical spectrum analyzer with 0.05 nm is shown in Fig. 2(c). No SRS, ASE, or residual pump light is observed in the output beam. The linewidth was 0.27 nm (69 GHz). There was no spectral broadening, and all nonlinear effects were negligible in our MOPA. We also used a beam profiler (Thorlabs BP104-IR) to measure the beam quality (M^2) to 1.15 and 1.21 in orthogonal directions, at full power after the PBS and a 3 mm aperture which clipped 8% of the power.

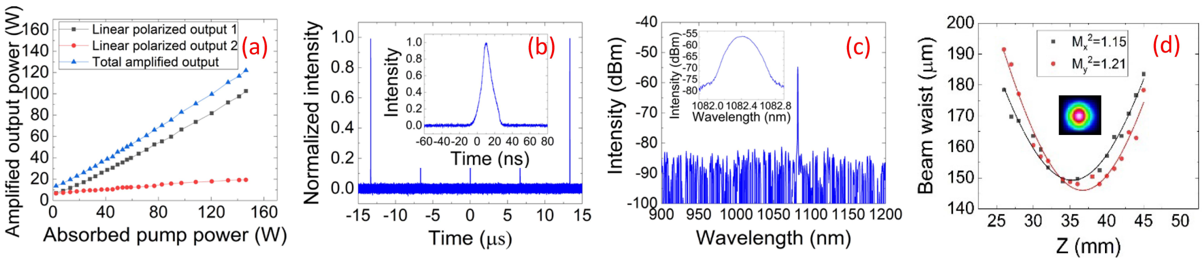

Fig. 2 (a) Output power of the 1083nm narrow linewidth YDF pulsed amplifier (b) Spectra (c) pulse shape (d) beam quality.

In conclusion, a high-power narrow-linewidth linearly-polarized nanosecond fiber amplifier is reported. The high-concentration, 0.028 NA 40/400 μm LMA fiber is key to both mitigating optical nonlinearities and maintaining high beam quality at a wavelength of 1083 nm. The fiber is also able to maintain a high degree of linear polarization over a distance as large as 5 m, despite its low birefringence.

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4. References

[1] D. J. Richardson, J. Nilsson, W. A. Clarkson, "High power fiber lasers: current status and future perspectives," JOSA B **27**, B63-B92 (2010).

[2] Christopher D., Brooks, Fabio Di Teodoro, "1-mJ energy, 1-MW peak-power, 10-W average power, spectrally narrow, diffraction-limited pulses from a photonic-crystal fiber amplifier," Opt. Express. **13**, 8999-9002 (2005).

[3] Brian M. Anderson, Angel Flores, and Iyad Dajani, "Filtered pseudo random modulated fiber amplifier with enhanced coherence and nonlinear suppression," Opt. Express. **25**, 287873-2878784 (2017).

[4] Wei Liu, Pengfei Ma, Chen Shi, Pu Zhou, and Zongfu Jiang, "Theoretical analysis of the SRS-induced mode distortion in large-mode area fiber amplifiers," Opt. Express. **26**, 15793-15803 (2018).

[5] Fanting Kong, Christopher Dunn, Joshua Parsons, Monica T. Kalichevsky-Dong, Thomas W. Hawkins, Maxwell Jones, and Liang Dong, "Large-mode-area fibers operating near single-mode regime," Opt. Express. **24**, 10295-10301 (2009).