

# 87-W, 1018-nm Yb-fiber ultrafast seeding source for cryogenic Yb:YLF amplifier

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**Abstract:** We demonstrate a compact Ytterbium-fiber MOPA system operating at 1018 nm, serving as powerful and compatible seed for cryogenically-cooled Yb:YLF amplifier. The output average power reaches 87 W with pulse energy of 4.9  $\mu$ J.

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Yb-doped materials have attracted much attention for their high optical-to-optical efficiency enabling the generation of high energy pulses at high average power. Among them, cryogenically cooled Yb:YLF exhibiting spectral width of several-nm has shown potential achieving sub-picosecond pulse duration with several-mJ energy at kHz repetition rate [1]. Cryogenically cooled Yb:YLF offers a saturation fluence higher than that of cryogenically cooled Yb:YAG, a longer excited state lifetime, and a smaller quantum defect therefore suggesting potential for high energy extraction at high repetition rate. These attractive spectroscopic properties however require for a seed laser operating at 1018 nm central wavelength and with a large stretching factor to permit efficient and damage-free energy extraction in subsequent 100 mJ-class amplifiers we are developing. In a previous implementation [1], a Ti:sapphire laser with low pulse energy and limited stretching ratio was used. A Yb-doped fiber-based, high energy seed would facilitate the implementation of a 100 mJ cryogenically cooled Yb:YLF amplifier chain, mitigating ASE as well as gain-narrowing in the onwards amplifier chain and incorporating the advantage of low-cost and reliability.

Here, we demonstrate the first high power fiber-based system specifically designed to optimally seed a high energy Yb:YLF amplifier chain. The fiber-based master-oscillator-power-amplifier (MOPA) seed system operating at a repetition rate of 17.88 MHz produces 87-W, 4.9- $\mu$ J pulses centered at 1018 nm with 1-ns stretched duration and 2-nm bandwidth, ideally matching the emission spectrum of cryogenic Yb:YLF crystals.

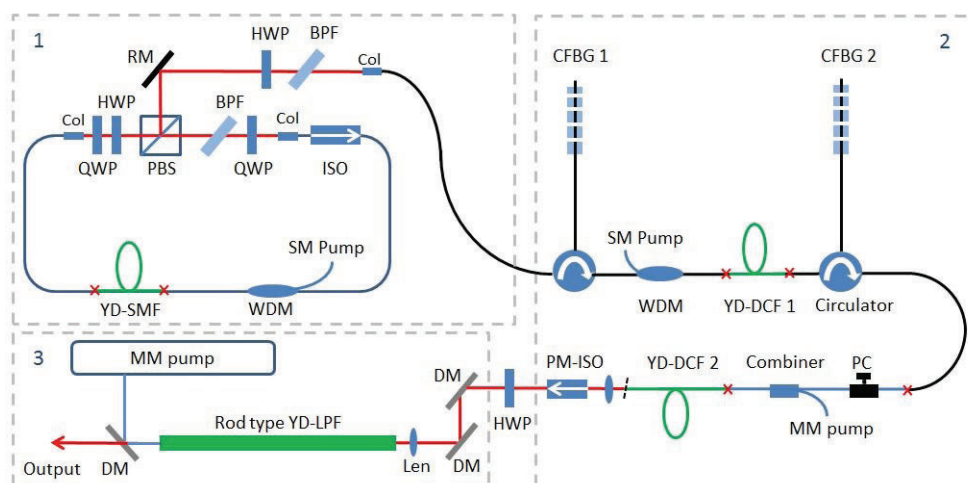


Fig. 1: Schematic of 1018 nm MOPA system. HWP: half-wave plate, QWP: quarter-wave plate, BPF: band-pass filter, PBS: polarization beam splitter, RM: reflecting mirror, Col: collimator, WDM: wavelength division multiplexer, SM: single mode, CFBG: chirped fiber Bragg grating, PC: polarization controller, MM: multimode, PM-ISO: polarization sensitive isolator, DM: dichroic mirror, YD: ytterbium-doped, SMF: single mode fiber, DCF: double-clad fiber, LPF: large-pitch fiber, blue line: non PM fiber, black line: PM fiber

The experimental setup (Fig. 1) consists of three parts. Part 1 includes a 17.88-MHz oscillator mode-locked at 1020 nm central wavelength via an intra-cavity narrow band-pass filter (BPF) and nonlinear polarization evolution (NPE) mechanism. Another BPF – outside the cavity – selects a 2-nm wide spectral band around 1016 nm (Fig. 2(a) – red curve) from the broadband output of the oscillator (Fig. 2(a) – blue curve). A half-wave plate adjusts the polarization direction of the pulses coupled into the polarization maintaining (PM) fiber.

Part 2 includes two PM circulators connected to two PM chirped fiber Bragg gratings (CFBGs), which stretch the laser pulse to  $\sim 1$  ns duration therefore alleviating nonlinear effects in subsequent amplifier stages. A pre-amplifier based on 2-m double cladding PM Yb-doped fiber is inserted between the two circulators to compensate the losses introduced by the circulators and CFBGs. Since the peak gain of this fiber amplifier is near 1030 nm, the center wavelength of the pulses shifts from 1016 nm to 1018 nm at this stage. Spliced directly to the port 3 of circulator 2, the second amplifier consists of a (2+1) beam combiner, a multi-mode pumping diode, and 1-m absorption-flattened Yb-doped double-clad fiber (FP fiber). This FP fiber provides higher gain at 1018 nm than 1030 nm, and thus efficiently amplifies the signal wavelength to an average power of 4 W. Figure 2(b) shows that the slope efficiency of FP fiber amplifier is 78%. Although FP fiber is non-PM, adjusting the polarization controller at the combiner input results in 18-dB polarization extinction ratio. The output spectrum from part 2 is shown in Fig. 2(b) (inset).

Part 3 is the power amplifier consisting on a 1.2-m Yb-doped rod-type large-pitch fiber (LPF) [2], which can produce 100 W, high quality  $\mu\text{J}$  pulses configured in pre-chirp managed amplification [3]. The signal and pump are coupled into the LPF from opposite direction. Figure 2(c) shows the output spectrum versus average power of the amplified pulses. The signal spectrum remains unchanged, suggesting a linear amplification. Broadband ASE peaking at 1030 nm grows with the increased pump power, yet remains 26 dB below the signal spectral peak even at the highest average power of 87 W. The slope efficiency of the LPF amplifier is limited to 49% (Fig. 2(d)) because the rod type fiber has its gain peaking at 1030 nm. Inset of Fig. 2(d) shows the excellent spatial profile of the 87-W amplified pulses.

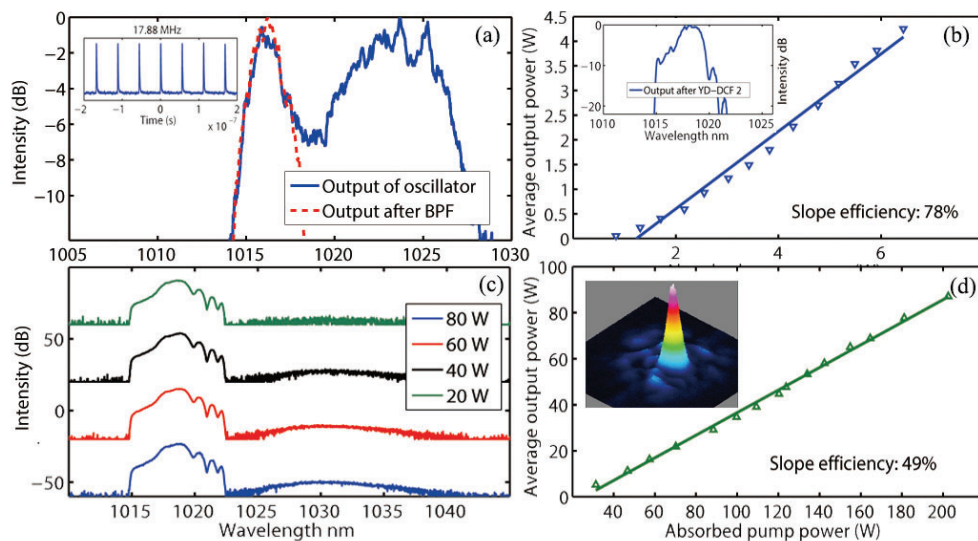


Fig. 2. (a) Measured output spectrum of oscillator (blue curve), spectrum after BPF with 2 nm bandwidth at 1016 nm (red curve) and 17.88 MHz pulse train (inset); (b) measured characteristics output power versus absorbed pump power of FP fiber amplifier and output spectrum of FP fiber at 1018 nm at 4 W power (inset); (c) measured output spectrum of rod-type LPF amplifier at 1018 nm for increasing pump powers; (d) measured characteristics output power versus absorbed pump power of rod-type LPF amplifier and spatial profile (inset).

In conclusion, we report a high-power Yb-fiber MOPA system operating at 1018 nm with 4.9  $\mu\text{J}$  pulse energy. With its output spectrum precisely matching the gain bandwidth of Yb:YLF crystal, this laser system serves as a desired seed source for subsequent 100 mJ-class, sub-ps duration cryogenic Yb:YLF amplifiers.

## References

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