Single-frequency, polarized ytterbium-doped fiber MOPA source with 264 W output power

Y. Jeong[1], J. Nilsson[1, 2], J. K. Sahu[1, 2], D. B. S. Soh[1], C. Alegria[1], P. Dupriez[1], C. A. Codemard[1], D. N. Payne[1, 2], R. Horley[2], L. M. B. Hickey[2], L. Wanzcyk[2], C. E. Chryssou[2], J. Alvarez-Chavez[2], and P. W. Turner[2]

1. Optoelectronics Research Centre, Southampton University, Southampton SO17 1BJ, England
2. Southampton Photonics, Inc., 3 Wellington Park, Hedge End, SO30 2QU, England

A single-frequency, single-mode, plane-polarized ytterbium-doped all-fiber master-oscillator – power amplifier source at 1060 nm generated 264 W of cw output power (pump-power limited) The final-stage amplifier operated with a high gain of 19 dB and a high conversion efficiency of 68%.

Cladding-pumped ytterbium-doped fiber sources have been power-scaled to the kW-level with good or even diffraction-limited beam quality [1 – 3]. Furthermore several options have been investigated for polarization-maintaining (PM) fibers for single-polarization operation, resulting in powers of up to ~300 W with good polarization-extinction ratio (PER) [3 – 5]. Technological improvements in diode pump sources, fiber fabrication and gain medium, as well as fiber design, device configuration, and heat-sinking, have enabled this spectacular progress. Applications such as coherent combination [6] and gravitational wave detection [7] in addition require single-frequency sources with narrow linewidth. However, stimulated Brillouin scattering (SBS) has limited the power from single-frequency fiber sources to ~100 W [8]. While short fibers and large cores mitigate SBS, further power-scaling of single-frequency fiber sources has remained uncertain. We present here a single-frequency, single-mode, plane-polarized ytterbium-doped fiber master-oscillator – power amplifier (MOPA) source with 264 W of cw output power, limited only by available pump power.

Figure 1 depicts the MOPA. A 1060 nm, 80 mW, plane-polarized Yb-doped fiber DFB laser (master oscillator) from Southampton Photonics, Inc. (SPI) was followed by four Yb-doped fiber amplifiers. The DFB laser and the final amplifier are the key components, while three standard non-PM amplifiers (SPI) were used in intermediate stages. The DFB laser linewidth was < 60 kHz (resolution-limited).

The final-stage amplifier comprised a 7 m long double-clad birefringent Yb-doped fiber fabricated by SPI. It had a 25 ìm diameter, 0.06 NA core. The inner cladding was D-shaped with a 380 ìm diameter. A low-index polymer coating provided a nominal inner-cladding NA of 0.48. The fiber incorporated a pair of borosilicate stress rods which, in this design, leads to a core birefringence of $\sim 2\times 10^{-4}$. Up to 390 W of pump power was launched into the signal output end of the fiber from a 975 nm diode pump source. The pump absorption was 2 dB/m. A dichroic mirror separated the signal output and pump beam paths. Both fiber ends were angle-cleaved. With proper adjustment of the polarization from the non-PM amplifier chain, 3 W of signal input power could be launched into the final-stage amplifier through a polarizing free-space isolator. The polarization was aligned on a birefringence-axis of the final-stage fiber.

Figure 2 shows the MOPA power characteristics as the pump power of the final-stage amplifier was varied. Other components operated at their maximum power (see Fig. 1). The maximum output power (264 W) was limited by available pump power, and there was no sign of any roll-over. The power conversion efficiency was 68% at maximum power and the slope efficiency was 72% with respect to launched pump power. The linewidth of the output was still below the 60 kHz resolution limit (Fig. 2). The PER was 16 dB, and the beam quality factor (M^2) was better than 1.1.

With textbook values for the Brillouin gain coefficient (5×10^{-11} m/W), we estimate the Brillouin gain to ~200 dB in the last-stage amplifier. This should lead to substantial SBS, but there was no sign of this. We conclude that our simple estimate exaggerates the Brillouin gain. Temperature and fiber compositional variations, which broaden the Brillouin gain, may be the explanation.

In summary, we have demonstrated a 1060 nm single-frequency fiber MOPA source with 264 W of output power, limited by available pump power. The polarization extinction ratio was 16 dB and the M^2value was < 1.1. While stimulated Brillouin scattering is expected to degrade single-frequency performance, SBS was not observed.

[1] Y. Jeong, J. K. Sahu, D. N. Payne, and J. Nilsson, "Ytterbium-doped large-core fiber laser with 1 kW of continuous-wave output power", Proc. Advanced Solid State Photonics, Santa Fe, NM, USA, February 1-4, 2004, post-deadline paper PD1
[2] C.-H. Liu, A. Galvanauskas, B. Ehlers, F. Doerfel, S. Heinemann, A. Carter, K. Tankala, and J. Farroni, "810-W single transverse mode Yb-doped fiber laser," Proc. Advanced Solid State Photonics, Santa Fe, NM, USA, February 1-4, 2004, post-deadline paper PD2
[3] Y. Jeong, J. K. Sahu, S. Baek, C. Alegria, C. A. Codemard, D. B. S. Soh, V. Philippov, R. B. Williams, K. Furusawa, D. J. Richardson, D. N. Payne, and J. Nilsson, "The rising power of fiber lasers", IEEE/LEOS Annual Meeting, Tucson, AZ, USA, Oct. 26-30 2003, paperThD1 (invited)
[4] Y. A. Barannikov, A. I. Oussov, F. V. Shcherbina, R. I. Yagodkin, V. P. Gapontsev, N. S. Platonov, "250 W, single-mode, CW, linearly-polarized fibre source in Yb wavelength range", Conference on Lasers and Electro-Optics 2004, San Francisco, CA, USA, May 16-21, 2004, paper CMS3
[5] A. Liem, J. Limpert, T. Schreiber, M. Reich, H. Zellmer, A. Tünnermann, A. Carter, and K. Tankala, "High power linearly polarized fiber laser", Conference on Lasers and Electro-Optics 2004, San Francisco, CA, USA, May 16-21, 2004, paper CMS3
[6] M. Wickham, J. Anderegg, S. Brosnan, D. Hammons, H. Komine, and M. Weber, "Coherently coupled high power fiber arrays", Proc. Advanced Solid State Photonics, Santa Fe, NM, USA, February 1-4, 2004, paper MA4
[7] Advanced LIGO homepage: http://www.ligo.caltech.edu/advLIGO
[8] A. Liem, J. Limpert, H. Zellmer, and A. Tünnermann, "100-W single-frequency master-oscillator fiber power amplifier", Opt. Lett. **28**, 1537-1539 (2003)

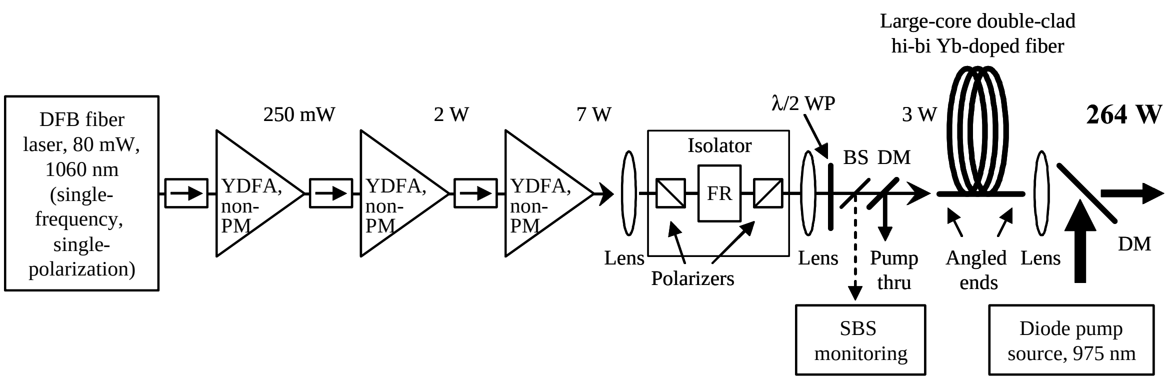

Figure 1. Experimental setup. YDFA: Yb^{3+}-doped fiber amplifier; DM: dichroic mirror; BS: beam splitter; FR: Faraday rotator; WP: waveplate.

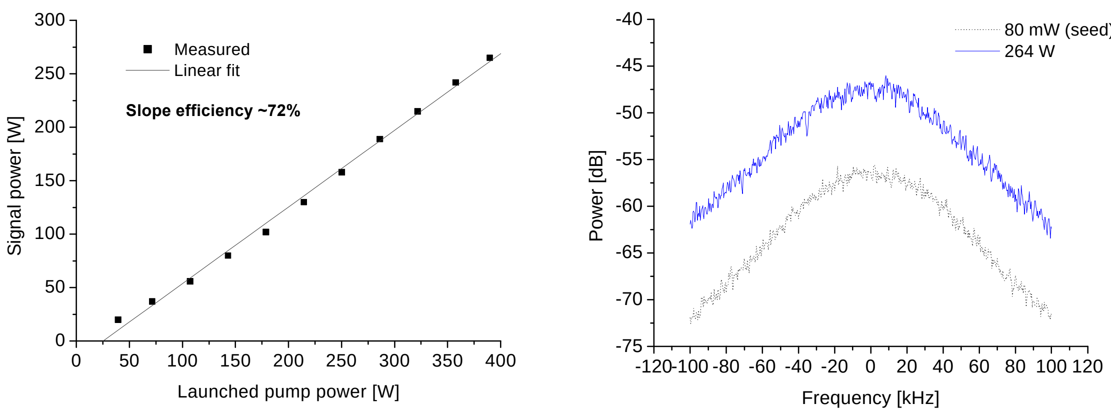

Figure 2. Left: Signal output power vs. final-stage pump power. Right: Heterodyne RF spectra from linewidth measurements, showing resolution-limited linewidths of < 60 kHz for both seed source and amplified output.

This work was supported in part by DARPA under contract MDA972-02-C-0049.