

Single-frequency 1 W hybrid Brillouin/ytterbium fiber laser

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A high-power hybrid Brillouin/ytterbium fiber laser has been demonstrated with an output power of 1 W. The laser operates in the single-frequency regime with an optical signal-to-noise ratio greater than 55 dB in a 0.1 nm bandwidth. © 2009 Optical Society of America
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Single-frequency fiber lasers have applications in data storage, sensing, communications, and high-resolution spectroscopy. Watt-level single-frequency fiber lasers have been demonstrated using short linear cavities [1] and ring cavities with embedded filters [2]. Master-oscillator/power-amplifiers can be used to generate multiwatt single-frequency output [3], but the amplified spontaneous emission (ASE) noise degrades the optical signal-to-noise ratio (OSNR) of the single-frequency master oscillator. Additionally, multiple-order stimulated Brillouin scattering (SBS) of the narrowband seed limits the performance of single-frequency amplifiers [4].

The gain bandwidth of SBS can be used as a narrowband filter for selecting single-frequency laser output. Single-frequency Brillouin/rare-earth fiber lasers have been demonstrated with output power of up to tens of milliwatts [5–7], which is limited by the relatively low pump power available from single-spatial-mode pump-laser diodes. In this Letter, a watt-level single-frequency hybrid Brillouin/ytterbium fiber laser is demonstrated using multimode pump-laser diodes and dual-clad ytterbium fiber.

In the experimental setup shown in Fig. 1 a fused, tapered pump combiner was used to couple the pump light from two 915 nm laser diodes into the inner clad of the dual-clad, ytterbium-doped fiber. The maximum-achievable pump power was 14 W after the combiner. The 12-m-long active fiber was ytterbium doped with a pump absorption rate of 0.5 dB/m at 915 nm. The total cavity length of this ring resonator was 15 m. A 1 MHz bandwidth, distributed-feedback semiconductor laser source at 1080 nm with 2 mW was amplified to 300 mW by a dual-clad, ytterbium-doped fiber amplifier and then coupled through a 70/30 coupler into the laser cavity. The active fiber functioned as the Brillouin gain medium. An SBS Stokes wave was generated in the active fiber and circulated in the ring cavity. An isolator with an insertion loss of 1.5 dB at 1080 nm prevented the laser from injection locking to the Brillouin pump. The 70/30 coupler coupled the Brillouin pump into the cavity and the laser light out of it through the

30% port, while 70% of the laser light remained in the cavity.

In this configuration, the required Brillouin seed power for a 1 W single-frequency output power was 300 mW. When the Brillouin seed was below this value, the laser was partially injection locked to the Stokes wavelength and operated in the multiple-frequency regime. When the Brillouin seed was above 300 mW, the single-frequency laser output was collected using another coupler with a coupling efficiency of 4% and back calculated to achieve the output power. Figure 2 shows the output power as a function of the pump power when the Brillouin seed was 300 mW. The laser pump threshold was 1.2 W, and the output power reached 1 W at a pump power of 10 W. The Brillouin seed wavelength was 1080.20 nm, while the laser output power was 1080.26 nm. The frequency difference between the Brillouin seed and the laser output matched the Brillouin Stokes shift at the operating wavelength. The OSNR was measured with an optical spectrum analyzer (OSA) set to 0.1 nm resolution. As shown in Fig. 3, the laser OSNR of the laser operating at 1 W was greater than 55 dB, while the OSNR of the 300 mW Brillouin seed had an OSNR of about 35 dB. This demonstrates that the OSNR of the hybrid single-frequency fiber laser can be 20 dB better than the seed source owing to the intensity and phase-noise reduction of the SBS process [8,9]. The noise of the Brillouin seed comes from the noise of the semicon-

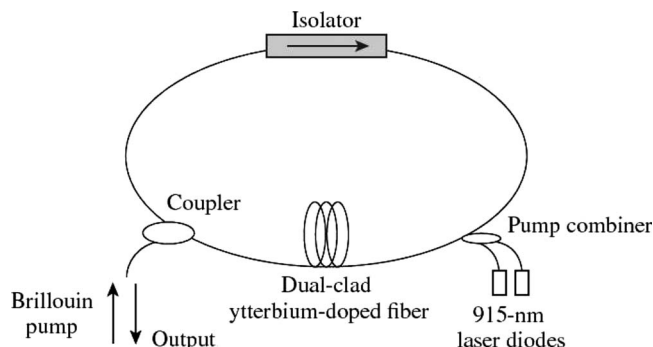


Fig. 1. Schematic diagram of the single-frequency hybrid Brillouin/ytterbium fiber laser.

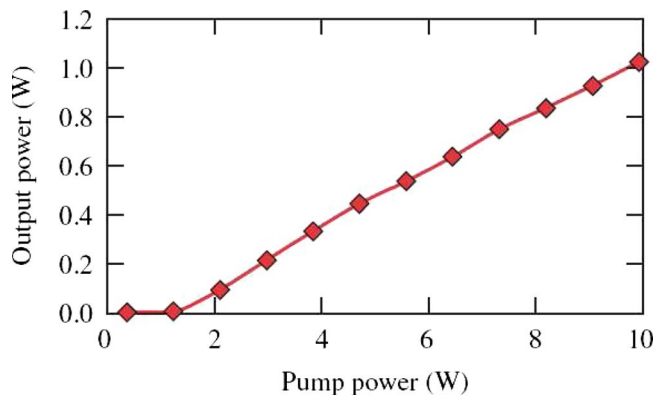


Fig. 2. (Color online) Single-frequency output power as a function of the pump power with a 300 mW Brillouin seed.

ductor laser and the ASE in the fiber amplifier. Therefore a low-noise, high-power fiber laser can be achieved in this single-frequency hybrid Brillouin/ytterbium laser structure.

The single-frequency output was verified with a scanning Fabry–Perot (FP) spectrometer. The 15 cm cavity length corresponded to a free spectral range of 1 GHz. With a finesse of 150, this FP spectrometer gave a resolution of about 6.7 MHz. Compared to the cavity mode spacing of 14 MHz for the 15 m laser ring cavity, the cavity modes of the fiber laser can be resolved. The single-frequency operation is shown in Fig. 4. Although two cavity modes can in principle coexist in the 20 MHz SBS gain bandwidth, the SBS gain profile provides enough discrimination to make the laser operate in the single-frequency regime. Because of the relatively short length of the laser cavity, no mode hopping was observed at any pumping levels in the measurement.

Higher-power single-frequency output can be attained using higher pump power. The NA mismatch

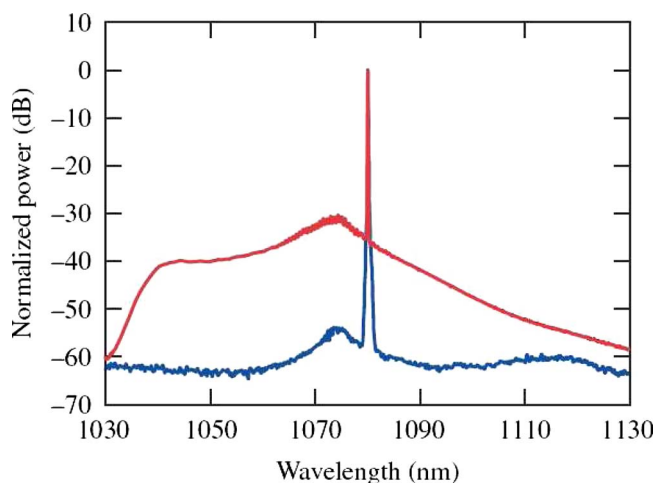


Fig. 3. (Color online) Normalized OSA spectrum of the Brillouin seed and laser output with an output power of 1 W. The black curve is the Brillouin seed; the gray curve is the laser output. The OSA resolution was 0.1 nm.

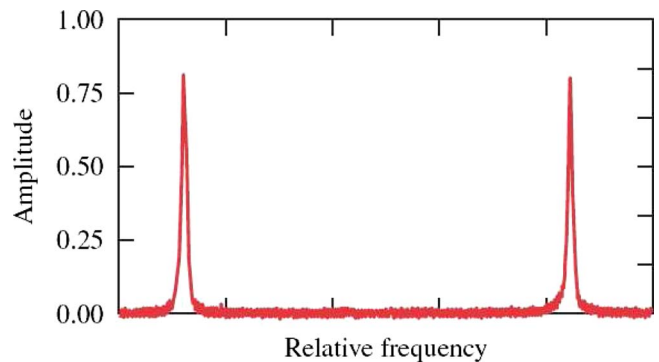


Fig. 4. (Color online) Laser output spectrum on the scanning FP spectrometer with an output power of 1 W. The spectrum was measured with a coupler.

between the fused, tapered pump combiner and the dual-clad fiber generates heat and can burn the fiber interface. This can be eliminated by proper engineering of the pump combiner and dual-clad fiber. Ultimately, the power-scaling limit of this architecture is defined by higher-order SBS [4] and the power-handling capacity of the intracavity isolator.

In conclusion, a high-power hybrid Brillouin/ytterbium fiber laser has been demonstrated with an output power of 1 W. The laser operates in the single-frequency regime with an OSNR greater than 55 dB in a 0.1 nm bandwidth.

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