Power scaling of single-frequency fiber amplifiers at 976 nm

Jingwei Wu[1], Xiushan Zhu[1*], Valery Temyanko[2], L. LaComb[2], R. A. Norwood[1], and N. Peyghambarian[1]

[1]*College of Optical Sciences, University of Arizona, Tucson, Arizona, USA 85721, *xszhu@email.arizona.edu,*

[2]*TIPD LLC, 1430 N. 6th Ave., Tucson, AZ 85705*

Abstract: Cladding pumped single-frequency Yb^{3+}-doped fiber amplifiers at 976 nm were investigated. Over 4 W output power was obtained and further power scaling can be achieved by reducing the cladding diameter of the Yb^{3+}-doped fiber.

OCIS codes: 060.2320 (Fiber optics amplifiers and oscillators).

1. Introduction

High power single-frequency lasers below 1 μm are excellent pumps for second and fourth harmonic generation in the blue and deep ultra-violet, which have found extensive applications in Raman spectroscopy, industrial micro-machining, laser cooling and trapping, laser inspection, optical data storage, submarine imaging, full color displays, metrology, biomedical applications, and laser lithography. Single frequency ytterbium (Yb^{3+})-doped fiber lasers and amplifiers below 1 μm, namely the three-level Yb^{3+} fiber lasers and amplifiers, have attracted significant interest due to the advantages of narrow linewidth, excellent beam quality, high wavelength stability, ultralow relative intensity noise (RIN), and super power scalability. We have previously demonstrated a single-frequency distributed Bragg reflector (DBR) fiber laser and a core-pumped fiber amplifier at 976 nm based on highly Yb^{3+}-doped phosphate fibers [1, 2]. In this paper, we report our investigation on further power scaling of 976 nm single-frequency laser by using cladding-pumped Yb^{3+}-doped fiber amplifiers.

2. Experimental setup

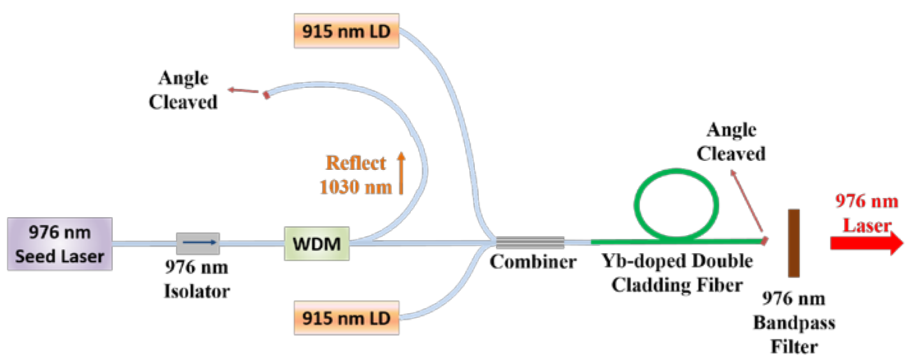

Fig. 1. Experimental setup of a 976 nm Yb^{3+}-doped fiber amplifier.

The experimental setup of a 976nm Yb^{3+}-doped fiber amplifier is depicted in Figure 1. A 976 nm single frequency laser diode was used as the seed laser. A polarization maintaining (PM) isolator and a 976/1030 nm PM WDM were used to protect the seed laser by blocking the backward amplified spontaneous emission (ASE) and possible parasitic laser emission. The Yb^{3+}-doped double cladding fiber was pumped by two multimode laser diodes at 915 nm via a (2+1)×1 PM fiber combiner. The output end of the gain fiber was angle cleaved (~8°) to eliminate the influence of the Fresnel reflection. A bandpass filter at 976 nm was used to remove the residual pump. The laser spectrum was measured with an optical spectrum analyzer (Ando, AQ6317). The output powers were measured by a thermal power meter (Thorlabs, SC310C). Commercial Yb^{3+}-doped fibers with core diameters of 6, 10 and 20 μm were investigated.

3. Experimental results and Conclusion

The output powers of the 6-µm, 10-µm, and 20-µm core fiber amplifiers at their corresponding optimized lengths (52 cm, 58 cm, and 48 cm) were measured with an input signal power of 100 mW and are shown in Fig. 2. The slope efficiency of the three fiber amplifier are 20.14%, 14.96%, and 12.97%, respectively. The slope efficiency is much lower than that of a core-pumped Yb-doped phosphate fiber amplifier [2]. This is due to the lower pump power density with the cladding pumping configuration and the deleterious concentration quenching of Yb^{3+} in the silica fibers. The spectra of the 6 µm fiber amplifiers with different fiber lengths at the maximum pump power were measured and are shown in Fig. 3. Different from the opitcal spectrum of a Yb^{3+}-doped phosphate fiber amplifier, the Yb^{3+}-doped silica fiber amplifier exhibts ASE with a peak at 980 nm, indicating that the gain peak of Yb^{3+}-doped silica is longer than the 976 nm gain peak of Yb^{3+}-doped phosphate. The optical spectra also shows that the ASE at 980 nm and 1030 nm increases with the increased fiber lengths because the tranistion corresponding to the emission at long wavelength is graudally dominant as the fiber length increases. Because the three-level amplifier requires high pump power density to ensure over 50% population inversion, higher pump power and smaller cladding diameter are required to increase the brightness of the pump and consequently increase the efficiency of a 976 nm fiber amplifier. Figure 4 shows the simulation results of the 976 nm fiber amplifiers when the 58-cm 10-µm core Yb^{3+}-doped fiber has different cladding diameters. Clearly, the efficiency increases with the decreased cladding diameter and more than 45 W output power can be obtained at a pump power of 100 W when the cladding diameter of the fiber is 50 µm. A custom-designed Yb^{3+}-doped phosphate fiber is being fabricated and a cladding-pumped phosphate fiber amplifier will be investigated and reported at the conference.

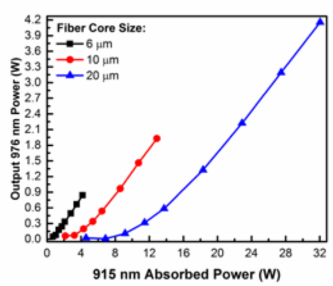

Fig. 2. Output powers of the 976 nm fiber amplifiers as a function of 915 nm absorbed power.

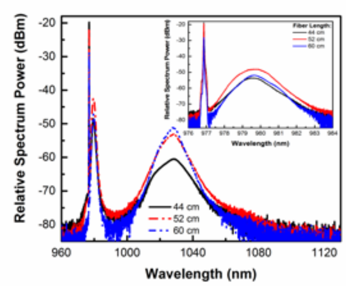

Fig. 3. Optical spectra of the 6 µm core fiber amplifiers with different fiber lengths (resolution: 0.1 nm). Inset: spectra of 0.01 nm resolution.

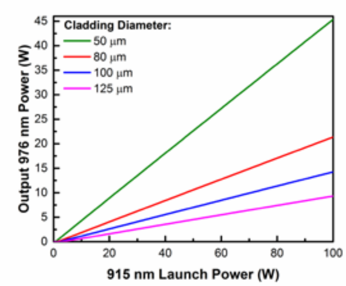

Fig. 4. Calculated output powers of the 976 nm fiber amplifiers as a function of the 915 nm launch power for fibers with different cladding diameters.

In conclusion, we have investigated cladding pumped fiber amplifiers at 976 nm using 6, 10, and 20 µm core Yb^{3+}-doped silica fibers. Our simulation results show that 50-watt-level single-frequency fiber amplifier with efficiency close to 50% can be achieved with fibers with smaller cladding diameters. Further power scaling of the 976 nm single-frequency fiber amplifier is currently under way by using higher pump power and custom-designed Yb^{3+}-doped phosphate fibers.

This work was supported by the NASA STTR Phase II Project “Ultra-stable and Compact Deep UV Laser Source for Raman Spectroscopy” and Technology Research Initiative Fund (TRIF) Photonics Initiative of University of Arizona.

References:

[1] X. Zhu et al., “976 nm single-frequency distributed Bragg reflector fiber laser,” Opt. Lett. 37, 4167-4169 (2012).

[2] X. Zhu et al., "976 nm single-polarization single frequency yetterbium-doped phosphate fiber amplifiers,” IEEE Photon. Technol. Lett. 25, 1365-1368 (2013).