

Cladding-pumped continuous-wave Raman fiber laser

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We report for the first time continuous-wave Raman lasing in a cladding-pumped fiber. The double-clad germanosilicate fiber was pumped by an Er/Yb co-doped fiber laser at 1545 nm. We obtained 3.4 W of output power at 1660 nm with a slope efficiency of 67%.

Cladding-pumped Raman fiber devices have been recently proposed [1] and demonstrated in the pulsed regime [2]. Here, we believe for the first time, a cladding-pumped continuous-wave (cw) Raman fiber laser is reported.

Our experimental set-up is shown in Fig. 1. Our pump source was an Er/Yb co-doped fiber (EYDF) laser which in turn was cladding-pumped by multi-mode laser diode at 975 nm. The EYDF had a 25 μm diameter, 0.22 NA core, and a 400 μm diameter D-shaped inner cladding, surrounded by a polymer outer cladding of a low refractive index. The EYDF laser output power was up to 26 W at 1545 nm. The output was free-space coupled into a 1.42 km long double-clad Raman fiber (DCRF) via a dichroic mirror. The DCRF had a pure silica outer cladding and a germanosilicate inner cladding (diameter 21.6 μm , NA 0.22) and core (diameter 9 μm , NA 0.14, estimated cutoff wavelength 1630 nm). The inner cladding and core propagation losses at 1545 nm were 2.3 dB/km and 3.1 dB/km, respectively. Both the EYDF and the DCRF were fabricated by us.

A cutback measurement showed that we could launch up to 55% of the EYDF laser's output power into the DCRF. Of the launched power, around 6.8% was in the core mode. This was evaluated by splicing a standard single-mode fiber to a short piece of DCRF. In the DCRF, the 1545 nm pump beam generated Raman gain with a peak at \sim 1658 nm. The Raman laser cavity was formed by a perpendicularly cleaved, 4% reflecting, facet at the pump launch end, and a fiber grating, written directly in the DCRF, in the other end of the fiber. The reflectivity of the grating was $> 99\%$ at 1660 nm with a bandwidth less than 0.2 nm.

Figure 2 shows the launched pump power (at 1545 nm) vs. Raman laser output power. The laser threshold was 7.1 W, the slope efficiency was 67%, and the maximum output power was 3.4 W at 1660 nm for a 27% power conversion of launched pump power. Assuming a 22 dB round-trip loss, the gain coefficient becomes 0.525×10^{-13} m/W, in fair agreement with theory.

Unlike in a traditional rare-earth doped double-clad fiber, gain occurs both in the inner cladding and the core in our DCRF. Therefore, core-mode lasing must be promoted over cladding-mode lasing. In our case, the fiber Bragg grating selects the core mode. While also the inner cladding is photosensitive, and a grating is likely to have been formed in it, this grating may have a small overlap with cladding-modes and therefore a low modal reflectivity. In addition, the higher Ge-content in the core leads to higher Raman gain there. In any case, any grating in the inner cladding would reflect shorter wavelengths than that in the core (by \sim 10 nm or more), but lasing did occur on the wavelength of the fiber Bragg grating in the core. Figure 3 shows the output spectrum of the cladding-pumped cw Raman fiber lasers at maximum output power. Though we did not measure output beam quality, the clean spectrum is a clear signature of single-mode operation and thus brightness-enhancement in our cladding-pumped fiber laser.

Additional results will be presented at the conference.

1. R. R. Rice, "Multimode Raman fiber amplifier and method", US patent no. 6,353,087 (2002)
2. J. Nilsson, J. K. Sahu, J. N. Jang, R. Selvas, D. C. Hanna, and A. B. Grudinin, "Cladding-pumped Raman amplifier", in Proc. Topical Meeting on Optical Amplifiers and Their Applications, post-deadline paper PDP2, Vancouver, Canada, Jul. 14 – 17, 2002

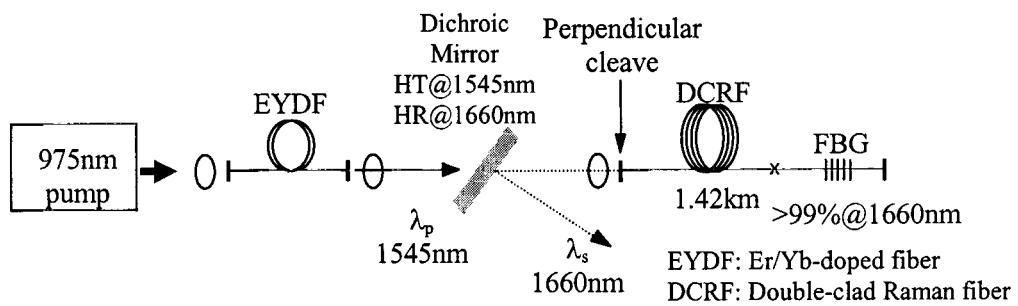


Fig. 1. Experimental set-up for cladding pumped Raman fiber laser.

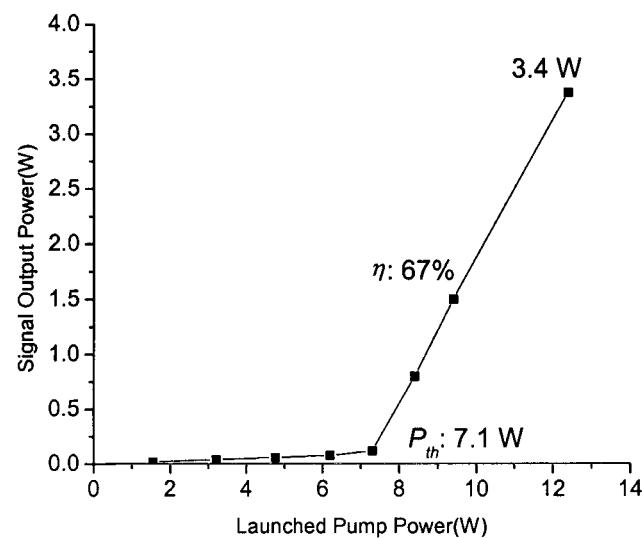


Fig. 2. Output power vs. launched pump power.

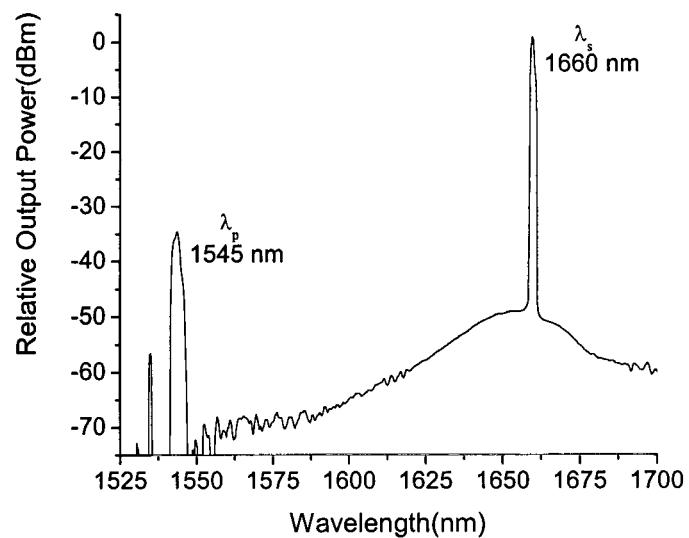


Fig. 3. Output spectrum of cladding-pumped CW Raman fiber laser at 3.4 W output power.