High power continuous-wave Yb-doped fiber laser with true single-mode output using W-type structure.

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Abstract : We demonstrate 314 W continuous-wave fiber laser output at 1077 nm from a true single-mode Yb-doped fiber core without any sign of stimulated-Raman-Scattering. The suppression of stimulated-Raman-Scattering was obtained by using a W-type waveguide filtering structure.

OCIS codes : (140.3510) Lasers, fiber, (140.3570) Lasers, single-mode, (060.2280) Fiber design and fabrication, (060.2320) Fiber optics amplifiers and oscillators

1. Introduction

High power, high brightness Yb-doped fiber sources at around 1.1µm are of interest for various applications such as micro-machining, welding and material processing, and their output power has grown considerably in recent years [1, 2]. However, power scaling with a true single mode output beam quality, which requires a small core fiber, still remains a technological challenge, in the first instance because of the nonlinear scattering in the fiber. In particular, stimulated Raman scattering (SRS) is the main constraint on increasing the output power of a fiber based system [3]. In order to mitigate SRS in the fiber, a larger core and a short fiber length are two of the obvious choices that work by reducing the optical power density in the doped-core and the interaction length of the optical field along the fiber. The increased core size, however, leads to a multimode core and thus a significant degradation of the output beam quality. A single mode output can still be obtained using a large core fiber with filtering of higher order mode, e.g., with a fiber taper [4] or through bending the fiber [5]. However, this approach complicates the fiber laser and remains largely unproven in real-world applications. A true single mode core remains an ideal solution in terms of the output beam quality. Recently, a number of groups have demonstrated the SRS suppression in a rare-earth doped single mode core by introducing a wavelength-dependent bend loss in the fiber [6]. However, SRS suppression obtained just by bending a normal step index fiber will introduce a significant amount of loss at the signal wavelength too because of the relatively slow dependence of the bend loss on the wavelength in such fiber.

In this paper, we present 314 W of output power from a truly single mode Yb-doped core at 1077 nm without any SRS. The SRS in the fiber was suppressed by using a W-type fiber design [7] with fundamental, LP_{01}, mode cut-off located between the signal and the 1st order Raman Stokes wavelength, so that the fiber filters out the Stokes signal efficiently without introducing any additional loss at the signal wavelength.

2. Experiment and results

The laser configuration is shown in figure 1. The Yb-doped W-type fiber was cladding pumped by a 972 nm diode stack source through a combination of collimating lenses. The maximum pump power launched into the fiber was 472 W. A simple laser cavity was formed between perpendicularly polished end facets of the fiber, providing 4% Fresnel reflection, and a lens coupled 100% dichroic mirror with a high broadband reflection from 1030 to 1150nm.

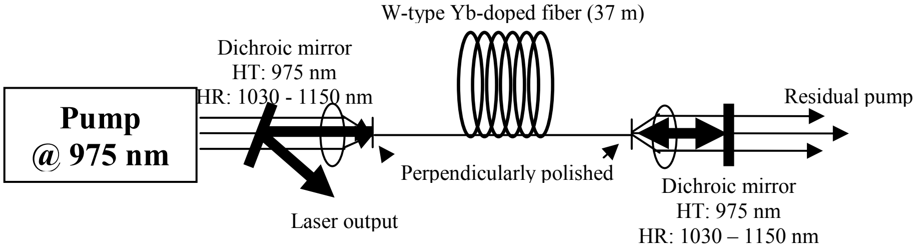

Figure 1. Experimental setup. HR: high reflectivity, HT: high transmission.

The Yb-doped W-type fiber preform was fabricated in house using a standard MCVD and solution doping technique. The preform was further jacketed in order to increase the inner cladding size, for efficient pump coupling into the fiber from the diode stack, whilst maintaining the single mode core size in the fiber. Before being drawn into the fiber, the preform was milled to a D-shape in order to maintain a uniform pump absorption along the fiber. The preform was then drawn to a fiber of 370 µm inner-cladding diameter and coated with a low-index polymer outer cladding, which provide a nominal inner-cladding NA of 0.5. The inner cladding size was chosen for efficient pump coupling from the diode stack. The fiber has a core diameter of 7 µm, with a depressed ring in the inner cladding of thickness 7µm. The core and the depressed cladding index differences are 0.003 and 0.002, respectively, both with respect to the silica inner cladding. The small signal absorption at the pump wavelength was ~0.3dB/m. The fundamental LP_{01} mode cut-off in the fiber is calculated to be ~1100 nm. Thus a significant loss at the 1st order Raman Stokes band at around 1120 nm can be expected.

Figure 2 shows the laser output characteristics. The output power reached 314 W with a slope efficiency of 65% with respect to the absorbed pump power at 1077 nm. Based on the Raman threshold calculation using the equation from ref [8], the Raman oscillation threshold of a fiber with such a core size is around 140 W. However, the W-type fiber we use has the fundamental LP_{01} mode cut-off at ~1100 nm, and can introduce a large loss (leakage), ~5dB/m, for light generated in the core at the 1st order Stokes wavelength. The effective area at around 1120 nm is calculated and found to be 45 times larger than the similar core size of a normal step index fiber. Therefore, W-type fiber has the potential to increase the Raman threshold to several hundreds of kilowatts. In our experiment, even though the output power we achieved is high enough to generate SRS in a similar step index core fiber, the suppression of SRS is possible because of the LP_{01} mode cut-off. The relatively low slope efficiency is due to background loss caused by the long length of the fiber. When a 23 m long fiber was used, the slope efficiency was 74% with respect to the absorbed pump power and we obtained over 300 W of output power at 1077 nm (inset in figure 2).

The laser wavelength can be tuned to the shorter wavelength region by bending the fiber as shown in figure 3. When the bending radius was changed from 15 cm to 7 cm, the slope efficiency was 73.7% with respect to the absorbed pump power with the central lasing wavelength of 1058 nm (inset in figure 2).

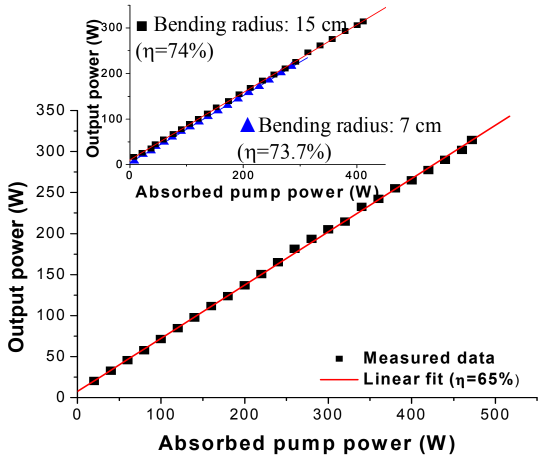

Figure 2. Laser output characteristics of Yb-doped W-type fiber laser, 37 m long fiber. Inset: 23 m long fiber with bending radius 15 cm and 7 cm.

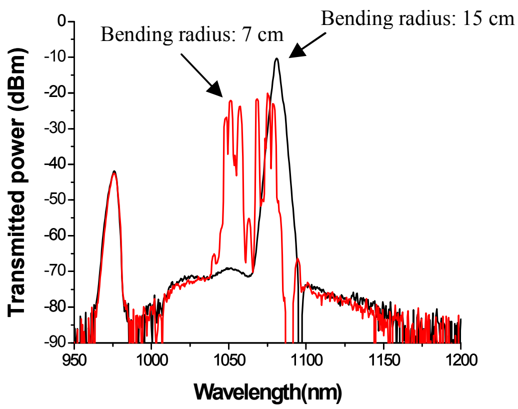

Figure 3. Optical spectra of Yb-doped W-type fiber laser when fiber bending radius is 15 cm and 7 cm at maximum output. (resolution 2 nm, fiber length : 23m)

3. Conclusion

We demonstrated for the first time a true single mode, small-core, Yb-doped fiber laser that generated 314 W output power with 65% slope efficiency with respect to the absorbed pump power. The output power was only limited by the pump power. The SRS in the fiber was suppressed efficiently by properly designing a W-type waveguide structure. This result shows promising prospects to scale up the output power in a single mode core fiber to multi kW level.

4. References

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