Ytterbium Doped Nano-crystalline Optical Fiber for Reduced Photodarkening

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Abstract: We report suppression of photodarkening in Yb-doped nano-crystalline fibers in silica host. The photodarkening induced loss reduced by 20 times compared to Yb-doped aluminosilicate fibers. The laser efficiency of the nano-crystalline fiber was 79%.

OCIS codes: (160.2290) Fiber materials; (060.2320) Fiber optics amplifiers and oscillators

1. Introduction

Ytterbium-doped silica fiber lasers has been a front runner in the race for higher powers due to its excellent conversion efficiency. However, pump induced photodarkening in Yb-doped fibers has been recognized as a bottleneck for power scaling in many applications. The photodarkening process is host material dependent. The induced loss is much more pronounced when the Yb^{3+} ions are incorporated in aluminosilicate host than in phosphosilicate host [1,2]. Thus, the photodarkening appears to be suppressed by modifying the host composition.

Here, we investigate Yb doped Y_2O_3 (or $Y_3Al_6O_{12}$) nano-crystalline in a silica rich matrix for reduced photodarkening. Y_2O_3 is an attractive material for laser applications and efficient Yb^{3+}:Y_2O_3 ceramic lasers have been reported in [3,4]. It is expected that Y_2O_3 nanoparticles will provide different surroundings for the Yb^{3+} ions which helps to reduce the photodarkening even in high Yb^{3+} concentration.

2. Experiments and results

The Yb-doped Y_2O_3 (or $Y_3Al_6O_{12}$) nanoparticles were attained from SiO_2-Al_2O_3-P_2O_5-Li_2O-BaO core glass of an optical fiber preform through a standard MCVD-solution doping technique. The presence of crystalline nanoparticles in a heat treated preform were confirmed under transmission electron microscope (TEM) measurement [5]. The D-shaped fibers were pulled in double clad structure from the preforms and high power operation was demonstrated with good lasing efficiency [5]. Figure 1 represents refractive index profile of the nano-crystalline fibers with cross-sectional view in the inset. The core diameter was 18 µm with 0.136 of core NA. The background loss was ~ 70 dB/km at 1285 nm measured by high resolution OTDR. The Yb concentration was ~6000 ppm wt%.

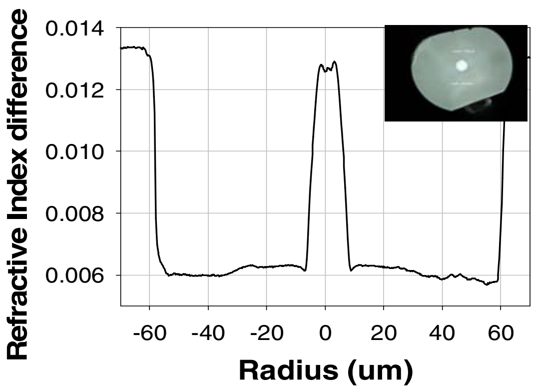

Fig. 1. Refractive index profile of Yb^{3+}-doped nano-crystalline fiber. Inset: cross-sectional view of the fiber

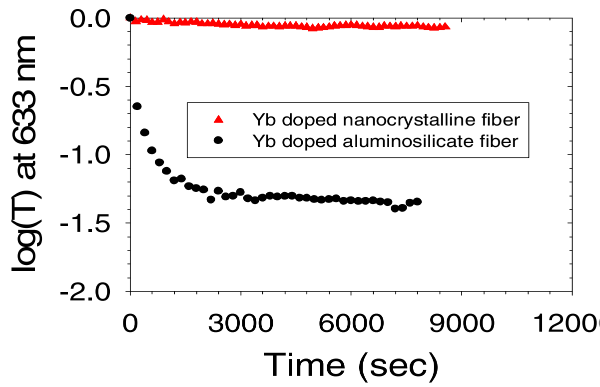

Fig. 2. Temporal characteristics of transmitted power at 633 nm for Yb-doped nano-crystalline fiber and aluminosilicate fiber

The photodarkening of the Yb-doped nano-crystalline fibers was evaluated by monitoring the transmitted output power through the fiber under 965 nm irradiation. We used fiber-coupled single mode laser diode as a pump source. The output end of the pump fiber was spliced to the fiber under test. A He-Ne laser at 633 nm was used as a

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probe beam which coupled to the nano-crystalline fiber and propagated the same direction as the pump beam. The probe beam was chopped and the output was detected by photodiode and lock-in amplifier. We used 1 cm of the fibers to suppress the amplified spontaneous emission. We measured photodarkening induced loss of a Yb-doped aluminosilicate fiber fabricated in-house for comparison. The pump input power was maintained to provide ~35% of population inversion of Yb^{3+}. The temporal characteristics of the transmitted probe power are represented in Fig. 2. The photodarkening induced loss is significantly reduced in Yb-doped nano-crystalline fiber. When we fitted the measured results with stretched exponential form, we found that the saturated induced loss in Yb-doped nano-crystalline fiber reduced by 10-20 times compared to the aluminosilicate counterpart, depending on the host material compositions.

The laser efficiency of the fiber was tested under 976 nm end pumping configuration. A linear 4%- 4% reflecting cavity was formed by perpendicularly cleaved end facets. A dichroic mirror at the pump throughput end separated the pump and signal wavelength. The laser performance is shown in Fig. 3(a). The slope efficiency was 79% with respect to the launched pump power. Figure 3(b) shows the laser spectrum which is quite broad covering from 1036-1072 nm. The measurement resolution was 1 nm.

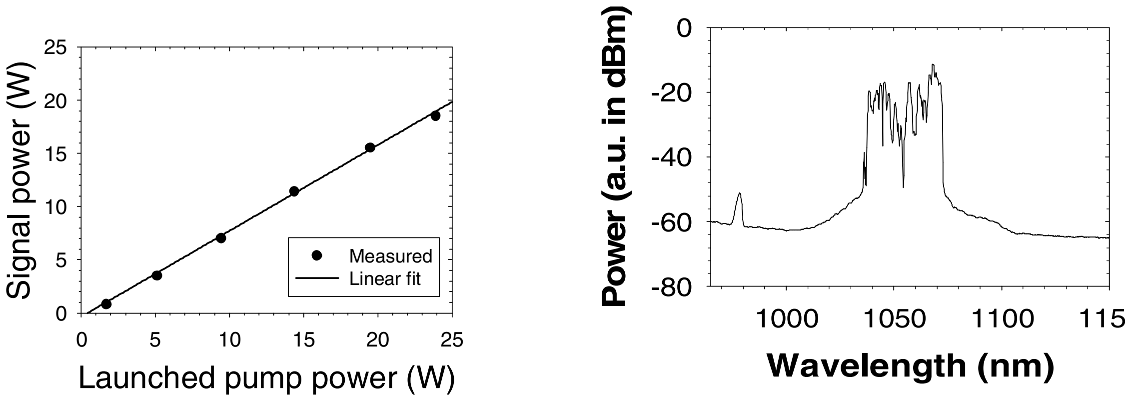

Fig. 3. Laser performance of Yb-doped nano-crystalline fiber (a) and laser operating wavelength (b)

3. Conclusion

In conclusion, we reported Yb-doped Y_2O_3 nano-crystalline fibers fabricated by a conventional MCVD-solution doping technique. The fiber exhibited low photodarkening induced loss compared to the Yb-doped aluminosilicate fiber, with good laser efficiency. This class of fibers will keep the advantage of the mechanical properties of silica glass, whereas the surrounding of RE ions can be engineered by varying the nanoparticle compositions.

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