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Recent Progress on 2-Micron Fiber Lasers

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Abstract: Highly Tm-doped silicate glasses and fibers were developed, which exhibit a high slope efficiency of 68.3% and a gain per unit length of greater than 2dB/cm. Single frequency fiber lasers with laser linewidth less than 3kHz, Q-switched single frequency fiber lasers, and mode-locked fiber lasers near 2 micron wavelength were demonstrated using this newly developed fiber.

Thulium-doped fiber laser near 2 μm is of great interest because it combines high efficiency, high output power and retina safety together, which has a variety of applications including materials processing, remote sensing, biomedical, as well as homeland security applications. Thulium exhibits a unique feature that the slope efficiency can exceed the Stokes limit [1]. Quantum efficiency near 2 can be achieved for thulium ions' $^3F_4 \rightarrow {}^3H_6$ transition (near 2 μm) because of the so-called cross-relaxation energy transfer between thulium ions. During the cross-relaxation energy transfer process, two ground-level thulium ions can be excited to the upper lasing level of the $^3F_4 \rightarrow {}^3H_6$ transition by absorbing only one pump photon near 800 nm, which means one excited Tm^{3+} ion at the $^3H_4$ level generates two Tm^{3+} ions at the $^3F_4$ upper laser level. Near 1kW output power was demonstrated in Tm-doped silica fiber with slope efficiency of 53.2% [2]. Tm-doped germanate glasses and fibers were developed in order to take advantage of the high doping concentrations, and a slope efficiency of 68% was achieved [3,4].

In this presentation, we mainly focus on a new glass fiber, i.e., highly Tm-doped silicate glass fiber. The new glass host was fabricated in-house by mixing and melting chemical compounds together to form the multi-component glass, instead of CVD process for doped silica fibers. Due to the less defined glass network, the multi-component glass permits high doping concentration of rare earth ions (Tm^{3+}) which in turn enables high pump absorption over a relatively short active fiber length and allows for taking advantage of "2 for 1" cross-relaxation process in heavily doped Tm^{3+} system. The main glass network former in our glass host is SiO_2, the same material as standard silica glass fiber. Therefore, this fiber provides much stronger mechanical strength and better compatibility with silica fiber than germanate glass fiber, yielding more robust fusion splicing between the active fiber and standard passive silica fiber needed for fiber Bragg gratings (FBGs).

Tm-doped silicate glasses, undoped cladding glasses, and fiber preforms were designed and fabricated in house. The Tm^{3+}-doping concentrations varies from 4wt% to 7wt%. Rod-in-tube technique was used to fabricate single-mode double glass-cladding fibers. Fiber drawing was carried out on our in-house fiber drawing tower, which is optimized for gain fiber fabrication. Fibers with a variety of configurations were fabricated for laser efficiency characterization and for demonstrations of single frequency 2 micron fiber laser, Q-switched 2 micron fiber laser, and mode-locked fiber laser.

Figure 1 illustrates the laser output power vs. the absorbed pump power of the fiber with core diameter of 18 μm, core NA of 0.07, inner cladding diameter of 125 μm, inner cladding NA of 0.58, and outer cladding diameter of 160 μm pumped with 798nm diode laser. The Tm-doped fiber is 20-cm long. Dielectric coating at the end of the pump delivery fiber was used as the high reflector. Fresnel reflection at the end of the Tm-doped silicate glass fiber (~4%) was used as the output coupler. A high slope efficiency of 68.3% was achieved.

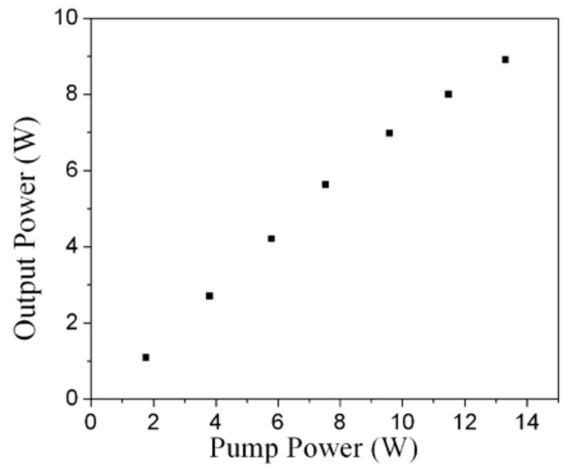

Figure 1. The laser output power vs. the absorbed pump power of the 20cm long Tm-doped silicate fiber

A fiber with core diameter of 10μm, core NA of 0.136, inner cladding diameter of 125 μm, outer cladding diameter of 160 μm, and inner cladding NA of 0.58 was used for ASE spectrum characterization, single frequency fiber laser demonstration and mode-locked fiber laser demonstration. The ASE output exhibits FWHM bandwidth of ~92nm and average power of 80mW with 5-meters long fiber. By using the identical experimental setup the ASE output from Tm-doped silica fiber has FWHM bandwidth of ~45nm, which is less than half of Tm-doped silicate fiber.

Efficient single-frequency laser operation has been demonstrated in a short-cavity (a few cm long) DBR fiber laser in both cladding- and core-pump configurations. The gain per unit length of this fiber is greater than 2 dB/cm, and a piece of 2-cm long fiber was used for single frequency fiber laser. Less than 3-kHz linewidth has been demonstrated in a core-pumped Tm-doped DBR fiber laser, which is, to the best of our knowledge, the narrowest linewidth demonstrated to date from 2-μm single-frequency fiber lasers [5].

All-fiber single-frequency Q-switched laser operating in the 2μm region has been demonstrated based on polarization modulation of a short-cavity fiber laser by using stress-induced birefringence [6] . The Q-switched laser can be operated in a wide range of repetition rate ranging from 10s Hz to >100kHz with several milli-watt average output power [7]. Power of the narrow-linewidth Q-switched laser pulses can be readily boosted by using multi-stage Tm-doped fiber amplifiers.

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Self-starting passively mode-locked fiber lasers with a saturable absorber mirror was also demonstrated by using a piece of 30-cm long newly developed highly Tm-doped silicate glass fibers. The mode-locked pulses operate at 1980 nm with duration of 1.5 ps and energy of 0.76 nJ [8].

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