L.2: Generation of 100 W of output power from Tm-doped CW fiber laser

Thulium-doped fiber lasers (TDFL) provide emission in the wavelength region of 1850-2100 nm, and are known as 'eye-safe' due to high absorption of this wavelength region in water, which prevents damage of retina. Further, due to water absorption peak at 1940 nm, laser generation at this wavelength is particularly important since water being main constituent of biological tissues, strong absorption and substantial heating of small areas of biological tissues can be easily achieved. Since very precise cutting of biological tissues can be achieved and bleeding during the process of laser cutting is also suppressed by coagulation, lasers at 1940 nm become ideal source for surgical procedures. Fiber lasers at 1940 nm also find application in lithotripsy, urology, gas sensing, and plastic welding for medical devices. Tm-doped fibers can be easily pumped using readily available 793 nm laser diodes, but due to higher quantum defect, theoretical limit for efficiency is ~41%. However, due to cross-relaxation process, two excited Tm-ions can be obtained for one pump photon and much higher efficiencies as compared to theoretical value can be achieved. Higher power generation from Tm-doped fibers can be achieved either by using oscillator configuration or by means of master oscillator power amplifier (MOPA) configuration. In this direction, generation of more than 100 W of CW output power at 1940 nm from an all-fiber oscillator configuration has been carried out with an optical-to-optical conversion efficiency of 45%.

Figure L.2.1 shows a schematic of all-fiber TDFL for the generation of more than 100 W of output power at 1940 nm. The laser resonator consists of commercially available large mode area Tm-doped fiber (TDF) with core and cladding diameter of 25/400 μm and corresponding numerical apertures of 0.10/0.46. The pump signal absorption at 793 nm is 2 dB/m. Six number of fiber pig-tailed diode lasers at 793 nm with fiber core/clad diameter of 105/125 μm and NA of 0.22 were used and output from all the six diodes was combined using a multimode pump combiner (MPC), which has six pump input ports, one input signal port and one output port. The signal port has core and clad diameter of 10/125 μm and the output port of the MPC is compatible with active fiber and has core and clad diameter of 25/400 μm. Two fiber Bragg grating mirrors (FBG), one with 99.8% reflectivity and full width at half-maximum (FWHM) linewidth of 3 nm and the other with 10% reflectivity and FWHM linewidth of 1 nm at the center wavelength of 1940 nm has been used to form the linear cavity with the Tm-doped gain fiber. The output port of the MPC is spliced with the highly reflecting fiber Bragg grating mirror (HR-FBG) and the output end of the HR FBG is spliced with the TDF, which in turn is spliced with the 10% reflectivity FBG mirror. An end cap is spliced at its output end, which reduces the power density at the exit fiber end and hence prevents damage of the fiber ends at the higher output power. Due to higher quantum defect, efficient removal of heat from gain fiber is required. For this purpose, a water cooled heat sink with circular grooves has been developed to remove heat load from Tm-doped fiber.

Initially, 8 m length of Tm-doped fiber was selected to have efficient pump absorption of 16 dB (97.5%), but repetitive damage of the gain fiber was observed. Since TDF was pumped using continuous wave (CW) diodes, a CW output signal was expected, but unexpectedly output contained irregular self-pulses. These self-pulses of nanosecond duration raise the peak power density to reach the bulk damage threshold of silica fibers and in the presence of these self-pulses catastrophic damage of doped-fiber was observed repeatedly. Signal was also generated at ~2000 nm rather than 1940 nm in spite of the fact that the FBGs used in the cavity were at 1940 nm. This was due to higher signal absorption at 1940 nm and lower gain at 1940 nm as compared to that at 2000 nm. Similar phenomenon was also observed when 6 m length of TDF was selected.

With 4 m length of TDF providing pump absorption of ~8 dB (84%), no self-pulsing was observed and CW lasing at the expected wavelength of 1940 nm was also observed. The 4 m length of TDF was found to be optimum for lasing at 1940 nm. Thus, optimization of gain fiber length, efficient heat removal from Tm-doped fiber and suppression of self-pulsing are the major factors, which need to be carefully addressed for generation of high power output from Tm-doped fiber lasers at 1940 nm. Figure L.2.2 shows table-top view of 100 W Tm-doped CW fiber laser. Now, developoment of an engineered version of this laser will be carried out for different applications.

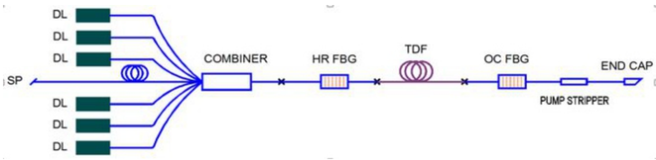

Fig. L.2.1: Schematic of 100 W Tm-doped CW fiber laser oscillator.

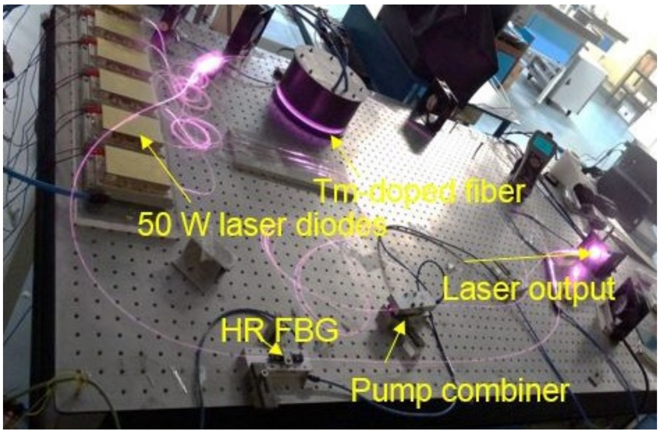

Fig. L.2.2: Table-top view of 100 W Tm-doped CW fiber laser at 1940 nm.

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