L.4: Development of all-fiber thulium-doped CW fiber laser

Thulium-doped fiber lasers (TDFLs) emitting near 2 μm eye-safe wavelength region have wide range of applications in material processing of metals, non-metals, medical surgery, procedures such as lithotripsy, defence, gas sensing, and space. Large absorption coefficient of ~100 cm^{-1} of water near 2 μm, reduces the penetration depth in tissue to a few hundred microns. Thus, this wavelength is highly suited for medical surgery. Due to versatile applications of these lasers, RRCAT has initiated work on development of high power narrow linewidth TDFLs and generated ~18 W of CW output power at 1940 nm with spectral width of ~ 0.2 nm, using commercially available off-the-shelf thulium-doped fiber (TDF) as the gain medium. These power levels are suitable to weld clear plastics as well as for surgery.

Fig. L.4.1 shows a schematic of TDFL set-up. The laser system design is based on all-fibre architecture that provides high stability and ruggedness. A contra-directional pumping configuration was employed in our laser system. In this configuration, the output signal was coupled out from input signal port of pump and signal combiner (PSC) and hence no special means are required for separation of unabsorbed pump power from the output signal, as the isolation between pump and signal ports of PSC is sufficient for high degree of suppression of pump power. The fiber coupled pump laser diode module having a 100 μm multimode fiber pig-tail provides a maximum pump power of ~60 W with an emission wavelength of 793 nm. Fiber pigtail of pump diode has been spliced with input pump port of compatible PSC. The output port of PSC has been spliced with TDF of ~ 2 m length, which has a double-clad structure with core, inner clad, and outer clad diameters of 12 μm, 130 μm, and 250 μm, respectively. Numerical apertures of the core and inner cladding are 0.14 and 0.46, respectively. Pump light from PSC is coupled through 130 μm inner cladding of TDF and is guided in the inner clad by means of low refractive index of flouroacrylic coating, which acts as outer clad of the doped fiber. As the pump light propagates along the length of the Tm-doped fiber, it is absorbed in the core region. The laser resonator is constructed by splicing two fiber Bragg grating mirrors (FBGs), one of them having high reflectivity with R>99.9% at 1940 nm spliced to the free-end of TDF, and another FBG acting as output coupler with R=10% at 1940 nm to signal port of PSC for laser output. The un-spliced ends of both the FBGs have been angle cleaved at 8^o to avoid interference from 4% Fresnel reflection from flat end faces of FBGs. Inner clad pump absorption of TDF at 793 nm is about 5 dB/m. Due to large pump absorption per unit length and large quantum defect of ~ 41%, an effective cooling of active fiber was necessary. For efficient heat removal, active fiber was wrapped around an aluminium mandrel, which has a thermal contact with a water cooled block. During this development, significant heating of passive-to-active fiber splice joint (PSC-TDF splice joint) was observed, which lead to the destruction of splice joint at higher operating power. Thus, in order to avoid damage of splice joint, adequate heat dissipation mechanism has been provided by mounting the splice joint on a water cooled block. This TDF is slightly multi-moded at 1940 nm having a V-number of ~2.7. Normally, it will provide two modes in the laser output, however, filtering of higher order LP11 mode is possible by coiling it on a smaller diameter aluminium mandrel for single transverse mode operation.

Using this laser set-up, a maximum output power of ~ 18.2 W has been achieved with an optical-to-optical conversion efficiency of ~ 43%. Fig. L.4.2 shows a table-top view of the developed TDFL. Output power increased linearly with increase in input power, which suggests scope for further scaling of output power. Laser output power is limited only by the power handling capacity of pump port of PSC, which is 50 W. An additional pump port of PSC could not be utilised due to non-availability of second pump diode. Further work is being planned to enhance CW output power and for pulsed operation of laser system.

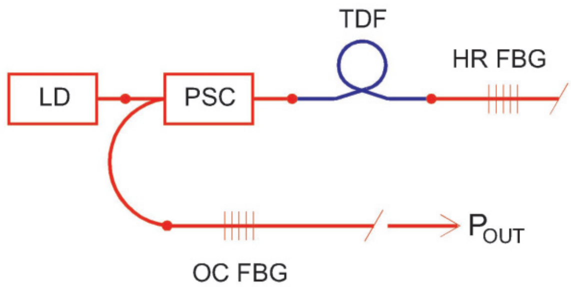

Fig. L.4.1: Schematic of TDFL set-up.

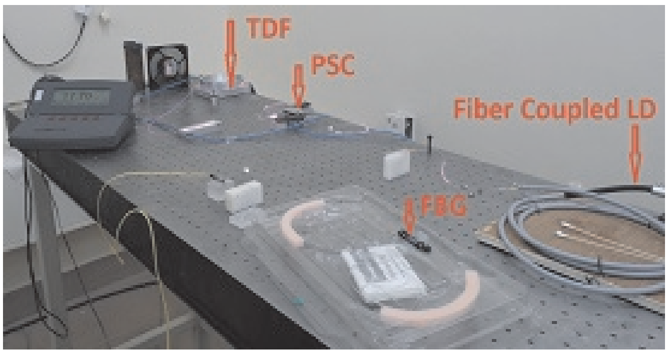

Fig. L.4.2: Table-top view of the Tm-doped fiber laser

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