L.1: Development of monolithic 1 kW single transverse mode Yb-doped CW fiber laser

Monolithic high power fiber lasers have been widely adopted as laser sources for industrial applications as well as for defence applications. They offer several advantages over other bulk solid state lasers such as high wall-plug efficiency, beam quality, compactness, robustness, no misalignment sensitivity and efficient heat dissipation due to large surface area to volume ratio along with all-fiber integration. Two major configurations dominate in high-power all-fiber laser systems, namely: (a) oscillator configuration, and (b) master oscillator power amplifier (MOPA) configuration, which amplifies seed signal from oscillator stage.There are several challenges faced in the development of kilowatt class all-fiber laser systems, which include availability of high power compatible fiber laser components like fiber coupled pump diodes, fiber optic pump & signal combiner and fiber Bragg gratings (FBG), minimization of splice loss and removal of hotspots in recoated splice joints. Further to this, efficient heat removal from thin polymer coated all-fiber components, gain fiber, suppression of self-pulsing, nonlinear effects, mitigation of transverse mode instability, phenomena like fiber fuse effect and photo darkening pose additional challenges. In this direction, development of a monolithic all-fiber single transverse mode Yb-doped CW fiber laser (YDFL) of 1 kW output power using single-end pumped oscillator configuration has been performed.

A schematic of monolithic 1 kW all-fiber Yb-doped CW fiber laser is shown in Figure L.1.1. In this all-fiber laser setup, a Yb-doped double-clad (DC) fiber has been used as the gain medium having core/inner clad/outer clad diameter of 20/400/550 µm and has a cladding absorption of 0.4 dB/m at 915 nm. Numerical apertures of the core & inner clad are 0.075 and 0.46, respectively. Yb-doped fiber section of 40 m length has been used for efficient absorption of the pump power providing a total pump absorption of 16 dB (~97%). Seven fiber-coupled laser diodes of 200 W output power at 915 nm wavelength have been used for pumping of Yb-doped double-clad fiber. All the seven fiber-coupled laser diodes are spliced with the pump input ports of a 7x1 fiber optic pump combiner providing a maximum combined pump power of 1370 W. The output end of fiber optic pump combiner has been fusion spliced with the input end of highly reflecting (HR ~99.5%) fiber Bragg grating (FBG) mirror at 1080 nm having FWHM linewidth of ~3 nm and the output end of FBG has been carefully spliced with the octagonal shaped Yb-doped DC gain fiber, which has been further spliced with low reflectivity (LR) output coupler (OC) FBG mirror having ~10% reflectivity at 1080 nm and has a 3 dB FWHM bandwidth of 1 nm. Laser resonator is formed between HR FBG mirror and OC FBG mirror. A cladding mode stripper (CPS) has been used to remove the residual unabsorbed pump power from the inner cladding to have a pure laser signal without any residual pump power.

The output end of CPS has been spliced with a 20 m long quartz block head (QBH) connectorized 20/400 µm fiber optic cable for remote material processing applications. All the components of the fiber laser have been carefully mounted on a single heat removal cooling block working as fiber laser engine. Splice joints are very critical and any irregularity in the splice joints, defect in splicing or re-coating degrades the quality of joints. It has been observed that when the temperature of the splice joint reaches above 80 °C, the joints get burnt. Thus, the temperature of all the splice joints have been kept below 50 °C for long term reliable operation.

Laser output power varies linearly as a function of input pump power, which shows that there is no saturation in the output power due to any thermal or nonlinear problems and indicates a possibility for further scaling of output power with an increase in input pump power. Pure laser signal power of 1014 W without any residual pump has been achieved at an input pump power of 1370 W with an optical-to-optical conversion efficiency of 74% and beam quality factor $M^2 \sim 1.25$. The laser output spectrum is peaked at 1080.25 nm with FWHM linewidth of ~ 1.5 nm at 1 kW of output power. Figure L.1.2 shows a view of in-house developed 1 kW single transverse mode all-fiber Yb-doped CW fiber laser. The development of an engineered version of 1 kW Yb-doped CW fiber laser is underway for material processing applications.

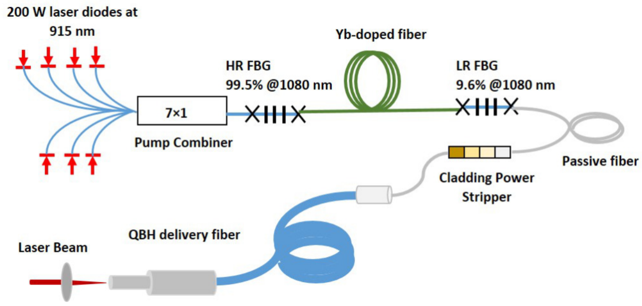

Fig. L.1.1: Schematic of monolithic 1 kW Yb-doped CW fiber laser.

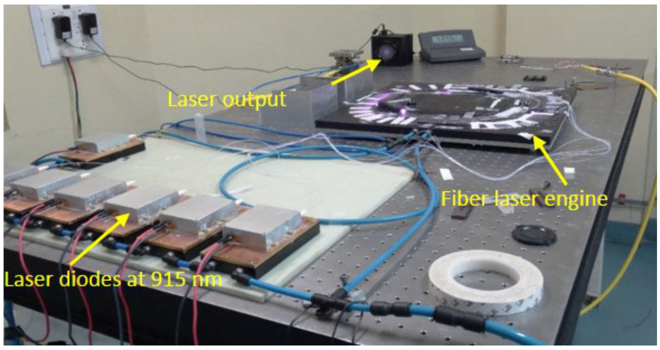

Fig. L.1.2: A view of 1 kW single transverse mode all-fiber Yb-doped CW fiber laser at 1080 nm.

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