Energy Transfer From Yb to Tm in Yb/Tm-doped Optical Fiber Amplifier

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We report the realization of the Yb/Tm co-doped silica glass optical fiber amplifier operating at 1470 nm upon 980 nm pumping. The energy transfer coefficient from Yb to Tm was estimated using the threshold condition of the optical amplifier.

The S-band (around 1470 nm) emission of the Tm-doped optical fibers has found applications in the field of optical communication as an amplifier operating at 1470 nm [1, 2]. Although the Tm-doped optical fiber has a good absorption at 1200 nm, efficient and economical laser sources are not available at this wavelength. Co-doping Tm with Yb can address the problem as the $^2F_{5/2}$ energy level of Yb approximately matches with the $^3H_5$ energy level of Tm and the low cost, high power and commercially available laser sources such as 980 nm laser diodes can be used as the pumping source. Though energy transfer from Yb to Tm has been reported for the bulk glass, no such reports are available for the energy transfer in optical fiber [3, 4].

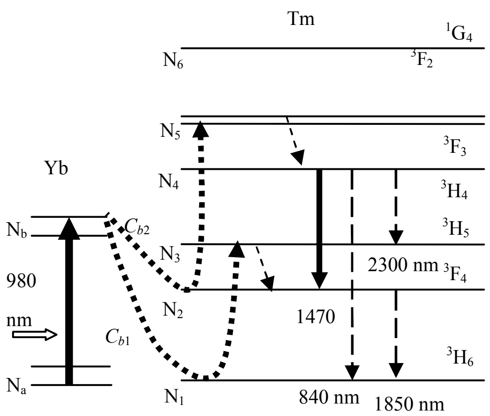

Fig. 1. The energy level diagram of Yb^{3+}/Tm^{3+} ions in Yb/Tm co-doped silica glass optical fiber.

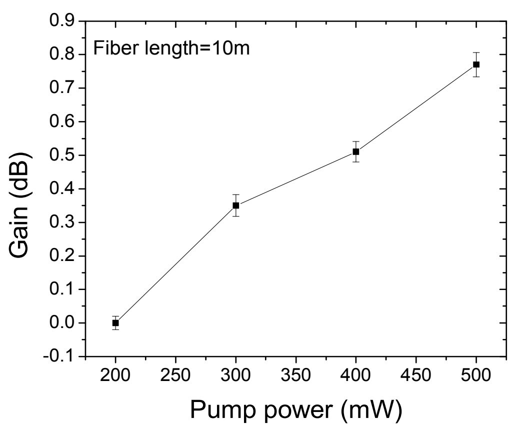

Fig. 2. Measured gain variation at 1470 nm with respect to launched pump power at 980 nm

The energy levels of Yb and Tm ions in the silica glass are shown in Fig. 1. Because of the fast transitions $N_3 \rightarrow N_2$ and $N_5 \rightarrow N_4$, Tm ions population densities at levels N_3 and N_5 are neglected which simplify the rate equations of 980 nm pumped system. The transition rate $1/t_{43}$ is also neglected due to 2% branching ratio from N_4 to N_3. The steady state rate equations considering the significant levels (Tm: N_1,N_2, N_4; Yb: N_a, N_b) are written as

$$0 = \frac{dN_b}{dt} = W_{abp} N_a - W_{bap} N_b - \frac{N_b}{\tau_{ba}} - C_{b1} N_b N_1 - C_{b2} N_b N_2 \quad (1)$$

$$0 = \frac{dN_1}{dt} = \frac{N_4}{\tau_4} + \frac{N_2}{\tau_2} - C_{b1} N_b N \quad (2)$$

$$0 = \frac{dN_4}{dt} = W_{24s} N_2 - W_{42s} N_4 - \frac{N_4}{t_{42}} - \frac{N_4}{\tau_4} + C_{b2} N_b N_2 \quad (3)$$

$$N_{Tm} = N_1 + N_2 + N_4 \,; \; N_{Yb} = N_a + N_b \quad (4)$$

where N_i is concentration of the rare earth ions in ions/m^3 at a level i, N_{Tm} and N_{Yb} are Tm and Yb ions concentrations, respectively, in the fiber core, $W_{lm(p,s)}$ is the probability of transition from level l to m at pump (p) or signal (s) wavelengths, C_{bj} is the energy transfer coefficient from the level b to j, the lifetimes τ_{ba} , τ_2 , τ_4 are for N_a, N_2 and N_4 levels, respectively, $1/t_{42}$ is the $N_4 \rightarrow N_2$ spontaneous emission transition rate in s^{-1} and t is the time. The threshold factor for the pump power to start amplification is defined as $(\sigma_{es} N_4 - \sigma_{as} N_2)/(\sigma_{es} N_4 + \sigma_{as} N_2)$, in which $\sigma_{e,a}$ is emission (e) or absorption (a) cross-section. If the threshold pump power for the Yb/Tm co-doped optical fiber to start the amplification is known, the values of unknown energy transfer coefficients can be estimated from (1) to (4).

The silica glass optical fiber preform was fabricated using the Modified Chemical Vapor Deposition (MCVD) process and it was doped with Yb^{3+} and Tm^{3+} ions using the modified solution doping technique developed earlier by our group. Fiber parameters: Core diameter=19 µm, Attenuation=1.8 dB/m @ 980 nm and =0.3 dB/m @1470 nm, Numerical Aperture=0.14, Rare earth concentrations: Yb=4$\times 10^{25}$ ions/m^3, Tm=2.3$\times 10^{25}$ ions/m^3. When the Yb/Tm co-doped silica glass fiber was pumped with the 980 nm LD, the dependence of gain at 1470 nm on the pump power is illustrated in Fig. 2 for the fiber length of 10 m. The threshold pump power for amplification at 1470 nm was obtained at about 200 mW. Using the experimentally determined threshold pump power value, the equations (1) to (4) were solved for the set of unknowns i.e., the energy transfer coefficients, C_{b1} and C_{b2}. The estimated values of C_{b1} and C_{b2} were 3.33$\times 10^{-25}$ m^3/s and 1.35$\times 10^{-21}$ m^3/s, respectively. A low value of C_{b1} is an indicative of the fact that Yb:$^2F_{5/2}$ to Tm:$^3H_5$ energy transfer is not significant while a high value of C_{b2} represents an efficient energy transfer from Yb:$^2F_{5/2}$ to Tm:$^3F_3$, which is because the energy difference $^2F_{5/2} \rightarrow {}^2F_{72}$ of Yb matches well with the energy difference $^3F_3 \rightarrow {}^3F_4$ of Tm.

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