Concentration optimization of Tb/Yb co-doped alumino-germano-silicate optical fiber for upconversion visible laser applications

Aoxiang Lin, Pramod R. Watekar, Xueming Liu, Hye Jin Cho, Youngjoo Chung, Won-Taek Han*

Department of Information and Communications, School of Photon Science and Technology,

Gwangju Institute of Science and Technology (GIST), Republic of Korea.

Tel: 062-970-2215, Fax: 062-970-2204, E-mail: wthan@gist.ac.kr

Abstract We report on the visible photoluminescence of the Tb/Yb co-doped alumino-germano-silicate fibers for visible fiber laser application. By changing the concentration ratios of Tb^{3+} to Yb^{3+}, we optimized the solution doping conditions and obtained the highest emission efficiency at 546nm. The luminescence intensity at 546nm was found to increase with the relative increase of Tb^{3+} ions.

1. Introduction

Upconversion lasers are among the most efficient sources of coherent visible and near-ultraviolet radiation, which can provide practical solutions for device applications such as medical diagnosis and treatment, bioscience gene sorting, underwater surveillance and communications, red-green-blue(RGB) all-solid displays, high-density data storage, high-resolution printing, and advanced scientific instrumentation [1,2]. Compared with frequency doubling schemes, upconversion lasers have a much broader pumping wavelength tolerance, excellent output spatial-mode quality, insensitivity to pump polarization and high efficiency [2]. Although impressive progress in the development of GaN-based short-wavelength semiconductor lasers has been made in the last few years, it is likely to take years before semiconductor lasers could become capable of producing diffraction-limited and continuous-wave output greater than 1W [3].

In this study, we fabricated a group of Tb^{3+}/Yb^{3+} co-doped fibers based on the energy transfer upconversion (ETU) mechanisms to develop fiber-type green laser gain media [3,4], which are relatively inexpensive, compact and easy to install, length-controllable, self-cooling at low-power level, and delivering a high quality beam compatible with the current silica-based optical communication systems. The optimum concentration to get the highest photoluminescence at 546nm was found to be 8:4 as to Tb:Yb ratio in volume.

2. Experiment and results

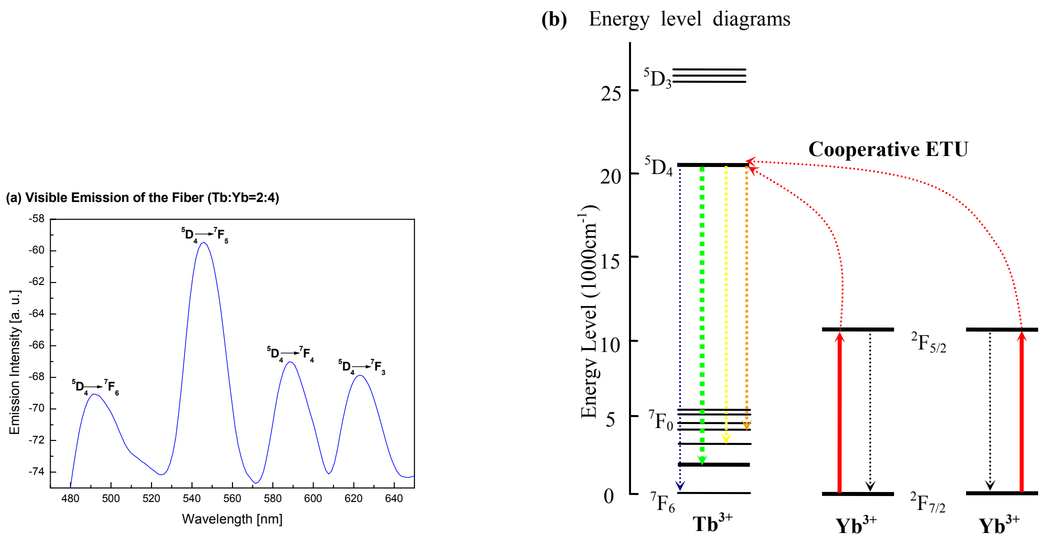

Fig.1.(a) Visible emission spectrum of the Tb^{3+}/Yb^{3+} codoped alumino-germano-silicate fiber (Tb:Yb=2:4) and the energy level transitions responsible for the corresponding fluorescence peaks; (b) Energy level diagrams of Yb^{3+} and Tb^{3+} ions to explain the two-photon assistant ETU processes [8].

Four Tb^{3+}/Yb^{3+} co-doped alumino-germano-silicate glass fibers with different dopant concentration level were fabricated in house using the modified chemical vapor deposition (MCVD) and solution doping techniques [5,6]. The concentration ratios in volume of Tb^{3+} to Yb^{3+} are as follows: 1:4, 2:4, 4:4, and 8:4. In order to prevent the possible concentration quenching and improve the uniformity of the dopants, aluminum was incorporated into the fiber core. The absorption spectrum of the fibers was measured by the optical spectrum analyzer (OSA, Ando AQ6315B). A commercially available laser diode (LD) at 976nm (M-Tech., MSMF-10) with maximum power of 400mW was used to measure the fluorescence of the fibers.

The four emission peaks appeared at 490, 546, 589 and 623nm in Fig. 1(a) [7,8], which were due to $^5D_4 \rightarrow {}^7F_J$ (J=6, 5, 4, and 3) transitions of Tb^{3+} ions, resulted from possible cooperative ETU processes. Population inversion of Tb^{3+} ions at $^5D_4$ excited-state level was thought to accomplish through cooperative energy transfer among a pair of Yb^{3+}-donor ions and an Tb^{3+}-acceptor ion. The cooperative ETU processes can be simplified as follows [8,9]:

$$2\times Yb^{3+}(^2F_{5/2}):Tb^{3+}(^7F_6) \Rightarrow 2\times Yb^{3+}(^2F_{7/2}):Tb^{3+}(^5D_4)$$

From the $^5D_4$ level, Tb^{3+} ions were radiatively relaxed to the ^7F_J lower laying levels generating the recorded visible emission signals as shown in Fig. 1(a) and (b) [8].

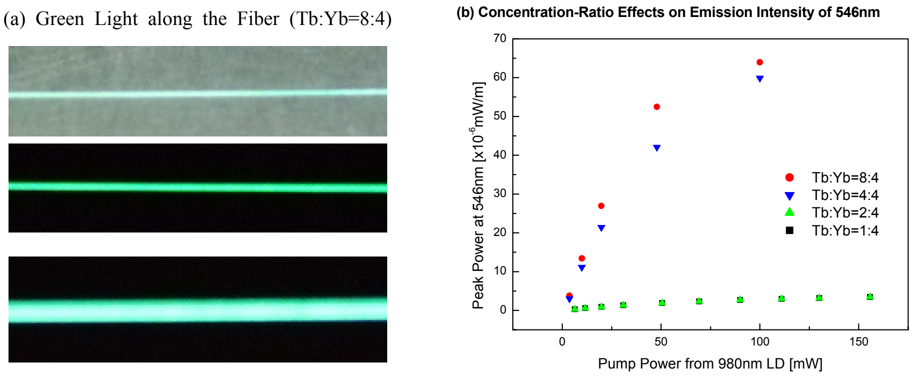

Fig.2. (a) Green light illumination along the Tb^{3+}/Yb^{3+} co-doped fiber tested during the pumping experiments: from top to bottom: "in the daylight", "against the dark background", and "against the dark background (enlarged)" (b) Concentration-ratio effects on the green photoluminescence intensity at 546nm.

Note that the fluorescence from the fibers appeared as a green light along the fibers, easily seen by naked eyes as shown in Fig. 2(a). The concentration ratio of Tb^{3+} to Yb^{3+} played a key role as to enhancing the green emission at 546nm as shown in Fig. 2(b), indicating that the relative increase of Tb^{3+} ions contributed to the observed green photoluminescence emission.

3. Conclusion

In summary, the Tb/Yb co-doped alumino-germano-silicate optical fibers were successfully made aiming to develop visible fiber lasers, especially the 546nm green fiber lasers. The macro-luminescent phenomenon was explained by the micro-cooperative energy transfer upconversion mechanism between the rare-earth ions of Tb and Yb. The concentration ratio of Tb^{3+} to Yb^{3+} was optimized to enhance the green photoluminescence in this study, laying solid foundation for developing really applicable green fiber lasers in the future.

Acknowledgements

This research was partially supported by the National Core Research Center (NCRC) for Hybrid Materials Solution of Pusan National University, by the GIST Top Brand Project (Photonics 2020, PhoST), Ministry of Science and Technology, by the GIST Technology Initiative (GTI), and by BK-21 Information Technology Project, Ministry of Education and Human Resources Development, Republic of Korea.

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