Modification of Spectroscopic Properties of Bismuth Doped Silica Fiber by Post-fabrication Process and Different Fabrication Methods

Mridu P. Kalita, Seongwoo Yoo, Andrew S. Webb, Robert J. Standish, Morten Ibsen and Jayanta K. Sahu
Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ
Email: mpk@orc.soton.ac.uk

Abstract: The spectroscopic properties of pristine and H_2-loaded MCVD based Bi-doped aluminosilicate fibers were investigated. Also, the properties of Bi-doped fiber, fabricated by powder-in-tube method, have been compared to MCVD based Bi fiber.

OCIS codes: (060.2290) Fiber materials; (140.3510) Lasers, fiber

1. Introduction

In recent years, significant research has been carried out on the spectroscopic properties of Bi-doped fiber fabricated by the modified chemical vapor deposition (MCVD) technique, with various glass compositions [1-3]. However, the origin of the luminescent center responsible for the Bi-emission is still unclear. In addition, improvement in the lasing efficiency of the Bi-doped fiber laser is necessary for possible practical applications. It is therefore interesting to investigate the dependence of the luminescence properties of Bi-doped fiber on external influences. A recent study on the influence of high temperature annealing and hydrogen-loading then annealing showed that Bi-related luminescence is very sensitive to the annealing process [4].

At the same time, new information on the nature of the luminescence center can be obtained by studying Bi-doped fiber fabricated by technique that is significantly different from the MCVD. Lately, plasma chemical technology has been successfully applied to Bi-doped fiber and the spectroscopic properties do not differ from the MCVD counterpart [5].

Here, we report the influence of H_2-loading on the spectroscopic properties of a Bi-doped fiber fabricated by the MCVD process. Results are compared between pristine and H_2-loaded fiber. In addition, a Bi-doped fiber has been fabricated with the powder-in-tube (PIT) technology and their luminescence properties, under different excitation sources, are compared to fibers fabricated by the MCVD technique.

2. Spectroscopic properties of H_2-loaded Bi-doped fiber

The fiber under investigation was fabricated by MCVD and the solution doping technique with a core glass composition of Al:SiO_2. The outer and core diameter of the fiber was 125 and 10 μm respectively, with a core numerical aperture (NA) of 0.16. The fiber was hydrogen loaded following typical condition for the fiber Bragg grating fabrication and was kept in H_2 atmosphere at 70^{o}C for four days, under the pressure of 190 atm. No index change was observed due to H_2-loading of the fiber.

The small signal absorption in the fiber was measured by the standard cut-back technique, using a white light source and an optical spectrum analyzer (OSA) and the background loss was measured with a Sunrise Luciol optical time domain reflectometer (OTDR) at 1285 nm. The fluorescence spectrum was collected from the side of the fiber using a multimode fiber and measured with an OSA. A 1090 nm GT Wave Yb-doped fiber laser was used as an excitation source. All measurement was carried out at room temperature.

The measured absorption spectra in the wavelength region of 800 – 1400 nm, for the pristine and H_2-loaded fiber are shown in Fig. 1. The small signal absorption at 1090 nm for the pristine and H_2-loaded fiber was 1.5 and 2.2 dB/m respectively. The peak around 900 nm in the hydrogen loaded fiber accounts for water peak. A small peak around 980 nm indicates contamination from Yb ion. The corresponding background loss at 1285 nm was 60 and 90 dB/km for the pristine and H_2-loaded fiber.

The unsaturable losses in both the fibers were measured at the pump wavelength of 1090 nm. The unsaturable loss remains unchanged after the H_2-loading. Thus, the ratio of unsaturable absorption to small signal absorption reduced from 65 to 45% after the H_2-loading. No change in fluorescence shape, under 1090 nm pump wavelength, was observed due to H_2-loading. However, enhancement of emission after the H_2-loading was reported in [6]. We measured fluorescence decay time from the fibers. The decay time dropping to *1/e* of its original intensity becomes significantly shorter after the H_2-loading. The measured decaying times are shown in Fig. 2. The decay times are ~ 770 μsec in the pristine fiber, but it drops to ~290 μsec in the H_2-loaded fiber. It appears that the active Bi ions are quenched by the loaded hydrogen [7].

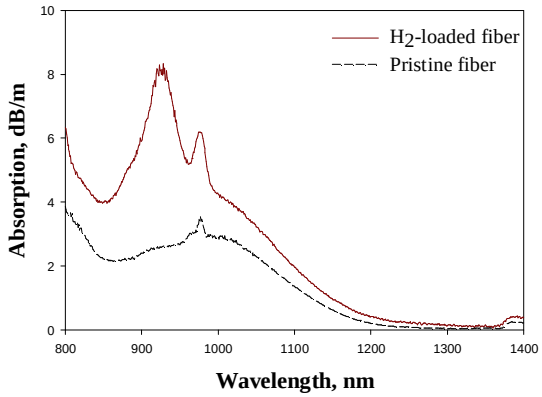

Fig 1. Absorption spectrum of H_2-loaded and pristine Bi-doped Al:SiO_2 fiber.

We tested laser performances of the fibers in a ring cavity with 2% output coupling. With a 15 m long pristine fiber, when pumped at 1090 nm, the oscillation at 1178 nm was observed, but the efficiency was less than 1%, due to high unsaturable loss present in the fiber [8]. The H_2-loaded fiber, when tested in the same setup, failed to lase, with 6 W of available pump power. The fiber length was 12 to 15 m, allowing 15 to 20 dB pump absorption, in laser configuration. Hence, our results suggest that although the H_2-loading may increase the fluorescence intensity [6], the quenching of the Bi ions by the hydrogen eventually limits the laser performance. Further studies on optimizing the H_2-loading condition with proper annealing process are under progress.

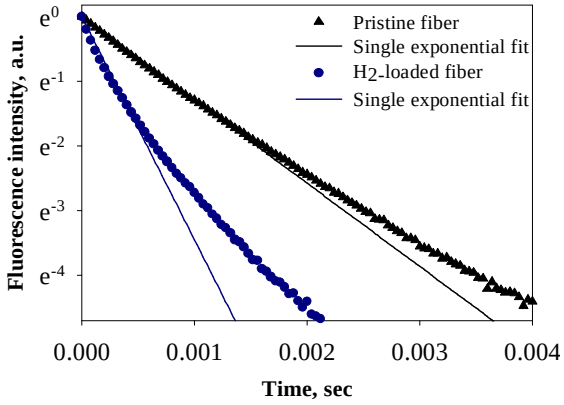

Fig.2. Fluorescence decay in a pristine fiber and H_2-loaded fiber.

3. Spectroscopic properties of Bi-doped fiber fabricated by PIT technology

The Bi-doped fiber was fabricated by PIT technology. The core glass was composed of 94.5 mol% SiO_2 (99.6%), 5.0 mol% Al_2O_3 and 0.5 mol% Bi_2O_3 (99.9%). The powders were mixed in a mortar, using an ultrasonic bath for intimate mixing of the powders. The mixture was then poured in to a silica substrate tube and annealed in a furnace at 1750^{o}C, for an hour. The tube was then drawn in to a cane of 1 mm diameter.

Figure 3 shows the fluorescence comparison spectra of the PIT and MCVD based Bi-doped fibers of similar glass compositions. It is clearly shown that the emission is dependent on the fabrication method. The PIT fiber showed broad fluorescence band centered at 1250 nm under 808 nm excitation [Fig. 3 (a)]. Its full width half maximum (FWHM) bandwidth is ~270 nm. The fluorescence looks close to that of Bi-doped aluminosilicate glasses fabricated by the melt and quenching method [9]. However, in case of the MCVD Bi-doped fiber, the peak appeared in the shorter wavelength of 1000 nm with 200 nm of FWHM bandwidth, which well agrees with other Bi-doped aluminosilicate fibers by the MCVD process [10]. Under 1090 nm pumping, the peak position for both the fibers

remains same, while the PIT fiber shows broader fluorescence [Fig. 3 (b)]. The PIT seems promising for the construction of broadband sources based on Bi-doped fibers.

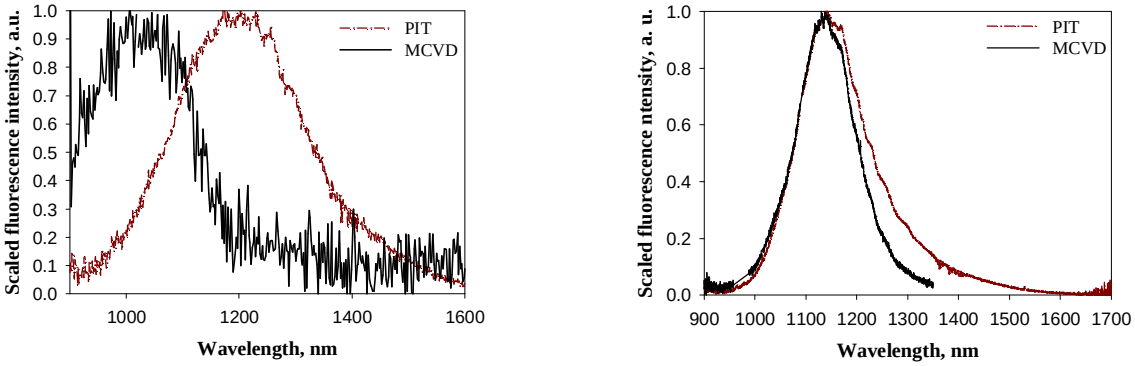

Fig 3. Normalized emission spectra of Bi-doped fiber fabricated by PIT and MCVD technique, at pump wavelength of (a) 808 nm and (b) 1090 nm.

4. Conclusion

In conclusion, we have reported the dependence of spectral characteristics in Bi aluminosilicate fiber after H_2-loading. The absorption in H_2-loaded fiber seems to increase but it also causes quenching. The Bi-doped fiber fabricated by PIT technology, which is a non chemical vapor deposition process, shows significant change in luminescence, as compared to Bi-doped fibers fabricated by MCVD.

5. References

[1] V. V. Dvoyrin, V. M. Mashinsky, and E. M. Dianov, "Efficient Bismuth-Doped Fiber Lasers," IEEE J. Quantum Electron. **44**, 834-840 (2008).

[2] M. P. Kalita, S. Yoo, and J. Sahu, "Influence of cooling on a bismuth-doped fiber laser and amplifier performance," Appl. Opt. **48**, G83-G87 (2009).

[3] I. Razdobreev, L. Bigot, V. Pureur, A. Favre, G. Bouwmans, and M. Douay, "Efficient all-fibre bismuth-doped laser," Appl. Phys. Lett., **90**, 031103- 031103-3 (2007).

[4] V. G. Truong, L. Bigot, A. Lerouge, M. Douay, and I. Razdobreev, "Study of thermal stability and luminescence quenching properties of bismuth-doped silicate glasses for fiber laser applications," Appl. Phys. Lett. **92**, 041908- 041908-3 (2008).

[5] I. A. Bufetov, K. M. Golant, S. V. Firstov, A. V. Kholodkov, A. V. Shubin, and E. M. Dianov, "Bismuth activated alumosilicate optical fibers fabricated by surface-plasma chemical vapor deposition technology," Appl. Opt. **47**, 4940-4944 (2008).

[6] C. Ban, L.I. Bulatov, V.V. Dvoyrin, V.M. Mashinsky, H.G. Limberger, and E.M. Dianov, "Infrared Luminescence Enhancement by UV-Irradiation of H_2-loaded Bi-Al-doped Fiber," in ECOC 2009, paper 6.1.5.

[7] J. D. Prohaska, D. P. Machewirth, and E. Snitzer, "Quenching of neodymium fluorescence by molecular hydrogen," Opt. Lett. **20**, 719-721 (1995).

[8] M. P. Kalita, S. Yoo, and J. Sahu, "Bismuth doped fiber laser and study of unsaturable loss and pump induced absorption in laser performance," Opt. Express **16**, 21032-21038 (2008).

[9] Y. Fujimoto and M. Nakatsuka, "Infrared Luminescence from Bismuth-doped Silica Glass," Jpn. J. Appl. Phys. **40** L279 (2001).

[10] I.A. Bufetov and E.M. Dianov, "Bi-doped fiber lasers," Laser Phys. Lett. **6**, 487-504 (2009).