Bi-doped Fiber Lasers and Amplifiers for a Wavelength Range of 1300-1500 nm

E.M. Dianov
Fiber Optics Research Center of the Russian Academy of Sciences
38 Vavilov Street, 119333 Moscow, Russia
dianov@fo.gpi.ru

Abstract: Bi-doped fibers are a promising medium for lasers and amplifiers in the 1150-1600nm wavelength range. We present the results on the development of Bi-doped fiber lasers and amplifiers for telecom window of 1300-1500nm in particular.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (140.3510) Lasers, fiber

Since the appearance of the first lasers in 1960 great attention has been paid to the search and the creation of new active laser media. This made it possible to improve the characteristics of the existing lasers and to develop new ones. Active glass optical fibers are one of the most efficient laser media. Until recently there existed only rare-earth-doped fiber lasers, which have found a widespread use in optical communication, medicine, material processing and other applications in the near IR region.

But there is a spectral region of 1150-1500nm where in fact no efficient fiber lasers exist (Fig.1). This spectral region is very promising for a number of applications, such as advanced optical communication systems, medicine, astrophysics. In 1999 and 2001 Fujimoto et al published the papers, where the observation of luminescence in the spectral region 1000-1600 nm in Bi-doped silica glass was reported [1, 2]. It is important that one of the luminescence bands (at the peak wavelength 1250nm) was extremely wide - the full width at half maximum amounted to 330nm. However only several years later (in 2005) the first Bi-doped silica-based optical fibers were fabricated by FORC and Sumitomo [3, 4].

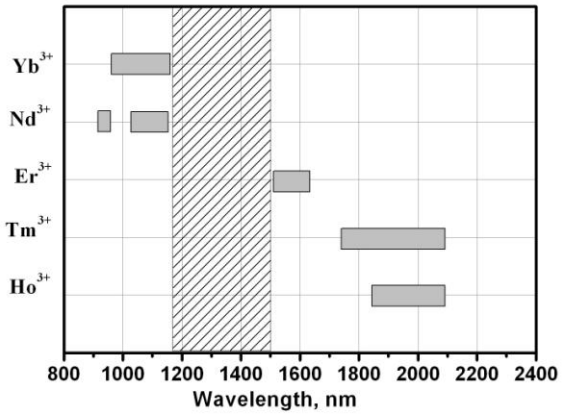

Fig.1. Spectral regions of the existing efficient rare earth fiber lasers. The shaded area indicate the wavelength region that can covered by Bi fiber lasers.

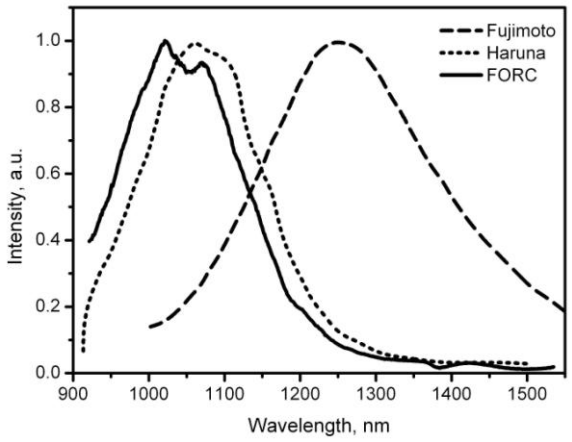

Fig.2. Luminescence spectra of Bi-doped silica glass (Fujimoto et al., 2001) and MCVD fibers (Haruna et al., 2005; FORC) pumped at 800 nm.

In the first Bi-doped silica-based fibers the luminescent spectra didn't have the broadband 1250nm band, instead of it a luminescent band with the peak wavelength near 1150nm was observed (Fig. 2). So the first Bi-doped fiber lasers operated in the spectral region 1150-1200nm. The development of Bi-doped silica-based fibers and the first demonstration of a CW Bi-doped fiber laser [5] has strongly increased interest in Bi-doped fibers and fiber lasers and amplifiers. One could see two main directions of researches. The first – the development and investigation of Bi-doped fiber lasers of different types, the second – the fabrication and study of new Bi-doped glasses and the investigation of a nature of Bi-related centers, emitting in near IR. But up to now the nature of Bi-related luminescence centers is not clear. There are several hypotheses, which suggest a source of near IR luminescence: Bi^{5+} [2, 6], Bi^{+} [7, 8], BiO [9], Bi_2, Bi_2^{-}, Bi_2^{2-} [10-12], point defects in glasses [13, 14]. But there are no direct proofs to confirm any of these hypotheses now. In spite of this a family of fiber lasers for a wavelength range of 1150-

OMG6.pdf

1215 nm has been successfully developed, using Bi-doped alumosilicate fibers. It includes CW, Q-switched, mode-locked and yellow frequency-doubled Bi-doped fiber lasers. The results of these researches and corresponding references are presented in the review papers [15, 16].

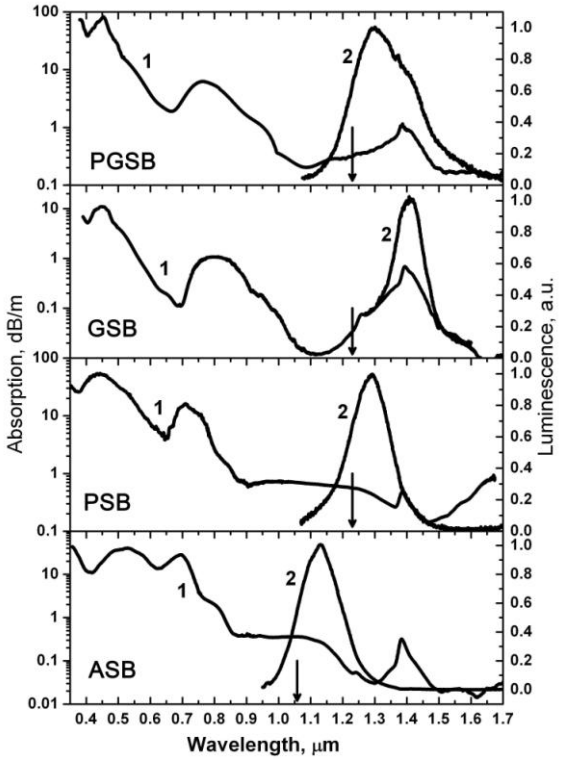

Fig.3. Optical losses (1) and luminescence spectra (2) of phosphogermanosilicate (PGSB), germanosilicate (GSB), phosphosilicate (PSB), and alumosilicate (ASB) Bi-doped fibers. Vertical arrows indicate the pump wavelengths.

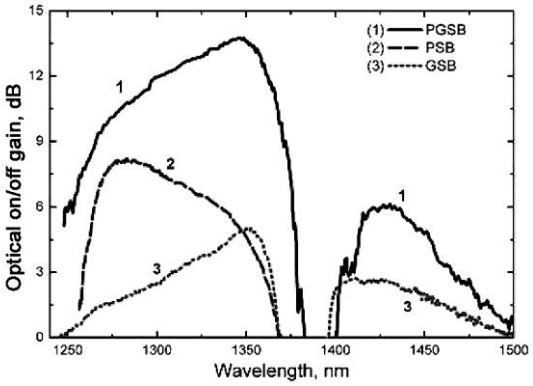

Fig.4. Optical gain spectra in PGSB, PSB and GSB fibers, pumped at 1230 nm. Pump radiation was launched into the core of the fiber, pump power was equal to 50 mW, the length of the fiber was equal to 30 m in all cases.

Despite the considerable progress in creating Bi-doped fiber lasers for a spectral region of 1150-1215nm the most important task is the development of efficient Bi-doped fiber lasers and amplifiers for a wavelength range of 1300-1500nm, which are promising for advanced optical fiber communication systems. To extend the laser generation band to this wavelength range we have developed a new type of Bi-doped fibers – alumina-free phosphogermanosilicate fibers.

Fig.3 shows the luminescence and the loss spectra of Bi-doped phosphogermanosilicate, germanosilicate and phosphosilicate fibers and an aluminosilicate fiber for comparison. One can see that it is possible to shift the luminescence bands to the wavelength range 1300-1500nm using these fibers.

Fig.4 shows on/off gain spectra of the fibers [17]. It is seen that these fibers can be used for the creation of fiber lasers and amplifiers for O, E and S spectral bands.

We have carried out experiments on laser generation using Bi-doped phosphogermanosilicate fibers as an active medium and Raman fiber lasers as a pump source.

Laser generation has been obtained practically in the whole wavelength range 1300-1500nm with quite high slope efficiency (up to ~ 20%) [18].

Fig.5 summarizes our results on the development of Bi-doped fiber lasers.

New results on the development of fiber lasers and amplifiers for the spectral region 1300-1500nm will be presented at the Conference.

OMG6.pdf

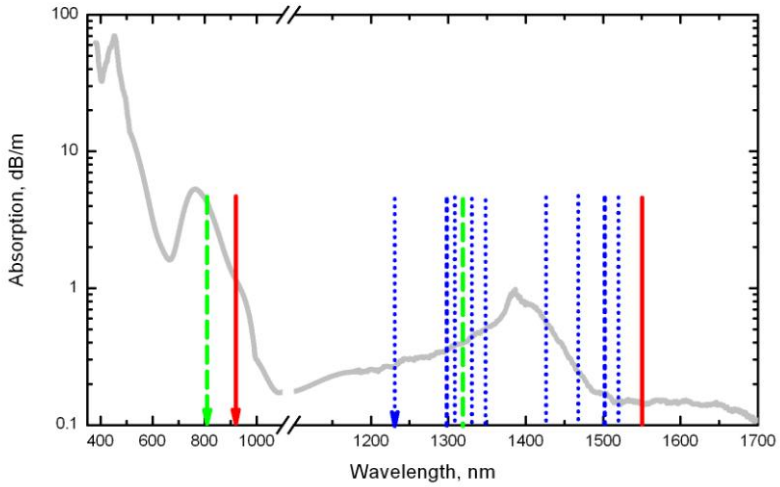

Fig.5. Laser generation wavelengths revealed in Bi-doped fibers in the wavelength region 1300-1550 nm at different pump wavelengths on the background of the loss spectra of Bi-doped fiber. Arrows indicate pump wavelengths; laser generation and corresponding pump wavelengths are shown by lines of the same type.

References

1 K.Murata, Y.Fujimoto, T.Kanabe, H.Fujita, M.Nakatsuka, "Bi-doped SiO_2 as a new laser material for an intense laser", Fusion Engineering and Design, **44**, 437-439 (1999).

2 Y.Fujimoto and M.Nakatsuka, "Infrared luminescence from bismuth-doped silica glass ", Jpn. J. Appl. Phys., **40**, L279-L281 (2001).

3 V.V.Dvoyrin, V.M.Mashinsky, E.M.Dianov, A.A.Umnikov, M.V.Yashkov, A.N.Guryanov, "Absorption, Fluorescence and Optical Amplification in MCVD Bismuth-Doped Silica Glass Optical Fibres", ECOC, Glasgow, paper Th3.3.5, Sept. 25-29 (2005).

4 T.Haruna, M.Kakui, T.Taru, Sh.Ishikawa, M.Onishi, "Silica-Based Bismuth-Doped Fiber for Ultra Broad Band Light-Source and Optical Amplification around 1.1μm", Optical Amplifiers and their Application Topical Meeting, Budapest, paper MC3, August 7-10 (2005).

5 E.M.Dianov, V.V.Dvoyrin, V.M.Mashinsky, A.A.Umnikov, M.V.Yashkov, A.N.Guryanov, "CW bismuth fibre laser", Quant. Electron., **35**, 1083-1084 (2005).

6 T.Ohkura, Y.Fujimoto, M.Nakatsuka, "Local Structures of Bismuth Ion in Bismuth-Doped Silica Glasses Analyzed Using Bi L_{III} X-Ray Absorption Fine Structure", J. Am. Ceram. Soc., **90**, 3596-3600 (2007).

7 X.Meng, J.Qiu, M.Peng, D.Chen, Q.Zhao, X.Jiang, C.Zhu, "Near infrared broadband emission of bismuth-doped aluminophosphate glass", Opt. Express, **13**, 1628-1634 (2005).

8 Sh.Zhou, N.Jiang, B.Zhu, H.Yang, S.Ye, G.Lakshminarayana, J.Hao, J.Qiu, "Multifunctional Bismuth-Doped Nanoporous Silica Glass: From Blue-Green, Orange, Red, and White Light Sources to Ultra-Broadband Infrared Amplifiers", Advanced Function Mater., **18**, 1407-1413 (2008).

9 J.Ren, L.Yang, J.Qiu, D.Chen, X.Jiang, C.Zhu, "Effect of various alkaline-earth metal oxides on the broadband infrared luminescence from bismuth-doped silicate glasses", Solid State Commun., **140**, 38-41 (2006).

10 S.Khonthon, S.Morimoto, Y.Arai, Y.Ohishi, "Effect of various alkaline-earth metal oxides on the broadband infrared luminescence from bismuth-doped silicate glasses", J.Ceram. Soc. Jpn., **115**, 259-263 (2007).

11 V.O.Sokolov, V.G.Plotnichenko, E.M.Dianov, "Origin of broadband near-infrared luminescence in bismuth-doped glasses", Opt. Lett., **33**, 1488-1490 (2008).

12 B.Denker, B.Galagan, V.Osiko, I.Shulman, S.Sverchkov, E.Dianov, "The IR Emitting Centers in Bi-doped Mg–Al–Si Oxide Glasses", Laser physics, **19**, 1105-1111 (2009).

13 M.Yu.Sharonov, A.B.Bykov, V.Petricevic, R.R.Alfano, "Spectroscopic study of optical centers formed in Bi-, Pb-, Sb-, Sn-, Te-, and In-doped germanate glasses", Opt. Lett., **33**, 2131-2133 (2008).

14 G.Lakshminarayana, R.Yang, M.Mao, Y.Zhang, J.Qiu, "Spectral analysis of optical centres formed in Bi-, Bi/Yb-, Pb-, Pb/Yb-, Sb-, Sb/Yb- and Sn-, Sn/Yb-co-doped germanate glasses", J. Phys. D: Appl. Phys., **42**, 145108 (2009).

15 E.M.Dianov, "Bi-doped optical fibers: a new active medium for NIR lasers and amplifiers", Proc. SPIE, **6890**, 68900H-1-11 (2008).

16 I.A.Bufetov and E.M.Dianov, "Bi-doped fiber lasers", Laser Physics Letters, **6**, 487-504 (2009).

17 E.M.Dianov, S.V.Firstov, O.I.Medvedkov, I.A.Bufetov, V.F.Khopin, A.N.Guryanov, "Luminescence and laser generation in Bi-doped fibers in a spectral region of 1300-1520 nm", OFC'2009, paper OWT3.

18 S.V.Firstov, I.A.Bufetov, V.F.Khopin, A.V.Shubin, A.M.Smirnov, L.D.Iskhakova, N.N.Vechkanov, A.N.Guryanov, E.M.Dianov, "2 W bismuth doped fiber lasers in the wavelength range 1300 – 1500 nm and variation of Bi-doped fiber parameters with core composition", Laser Physics Letters, **6**, 665-670 (2009).