ALT'12 Advanced Laser Technologies
2 – 6 September 2012, Thun, Switzerland

ALT 12
c/o Bern University of Applied Sciences
Engineering and Information Technology
Pestalozzistrasse 20, CH-3400 Burgdorf
info@alt12.org, www.alt12.org
0041 (0) 34 426 42 06

BROADBAND SUPERFLUORESCENT SOURCE BASED ON BISMUTH-DOPED GEO2-SIO2 FIBER

Authors:

M. A. Melkumov, K. E. Riumkin, I. A. Bufetov, A. V. Shubin, S. V. Firstov, V. F. Khopin, A. N. Gurianov, E. M. Dianov

DOI: 10.12684/alt.1.75

Corresponding author: K. E. Riumkin

e-mail: 3bc@mail.ru

Broadband Superfluorescent Source Based on Bismuth-Doped GeO_2-SiO_2 Fiber

M. A. Melkumov[1], K. E. Riumkin[1], I. A. Bufetov[1], A. V. Shubin[1], S. V. Firstov[1], V. F. Khopin[2], A. N. Gurianov[2], E. M. Dianov[1]

[1]Fiber Optics Research Center, Russian Academy of Sciences,
38 Vavilov str., Moscow 119333, Russia
[2]Institute of Chemistry of High-Purity Substances, Russian Academy of Sciences,
49 Tropinin str., Nizhny Novgorod 603600, Russia

Abstract

The first bismuth-doped superfluorescent fiber source operating at 1.44-µm was developed. At pump power of 200 mW and pump wavelength of 1310 nm, its output signal reaches 57 mW with spectrum width of 25 nm.

Introduction

Superfluorescent fiber sources are widely used for many applications including optical gyroscopes and sensors, optical time-domain reflectometers (OTDRs), optical coherence tomography (OCT), and wavelength-division-multiplexing (WDM) systems [1]. Diode pumped rare-earth doped superfluorescent fiber sources (SFSs) have emerged as highly stable broadband sources [2]. However, the gain bands of the rare-earth elements do not cover the full transparency range of the silica fiber, where the broadband sources are needed most. One possible candidate is the superluminescent laser diode (SLD). However, their output power is not very high and their mean wavelength exhibits a high dependence on temperature, typically 400 ppm/°C. The bismuth-doped optical fibers having a fairly wide band of the laser transition in the uncovered range and relatively high efficiency seem promising active medium for the creation of SFS. An additional advantage is that the various glass hosts allow obtaining gain at different wavelengths: a phosphosilicate (1.3 µm), silicate (1.4 µm), aluminosilicate (1.1 µm) [3,4].

Experimental Setup

We used the double-pass backward pumped configuration to build our SFS (Figure 1). The primary advantage of the double-pass configuration is its higher efficiency than one of a single-pass SFS. The length of fiber that maximizes its efficiency is shorter than for a forward SFS.

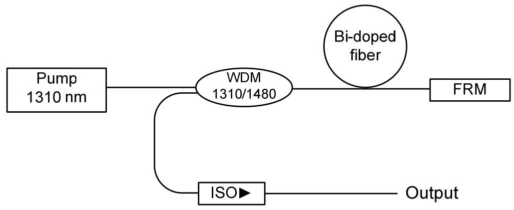

Figure 1 Bi-doped SFS scheme.

As a pump source we used Raman fiber laser at 1320 nm, but it is also possible to use commercial semiconductor laser diode (e.g. Innolume LD-1310-BF-250). The pump radiation was launched into the active fiber through a 1310/1480 nm WDM coupler. A Faraday rotator mirror was used at the other end of the Bi-doped fiber, to propagate the ASE through the fiber a second time. High-extinction isolator was placed at the SFS output.

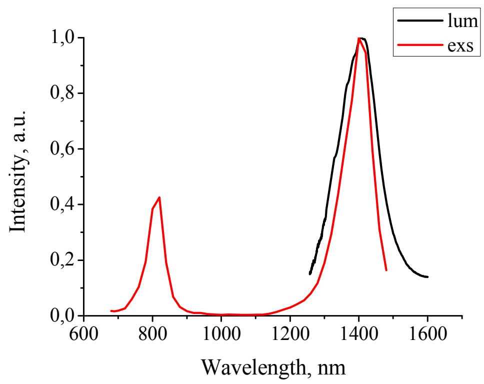

Figure 2 Excitation and luminescence (λ_{exc} = 1320 nm) spectra of the germanosilicate Bi-doped fiber.

To build an SFS with a mean wavelength of 1440 nm, we used germanosilicate Bi-doped fiber [5 ,6]. It was shown that the emission of this fiber near 1400 nm originated from silica-associated bismuth active centers [7]. Its cutoff wavelength was near 0.9 µm. The index difference between the core and the cladding was $\Delta n \approx 8\times10{-}3$. The Bi concentration was below 0.1 wt%. The fiber optical losses were quite low: 12 dB/km at λ = 1100 nm. The length of active fiber was 200 m. The excitation and luminescence (λ_{exc} = 1320 nm) spectra of the germanosilicate Bi-doped fiber are shown in the Figure 2.

The measurement of the net gain spectra is useful during laser or amplifier development and allows estimating the proper length of active fiber for the certain configuration and range of the superfluorescence. The net gain spectra of the Bi-doped amplifier pumped with a laser diode (LD) at 1320 nm are presented in Figure 3 for several values of pump power. The maximum launched power was limited by LD and amounted to 65 mW.

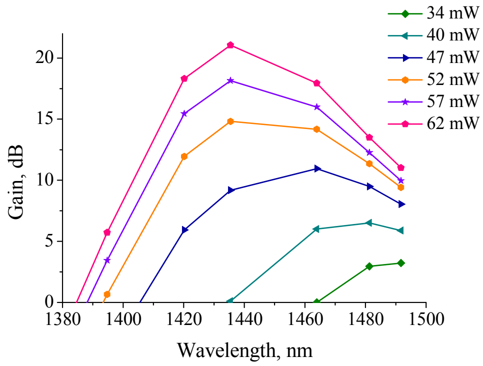

Figure 3 Gain spectra for different pump powers.

The spectra and power of the output signal were measured with optical spectrum analyzer Agilent 86140B and optical power meter EXFO FLP-650 correspondingly.

Results

The SFS output spectrum at room temperature and pump power of 200 mW is shown in Figure 4 (red line). The form of output spectrum was close to the Gaussian shape. The full width at half maximum (FWHM) of 25 nm was achieved without the use of additional filters, long period gratins, pieces of passive Bi-doped fibers or other components manipulating spectrum, which are required in case of Er-doped SFS to widen output spectrum. The output spectrum of the Er-doped SFS in the same configuration, but with filter between FRM and active fiber is shown In the Figure 4 (blue line). At pump power of 100 mW and pump wavelength of 980 nm, its output signal reaches 30 mW with spectrum width of 20 nm.

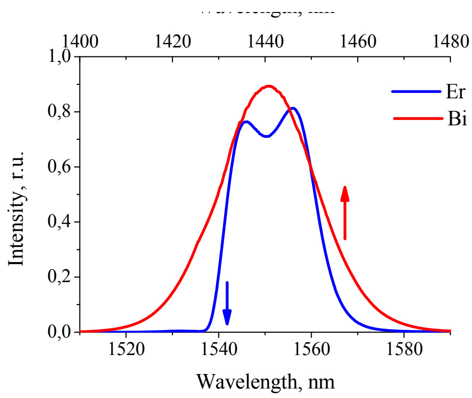

Figure 4 The SFS output spectra at room temperature

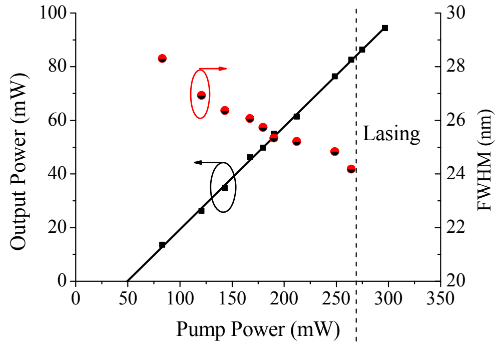

Figure 5 Dependence of the output power and the output spectrum FWHM on the launched pump power.

The spectra and the output power were measured at different values of pump power to determine the energy characteristics of the SFS. In the Figure 5 one can see that the lasing starts when the pump power is higher than 264 mW.

Figure 5 shows a plot of the SFS output power versus the pump power. The slope efficiency is about 38%. Figure 5 also shows dependence of the output spectrum FWHM on the launched pump power. The spectrum FWHM decreases when increasing the pump power and amounts to 25 nm at 260 mW. With a further increase the lasing starts. The low lasing threshold is caused by Rayleigh scattering in a long active fiber. The lasing threshold can be increased by using two-stage scheme of SFS. Dependence of the output spectrum mean wavelength on the pump power is shown in the Figure 6.

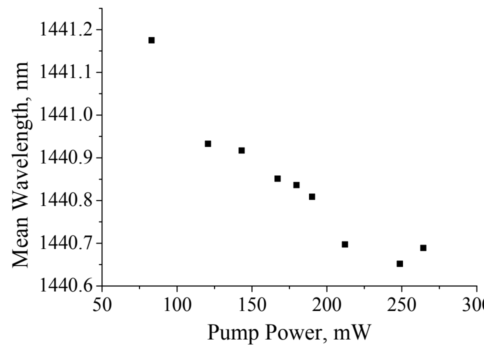

Figure 6 Dependence of the output spectrum mean wavelength on the pump power.

Stability of the SFS output signal characteristics from external influences in particular the mean wavelength dependence on the temperature is critical for wide range of applications. To measure temperature dependence of the SFS characteristics the fiber coil was placed in the thermal cycling setup. The fiber temperature was varied from -55 to 65 °C.

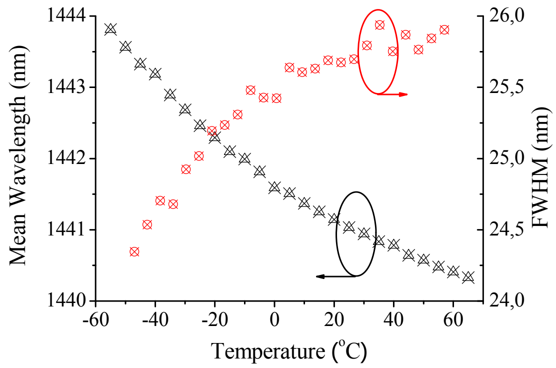

Figure 7 Dependence of the mean wavelength and the output spectrum FWHM on the temperature.

The spectrum forms are close to Gaussian shape and virtually remain same with the temperature. There is a slight shift of the peak and a change in the intensity. Figure 7 shows dependence of the mean wavelength and the output spectrum FWHM on the temperature. When increasing temperature, the mean wavelength of the output radiation decreases steadily from 1444 to 1440.5 nm, showing the change of 3.5 nm within the range of 120 degrees ˚C. The FWHM varied from 24.4 to 26 nm.

Conclusions

In this paper we have demonstrated for the first time to our knowledge the operation of bismuth-doped SFS with mean wavelength of 1441 nm. SFS has a fairly high efficiency of 28%, maximum output power in our configuration is 57 mW at pump power of 200 mW. The temperature stability of the mean wavelength over the range from -55 to +65 ˚C amounts to 0.27%. The output spectrum is close to Gaussian shape with FWHM of 25 nm. The main disadvantage is the need to use the long active fiber (200 m) because of its low gain per meter. The length of the fiber could be a reason for the low lasing threshold. At present high efficiency can be achieved only at low concentration of bismuth. Bismuth concentration increase results in the growing of unsaturable losses and decrease of the efficiency. Further optimization of scheme configuration and optical properties of active fibers can result in the significant improvement in the Bi-doped SFS performance.

The origin of near-IR luminescence in Bi-doped materials has been studied in many works [8,9,10]. However, the nature of Bi-related centers is still unknown and we believe that clearing up this point will result in considerable improvements of Bi-doped SFS characteristics.

References

[1] M.J.F. Digonnet, “Broadband Fiber Sources,” *Rare-Earth-Dope Fiber Lasers and Amplifiers,* 2nd ed. Marcel Dekker, Inc., New York, Basel, Stanford, California, 2001, pp. 313-337,

[2] P. F. Wysocki, M. J. F. Digonnet, B. Y. Kim, H. J. Shaw, Characteristics of erbium-doped superfluorescent fiber sources for interferometric applications. J. *Lightwave Technol.,* vol. 12, pp. 550–567, 1994.

[3] E. M. Dianov, M. A. Melkumov, S. V. Firstov, A. V. Shubin, O. I. Medvedkov, and I. A. Bufetov, “Efficient Bi- doped fiber lasers and amplifiers for the spectral region 1300-1500 nm,” Proc. SPIE 7580, 758014 (2010).

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

[5] I.A. Bufetov, S.V. Firstov, V.F. Khopin, O.I. Medvedkov, A.N. Guryanov, E.M. Dianov, “Bi-doped fiber lasers and amplifiers for a spectral region of 1300–1470 nm,” *Optics Letters* , vol. 33, no. 19, pp 2227-2229, October 2008.

[6] M. A. Melkumov, I. A. Bufetov, A. V. Shubin, S. V. Firstov, V. F. Khopin, A. N. Guryanov and E. M. Dianov, “Laser diode pumped bismuth-doped optical fiber amplifier for 1430 nm band,” Opt. Lett. vol. 36, no. 13, 2408–2410 (2011).

[7] I. A. Bufetov, M. A. Melkumov, S. V. Firstov, A. V. Shubin, S. L. Semenov, V. V. Vel'miskin, A. E. Levchenko, E. G. Firstova, and E. M. Dianov, “Optical gain and laser generation in bismuth-doped silica fibers free of other dopants,” Opt. Lett. vol. 36 (2), 166–168 (2011).

[8] E. M. Dianov, “Bismuth-doped optical fibers: a challenging active medium for near-IR lasers and optical amplifiers,” Light Sci. Appl. 1, e12 (2012).

[9] M. Peng, G. Dong, L. Wondraczek, L. Zhang, N. Zhang, J. Qiu, “Discussion on the origin of NIR emission from Bi-doped materials,” J. Non-Cryst. Solids vol. 357, no. 11–13, 2241–2245 (2011).

[10] A. N. Romanov, Z. T. Fattakhova, D. M. Zhigunov, V. N. Korchak, V.B. Sulimov “On the origin of near-IR luminescence in Bi-doped materials (I). Generation of low-valence bismuth species by Bi3+ and Bi0 synproportionation” Opt. Mater. vol. 33, no. 4, 631–634 (2011).