

LETTERS

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A new bismuth-doped fibre laser, emitting in the range 1625 – 1775 nm

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Abstract. **CW lasing of a Bi-doped germanosilicate fibre in a wavelength range that covers the spectral region between the emission bands of Er and Tm fibre lasers has been demonstrated for the first time.**

Keywords: *bismuth, laser, optical fibre.*

Since the advent of the first bismuth-doped fibre laser in 2005 [1], considerable attention has been paid to a search for new glass compositions for the core of bismuth-doped fibres and to their luminescence spectra. The results demonstrate that the bismuth-doped fibres are attractive gain media for lasers and optical amplifiers operating in the spectral region 1000 – 1800 nm [2].

The first bismuth-doped fibre laser, with an aluminosilicate glass-based gain medium, emitted in the spectral region 1140 – 1215 nm [1]. Later, bismuth-doped fibre lasers operating in the range 1270 – 1550 nm and having a phosphogermanosilicate, germanosilicate or silica glass core were demonstrated (see e.g. reviews by Dianov [3] and Bufetov et al. [4] and references therein). In addition, an efficient bismuth-doped fibre amplifier was created, with a maximum gain coefficient of 25 dB at a wavelength of 1430 nm [5].

However, no bismuth-doped fibre lasers or amplifiers operating in the spectral region 1600 – 1800 nm have been reported to date. At the same time, there is an obvious need for such devices, especially for those operating in the wavelength range 1620 – 1700 nm, where the optical loss in silica-based fibres is sufficiently low (within 0.4 dB km^{-1}),which makes this range attractive for information transfer through optical fibre communication links. The problem of utilising this spectral region for information transfer is currently related to the lack of components for optical fibre communication systems, primarily of fibre lasers and optical amplifiers.

In this paper, we report the fabrication of bismuth-doped fibres luminescing in the spectral region 1600 – 1800 nm and fibre lasers based on such fibres.

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Optical fibres differing in the SiO_2/GeO_2 and Bi_2O_3 content of their core (bismuth-doped germanosilicate fibres; hereafter, BGSFs) were fabricated by the MCVD process. Detailed data on the chemical composition of the core glass of the active fibres will be presented in a subsequent communication. Of the fibres obtained, we chose samples with bright luminescence of bismuth-related active centres (BACs) in the spectral region 1600 – 1800 nm, which was the first step towards lasing in this region.

Figure 1 shows the optical loss, luminescence and luminescence excitation spectra of the BGSF that was used to demonstrate lasing. The absorption spectrum [curve (*1*)] contains bands peaking at wavelengths of 830 and 1400 nm, which are due to BACs associated with SiO_2, and bands at 460, 950 and 1650 nm, arising from BACs associated with GeO_2 [6]. Under excitation with a semiconductor laser diode (λ_p = 975 nm) and a bismuth-doped fibre laser (λ_p = 1460 nm [7]), the BGSF showed a broadband IR luminescence in the range 1550 – 1800 nm. The shape of its luminescence spectrum depended little on the excitation wavelength. A typical luminescence spectrum of the BGSF is represented by curve (*2*). Under 975-nm pumping, the 1700-nm luminescence lifetime was 500 μs (the luminescence decay curve was well represented by an exponential function). The excitation spectrum of this luminescence band [curve (*3*)] shows bands peaking at 460 and 950 nm and the short-wavelength edge of a band peaking around 1600 – 1650 nm.

Figure 2 shows the optical loss spectra of the BGSF under laser pumping at λ_p = 1460 nm and without pumping. From these spectra, we can locate optical amplification and induced (excited-state) absorption regions under pumping [8]. Curve (*2*) represents the net optical gain in the region where the optical loss is negative. It is seen that the BGSF offers optical

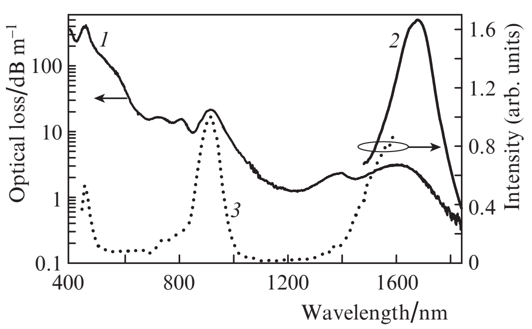

Figure 1. Optical characteristics of the BGSF: (*1*) optical loss spectrum, (*2*) luminescence spectrum under excitation at a wavelength of 975 nm and (*3*) excitation spectrum of the 1700-nm luminescence.

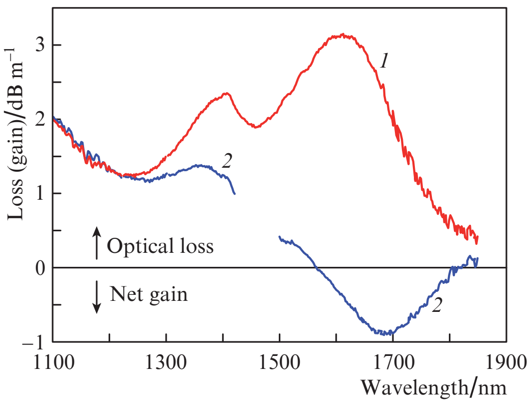

Figure 2. Optical loss spectra of the BGSF (*1*) without pumping and (*2*) under pumping at a wavelength λ_p = 1460 nm.

amplification in a wide spectral region, from 1560 to 1800 nm. Comparison of curves (*1*) and (*2*) demonstrates that, throughout the range 1100–1800 nm, the optical loss of the BGSF under pumping does not exceed that without pumping. This indicates that there is no excited-state absorption.

The bismuth-doped germanosilicate fibre whose optical properties are described above was used as the gain medium of a laser. The bismuth fibre laser had a standard linear configuration, with a cavity formed by an active fibre segment and fibre Bragg gratings, which determined the laser wavelength λ_{las}. To obtain lasing at wavelengths of 1625 and 1775 nm, we used a pair of Bragg gratings with a near 100% reflectivity. In the case of lasing at 1688, 1703 and 1735 nm, the active fibre end face served as the output coupler. The pump sources used in our lasing experiments were a bismuth-doped fibre laser with λ_p = 1460 nm and an Er–Yb codoped fibre laser with λ_p = 1568 nm. The pump beam was coupled into the core of the active fibre. The active fibre length was varied from 15 to 20 m. All measurements were made at room temperature.

As a result, we obtained lasing at wavelengths λ_{las} = 1625, 1688, 1703, 1735 and 1775 nm under pumping at λ_p = 1460 nm. The threshold pump power was about 40 mW. Figure 3 shows the output power at a wavelength λ_{las} = 1703 nm as a function of launched pump power (λ_p = 1460 nm). The slope efficiency of the laser did not exceed 1.5%. This low efficiency at λ_p = 1460 nm seems to be the result of the strong pump absorption by the BACs associated with SiO_2, which do not contribute to lasing near 1700 nm. To improve the efficiency of the bismuth-doped fibre laser, we used pumping at a wavelength longer than 1460 nm, namely, by the output of the Er–Yb codoped fibre laser (λ_p = 1568 nm). As a result, the slope efficiency of the bismuth fibre laser at λ_{las} = 1703 nm increased markedly, reaching 6% (Fig. 3), and its maximum output power exceeded 150 mW. Similar parameters were offered by the bismuth fibre laser with λ_{las} = 1735 nm.

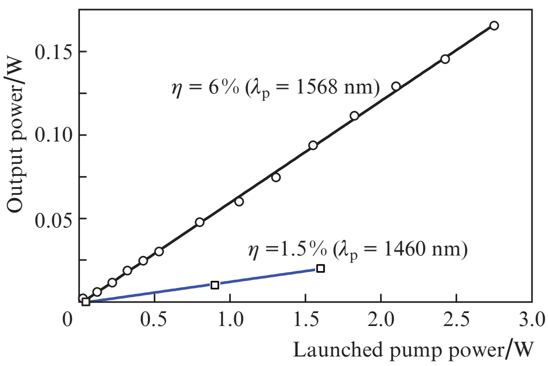

Figure 3. 1703-nm bismuth fibre laser output power as a function of launched pump power at λ_p = 1460 and 1568 nm. η is the slope efficiency.

Figure 4 shows the net optical gain spectrum, with the lasing wavelengths indicated. The gain band of the bismuth-doped germanosilicate fibre laser had a full width at half maximum of 150 nm.

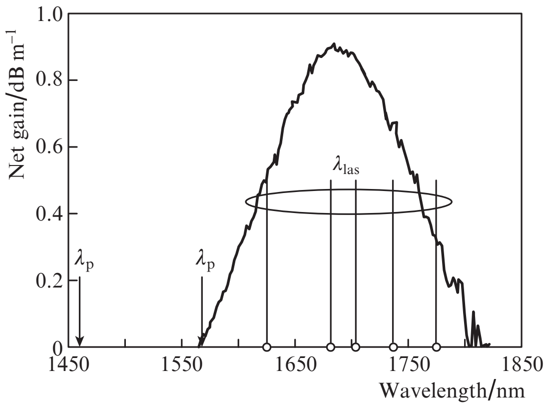

Figure 4. Net optical gain spectrum of the BGSF. The arrows and open circles indicate the pump and lasing wavelengths, respectively.

Thus, we have demonstrated a bismuth-doped germanosilicate fibre that ensures optical amplification in the range 1560–1800 nm. The fibre is potentially attractive as a gain medium for lasers and amplifiers operating in this spectral range, as evidenced by the first results on lasing at wavelengths of 1625, 1688, 1703, 1735 and 1775 nm. Clearly, the efficiency of the proposed bismuth fibre lasers can be improved by optimising the parameters of the active fibre and the main fibre fabrication steps.

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