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Superluminescent bismuth-doped fibre IR source for the range 1700 – 1750 nm

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Abstract. **We have demonstrated the first superluminescent IR (1700 – 1750 nm) source based on bismuth-doped high-germania fibre. Its main output characteristics are as follows: centre wavelength, 1730 nm; emission bandwidth, 50 nm at an output power of ~7 mW; optical efficiency, ~1 %.**

Keywords: *bismuth, superluminescence, optical fibre, IR radiation.*

1. Introduction

Optical fibres doped with active ions are unique gain media that can be used to produce optical devices for a variety of practical applications. Such devices include superluminescent fibre sources (SFS’s), which are attracting more and more interest because they have a wide range of potential applications (fibre-optic gyroscopes in the aerospace industry [1], optical coherence tomography in medicine [2] and others) and significant advantages over other types of superluminescent sources (stability of output parameters, low magnetic field and temperature sensitivity and others).

Wide use is now made of SFS’s that employ fibres doped with rare-earth (Er, Tm, Ho and other) ions [3]. The emergence of new and development of existing directions in basic and applied research stimulate a search for gain media suitable for designing SFS’s emitting in hitherto inaccessible spectral ranges. This has led to the advent of SFS’s based on new types of fibre, including bismuth-doped fibre. To date, SFS’s have been demonstrated that emit at wavelengths around 1340 [4] and 1440 nm [5] and utilise phospho- and (low germanium content) germanosilicate fibres, respectively. The optical efficiency and maximum output power of the 1440-nm SFS reached ~30% and 82 mW and those of the 1340-nm SFS reached about 10% and 48 mW, respectively. The emission bandwidth of both SFS’s was 26 – 28 nm.

In this work, we demonstrate a new superluminescent bismuth-doped IR source, emitting in the spectral range 1700 – 1750 nm.

2. Experimental

The gain medium of the SFS was bismuth-doped high-germania silica fibre, such as had been used previously to make an optical amplifier and a number of lasers emitting in the wavelength range 1625 – 1775 nm [6 – 9]. The bismuth-doped fibre preform was produced by MCVD. The preform core contained ~50 mol % GeO_2 and less than 0.1 wt % Bi. The preform was drawn into a single-mode fibre with an outer diameter of 125 μm and a cutoff wavelength of about 1.1 μm. The fibre core diameter was about 2 μm.

The absorption spectrum of the fibre [Fig. 1, spectrum (*1*)] contains two bands, at 1400 and 1650 nm, which were shown previously to originate from bismuth centres with different luminescence bands, centred at 1430 and 1700 nm. Detailed information about the optical properties of such fibres was presented elsewhere [10, 11]. Special mention should be given to the fact that this type of fibre has a low sensitivity to ionising radiation [12], which allows such fibres and related devices to be employed in aerospace engineering.

To obtain luminescence/gain, the fibre was pumped at a wavelength above 1460 nm, which falls within the longer wavelength absorption band. The absorption spectrum of the fibre pumped at a wavelength of 1460 nm by a bismuth-doped fibre laser is also shown in Fig. 1 [spectrum (*2*)]. The pump

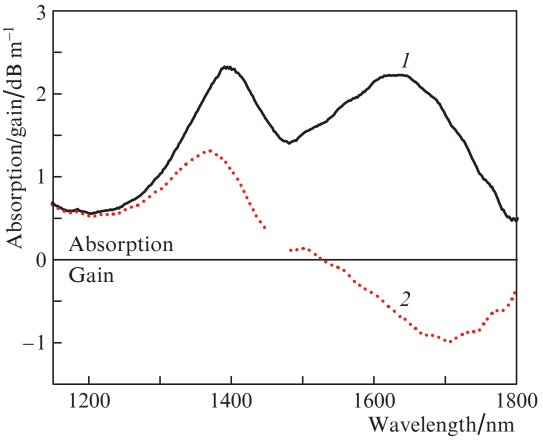

Figure 1. Absorption spectra of the active fibre (*1*) without pumping and (*2*) under pumping at 1460 nm.

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power, 300 mW, was adjusted so as to reach the population inversion limit throughout the length of the fibre. In addition to the absorption region, the spectrum contains an optical gain region. It is seen that the bismuth-doped high-germania fibre ensures an optical gain at wavelengths from 1550 to above 1800 nm. At a pump wavelength of 1460 nm and pump power of about 300 mW, the maximum gain was 1 dB m^{-1} at $\lambda = 1700$ nm.

The fibre was used to produce an SFS in a single-pass, backward pumping configuration (Fig. 2). The length of the active fibre was ~60 m. As a pump source, we used a 1568-nm Er–Yb fibre laser. The pump beam was launched into the core of the active fibre through a 1550/1700 nm wavelength division multiplexing (WDM) coupler. The other end of the fibre was angle-cleaved to prevent back reflection. To prevent lasing and reduce the effect of the return signal on the output parameters of the SFS, a fibre-optic isolator was placed at the output of the device. The fusion splice between the active fibre and SMF-28 standard fibre is indicated in Fig. 2 (the splice loss was ~1 dB). The other fibre splices are not shown because they caused negligible optical losses (under 0.1 dB).

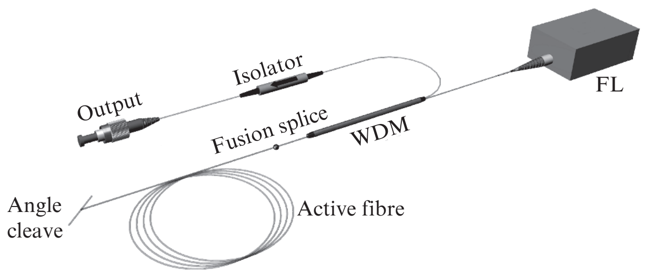

Figure 2. Configuration of the superluminescent bismuth-doped fibre IR source: (FL) Er–Yb fibre laser; (WDM) wavelength-division multiplexing coupler.

Output spectra of the SFS were obtained with an Agilent spectrum analyser (at wavelengths under 1700 nm) and FLSP920 spectrofluorometer (in the range 1700–1800 nm). The output power was measured with an Ophir Nova II power meter equipped with a 3A-FS sensor. All the measurements were made at room temperature.

3. Experimental results

Figure 3 shows emission spectra of the SFS at various output powers (from 0.5 to 7 mW). Note that the emission band is bell-shaped and is well represented by a Gaussian (also shown in Fig. 3). It is seen that both the peak emission wavelength (~1730 nm) and weighted-average wavelength are weak functions of pump power. In contrast, the emission bandwidth of the SFS decreases with increasing pump power. Figure 4 shows the emission bandwidth of the SFS as a function of launched pump power. At the highest output power, the emission bandwidth of the SFS is ~50 nm, which is about twice that of previously demonstrated SFS's based on bismuth-doped fibres.

Figure 5 shows the output power of the SFS as a function of launched pump power. The output power is seen to increase linearly with pump power. The highest power reached was 7 mW (at a pump power of 650 mW). The threshold power was then about 50 mW.

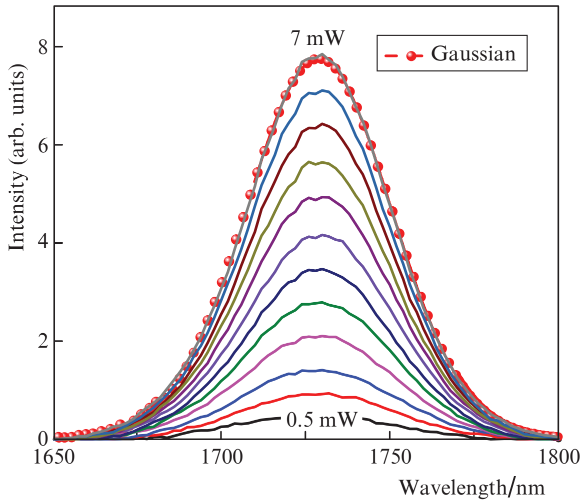

Figure 3. Emission spectra of the SFS at output powers from 0.5 to 7 mW.

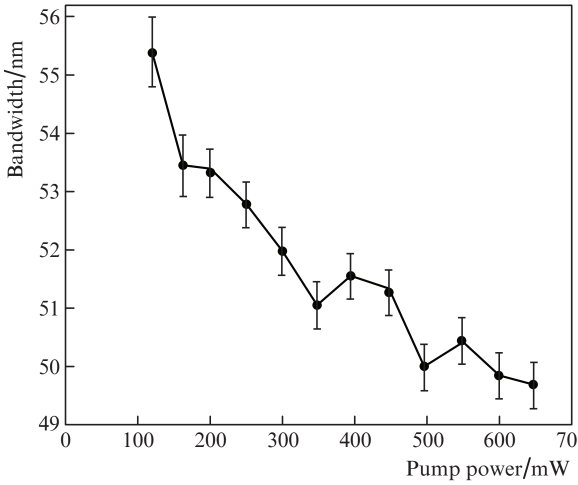

Figure 4. Emission bandwidth of the SFS as a function of launched pump power.

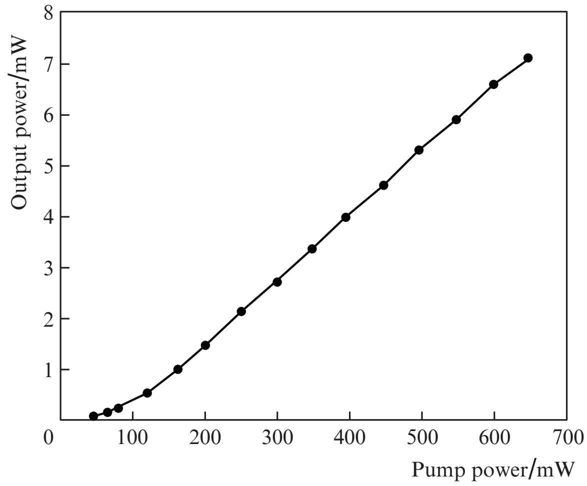

Figure 5. Output power of the SFS as a function of launched pump power.

The optical efficiency of the SFS was about 1%. The main cause of its low efficiency is the high level of bismuth-related unbleachable losses [6] at the signal and pump wavelengths. Improvements in the bismuth-doped high-germania fibre fabrication process and optimisation of the core glass composition will make it possible to create an enhanced performance gain medium for SFS's. Pump wavelength optimisation is also an important issue in improving the efficiency of SFS's.

4. Conclusions

We have presented characteristics of a superluminescent IR (1700–1750 nm) source based on bismuth-doped high-germania fibre. As a pump source, we used a 1568-nm Er–Yb fibre laser. The weighted-average emission wavelength of the SFS is 1730 nm, and its maximum output power reaches ~7 mW at a pump power of 650 mW. The emission bandwidth of the SFS is 50 nm, which is about twice that of existing SFS's based on bismuth-doped fibres.

It is important to note that we have demonstrated only one possible SFS configuration in the spectral range 1700–1750 nm. The configuration can be optimised to meet particular requirements for output characteristics (weighted-average wavelength stability, emission bandwidth, output power, and others).

Future work will concentrate on the stability of SFS output characteristics to ionising radiation, which is important for practical applications.

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