PUMP WAVELENGTH DEPENDANCE OF BISMUTH DOPED FIBRE LASER

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Abstract: We characterize Bi doped fibres in spectroscopic perspective under 915, 976 and 1090 nm pumping. The performance of Bi doped fibre lasers under different pumping bands is correlated to the spectroscopic characteristics. We found that the 915 and 976 nm pumping are not promising for core-pumping configuration because of the presence of pump excited state absorption.

1. INTRODUCTION

Bi doped fibre laser (BiDFL) operating at 1.15-1.21 μm recently received considerable attention as the emission band overlaps with the low-dispersion wavelength region of silica fibre, and is not covered by rare earth doped fibre lasers [1-3]. The creation of fibre laser and amplifier at this spectral region is important for many applications such as optical communications, medicine and astrophysics.

The absorption in Bi doped fibre (BiDF) covers an extremely broad band from 800 to 1090 nm. But the BiDFL demonstrated so far have been limited to the 1080 nm pumping band [1-3]. A laser diode (LD) pumped Yb-doped fibre laser serves as a pump source. Thus, alternative pumping band overlapping the emission band of readily available high power LD will make the BiDFL more compact and cost effective. In this report we examined the Bi spectroscopy under different excitation sources for the purpose of investigating the feasibility of direct LD pumping at 915 and 976 nm in addition to the 1090 nm.

2. EXPERIMENT AND RESULTS

2.1. Fibre fabrication

A BiDF preform with Ge:Al:SiO_2 core composition was fabricated by modified-chemical-vapour- deposition and the solution-doping technique. The preform was drawn into fibre with 125 μm outer diameter and 0.18 peak core NA.

2.2 Absorption measurements

Figure 1 shows the absorption spectra in the Bi fibre, measured by the cut-back technique, using a white light source and optical spectrum analyzer. The small signal absorption was 1.3, 1.8 and 1 dB/m at 915, 976 and 1090 nm respectively. The background loss of the fibre was found to be 40 dB/km at 1285 nm by OTDR (Luciol) measurement.

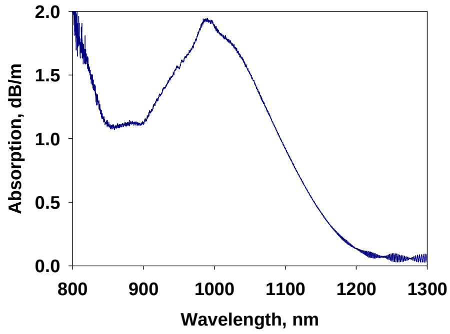

Fig. 1. Absorption spectra of the BiDF.

2.3 Fluorescence measurements

The fluorescence dependence on the pump wavelength was investigated under 915, 976 and 1090 nm pumping. Figure 2 presents the measured fluorescence spectra. Note that the peaks were scaled to unity for comparison. The fluorescence peak shifts towards longer wavelengths and becomes narrower with longer pump wavelengths.

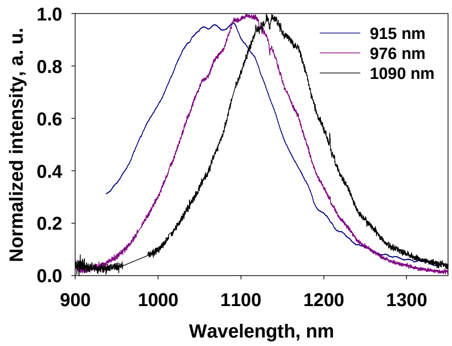

Fig. 2. Scaled fluorescence spectra of BiDF at different excitation wavelengths.

The fluorescence decay time also depends on the pumping wavelength. The recorded time under 1090 nm pumping was 750 μsec, but it reduced to 670 μsec under 915 and 976 nm (Fig. 3.). With the measured fluorescence spectra and decay time, we estimated smaller peak emission cross-sections by 915 and 975 nm pumping than that by 1090 nm pumping.

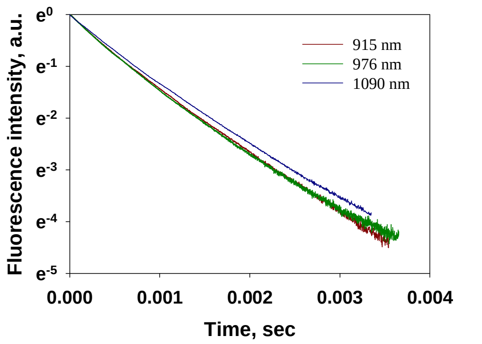

Fig. 3. Fluorescence decay profile of the BiDF at different excitation wavelengths.

2.4 Laser experiments

A. 1090 nm pumping

The BiDFL configuration is shown in Fig. 4. Core pumping configuration was arranged by using an Yb doped fibre laser at 1090 nm as a pump source. A linear with feedback of 4% in output coupling end and 100% in the other end was formed by a perpendicularly cleaved end facet in the signal output port of the WDM and a high reflecting broadband mirror butted to the fibre on the other end of the cavity. The optimum fibre length was 30 m.

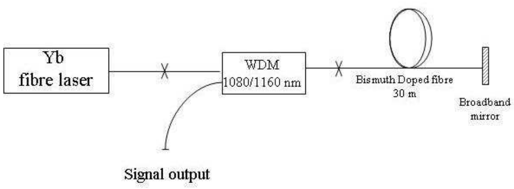

Fig. 4. Experimental set up for BiDFL.

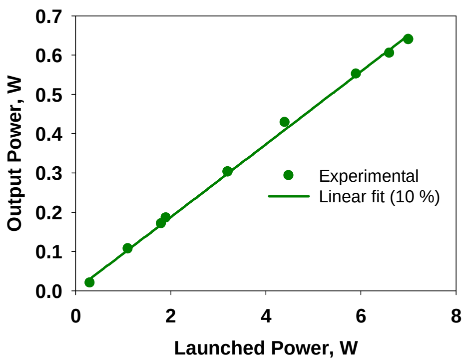

Fig. 5. Output power of BiDFL pumped at 1090 nm.

The fibre showed 10% slope efficiency with respect to the launched pump power (Fig. 5). Figure 6 shows a typical spectrum of 1170 nm BiDFL. The slope efficiency improved to 15% when the fibre was cooled to 10°C. The laser performance is less efficient compared to the well established rare-earth doped fibre lasers. Such poor efficiency can be attributed to the unsaturable loss present in BiDF [3].

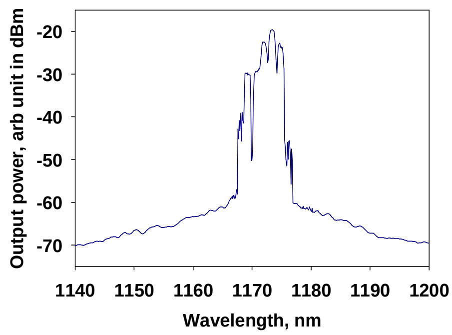

Fig. 6. Output spectrum of core pumped BiDFL at 1090 nm (OSA resolution 1 nm).

B. 976 and 915 nm pumping

Under 976 nm pumping, the same BiDF could not cross the threshold even in a ring cavity with 1 % output coupling. The fibre length was 6 m, permitting 10 dB pump absorption. With maximum available pump power of 250 mW, the fibre failed to oscillate, but exhibited growth of amplified spontaneous emission (ASE) at 1160 nm (Fig. 7).

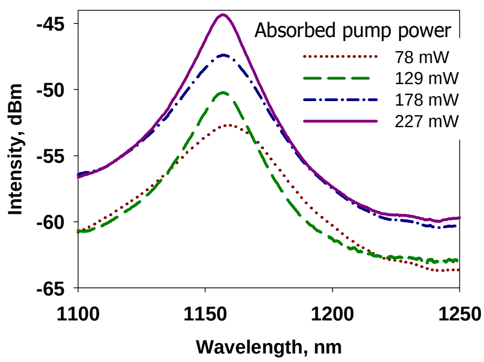

Fig. 7. Emission spectra of BiDF when core pumped at 976 nm.

We observed similar behavior under 915 nm pumping, i.e. growth of ASE but no lasing with the available pump power. The poor efficiency under 915 and 975 nm pumping is somewhat explained by the low emission intensity compared to that by 1090 nm pumping (See Fig. 2).

2.5 Excited state absorption

We aimed to reveal the possibility of existence of the excited state absorption (ESA) by measuring change in transmission with and without bleaching the ground state population. The experimental configuration for the ESA measurement in the BiDFs is shown in Fig. 8. Transmission change in the BiDF from 900 – 1200 nm was determined with an 800 nm pump on and off. A probe beam, white light source, was chopped at 37 Hz, and launched into one end of the BiDF. The transmitted probe beam from the fibre was sent through a monochrometer. An 800 nm Ti:Sapphire laser served as the pump source. Pump light was coupled into the fibre through a dichroic mirror (DM). Saturation in the change in transmission could be observed over 150 mW of the launched pump power. The measurement resolution was 2 nm. A small signal ground state absorption (GSA) was determined by cut-back method between fibre lengths of 2 and 0.8 m with pump off.

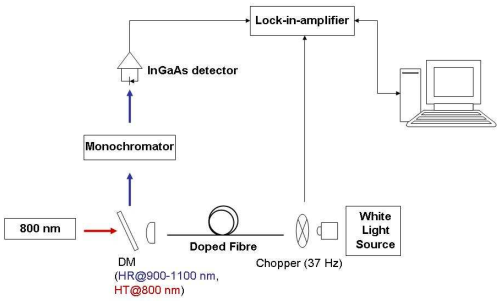

Fig. 8. Experimental set up for ESA measurement under 800 nm pumping.

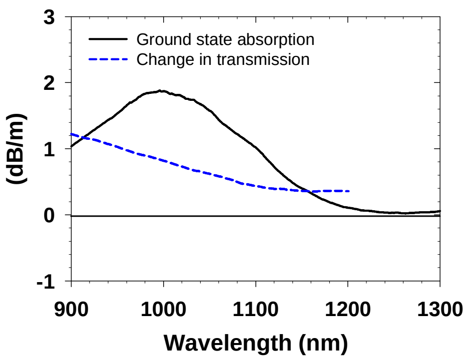

Fig. 9. Measured ground state absorption and changes in transmission in BiDF output spectrum under 800 nm pumping.

The measured change in transmission is determined by [4],

$$\Delta T = -\frac{1}{L}\ln\left(\frac{T_{on}}{T_{off}}\right) = N'(\sigma_{esa} - (\sigma_{gsa} + \sigma_e)) \quad (1)$$

where L is the fibre length, T_{on} and T_{off} are signal transmissions with pump on and off, respectively. N' is a constant accounting for the overlap between the signal and the population in the excited state, and σ_{esa}, σ_{gsa}, and σ_e are cross-sections of excited state absorption, ground state absorption, and emission, respectively. Equation (1) suggests that the ESA is dominant over the sum of σ_{gsa} and σ_e when the change is negative, i.e., when the transmission decreases with the pump turned on. The GSA and change in the transmission are shown in Fig. 9.

Under 800 nm pumping, the ESA is seen to be dominant all over the wavelengths investigated including the Bi emission band. Although the curve of transmission change did not extend to 800 nm, because of the limitation in the DM that covers the 900 nm to 1200 nm range, an increase in absorption at stronger pump power suggested the presence of ESA at 800 nm. The signal ESA on top of the pump ESA makes 800 nm pumping less promising.

The transmission change was also measured under 1047 nm pumping [5]. It revealed the existence of ESA in the band of 900 – 1000 nm, whereas the ESA is absent or insignificant above 1000 nm up to our measurement range, 1200 nm. Thus, the Bi fibre laser achieved under 1090 nm appears to agree with our ESA measurement, in addition to the smaller peak emission cross-sections by 915 and 975 nm pumping.

3. CONCLUSION

BiDF spectroscopy under 915, 976 and 1090 nm pumping schemes was investigated. The fluorescence of the BiDF strongly depends on the pump wavelength. The presence of the ESA at 915 and 975 nm was revealed. The pump ESA together with the strong dependence of the fluorescence contributed to the observed laser efficiency.

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