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Broadband amplified spontaneous emission from Er^{3+}-doped single-mode tellurite fibre*

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This paper reports on the fabrication and characterization of a newly erbium-doped single-mode tellurite glass-fibre applicable for 1.5-μm optical amplifiers. A very broad erbium amplified spontaneous emission in the range 1450–1650 nm from erbium-doped single-mode tellurite glass-fibre is obtained upon excitation of a 980-nm laser diode. The effects of the length of glass-fibre and the pumping power of laser diode on the amplified spontaneous emission are discussed. The result indicates that the tellurite glass-fibre is a promising candidate for designing fibre-optic amplifiers and lasers.

Keywords: amplified spontaneous emission, erbium-doped tellurite fibre, thermal stability

PACC: 0765, 4281, 4255N

1. Introduction

The current trend in advancing optical fibre networks is to increase the system capacity by transmitting multiple channels through a wavelength division multiplexing link. A wide bandwidth optical amplifier is vital to the development of multichannel transmission systems. Compared with the conventional Er^{3+}-doped silica fibre, which is hindered from being used for future dry fibre communications because of its bandwidth limitation (∼30 nm), the rare earth-doped tellurite glass, which incorporates the strong points of wide bandwidth (∼70 nm), wide transmission region (0.35–6 μm), good glass stability, rare earth ion solubility, slow corrosion rate, lowest phonon energy spectrum among oxide glass formers, high refractive index, and high nonlinear refractive index,[1] is now a promising candidate for use in fabricating novel optical amplifiers in the C-, L- and S-bands, and has attracted a great deal of attention.[2−7]

The amplified spontaneous emission (ASE) from Er^{3+} ions in silica glass covers the spectral range of 1520 – 1560 nm for the transition from $^4I_{13/2}$ to $^4I_{15/2}$. Its effective bandwidth, however, could be narrower due to nonuniform nature of the ASE, and the external filters are often required for spectral uniformity. In order to obtain broadband output spectra of ASE ranging from C-band to L-band in Er^{3+}-doped silica fibre, several approaches have been proposed.[8−11] However, these configurations seem a little complex because its experimental setups are always based on a two-stage or two- pump source. Er^{3+}-doped tellurite fibre (EDTF) has a very good gain flatness and broad amplification range in comparison with silica-based fibre.[2−4] Therefore, EDTF as a kind of Er^{3+}-doped fibre can be also used as ASE sources that can make the whole configuration simplified.[12] Although EDTFs with a broad amplification have been proposed,[12,13] thermal stability of the host-glass of EDTF is still an open problem.

In this paper, thermal stability and spectral properties of Er^{3+}-doped tellurite glasses have been investigated to examine whether they are competent for potential optical fibre amplifiers or not. A broad ASE with bandwidth up to 70 nm, which covers C- and L-bands simultaneously, is obtained based on an end

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pumping with a single pass backward (SPB) configuration.

2. Experimental details

2.1. Sample preparation

The core and cladding glass compositions of tellurite glass-fibre are based on TeO_2–ZnO–WO_3 and TeO_2–ZnO–BaO–K_2O–Nb_2O_5–GeO_2 glass systems respectively. Er^{3+}-doped tellurite glasses are prepared using a conventional melt method from powders of reagent-grade TeO_2, ZnO, WO_3, $Ba(NO_3)_2$, Nb_2O_5, GeO_2, K_2CO_3 and Er_2O_3 with more than 99.5% purity. The required quantities of raw materials are mixed and melted in a platinum crucible at 800 °C for 30 min in an electric furnace, and then quenched in preheated stainless steel blocks and annealed at their glass transition temperature for 2 h, followed by ramping down to room temperature.

Tellurite glass-fibre is fabricated by a rod-in-tube technique. An optical microscope equipped with a JVC CCD camera is used to measure the core and cladding diameters of the fabricated tellurite glass-fibres.

2.2. Measurements

Thermal analyses of tellurite glasses are made by using a Netzsch STA 449C Jupiter different scanning calorimeter (DSC) at a heating rate of 10 K/min from room temperature to 700 °C. Thermal expansion coefficients of core and cladding glass are measured by a Netzsch DIL 402 dilatometer at a heating rate of 10 K/min from room temperature to the soft-point, T_f, of the glasses.

Figure 1 shows the experimental setup of the proposed single pass backward (SPB) pumping configuration for C- and L-band ASEs. The SPB pumping configuration consists of a piece of EDTF with an optimal length of a few centimetres, a laser diode (LD) used as a pump source, and a fused wavelength division multiplexer (WDM) combining 980 nm and 1550 nm. The EDTF used in our experiment has a relative refractive index difference of 0.22%, an erbium concentration of 10000 ppm, and a fluorescence decay time of 2.8 ms. One of the ends of EDTF is polished and placed into a standard ceramic ferrule. The other end of the EDTF is cut by ultrasonic incision (YORK FK11), and has an end-pumping with SPB configuration by single mode 980-nm fibre pigtailed LD through a fused wavelength division multiplexer (WDM) combining 980 nm and 1550 nm with 0.5 dB insert loss. The common-port of the WDM is connected with the EDTF by a butt-butt method. The output of the ASE is coming out at the pump input end. The output signal is coupled out of the 1550-nm-port of the WDM. The output spectrum characterizations of ASE are conducted with an optical spectrum analyser (OSA) (Anritsu, MS9710C, Japan). The power output of ASE is measured with a power meter (Ophir, NOVA II, USA). The power of pump source is adjustable and the maximum power output is 107.2 mW. All measurements are performed at room temperature.

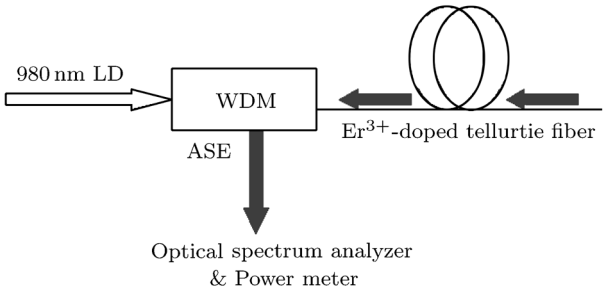


Fig.1. Experimental setup.

3. Results and Discussion

3.1. Thermal properties

The difference between the glass transition temperature (T_g) and the onset crystallization temperature (T_x), $\Delta T = T_x - T_g$, is frequently used as a rough indicator of glass formation ability or glass thermal stability. To avoid any crystallization during fibre drawing, it is desirable for a glass host to have as large ΔT as possible. The transition temperatures of the core and cladding are 361 °C and 374 °C, respectively, indicating both of the glasses exhibit good thermal stability, as shown in Fig.2. These glasses can resist crystallizing under the temperature around soft-point for about 3 h in our experiment.

Figure 3 shows the thermal expansion curves of the core- and cladding-glasses. The core glass has a thermal expansion coefficient of 146.9×10^{-7}/K at T_g, whereas the cladding has a thermal expansion coefficient of 163.3×10^{-7}/K. The difference in thermal expansion coefficient between these glasses is 16.4×10^{-7}/K only. In the rapid cooling process of fibre drawing, the difference in thermal expansion coefficient between the cladding and the core can cause

a residual stress. To avoid any damage due to this stress, the different should be as small as possible.

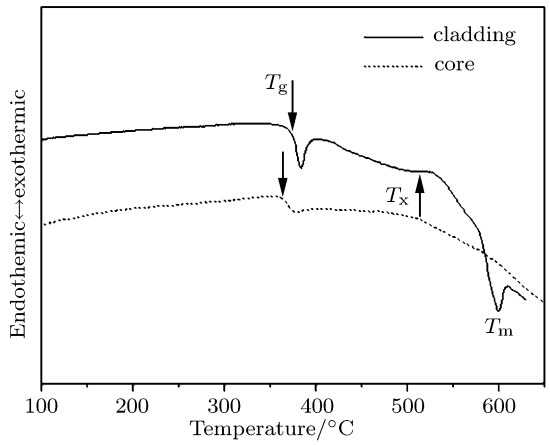


Fig.2. DSC traces of the glasses.

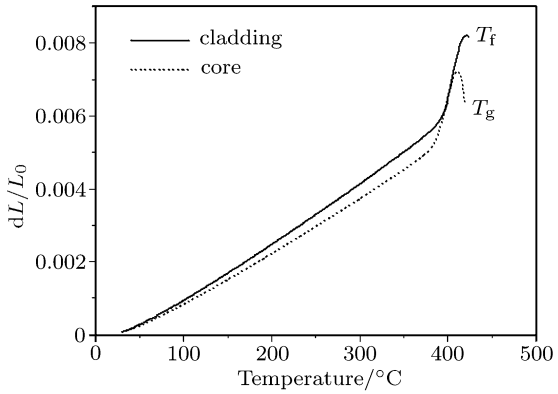


Fig.3. Thermal expansion curve of the glasses.

3.2. ASE spectra

The inset in Fig.4 shows an optical image of the magnified cross-section of the tellurite glass-fibre.

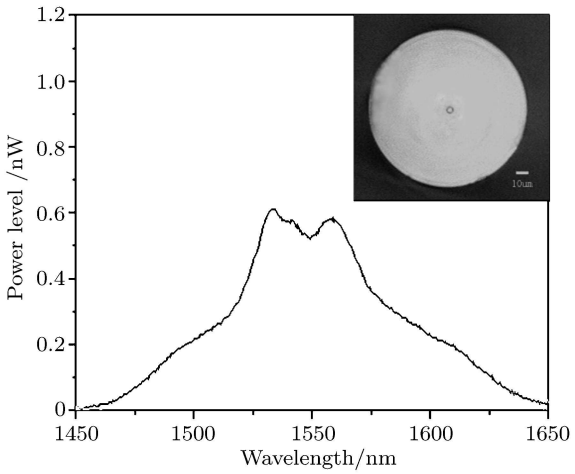


Fig.4. ASE spectra of the EDTF, with an inset showing an optical image of the magnified cross-section of the EDTF.

The fibre exhibits a cladding diameter of 125 μm, a core diameter of 5 μm, and a numerical aperture (NA) of 0.2. The conditions for single mode operation are determined by the normalized frequency ν, which can be given in the case of a step-index fibre by[14]

$$\nu = \frac{\pi d \mathrm{NA}}{\lambda} \leq 2.405, \tag{1}$$

where NA, d and λ are the numerical aperture of the fibre, its core diameter and the operating wavelength, respectively. According to Eq.1, when the fibre has an NA of 0.2, a core diameter $< 6\,\mu$m will be required for single mode operation.

ASE spectra of the EDTF with 6.0-cm length for pumping power of 49.4 mW are shown in Fig.4. A broad erbium ASE of 180 nm has been observed at around 1545 nm upon excitation of a 980 nm LD, covering C- and L-bands from 1450 nm to 1650 nm. The full width of the half maximum (FWHM) bandwidth is about 70 nm, which is broader than the reported results in Ref.[13].

ASE spectra of the EDTF with different lengths and different pumping schemes are shown in Figs.5 (a) and (b), respectively.

Tellurite glass fibres with different lengths have been tested, and all of them are found to be lasing in a range of 1450 – 1650 nm. The results are shown in Fig.5(a). When the pump power is fixed at 79.1 mW, all the output ASE spectra of these EDTF with various lengths display similar features, and the peak wavelengths of these fibres are around 1530 nm. It is noted that the power output of ASE increases with the tellurite glass-fibre length varying from 4 cm to 6.0 cm. However, a slight decrease is observed when the fibre length beyond 6.0 cm, which might be due to the propagation loss of glass-fibre and the fluorescent capture effect.[13] The measured butt-butt coupling efficiency of the end of EDTF with the Corning 1060 fibre is about 10%. The ASE spectra of the Er^{3+}-doped tellurite fibres with 6.0 cm in length at the different pump powers are shown in Fig.5(b). It is noted that the frequency components near the centre of the gain curve experience a higher gain than the components away from the line centre. The fluorescence spectra become narrow with increasing pump power as illustrated and discussed in Refs.[15,16]. The FWHM band of the tellurite glass-fibre decreases by about 25% from 80 nm to 60 nm with increasing the pump power from 18.8 mW to 107.2 mW.

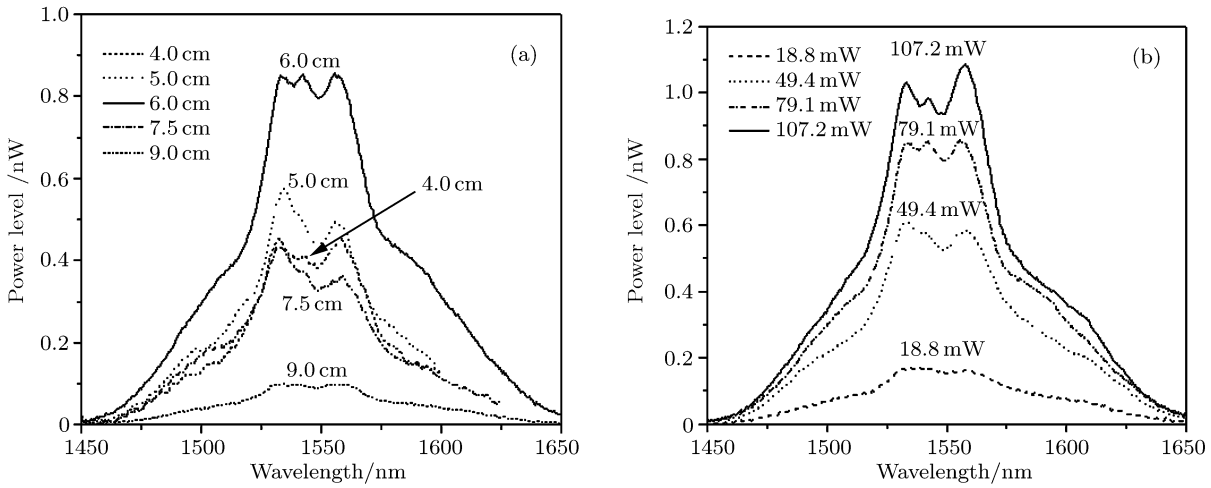


Fig.5. ASE spectra of the EDTF with different lengths (a) and pumping schemes (b).

4. Conclusions

Er^{3+}-doped tellurite single-mode glass-fibres have been prepared, and their thermal stability and spectral properties are investigated. A broad amplification bandwidth with FWHM up to 70 nm from 1450–1650 nm upon excitation of a 980-nm LD has been demonstrated. The advantages of this EDTF are the short EDTF length and the small pumping power required in such an SPB configuration.

Acknowledgments

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