NEARLY 10 dB NET GAIN FROM A THULIUM-DOPED TELLURITE FIBRE AMPLIFIER OVER THE S-BAND

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Abstract *For the first time a net S-band gain of 8 dB, corresponding to a pump-on/pump-off gain of 32 dB, is reported for a Thulium-doped Tellurite amplifier. Advantages with respect to known Fluoride-based fibres are a broader gain spectrum and a fabrication process common to hosts suitable for broadband Erbium operation.*

Introduction

Ultra-wide band optical amplification is a basic resource for high-capacity optical telecommunication networks. Besides the use of Erbium-Doped Fibre Amplifiers (EDFA's) for operation in the C- (1530-1565 nm) and L-bands (1565÷1625 nm), application of Praseodymium-based amplifiers to the O-band (1260÷1360) and of Thulium-doped devices [1] to the S-band (1460÷1530 nm) has been reported in the literature. The use of non-silica, low phonon energy glasses to host rare-earth dopants, make new optical transitions available to optical amplifiers. However, the technology of non-silica glasses is less mature than for silica, and this impacts on the efficiency and reliability of non-silica Optical Fibre Amplifiers (OFA's). In the literature, a triple-band optical amplifier, operating over the S, C and L bands, has been proposed [2]. The device is based on a parallel configuration of an Erbium-Doped Tellurite Fibre Amplifier (EDTFA) and a Thulium-Doped Fluoride Fibre Amplifier (TDFFA) and therefore relies upon the optimisation of two distinct non-silica host matrices. Furthermore, it suffers from a blind region of ~20 nm between S- and C-bands.

This paper describes a solution alternative to [2] and to all recently proposed Thulium-based S-band amplifiers. In the framework of the European research project "LOBSTER" (*Large Optical Bandwidth by amplifier Systems based on Tellurite fibres doped with Rare Earths*), a triple-band OFA has been fabricated, using the same glass matrix, namely a Tellurite glass, to separately host both Erbium and Thulium ions in a parallel-type OFA configuration. Moreover, a broader bandwidth is expected [3] in Thulium-Doped Tellurite Fibre Amplifiers (TDTFA's), and this would improve the spectral coverage of the (S+C+L)-band.

In the following, a description of the active fibre for the TDTFA will be given, followed by a preliminary characterisation of the S-band OFA. To the Authors' knowledge, it is the first time that a TDTFA is demonstrated and that net gain in the S-band from this new type of device is reported; previously, only on/off gain was obtained [4]. With respect to the state-of-art, a gain improvement in excess of 15 dB has been obtained.

Fibre fabrication

Tellurite glasses are batched from high grade commercial powder of purity higher than 99.99%. The clad and core glasses are derived from a ternary composition in mole % of (95-x)TeO_2:xLi_2O:5TiO_2. Glass melting takes place under oxygen atmosphere at a temperature of 850°C for an hour before casting. Preforms and glass tubes are fabricated by extrusion, which is carried out at a low temperature close to the glass transition temperature of ~270°C. Preforms with core to clad ratio between 0.3 to 0.5 are extruded from layered discs. The cladding tubes used to sleeve the preform have an outer diameter of 10 mm and an inner diameter of 1 mm and 4 mm. The sleeving process uses the rod-in-tube technique twice to obtain the fiber dimensions.

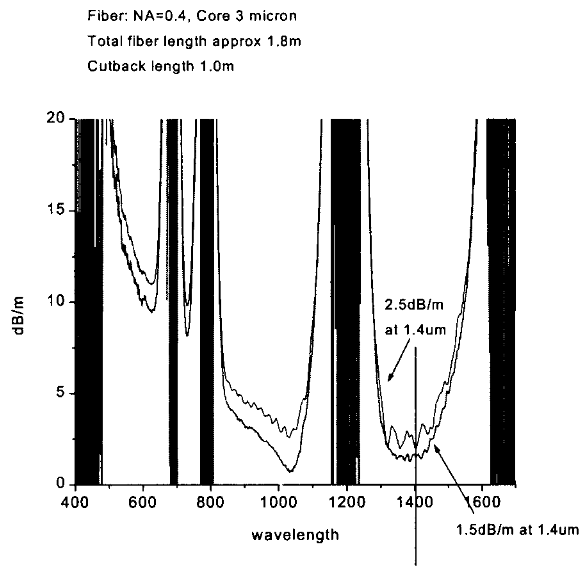

Fig. 1 - Fabrication of Thulium-doped active fibres

The fiber is doped with 4000 ppm of Tm^{3+}, has an NA of 0.4 and a core diameter of 3 µm. We measured a loss of about 2.0 dB/m at 1400 nm (Fig. 1). The parent preform before the final sleeving has a loss of 0.7 dB/m at 1400 nm.

Amplifier structure and characterisation

The TDTFA set-up is as follows. The active fibre is bracketed between input and output coupling devices, each containing an optical isolating component and a modal adapter (i.e., high-NA intermediate silica fibres). The basic pump wavelength is at 1047 nm, for both co-propagating and counter-propagating directions, while an additional pump source at 1605 nm is also used, to improve the ground state absorption of the up-conversion pump power. This solution has been proved useful for TDFFA's [5] and is also supported by TDTFA modelling. Estimated pump power levels into the active fibre are as follows: (i) ~200 mW for the co-propagating wave at 1047 nm; (ii) ~300 mW for the counter-propagating pump at 1047 nm; (iii) ~20 mW for the idle radiation at 1605 nm. Modelling would suggest indeed a better amplifier performance for a combined 795/1064 nm pumping, but suitable sources were not available to the Authors up to now.

The active fibre is 0.8 m long. Its total coupling loss to the line is 6.2 dB; when inserting the active fibre in un-pumped conditions, the total passive insertion loss of the TDTFA is 24.5 dB, due to: (i) resonant ground state absorption between the ground $^3H_6$ and the $^3F_4$ levels, (ii) mechanical coupling of the Tellurite fibre with the external line, performed through the modal adapters, and (iii) fibre background loss. A better fibre is under fabrication, according to the description given in the preceding Section, to get a reduction of ~6 dB in total insertion loss.

A preliminary multi-wavelength characterisation of the TDTFA was done with four optical channels at the nominal wavelengths of 1490, 1500, 1510, 1520 nm; an S-band tunable source will be shortly available for a full spectral investigation. That test would be exciting, since the fluorescence spectrum has a FWHM of ~105 nm around a peak at 1470 nm.

Figure 2 shows the gain at different input power levels: -20, -10 and 0 dBm/ch. For total input power levels below -4 dBm, the TDTFA supplies net optical gain for all envisaged channels. To the Authors' knowledge, it is the first time that practical operation of a TDTFA is reported. The corresponding small-signal pump on/pump off gain ranges from 26.5 to 32 dB. The new active fibre shortly available, should improve the gain performance of at least ~6 dB. An improved transparency also means a more efficient exploitation of the available pump power, resulting into a further increase of the gain values.

Figure 3 shows the channel noise figures. Taking into account the 3 dB input coupling loss, the noise figure could be as low as 5 dB, an interesting value in view of further improvements of the TDTFA structure. Indeed, the problem of coupling silica pig-tails to non-silica fibres has been solved in the literature, and coupling losses below 0.5 dB have been reported [6]. A total output signal power of 8 dBm is obtained in saturation conditions, over a set of channels 20 to 50 nm apart from the gain peak. Taking into account the possibility of reducing total coupling losses down to ~1.5 dB and to decrease the fibre non resonant loss of ~6 dB, a saturation power larger than 15 dBm is foreseen.

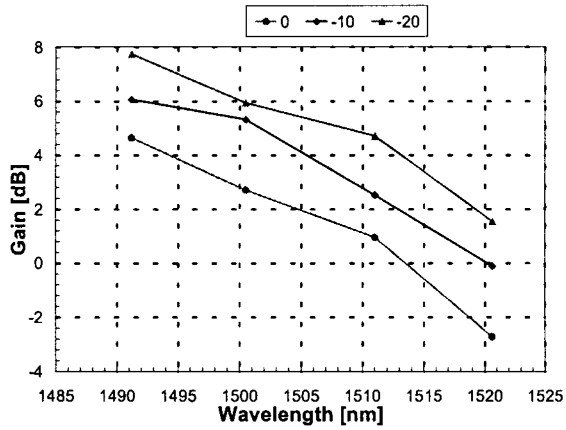

Fig. 2 - Channel gain of the TDTFA

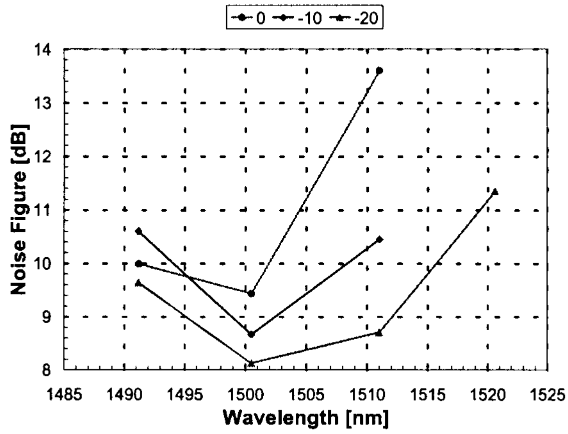

Fig. 3 - Channel noise figure of the TDTFA

Conclusions

To the Authors' knowledge, practical operation of a TDTFA is reported for the first time. Gain values obtained so far (8 dB) and further improvement of active fibre and OFA set-up, demonstrate the possibility of reaching net gain values around 20 dB, with noise figures limited to about 6 dB and saturation powers in excess of 15 dBm.

Acknowledgments

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