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Efficient amplification in the first telecommunications window

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Thulium-doped fluorozirconate fibre can be used as an efficient amplifier over the wavelength range 800–815 nm in the first telecommunications window. A small-signal gain of 23 dB has been achieved at 805 nm with 50 mW of launched pump power at 780 nm. The fibre used for this demonstration had a core diameter of 3.5 μm, numerical aperture 0.16 and thulium ion concentration ∼800 ppm by weight. The background loss of the fibre was measured to be less than 0.1 dB m^{-1}. These results suggest that a high gain 800 nm amplifier employing an AlGaAs diode-pumped thulium-doped fluorozirconate fibre can now be made.

1. Introduction

The advantages of the erbium-doped silica fibre amplifier in the third telecommunications window at 1.5 μm are now so convincingly demonstrated that it is of interest to explore the possibilities for efficient optical fibre amplifiers at other wavelengths. The telecommunications window around 800 nm is particularly important since cheap and efficient AlGaAs sources and detectors are readily available for this region. Two systems offering high-gain amplification in the first window have been reported, the Tm–ZBLAN system described here [1,2], and a system based on Er–ZBLAN which employed a two-step pumping process to give 23 dB gain at 850 nm with 700 mW pump at 801 nm [3]. The pump power requirements of the Tm–ZBLAN system are comparatively modest and it also operates as an efficient laser with good energy storage and a potential tuning range of ∼25 nm. A family of AlGaAs diode/Tm–ZBLAN fibre laser devices can be envisaged which have greatly extended laser capabilities compared with the diodes alone. In this paper, we summarise the amplifier performance which has been realised for a titanium sapphire laser-pumped monomode Tm–ZBLAN amplifier [2] and discuss the prospects for developing a diode-pumped Tm–ZBLAN amplifier.

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2. Experimental details

The fibre used here was fabricated by rotational casting, using cladding glass of the standard ZBLAN composition with PbF_2 added to the core glass to give a refractive index difference of 0.007 (numerical aperture 0.16). The fibre had an LP_{11} mode cut-off wavelength of 0.7 μm ensuring monomode propagation at both signal and pump wavelengths; its core diameter was ∼3.5 μm. In a cut-back experiment, the effective Tm ion concentration was found to be ∼800 ppmwt. This measured number contains the appropriate overlap integral between pump mode and dopant distribution.

In this system, the absorption and emission bands both correspond to transitions between the ^3H ground multiplet and the $^3F_4$ excited multiplet. Decay of the upper level is almost purely radiative in the low vibrational energy fluoride glass host, with a lifetime of 1.1 ms. Rapid thermalisation of the population within multiplets gives rise to a Stokes shift of ~ 15 nm between the emission and absorption bands [2].

To make gain measurements, a 780 nm pump beam was superimposed on a probe beam in a polarising beam splitter and the co-propagating beams launched into the fibre. Independently tunable pump and probe sources were provided by two titanium sapphire lasers. A monochromator was used to separate the emerging pump and probe beams and the ratio of the probe signals recorded with and without the pump beam was measured. To deduce the amplifier gain, it was necessary to subtract the unpumped host losses (background scattering losses and ground state reabsorption losses).

3. Results

Figure 1 shows how the maximum small-signal (< −20 dB m) gain, measured at 806 nm, varied with launched pump power at 780 nm. Slightly in excess of 20 mW launched pump was needed to make this three-level fibre amplifier transparent. For 50 mW launched power, a gain of 22 dB was measured. The variation of small-signal gain with signal wavelength is shown in fig. 2 measured with the launched pump power kept constant at 50 mW at 780 nm. A gain of greater than 10 dB was observed between 800 and 815 nm.

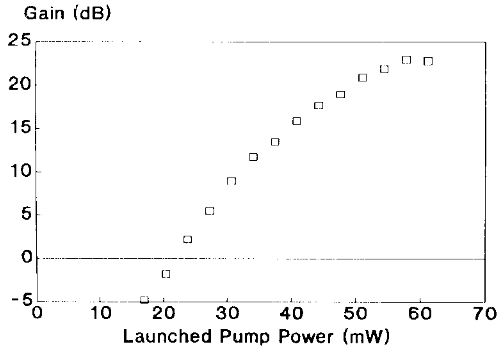

Fig. 1. Small-signal gain at 806 nm as a function of launched pump power for the Tm:ZBLAN fibre amplifier. Fibre length: 3 m; pump wavelength: 780 nm.

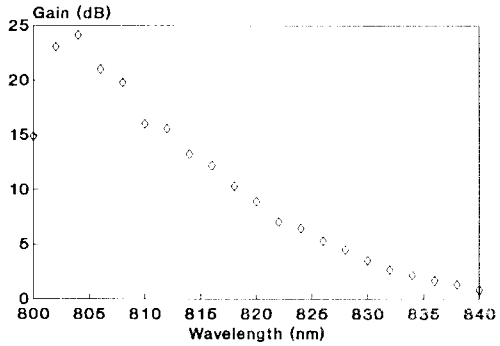

Fig. 2. Small-signal gain spectrum for the Tm:ZBLAN fibre amplifier. Fibre length: 3 m; pump: 50 mW launched at 780 nm.

The data shown here were measured with a 3 m length of fibre in which all but a few per cent of the launched pump light was absorbed.

4. Discussion

While the results achieved so far indicate that high gains can be achieved with reasonable efficiencies, the viability of the Tm–ZBLAN system as a practical amplifier in the first telecommunications window hinges on the realisation of a diode-pumped system and it is to this end that work is now proceeding. A 100 mW diode (SDL 5412) which provides diffraction-limited output at 785 nm has been used to pump the Tm–ZBLAN fibre. Detailed studies of diode–fibre coupling have been undertaken, resulting in a launch efficiency of 58%. A potential hazard of the 'in-band' pumping scheme is that, since the pump and signal wavelengths are so close, any intensity fluctuations at the signal wavelength, such as relaxation oscillations, will be transmitted back along much the same optical path as the pump and, if sufficiently intense, may cause damage to the laser facet.

Some improvement to the amplifier performance achieved to date may be possible through careful choice of fibre parameters. These must be chosen to achieve good overlap of the pump and signal beams with the doped region, to obtain a high power density in the core, and to enable efficient coupling of the diode laser to the fibre core. Indeed, the high amplifier efficiencies reported for the erbium-doped fibre amplifier (for the third telecommunications window) were achieved with numerical apertures about three times that of the fibre used here.

A significant fraction of population accumulates in $Tm(^3H_4)$ which has a measured lifetime of 6.4 ms, and the effect which this has on the amplifier performance has been investigated using a small-signal rate equation model. One effect of population storage in this level is that a greater length of fibre is required to achieve the greatest possible gain for a given pump power. It has been calculated that, for 60 mW pump power, the optimum fibre length (430 cm) is 35% greater than the value which would be predicted if the population of $Tm(^3H_4)$ were to be rapidly quenched.

5. Conclusion

An efficient Tm^{3+}–ZBLAN fibre amplifier operating around 800 nm has been demonstrated. A measured small-signal gain of 23 dB at 805 nm has been achieved with 50 mW of launched pump power at 780 nm. The prospects for improving this performance, and for realising a practical amplifier for the first telecommunications window have been discussed.

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