THULIUM-DOPED TELLURITE FIBER FOR S-BAND AMPLIFICATION

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Abstract: *Spectroscopy measurements and the first demonstration of fiber gain in thulium doped tellurite for S-band amplification is reported. The gain extends to longer wavelength than in fluorides showing improve overlap with the C-band EDFA.*

Introduction

The addition of new WDM amplification band is required to meet the rapid increase in data transmission. Thulium-doped fluoride fiber amplifiers have been reported to allow amplification in the S-band from 1480-1500nm. In this paper, we report on the spectroscopy and gain measurements in thulium(Tm^{3+}) doped tellurite glass.

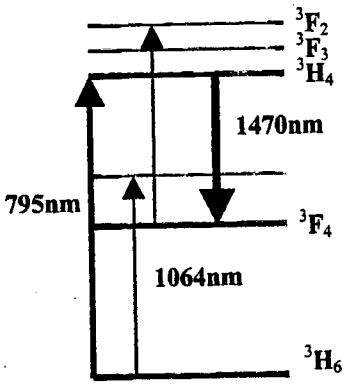

Figure 1: Tm^{3+} energy level diagram

From Figure 1, two considerations are crucial for the development of an efficient amplifier for operation at 1470nm; (i) a high quantum efficiency and (ii) a large population inversion between the $^3H_4$ and $^3F_4$ states. To obtain a high quantum efficiency, a glass with a phonon energy of ≈750cm^{-1} is required. The average phonon energy of our glasses from Raman measurements is ≈700cm^{-1}. Fluorides have a lower phonon energy but unfavorable due to a lack of glass stability and chemical durability. The 1470nm transition is self-terminating unless the $^3F_4$ level is depopulated. Several pumping schemes have been proposed and demonstrated to achieve a large population inversion[1-3]. The simplest pump scheme involves direct pumping at 795nm from the ground state $^3H_6$ to the upper $^3H_4$ state. The pump efficiency is high and the source is readily available. However, by incorporating a second pump source at 1064nm[1] or 1400nm[2], which have a large excited state absorption from the $^3F_4$ level, a larger population inversion between the levels $^3H_4$ and $^3F_4$ can be achieved by the removal of ions from the $^3F_4$ state and allowing the repopulation of the $^3H_4$ state.

Absorption and emission measurements

Tm^{3+}-doped tellurite glasses with ABT composition in mol% of : $xA_2O+yBO_2+zTeO_2$ have been melted in our laboratory. *A* is an alkali ion, the oxide up to 40% while *B* is a stabilizer ion, the oxide up to 10% and *z* is 40-90%. The glasses produced were clear with a light green colour. The composition presented here is LTT: $25Li_2O+5TiO_2+70TeO_2$[4]. Based on DTA measurement, the glass transition temperature is ≈270°C and there is no apparent crystallization.

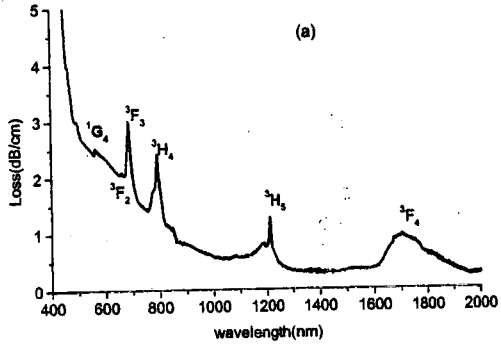

Figure 2: (a)Absorption spectra of Tm^{3+} in LTT glass uncorrected for baseline; (b)emission spectra

Figure 2(a) shows the absorption spectrum measured using a UV spectrophotometer. Of significance is the absorption at 795nm which is a wavelength available from a Ti:Sapphire laser. Fluorescence signal, measured at 90° to the pump light, is fed into a Chromax monochromator and collected by an InGaAs detector. Figure 2(b) shows a series of fluorescence emission spectra as a function of Tm^{3+} concentration. The curves are normalised to the peak at 1470nm. The fluorescence profile is independent of concentration. The full width at half maximum is ≈105nm which is at least 30nm broader than that reported in ZBLAN[3].

Fluorescence liftetime measurements

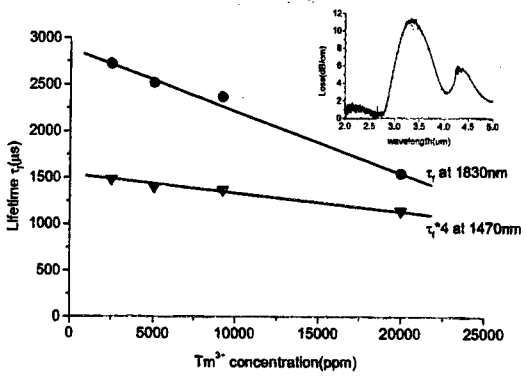

Figure 3: Fluorescence lifetime of $^3H_4$ and $^3F_4$ levels

The fluorescence decay from the $^3H_4$ and $^3F_4$ states were monitored on a Tektronix oscilloscope. The system response was 20μs. The results are shown in Figure 3. A few points are highlighted as follows: firstly, the lifetime of both the $^3H_4$ and $^3F_4$ states decreases with increasing Tm^{3+} concentration. The effect is more dramatic in the latter case due to OH aided concentration quenching. The inset shows that the OH fundamental is at 3300nm. The OH first overtone is expected at 1650mm. Secondly, the measured lifetime of the $^3H_4$ level for 2500ppm of Tm^{3+} is 370μs. Based on the Judd-Ofelt model, the calculated radiative lifetime was 380μs which results in a quantum efficiency of ≈97%. Thirdly, the lifetime of the $^3F_4$ state is approximately seven times longer than that of the $^3H_4$ state due to a larger energy gap between $^3F_4$-$^3H_6$(5860cm^{-1}). A major drawback is that the $^3H_4$-$^3F_4$ transition is a self-terminating process. To improve the population inversion between the two levels, alternative pumping schemes to depopulate the $^3F_4$ state such as upconversion using a single or dual pump scheme or codoping Tm^{3+} with an acceptor ion such as holmium(Ho^{3+}) need to be considered. Ho^{3+} is a good candidate as a codopant because it has no absorption at 795nm(pump) and 1470nm(signal). Our results on a 2000ppm Tm^{3+}-Ho^{3+} codoped LTT glass shows a 33% reduction in the lifetime of the $^3F_4$ state without affecting the lifetime of the $^3H_4$. It is estimated that a Ho^{3+} concentration of 10,000ppm is required[5].

Gain measurements

A singlemode tellurite fiber doped with 4000ppm of Tm^{3+} with a NA of 0.17 and a core diameter of 4.8μm was fabricated. The background loss is 8.5dB/m at 1.4μm. Gain measurements were performed on a 26.8cm length of fiber using a dual pump scheme. The pump sources used consisted of a Ti:Sapphire laser as a pump source at 795nm and a Nd:YAG source at 1064nm. An external cavity HP tunable laser diode between 1480nm and 1550nm was used as the signal source. The estimated pump power incident on the fiber core was ≈75mW at 795nm and ≈65mW at 1064nm whilst the signal input power was maintained at –22dBm. Figure 4 shows the internal gain using the 795nm only(∇) and the dual pumping scheme using 795nm and 1064nm(•). It illustrates the improvement obtained using the dual pumping scheme. According to the fluoride data, the ground state absorption cross section from $^3H_6$ to $^3H_4$ is comparable to the excited state absorption cross section from $^3F_4$ to $^3F_2$ [6]. In general, the advantage of this pumping scheme allows for a shorter length of fiber to be used as exemplified here. More significantly, the gain in tellurite extends by at least 15nm to longer wavelength than that reported in fluoride, which enables improved overlap with conventional EDFA(C-band).

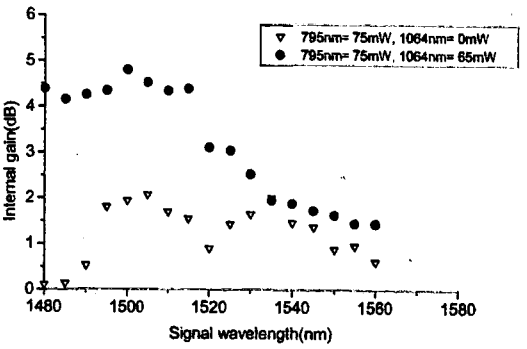

Figure 4: Gain profile of a Tm^{3+}-doped fiber

Conclusion

Spectroscopy measurements on Tm^{3+}-doped LTT glass have been presented. This glass offers advantages from an amplifier point of view. The 1470nm transition is ≈97% radiative, the glass can accept large dopant levels and the effect of OH quenching is minor. In addition, the fluorescence centered at 1470nm is broader than in fluorides. In comparison to fluorides, the expected gain in tellurite is three times smaller primarily due to its shorter lifetime. However, as presented here, tellurite glass has the advantage of a broader gain profile consistent with its broader fluorescence which extends into the C-band of EDFA for potential broadband WDM application. Higher gain comparable to fluorides can be achieved in tellurite fibers with fiber optimization, use of higher pump powers and more efficient pump schemes.

Acknowledgement

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