Line Shape Effects in the Operation of Thulium and Erbium Doped Fiber Amplifiers

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Abstract. This work describes the effect of Gaussian line shape on the comparison of the amplification characteristics (gain) and the Noise figure (NF) of the Thulium and Erbium in the host materials which the Yttria Alumina-Silica glass. The gain using this host material covers the range 1.45-1.65 μm. Thulium-doped fiber amplifiers operated in the region of wavelength (1480-1510 nm) which is called S-band. The main pump source is 1.04 and 1.55 μm which creates population inversion between 3F4 (upper laser level) and 3H4 (lower laser level), and Erbium-doped fiber amplifiers operated in the region (1510-1650 nm) which is called L –band with the pump wavelength 980 nm. It is found that the erbium doped yttria-alumina silicate fiber amplifier exhibits a maximum gain of 40.3 dB at the central wavelength 1540 nm and minimum noise figure 14 dB, but the broadening in the gain curve is 20 nm. Also it is found that the thulium doped yttria-alumina silicate fiber amplifier exhibits a maximum gain of 27.5 dB at the central wavelength 1467 nm and minimum noise figure 2.5 dB, with the broadening in the gain curve is 41 nm. Gain flatness was investigated and the results strongly confirm the feasibility of using this hosts’ glass doped with Thulium in practical ultra large capacity wavelength division multiplexing networks.

1. Introduction

In wavelength division multiplexing (WDM) systems, overall transmission capacity depends significantly on the spectral characteristics of the optical amplifiers, such as flatness, bandwidth, and the magnitude of the gain. Erbium-doped fiber amplifiers (EDFAs) have provided an efficient optical gain in the 1.5μm communication windows in conventional single-mode fibers (SMF) [1]. When the population is highly inverted, the stimulated emission cross section of erbium ions in silica provides ample gain over the 1520-1560 nm range, called the conventional band or C band. Increasing demands on the capacity of WDM transmission system now require newly developed transmission windows beyond the amplification band


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width supported by erbium doped fiber amplifiers (EDFAs). So Thulium doped fiber amplifiers (TDFAs) for S-band have been studied extensively in recent years, as the candidates for the next generation amplifiers competing with promising L-band EDFA’s, Raman amplifiers [2], [3]. Thulium doped fiber amplifiers are promising amplifiers for the 1400 nm band, they are reported to have high gain and low noise characteristics in the 1450-1480 nm region [4]. Thulium-doped fiber amplifiers (TDFAs) are a promising candidate for the S-band amplification because the amplification bandwidth of the T DFA is centered at 1470 nm [5], which falls within the S-band. A 1050 nm pumping scheme can be used to obtain the population inversion in a Thulium-doped fiber (TDF) [6]. The TDF length and pump power are the important parameters that determine the attainable gain and noise figure in T DFA, which provides gain in the S-and S+ band for such systems. Many different pumping schemes have been proposed to exploit the complex energy level transitions of Thulium in the -band, either by single-wavelength up conversion pumping or dual-wavelength pumping [8]. The most efficient scheme has been a combination of 800 and 1050 nm, which takes advantage of the strong ground state absorption (GSA) at 800 nm [8]. However, it has been reported in [8] that GSA in thulium at 690 nm is even stronger than that at 800 nm.

2. Model
The mathematical model for erbium and thulium was given in Refs. [9, 10].

3. Results and discussion
The emission and absorption cross section data fitted to Gaussian shape for both erbium and thulium in yttria glass are given in Tables 1 and 2, respectively.

| Table I: The emission and absorption for erbium doped yttria fiber |
|---------------------------------------------------------------|
| (i) | $a_i$ | $\lambda$(nm) | $\Delta\lambda$(nm) | $a_i$ | $\lambda$(nm) | $\Delta\lambda$(nm) |
|-----|-------|----------------|---------------------|-------|----------------|---------------------|
| 1   | 0.03  | 1462           | 50                  | 0.05  | 1462           | 30                  |
| 2   | 0.10  | 1499           | 42                  | 0.20  | 1482           | 35                  |
| 3   | 0.26  | 1525           | 32                  | 0.24  | 1499           | 36                  |
| 4   | 0.57  | 1533           | 11                  | 0.43  | 1522           | 34                  |
| 5   | 0.555 | 1553           | 31                  | 0.42  | 1532           | 13                  |
| 6   | 0.02  | 1561           | 10                  | 0.40  | 1547           | 30                  |
| 7   | 0.17  | 1586           | 60                  | 0.15  | 1562           | 30                  |

| Table II: The emission and absorption for Thulium doped yttria fiber |
|---------------------------------------------------------------|
| (i) | $a_i$ | $\lambda$(nm) | $\Delta\lambda$(nm) | $a_i$ | $\lambda$(nm) | $\Delta\lambda$(nm) |
|-----|-------|----------------|---------------------|-------|----------------|---------------------|
| 1   | 2.674 | 1732           | 25.1                | 0.6557| 1451           | 65.67              |
| 2   | 6.303 | 1761           | 65.08               | 2.47  | 1601           | 58.12              |
| 3   | 6.299 | 1701           | 24.54               | 0.7948| 1784           | 168.2              |
| 4   | 6.001 | 1788           | 103.7               | 3.004 | 1662           | 89.62              |

Figures 1 and 2 show the absorption and emission Gaussian fitted values for the erbium and thulium doped yttria alumina silicate glass fiber amplifier, respectively.
Figure 1. Absorption and emission cross section with Gaussian fitted values for erbium doped yttria alumina silicate glass fiber amplifier.

Figure 2. Absorption and emission cross section with Gaussian fitted values for thulium doped yttria alumina silicate glass fiber amplifier.

Figure 3 shows the gain in dB as function of the signal wavelength in nm at input pump power 100mW (for Tm, the second pump [dual pump] 1550 pump power also at 100mW) and fiber length 34 m for both Er and Tm doped tellurite glass fiber amplifier. From the figure the central wavelength for Er is 1530 nm at which the gain maximum 20 dB, with bandwidth 20 nm, while for Tm the central wavelength is 1474 nm at which the maximum gain is 9.29 dB with bandwidth 42 nm, this mean that erbium doped gives higher gain than thulium doped but the gain flatness in thulium is higher than erbium for the same glass fiber doped.
The gain spectrum for Er and Tm doped tellurite glass fiber amplifier is shown in Figure 3. From the figure, the noise figure is 2.38 dB at the central wavelength 1474 nm for thulium doped while 8 dB at the central wavelength 1530 nm for the erbium doped tellurite glass fiber amplifier. Finally, the noise figure as a function of the pump power at 34 m fiber length for the two signal wavelength 1530 and 1474 nm for both Er and Tm doped tellurite glass fiber amplifier respectively is plotted in Fig.4. As in figure, the noise figure decreases with pump power increases for both erbium and thulium but the decrease in noise for erbium is higher than thulium doped with the given glass.

4. Conclusion
In this paper, we studied the amplification characteristics (gain) and the Noise figure (NF) of the Thulium and Erbium in yttria host materials through the cross section calculation using Gaussian fitting. The gain using these host material covers the range 1.45-1.65 μm. It is found that the erbium doped yttria-alumina silicate fiber amplifier exhibits a maximum gain of 40.3 dB at the central wavelength 1540 nm and minimum noise figure 14 dB, but the broadening in the gain curve is 20 nm. Also it is found that the thulium doped yttria-alumina silicate fiber amplifier exhibits a maximum gain of 27.5 dB at the central wavelength 1467 nm and minimum noise figure 2.5 dB, with the broadening in the gain curve is 41 nm.

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