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Original research article

Performance evaluation of S-band Thulium doped silica fiber amplifier employing multiple pumping schemes

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ABSTRACT

Gain of Silica Thulium doped fiber amplifier (TDFA) is limited due to high phonon energy of Thulium ions. In this paper the gain performance of Silica based TDFA has been compared for 1050 nm, 1050 nm + 800 nm, 1050 nm + 1400 nm and1050 nm + 1400 nm + 800 nm pumping schemes. The gain enhancement of 6.5 dB in triple pumping scheme (1050 nm + 1400 nm + 800 nm) as compared to dual pumping (1050 nm + 1400 nm) and 14.5 dB enhancement than the 1050 nm single pump has been observed. In the wavelength region 1455 nm–1490 nm, the observed gain triple pumping is more than 20 dB with noise figure less than 5 dB, the maximum gain obtained is 26.5 dB at 1470 nm.

1. Introduction

The requirement of bandwidth expansion can be fulfilled by the seamless integration of S-band with C-band. The dominance of C-band optical systems is due to the availability of established amplification methods using EDFA (Erbium doped fiber amplifier), RAMAN amplifier, SOA (Semiconductor optical amplifier) and hybrid amplifiers [1–7]. In the wavelength region of 1460–1520 nm (S-band), TDFA and its hybrid configurations are the main amplification media [8]. TDFA in silica host is very easy to splice with normal silica fibers, but it yields a low gain at low and medium pump powers because of the high phonon energy of thulium in silica host [9,10] That is why TDFA in fluoride host is used in most of cases due to the fairly low phonon energy of thulium in fluoride host [11–16]. Low phonon energy leads to a high efficiency of the fluoride TDFA. Although the gain is high, Fluoride TDFAs are toxic in nature, inharmonious and difficult to splice with the commercial silica fibers [10]. Other limitations of fluoride glasses are their poor chemical resilience and prerequisite of the stringent manufacturing process to avoid crystallization [17]. It is crucial that the silica-based thulium doped fiber be improved to achieve high gain at low pump powers. Previously pumping schemes like 1050 nm [18], 690 nm, 1050 nm or 1400 nm[12], 1050 nm [9], 1550 + 980 nm, 1047 + 980 [19], 1064 nm [20], 1050 nm + 800 nm [21], 1410 nm and 1047 nm [10], 1050 nm, 1400 nm, 800 nm [22], have been reported by the researchers. The carefully worked-out model of thulium doped fiber amplifier in the silica host was presented by P. Peterka et al. [18], in their work they reported maximum gain of 20 dB with the single pump of 1064 nm having 2000 mW power. The gain performance of single pumping can be compared with the dual pumping and triple pumping. This paper is based on model presented by P. Peterka et al. [18] but compares gain for 1050 nm, 1050 nm + 800 nm, 1050 nm + 1400 nm and1050 nm + 1400nm + 800 nm pumping schemes. This paper is organized into five sections. First section covers the brief introduction of the paper. In second section, theoretical background with the model

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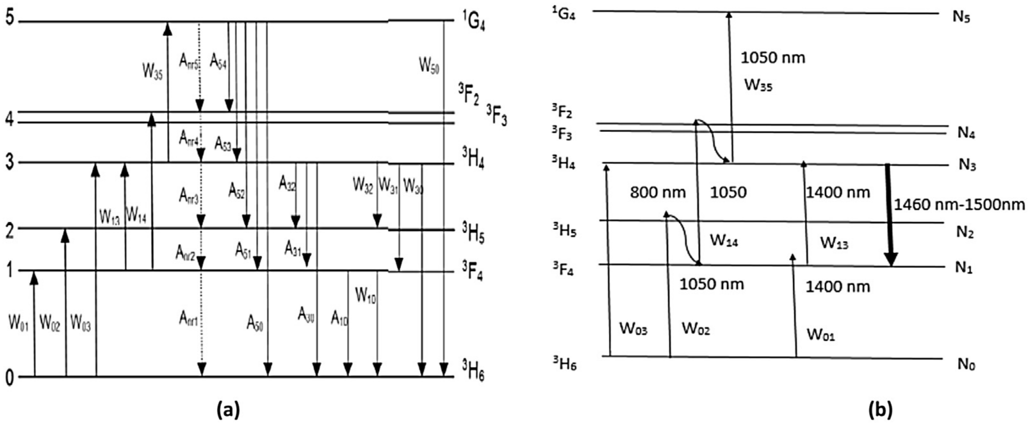

Fig. 1. (a): Detailed energy level diagram of Thulium [14], (b) Energy level diagram of TDFA with triple pumping (1050 nm + 1400 nm + 800 nm) [22].

used in the paper is described. The system setup used for the simulation is presented in the third section, the results and the conclusion are discussed in section four and five respectively.

2. Theoretical background

Fig. 1(a) shows a detailed energy level diagram of thulium ions [14]. Level $^3H_6$,$^3F_4$,$^3H_5$,$^3H_4$,$^1G_4$ are designated as level 0,1,2,3,5 respectively, the $^3F_2$ and $^3F_3$ levels are labeled combined as level 4 due to their proximity. The population of level 2 and level 4 can be neglected because of the high decay rates. Fig. 1 (b) shows the energy level diagram of Thulium ions for all the three pumps.

The pump of 1050 nm excites the electrons from $^3H_6$ level to $^3H_5$ level. The electrons in $^3H_5$ level have very low lifetime, so they quickly migrate to $^3F_4$ level by non-radiative transition, then the electrons from $^3F_4$ level get raised to $^3F_3$/$^3F_2$ (low lifetime) by absorbing 1050 nm pump. Finally electrons reach to the stable $^3H_4$ level by non-radiative transition. A few electrons get upraised from $^3H_4$ level to $^1G_4$ level with the absorption of 1050 nm pump, but they eventually return back to $^3H_4$ level by non-radiative emission. Likewise the absorption of 800 nm pump results in the transfer of electrons from ground level to $^3H_4$ level. The 1400 nm pump raises electrons from $^3H_6$ level to $^3F_4$ and then from $^3F_4$ to $^3H_4$ level. In this manner, all the three pumps create a population inversion by shifting electrons to $^3H_4$ level.

The rate equation can be written as proposed by P. Peterka et al. [18].

$$\frac{dN1}{dt} = N0.(W01 + W02) - N1.(W10 + W13 + W14 + Anr1 + A10) + N3.(W31 + W32 + Anr3 + A32) + N5.(A51 + A52) \tag{1}$$

$$\frac{dN3}{dt} = N0.(W03) + N1.(W13 + W14) - N3.(W35 + W32 + W31 + W30 + Anr1 + A32 + A31 + A30) + N5.(Anr5 + A54 + A53) \tag{2}$$

$$\frac{dN5}{dt} = N0.(W05) + N3.(W35) - N5.(W50 + Anr5 + A54 + A53 + A52 + A50) \tag{3}$$

$$\mathrm{AndNt} = \mathrm{N0} + \mathrm{N1} + \mathrm{N3} + \mathrm{N5} \tag{4}$$

In the above equalities $N_{0,}$ $N_{1,}$ $N_{3,}$ $N_{5,}$ are the population densities of ${}_3H^6$, ${}_3F^4$, ${}_3H^4$, ${}_1G^4$ levels respectively and N_t is total electron density, W_{ij} is the stimulated absorption and emission rates from level i to j. The radiative and non-radiative decay rates are symbolized as A_{ij} and A_{nrj} respectively. It has been presumed that the thulium ions are excited consistently across the fiber cross-section. The transition rates W_{ij} can be defined by. [15]

$$W_{ij}(z) = \int_0^\infty \frac{\sigma_\nu(\nu)}{h.\nu}.I(z,\nu).d\nu, \tag{5}$$

Where $I(z,\nu) = i(r,\phi,\nu).P_k(z)$