The Gain performance of Ytterbium Doped Fiber Amplifier

PAREKHAN M. JAFF
Department of Physics, College of Science, University of Sulaymania, Kurdistan Region, Iraq

Abstract
Ytterbium doping provides high capacity for producing large gain per unit length, and versatility in pump optimization for a given gain length .The paper presents gain characteristic of Ytterbium doped Fiber Amplifier in terms of amplifier length, Yb ion density, pump power and signal power at pump wavelength λp =910 nm and signal wave length λs =975 nm s.
A maximum gain of (39, 37 and 33dB) obtained for pump powers (150, 100 and 50 mw). The gain occurs over short length (tenth of centimeters) of the amplifier and increase with increasing Yb ion density. It begins to be moderately saturated when ion concentration exceeds 1.3 e+025. After certain pump power gain values become saturated while it decreases rapidly by increasing signal power. As a result of laboratories unavailability in the region the layout done by using Optisystem 8.0 software simulation (Optical Amplifier and Communication System Design Software)

Keywords: Ytterbium Doped fiber Amplifier (YDFA), Gain characteristic of YDFA, Optical Amplifier.

I. INTRODUCTION

S INCE its invention in 1985, the erbium-doped fiber amplifier [1], [2] (EDFA) has attracted great interest, principally by virtue of its major commercial applications in the field of communication technology. However, the use of
EDFAs have not been confined to telecommunications and there has been steadily growing interest in, for example the amplification of pulses to provide a source of very high peak powers. In such a context where the specific wavelengths advantage of the EDFA for telecommunications is no longer relevant, amplifiers based on other rare-earth dopants offer themselves for consideration. Ytterbium-doped fibers are a case in point, and while they have so

far been used mainly as lasers [4], [5] their ability to provide amplification over the very broad wavelength range from ~975 nm to ~1200 nm is expected to generate increasing interest in the new future.
A part from their broad gain bandwidth, Yb-doped fiber amplifiers (YDFAs) can offer high output power and excellent power conversion efficiency. Many of the complications which are well known from EDFAs are avoided. The high doping levels are possible leading to a high gain in a short length of fiber. The broad band-width is ideal for the amplification of ultrashort pulses, and the high saturation flounce allows for high pulse energies.

Given the growing interest in YDFAs, this paper is aimed at a general discussion of aspects of YDFAs that are of relevance. to potential users. While many of the general features of EDFAs, which have been treated very extensively in [5] and [6] are common to YDFAs, nevertheless there are also significant differences that need to be emphasized in this paper. The most obvious are the differences in spectroscopic features which are reviewed in section I.I and III.A. We have specified the relation between gain and Yb ion density for different fiber lengths in section III.B. The change of gain with amplifier length at different pump powers , the relation between signal gain and signal power at different pump powers are provided in sections III.C and III.D respectively .In Section III.E the relation between signal gain and pump power at different values of signal power is determined .

1.1 Spectroscopic properties of Yb^{3+}

The unique feature of the rare-earths including ytterbium is that their inner 4f shell is not completely filled and optical transitions within its sublevels can occur. The energy level diagram of Yb ions is very simple, except the $^2F_{7/2}$ level the Ytterbium ion has only one level $^2F_{5/2}$. Therefore the absorption spectrum of Yb^{3+} doped fibers consist of only one absorption band which has a complicated shape due to stark splitting [1].
Since the gain depends on both the absorption and emission cross sections, the cross-section of absorption and emission of Yb ions for different wavelengths is shown in (Fig1) it seems that the Yb

ions has a maximum cross section of emission around 975 and 1030 nm, and a maximum cross section of absorption around 910 and 975nm, the broad absorption allows an expanded choice of pump wave length [7].

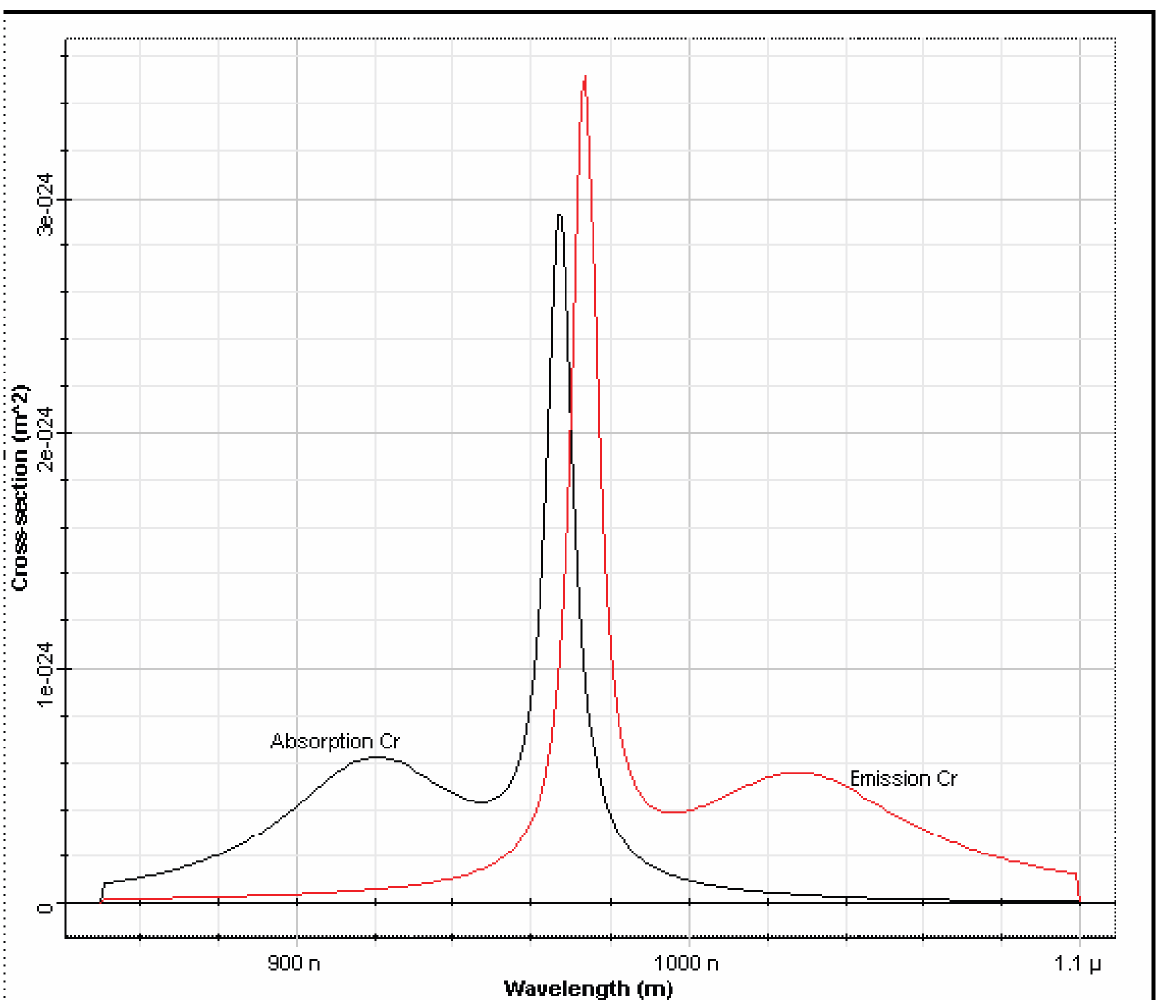

Fig. (1): ytterbium absorption and emission cross-sections[7]

The Ytterbium-Doped Fiber component is based on the solution of the rate and propagation equations of a two-level system. Rate equations are based on energy levels and describe the effects of absorption, stimulated emission, and spontaneous emission on the populations of the lower (n_1) and upper (n_2) states. For a two-level system with k optical beams the rate equations is given by:

Where h is the Planck constant, τ is the excited-state lifetime parameter, ν_k is the frequency and Pk is the power of the kth beam. The absorption and emission cross-section of the kth beam are $\sigma_a(\nu_k)$ and $\sigma_e(\nu_k)$, respectively, and nt is the local ytterbium ion density. The normalized optical intensity $i_k(\varphi, r)$ is defined as $i_k(\varphi, r) = I(\varphi, r, z) / P_k(z)$ where I is light intensity distribution of the kth beam.

The propagation equations describe the propagation of the beams through the doped fiber and are given by

Where each beam propagates in the forward ($u_k=+1$) or backward ($u_k=-1$) direction, and P0k means the spontaneous emission contribution from the local metastable population $n_2.P_{ok} = m.h.\Delta\nu_k$, where the normalized number of modes m is normally 2 and $\Delta\nu_k$ is the noise bandwidth.

Setting the time derivative in Equation (1a) to zero and using (1b), the problem is reduced to the steady-state case and the Yb upper-population is defined as:

With the specified boundary conditions at $Z=o$, and $Z=L$, equations (2) and (3) can be integrated over space and frequency [7,8].

III. (YDFA) CHARACTARISTICS OBTAINED WITH SIMULATION PROGRAM

The basic configuration of Ytterbium doped fiber amplifier is shown in Fig. (2). The pump light λp =910nm and the signal wavelength λs =975 nm coupled in to the doped fiber in the same direction, the required pump power is reduced using large core radius (1.7 μm)of Yb^{+3} doped optical fiber.

Table (1) shows the typical YDFA parameters used in the simulation program.

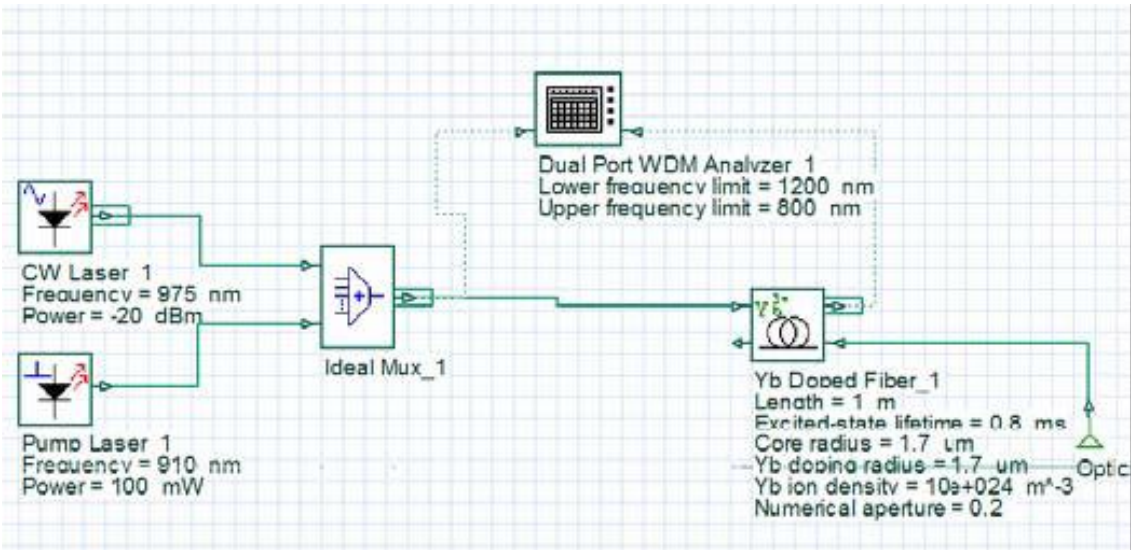

Fig. (2): Yb ion Doped Fiber Configuration

A .The Gain spectrum of Yb Ions in Typical YDFA:

The gain spectrum of Yb^{3+} obtained by the simulation program shown in Fig.(3) is quite broad ,the large band width makes it attractive for fiber optic communication applications., it has a double peak structure that varies from amplifier to amplifier even where core composition is the same because it also depends on a large number of device parameters such as Yb ion concentration, amplifier length, core-radius and pump power.

The gain spectrum corresponding to the $^2F5/2 \longrightarrow {}^2F7/2$ transitions has maxima in the regions (975-982) nm with maximum gain of 36dB and (1025- 1030) nm with maximum gain of 15dB.

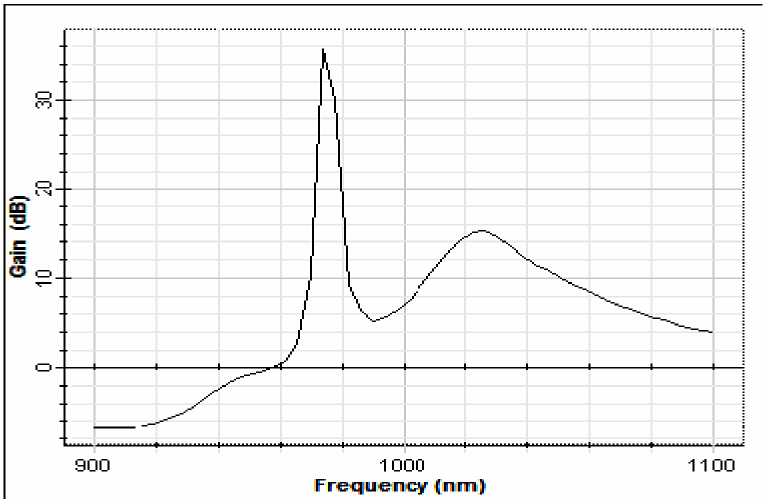

Fig.(3): Gain spectrum of YDFA ,

B.The relation between gain and Yb ion density for different fiber lengths

Fig.(4) shows the variation of gain with Yb ion density using three different lengths of the amplifier(0.4m,0.7m and1m) at 100 mw pump power ,the results show that the gain occurs over a short length (tens of centimeters) of the amplifier and signal gain increases with increasing fiber length.

For a given fiber length the gain increases as the Yb ion density increases and begins to be moderately saturated when the ion concentration exceeds 1.3 e +025 .However a maximum gain of more than 36dB is obtained for a fiber of 0.7 m length, fiber attenuation plays important role for longer fiber length (1m) and the gain slightly decreases at ion densities greater than 1.3 e +025due to insufficient pump.

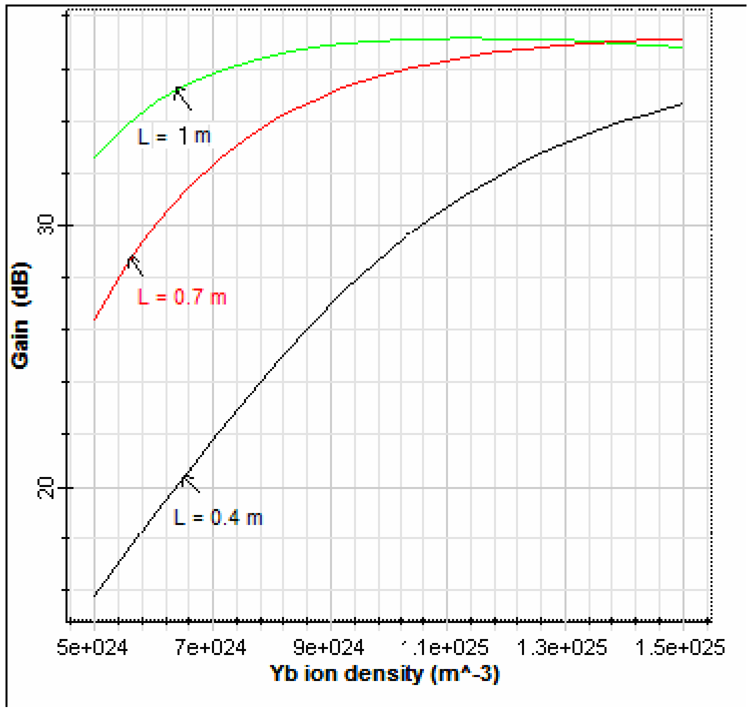

Fig. (4) Signal gain as a function of Yb ion density using three different lengths of the amplifier at 100 mw pump power

Generally, the higher the Yb concentration, the higher is the gain. However, there is a limitation in the sense of Ion-Ion interaction; a gain limiting process takes place in highly doped amplifiers.

C. Change of Gain with amplifier Length at different Pump Powers

Fig. (5) shows the signal gain as a function of fiber length at different pump powers, it is seen that the gain varies along the fiber length because of pump power variation, and increases with increasing fiber length and the pump powers, it remains constant (saturate) after certain level for each pump power, with increasing pump power the required length to obtain a saturated gain become less. . A maximum gain 39 dB at 150mw, 33dB at 100mw and 30dB at 50mw pump power is obtained.

The achievable gain in fiber amplifiers is often limited not by the available pump power, but by amplified spontaneous emission (ASE).

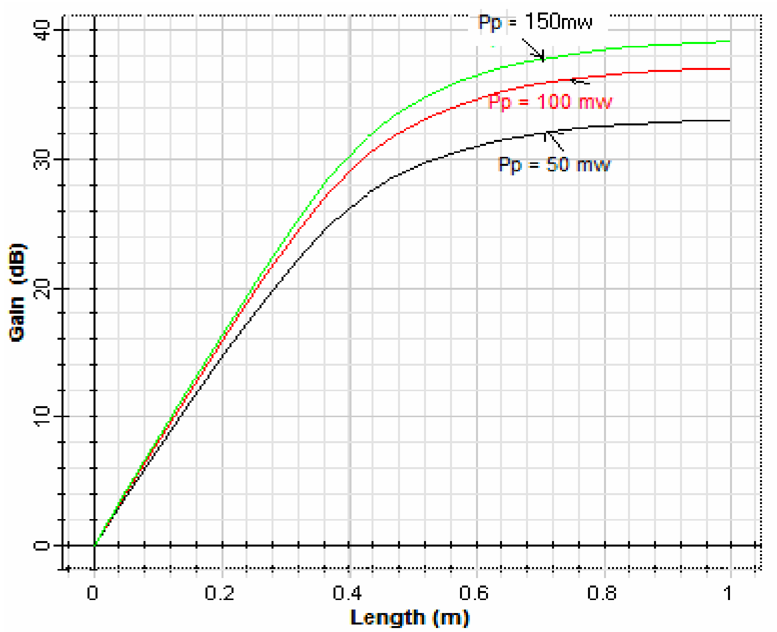

Fig. (5): signal gain in dB as a function of fiber length in (m) using different pump powers.

D. Signal Gain and Signal Power at Different Pump Powers.

Fig. (6) shows how the gain varies as a function of signal input power for different pumping powers at constant fiber length of 1m ,and constant Yb doping density, it is seen that the gain values are gradually decreased with the increment of signal power.

When the signal power is less than -30dBm the signal gain is independent of the input signal power, the amplifier works in the small -signal regime, the input signal power is very weak and the amplifier works in unsaturated gain regime, when the amplifier reaches the saturation the maximum gain dropped by 3 dB (a factor of 2) below its unsaturated value G_{max}. At higher input signal power level the strong signal significantly depletes the inversion and the pump is not able to replenish it as a result the gain decreases rapidly with signal power. This result shows the easier saturation of the YDFA at higher signal powers for a constant pump power.

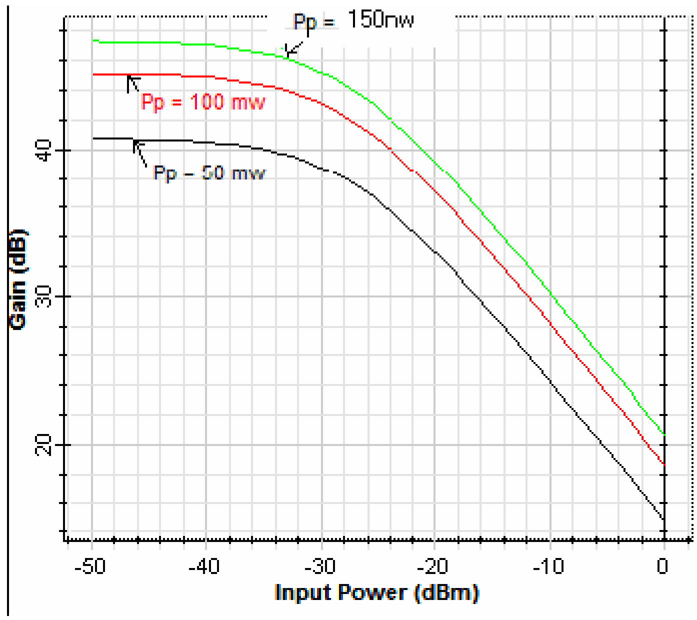

Fig. (6): Signal gain in dB as a function of signal power in dBm using injected pump power of 50,100and 150 mw at pump wavelength of 910nm

E. The relation between signal gain and pump power at different values of signal power

Signal gain in dB as a function of pump power in mw using YDFA at 975 nm signal wavelength and different injected signal powers of -10 dBm, -20 dBm and -30 dBm is illustrated in Fig.(7) .After certain pump power upper state population reaches almost to a constant level and for this reason after certain pump power gain values become saturated

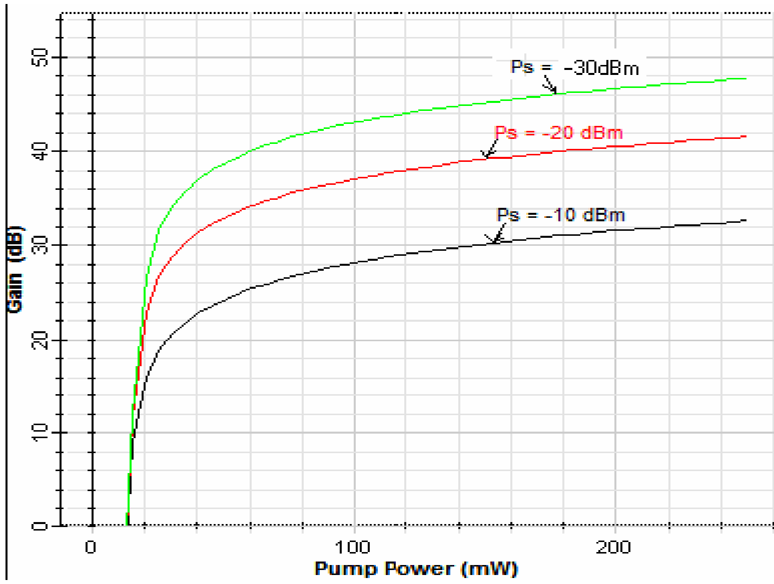

Fig.(7): Signal gain in dB as a function of pump power in mw using three different values of the signal power.

TABLE I

YDFA PARAMETERS USED IN THE SIMULATION PROGRAM

VI. CONCLUSION

1. The large bandwidth of Yb ions gain spectrum makes it attractive for fiber optic communications.
2. The cross-section of Yb ions for absorption of pump wavelength is high; there is a wide range of possible pump wave lengths.
3. The signal gain increase as the Yb ion density increases and saturated at a certain concentration of Ytterbium ions.
4. The gain increases with increasing fiber length, the gain occurs over short length (tenth of centimeters) Fiber attenuation plays important role for longer fibers. Systems. the gain values gradually decrease with increment of signal power at different values of the injected pump powers
5. The gain increases with increasing pump power, it saturates for certain level of each pump power, the maximum gain obtained for pump powers (50, 100 and 150)mw is about (33, 37 and 39) dB.

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