Research Journal of Applied Sciences, Engineering and Technology 2(4): 396-400, 2010
ISSN: 2040-7467

Submitted Date: May 09, 2010 Accepted Date: May 22, 2010 Published Date: July 10, 2010

Wavelength and Temperature Dependence of the Er^{+3} Concentration in the Erbium Doped Fiber Amplifier

Osama Mahran
Faculty of Science, University of Alexandria, Egypt

Abstract: A core graded-index and erbium-doped concentration are studied and optimized for an Erbium-doped Fiber Amplifier (EDFA) in a two-level model. Also the dependence of both core graded-index and erbium-doped concentration on temperature and wavelength of the signal guided are studied. There is evidence to show that the core graded-index has obvious influence on the gain bandwidth of the EDFA and the erbium concentration has effect on the bandwidth of the amplifier also both core graded-index and erbium-doped concentration are approximate linear dependence on wavelength and temperature.

Key words: Core-index, EDFA, erbium concentration, temperature, wavelength dependence

INTRODUCTION

A fundamentally new aspect in fiber design has been introduced by Rare Earth-Doped Fiber (REDF) for amplifier and laser applications (Becker *et al.*, 1999; Digonnet, 2001), where active rare earth ions were confined in the core to provide an optical gain by its emission cross section, whilst maintaining the conventional step index profile for efficient modal guidance for both pump and signal photons. In most of REDF, especially fabricated by Modified Chemical Vapor Deposition (MCVD) process, the fibers are triplelayered structure, central core, inner cladding, and outer cladding.

Typical glass compositions are GeO_2/Al_2O_3-SiO_2, P_2O_5/F-SiO_2, and SiO_2 for the core, inner cladding, and outer cladding, respectively (Nagel *et al.*, 1982; Ainslie and Day, 1986). Erbium- Doped Fiber Amplifiers (EDFAs), as key components in Wavelength Division Multiplexing (WDM) systems in optical telecommunication, have received great attention over the past 10 years. The rapid growth and the future commercial importance of multi-wave length optical networking create strong incentives for the development of EDFAs with higher gain and broader bandwidth. Many interesting research results were reported in recent years. For example, Chernyak and Qian (2002) established modeling high -concentration L-band EDF A at high optical powers based on inversion function. Johannes (2004) reported spatial distribution effects and laser efficiency in Er/Yb-doped fibers. Wei *et al.* (2004) utilized a genetic algorithm to optimize multistage erbium-doped fiber amplifier systems with complex structures. A remark able modeling was introduced by Giles and Desurvire (1991), which established the propagation and rate equations for a two-level homogeneous laser medium. This approximated model is suitable for analyzing open-loop optical fiber amplifiers and also the steady -state operation of the optical fiber networks.

For radial effects of the fibers on EDFA performances of the, there have been a few researches reported in recent years. One of the researches was presented by Martin (2001), who studied erbium transversal distribution influence on the effectiveness of a doped fiber by introducing a simple mathematical function, and significant gain differences were observed in active fibers.

It is apparent that the transmission performances are manipulated and optimized by controlling the optical and geometrical parameters in the fiber structures. As a result, any undesired variation in the fiber structure parameters, can perturb the transference performances. The refractive index variation as a function of temperature (dn/dT) is the important feature in the optical fibers. This factor determines the temperature characteristics of an optical fiber transmission system. Aerial optical systems are expected to face changes of temperature in several areas of the planet, which compel the essential demand to contemplate the thermal effect in the design of high-speed optical communication systems (Rostami and Makouei, 2008).

In this research the dependence of the erbium concentration on the core graded refractive index is done, also the core graded refractive index depend on the temperature of the fiber and the wavelength of the guided signal. So we can expected an approximate linear dependence of the erbium concentration on the temperature of the fiber and the wavelength of the guided signal, which is calculated by theoretical model which made by the author.

MATERIALS AND METHODS

This theoretical research of the dependence of the erbium concentration on the core graded refractive index

Table 1: the optimized values of a, Δn, α, β and δ of the EDFAs

Central concentration E_{r0} (cm^{-3})	β (μm)	δ	α	a (μm)	Δn
6.43×10^{19}	1.846	1.820	0.108	4.1	0.0063

Table 2: interpolated coefficient of the Equation (7)

G ($10^{-6/0}$)	J ($10^{-6/0}$)	λ_g (μm)	α_t ($10^{-6/0}$)
-1.6548	31.7794	0.109	0.45

is done, also the core graded refractive index depend on the temperature of the fiber and the wavelength of the guided signal was made by the author in 2009 at Faculty of science-University of Alexandria-Egypt.

Model: There are several functional forms that can be chosen to describe the radial distribution of the erbium ions. We use an exponential function as follows (Cheng and Xiao, 2005):

$$E_r(r) = E_{r0} \exp\left(-\frac{r}{\beta}\right)^{\delta} \quad (\beta, \delta > 0) \tag{1}$$

where, E_{r0} is the center concentration, β and δ are the parameters required to be optimized in the genetic algorithm. Eq. (1) can show various radial profiles with different values of β and δ. At r = 0, E_r reaches a maximum, which is coincident with actual erbium-doped concentration.

For the fibers with radial distributions of the core refractive index (i.e., graded-index fibers), some parameters (e.g., cut-off frequency) describing light propagation in a step- index are no longer available since the graded -index alters with the core radius. Some detail analyses on this aspect were already developed, and one of these is a usual variational method (Cheng and Xiao, 2005), in which a graded -index is reduced into an equivalent step- index. Here, a useful formula for the core refractive index is given by (Li and Cui, 2001).

$$n_{core}^2 = n_{core}^2\left[1 + 2\Delta n H\left(\frac{r}{a}\right)\right] \quad (r \le a) \tag{2}$$

where a is the fiber core radius and Δn is the relative refractive-index difference. The function H has the following form (Li and Cui, 2001):

$$H\left(\frac{r}{a}\right) = 1 - \left(\frac{r}{a}\right)^{\alpha} \quad 0 < \alpha < \infty \tag{3}$$

Then the core radius can give as:

$$r = \left[1 - \frac{1}{2\Delta n}\left(\frac{n_{core}^2}{n_{clad}^2} - 1\right)\right]^{1/\alpha} \tag{4}$$

The relation between the erbium concentration and the refractive index of the core can give by substituting the value of r in Eq. (1), we can give:

$$E_r(n_{core}) = E_{r0} \exp\left(-\frac{a}{\beta}\left[1 - \frac{1}{2\Delta n}\left(\frac{n_{core}^2}{n_{clad}^2} - 1\right)\right]^{1/\alpha}\right)^{\delta} \tag{5}$$

The values of a, Δn, α, β and δ are chosen to optimizing an erbium-doped fiber amplifier (EDFA), (Cheng and Xiao, 2005), and are given in Table 1.

The refractive index variation of the core due to temperature and wavelength is considered in this section. The method used in this paper has been introduced by Ghosh (Rostami and Makouei, 2008). This model is based on the subscription of both electrons and optical phonons. The optical constants computed from this model are then used to calculate the refractive indexes at any operating temperature or wavelength for the optical fiber transmission system. Thermo-optic coefficient dn_{core}/dT contains the contribution of electrons and optical phonons. Consequently, it can be described in the optical transmission range in terms of linear expansion coefficient α_t and the temperature variation of energy gap (dE/dT) by the following relation as (Rostami and Makouei, 2008):

$$2n\left(\frac{dn_{core}}{dT}\right) = \chi_e\left[-3\alpha t - \frac{2}{E_g} \cdot \frac{dE_g}{dT} \cdot \frac{E_g^2}{(E_g^2 - E^2)}\right] \tag{6}$$

where, χ_e, E, and E_g are the electronic susceptibity, photon energy and the suitable energy gap lying in the vacuum ultraviolet region respectively. Equation (6) can be rewritten in terms of a normalized wavelength as

$R = \dfrac{\lambda^2}{(\lambda^2 - \lambda_g^2)}$ (Rostami and Makouei, 2008):

$$2n\left(\frac{dn_{core}}{dT}\right) = GR + JR^2 \tag{7}$$

where, the constants G and J are related respectively to the thermal expansion coefficient (α_t) and the energy

gap temperature coefficient (dE/dT) according to the relations presented in (Cheng and Xiao, 2005) and their values are given in Table 2 for silica glasses (Cheng and Xiao, 2005).

RESULTS AND DISCUSSION

Table 1 lists some optimized results of the EDFA (Cheng and Xiao, 2005) and the required radial distribution of the core refractive index is shown in Fig. 1. Figure 2 shows the effect of the parameter β (describing erbium radial distribution, as defined in Eq. (1)) on the erbium concentration and consequently the gain bandwidth. With various β values, the radial distribution of the erbium concentration show different profiles, consequently, the gain and bandwidth also increase or decrease.

Figure 3 shows the effect of the parameter δ on the erbium concentration profile. However, it is shown that the parameter δ has no effect on the erbium concentration profile on the positive part of the core radius, but its effect on the negative part of the core radius.

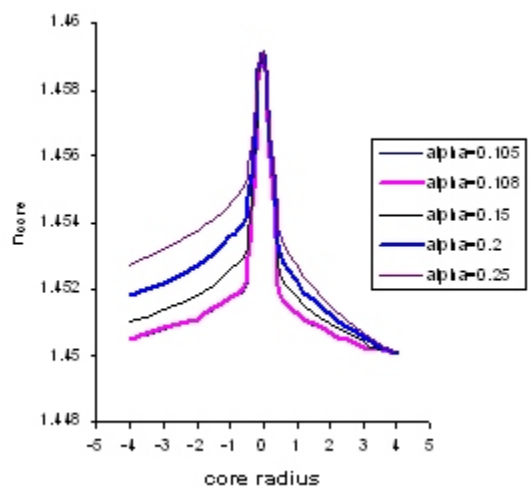

Fig.1: Profiles of the core refractive index

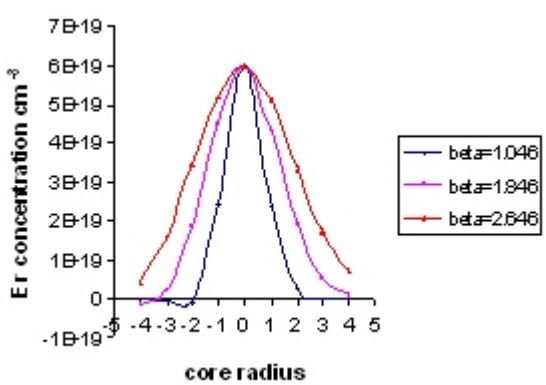

Fig. 2: Effect of β on Er-concentration

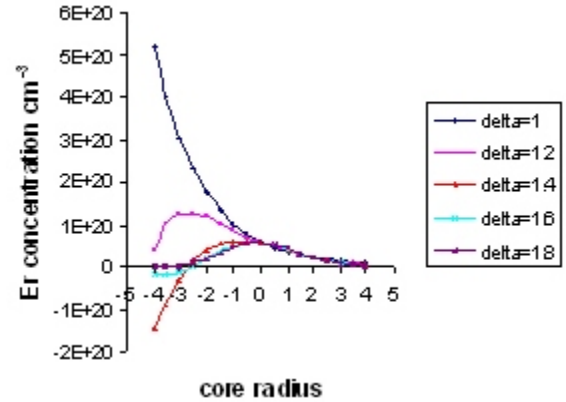

Fig. 3: Effect of δ on Er-concentration

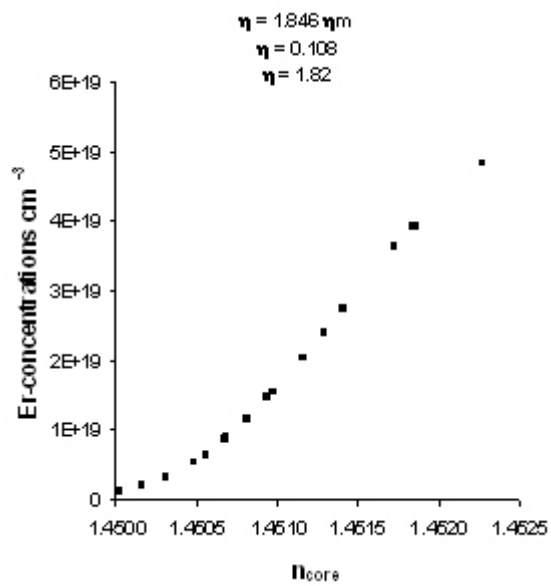

Fig. 4: The optimized values of α ,β and δ on Er-concentration with the effect of core refractive index

The optimized values of α, β and δ of the EDFAs on the calculation of the erbium concentration as a function the core refractive index according to Eq. (5) is shown in Fig. 4.

The effect of temperature on the core refractive index and erbium concentrations at constant signal wavelength 1560 nm according to the Eq. (5, 6 and 7) is plotted in Fig. 5 and 6, respectively. The value of wavelength of signal was chosen in the gain window of EDFA, and the two figures show small increases in the values of core refractive index and erbium concentrations with temperature increase.

The effect of signal wavelength on the core refractive index and erbium concentrations at room temperature

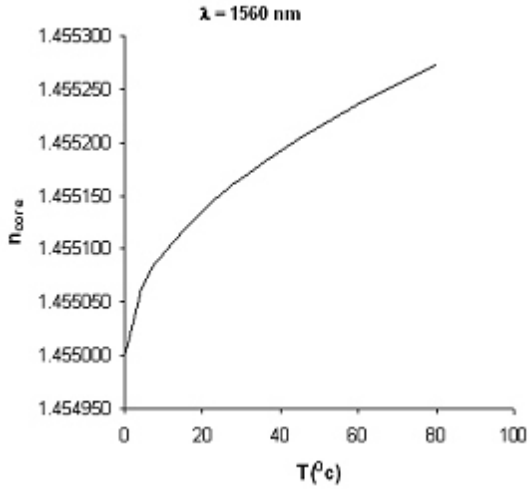

Fig. 5: The effect of temperature on the core refractive index at constant wavelength 1560 nm

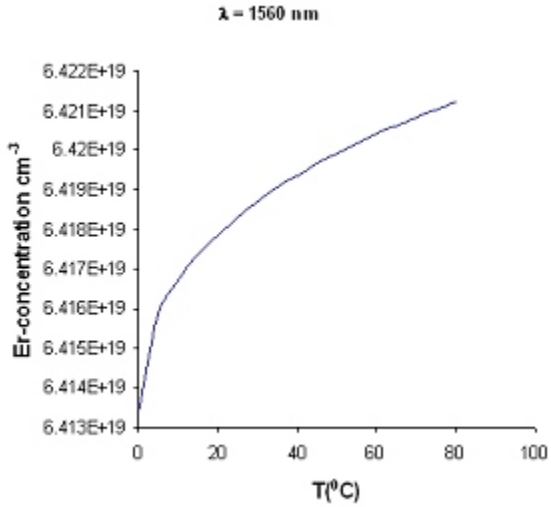

Fig. 6: The effect of temperature on the Er-concentration at constant wavelength 1560 nm

according to the Eq. (5, 6 and 7) is plotted in Fig. 7 and 8, respectively. The two figures show slightly decreases in the values of core refractive index and erbium concentrations with wavelength increase.

The wavelength dependence of the core refractive index and erbium concentrations at three values of temperature, which 27, 35 and 40ºC is plotted in Fig. 9 and 10 respectively.

Also the effect of temperature on the core refractive index and erbium concentrations at three values of signal wavelength, which 1400, 1500 and 1550 nm is plotted in Fig. 11 and 12, respectively. From Fig. 9, 10, 11 and 12 there are two oppositely factors affecting the core refractive index and erbium concentrations which the temperature increases both and the both decrease with wavelength of signal.

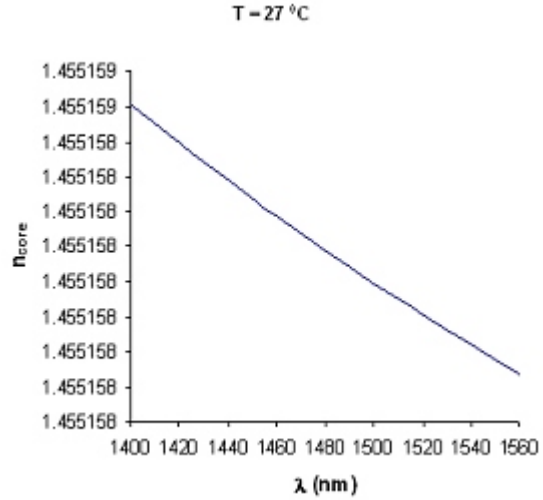

Fig. 7: The wavelength dependence of the core refractive index at constant temperature 27ºC

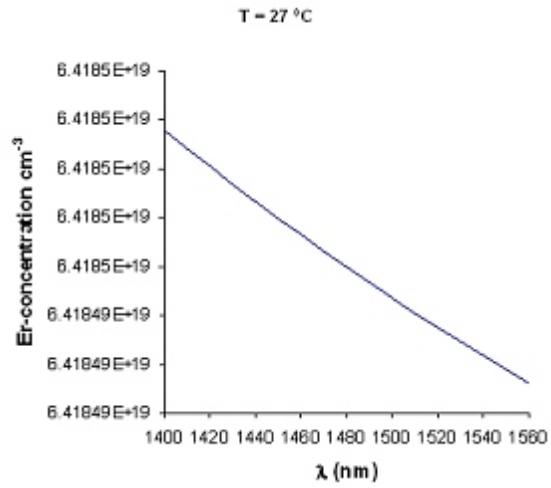

Fig. 8: The wavelength dependence of the Er-concentration at constant temperature 27 ºC

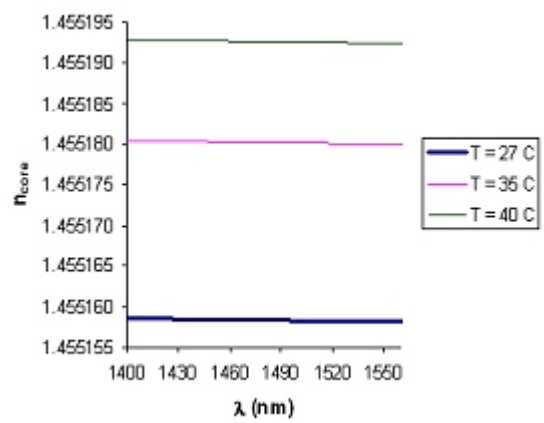

Fig. 9: The wavelength dependence of the core refractive index at different values of temperature

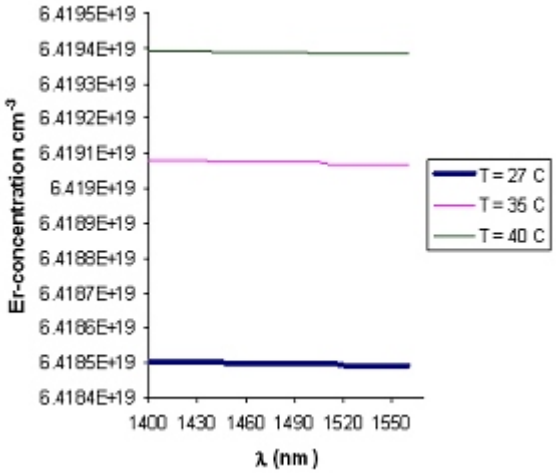

Fig. 10: The wavelength dependence of the Er-concentration at different values of temperature

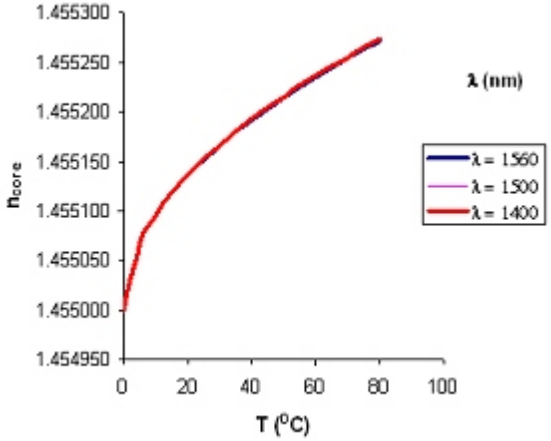

Fig. 11: The temperature dependence of the core refractive index at different values of wavelength

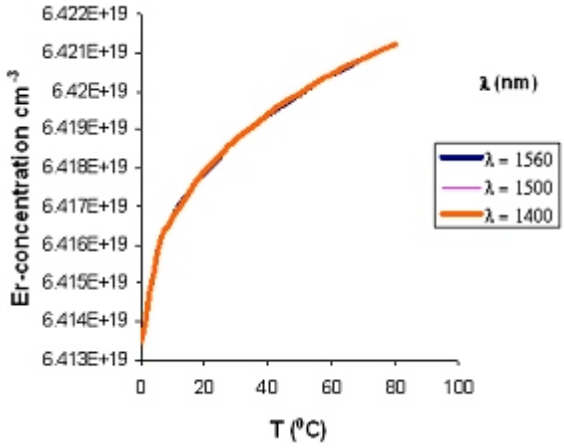

Fig. 12: The temperature dependence of the Er-concentration at different values of wavelength

CONCLUSION

Radial effects of the core graded-index and erbium-doped concentration are studied with the optimized parameters values α, β and δ for an erbium-doped fiber amplifier (EDFA) in a two-level model. Also the dependence of both core graded-index and erbium-doped concentration on temperature and wavelength of the signal guided are studied. There is evidence to show that the core graded-index has obvious influence on the gain bandwidth of the EDFA and the erbium concentration has effect on the bandwidth of the amplifier also both core graded-index and erbium-doped concentration are approximate linear dependence on wavelength and temperature.

REFERENCES

Ainslie, B. and C. Day, 1986. A review of single mode fibers with modified dispersion characteristics, J. Lightwave Technol., 4(8): 967-979.

Becker, P.C., N.A. Olsson and J.R. Simpson, 1999. Erbium-Doped Fiber Amplifiers. Academic Press, San Diego.

Cheng, C. and M. Xiao, 2005. Optimization of an erbium-doped fiber amplifier with radial effects. Opt. Commu., 254: 215-222.

Chernyak, V. and L. Qian, 2002. Modeling high-concentration L-band EDFA at high optical powers based on inversion function. IEEE J. Sel. Top. Quan. Elect., 8: 569.

Digonnet, M.F., 2001. Rare Earth-Doped Fiber Lasers and Amplifiers. 2nd Edn., Dekker, New York.

Giles, C.R. and E. Desurvire, 1991. The propagation and rate equations for a two-level homogeneous laser medium. J. Lightwave Technol., 9: 271.

Johannes, K., 2004. Spatial distribution effects and laser efficiency in Er/Yb-doped fibers. Proc. SPIE 5350: 222.

Li, Y.Q. and M. Cui, 2001. The Theories and Technologies of Optical Waveguides. The People Post Office Press, Beijng, (In Chinese).

Martin, J.C., 2001. Erbium transversal distribution influence on the effectiveness of a doped fiber. Opt. Commun., 194: 331.

Nagel, S.R., J.B. McChesney and K.L. Walker, 1982. An overview of the modified chemical vapor deposition (MCVD) process and performance. IEEE J. Quantum Elect., 18(4): 459-476.

Rostami, A. and S. Makouei, 2008. Temperature dependence analysis of the chromatic dispersion in wII-type zero-dispersion shifted fiber (zdsf). Prog. Electromagn. Res. B, 7: 209-222.

Wei, H., Z. Tong, T. Li and S. Jian, 2004. Utilized a genetic algorithm to optimize multistage erbium - doped fiber amplifier systems with complex structures. Opt. Exp., 12: 531.