Chromatic Dispersion in Traditional Fiber and Silicon Nanocrystal and Er Doped Fiber Optical Amplifier

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***Abstract*—In this paper, the chromatic dispersion at the traditional fiber and optical amplifier has been studied that is one of the important optical parameters is investigated by using of step index profile (traditional profile) and Silicon Nanocrystal and Er doped fiber (homogenous distribution profile) optical amplifier. At the traditional step index fiber, by changing of the reflective index and radius of core, zero dispersion is altered at the situation of 1.55µm that indicates the optical communication low loss occurrence at this wavelength. At least, the position of the zero chromatic dispersion is changed when Silicon Nanocrystal and Er are doped at the core of fiber for optical amplification goals. Therefore, these lead to have disturbance on the optical signal in the fiber, we have shown that with varying of those parameters of profile index fiber and amount of Silicon Nanocrystal, the dispersion coefficient is changed and the zero dispersion in 1.55µm situation would be attainable.**

Index Terms—Erbium doped fiber amplifier (EDFA), Si-Nc (silicon nanocrystal), semiconductor optical amplifiers (SOA) and wavelength (Landa)

I. Introduction

High-speed data communication and processing are basic industrial and scientific demand recently. Optical method is one of best alternatives for doing these tasks. Main physical medium for optical communication and processing is optical fiber [1-5]. Transmission bit rate in optical communication is higher than other data transmission methods. But, this is still far from the fundamental limit to the information transfer rate, and future systems are expected to reach data transfer rates of several terabits per second in a single fiber. For transmission over large distance, the optical signal needs to be amplified at regular intervals in order to maintain sufficient light intensity.

In order to loss compensation in optical communications, we need optical amplifiers which there are some alternatives such as Si-Nc Er-doped optical amplifier [6-7], semiconductor optical amplifiers (SOA) [8-11], Erbium doped fiber amplifier (EDFA) [12-15] and RAMAN amplifiers [16]. Another parameter in optical communication that has very confinement effect is chromatics dispersion [17]. In this paper, we focused on the chromatic dispersion in conventional (step index) and Si-NC–Er doped optical fibers (homogenous distribution profile) that the characteristics of the chromatic dispersion are discussed in detail in this paper. Since by adjusting fiber parameters, the chromatic dispersion in traditional fiber (step index) can easily be optimized, but in Si-NC–Er doped fiber amplifier (homogeneous distribution) by varying the essential fiber parameters manipulation of the dispersion characteristics are hard. Moreover, if the profile of Si-Nc Er doping was inhomogeneous the analytical method can't support the idea; we should use approximation methods for analyzing and will have highly variation on optimum situation of dispersion.

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II. Theoritical Background

First, we suppose the refractive index profile for traditional fiber that is shown in Fig. 1. Refractive index of each layer is expressed as follows:

$$n(r)=\begin{cases} n_1 & ,0<r<R_{core} \\ n_2 & ,R_{core}<r<R_{clad} \end{cases} \tag{1}$$

where 'r' is the radius situation, n_1, n_2 are refractive indexes for core and clad, respectively.

According to the wave equation and the boundary condition of electromagnetic field and under the LP approximation the characteristics equations in one region can be obtain as follows.

$$\det\begin{pmatrix} j_m(u_1) & -k_m(u_2) \\ u_1 j_m(u_1) & -u_2 k_m(u_2) \end{pmatrix}=0 \tag{2}$$

where j_m, k_m are the Bessel and the modified Bessel functions, respectively. The parameters used in determinant are defined as follows:

$$u_1 = R_{core}\sqrt{\left(k_0{}^2 n_1{}^2\right)-\beta^2} \tag{3}$$

$$u_2 = R_{core}\sqrt{\beta^2-\left(k_0{}^2 n_2{}^2\right)} \tag{4}$$

In above relation β is the longitudinal propagation constant of guided mode and k_0 is the wave number in the vacuum.

Finally, when Si-Nc and Er ions are doped at core, the profile of refractive index is changed that shown in Fig. 2.

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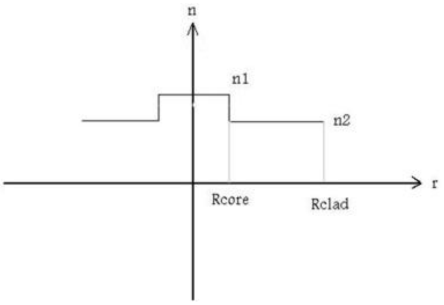

Fig. 1. Profile of step index traditional fiber.

In this Fig, we suppose the distributions of Er and Si-Nc are homogenous and R_{10} is radius of Si-Nc and Er ions distribution at core of fiber.

In this execute, we approximate the Gaussian profile with step index and solve the wave equation for three region of n_{eff} .

The refractive index of each layer is expressed as follows:

$$n(r)=\begin{cases} n_{10} & 0<R<R_1 \\ n_1 & R_1<R<R_{core} \\ n_2 & R>R_{clad} \end{cases} \tag{5}$$

Based on the wave equation and the boundary condition of electromagnetic field and under the LP approximation the characteristics equations in three regions can be obtain as follows.

For $n_1 < n_{eff} < n_{10}$

$$\det\begin{pmatrix} j(u_1) & -i(w_2) & -k(w_2) & 0 \\ 0 & i(w_{22}) & k(w_{22}) & -k(w_3) \\ u_1 j(u_1) & -w_2 i(w_2) & -w_2 k(w_2) & 0 \\ 0 & w_{22} i(w_{22}) & w_{22} k(w_{22}) & -w_3 k(w_3) \end{pmatrix}=0 \tag{6}$$

And for $n_2 < n_{eff} < n_1$

$$\det\begin{pmatrix} j(u_1) & -j(u_2) & -y(u_2) & 0 \\ 0 & j(u_{22}) & y(u_{22}) & -k(w_3) \\ u_1 j(u_1) & -u_2 j(u_2) & -u_2 y(u_2) & 0 \\ 0 & u_{22} j(u_{22}) & u_{22} y(w_{22}) & -w_3 k(w_3) \end{pmatrix}=0 \tag{7}$$

where j_m, y_m, k_m, I_m the Bessel and modified Bessel are functions. The parameters are used to determine are definition as follows:

$$u_1 = R_{10}\sqrt{\left(k_0^2 n_{10}^2\right)-\beta^2} \tag{8}$$

$$u_2 = R_{10}\sqrt{\left(k_0^2 n_1^2\right)-\beta^2} \tag{9}$$

$$w_2 = R_{10}\sqrt{\beta^2-\left(k_0^2 n_1^2\right)} \tag{10}$$

$$u_{22} = R_{core}\sqrt{\left(k_0^2 n_1^2\right)-\beta^2} \tag{11}$$

$$w_{22} = R_{core}\sqrt{\beta^2-\left(k_0^2 n_1^2\right)} \tag{12}$$

$$w_3 = R_{core}\sqrt{\beta^2-\left(k_0^2 n_2^2\right)} \tag{13}$$

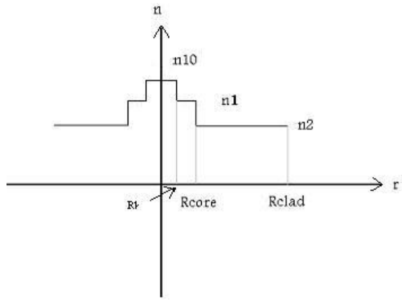

Fig. 2. Homogenous profile of Si-Nc and Er doped fiber

At simulation, the normalize frequency is considered as:

$$v = k_0 R_{core}\sqrt{n_{10}^2-n_2^2} \tag{14}$$

And the normalize propagation constant as:

$$B=\frac{\left(\beta^2 / k_0^2\right)-n_2^2}{n_{10}^2-n_2^2} \tag{15}$$

An optical parameter is defined as:

$$\Delta=\frac{n_{10}^2-n_2^2}{2n_2^2} \tag{16}$$

III. Mathematical Analysis of Chromatic Dispersion Coefficient:

According to the definition of chromatic dispersion coefficient, the expansion of chromatic dispersion coefficient can be obtained as follow:

$$Waveguide\ Dispersion=-\frac{N_2}{c}\frac{\Delta}{\lambda}v\frac{d^2(Bv)}{dv^2} \tag{17}$$

$$Material\ Dispersion=-\frac{\lambda}{c}\frac{d^2 n_2}{d\lambda^2}\left(1+\Delta\frac{d(Bv)}{dv}\right) \tag{18}$$

$$\frac{d(Bv)}{dv}=1+\left(\frac{u_1}{v}\right)\left(1-2\frac{u_1}{v}\frac{d(u_1)}{dv}\right) \tag{19}$$

$$v\frac{d^2(Bv)}{dv^2}=\left(\frac{d(u_1)}{dv}-\frac{u_1}{v}\right)^2-2u_1\frac{d^2(u_1)}{dv^2} \tag{20}$$

In Eq. 20, $N_2 = n_2-\lambda\frac{dn_2}{d\lambda}$ is the group index in outer cladding [17], [18].

IV. Results and Discussion

In this section, the impact of ΔR_{core} *and* Dn (varying of core radius and difference refractive index between core and clad, respectively) on dispersion coefficient at traditional step index fiber is investigated. According to numerical calculation for dispersion coefficient, the resulted $D-\lambda$ curve is shown in Fig. 3, Fig. 4 and Fig. 5. Also, the zero dispersion wavelength (Landa) occurs at situation of

$1.55\,\mu m$ which is shown with λ_0. Fig. 3 illustrates that the zero dispersion can obtain for specification parameters of fiber such as ($R_{core} = 2.5\,\mu m, n_1 = 1.5, n_2 = 1.4953$). Moreover, it is observed that in Fig. 4, with increasing of Dn the waveguide dispersion coefficient is enhanced due to the increasing of Dn .

Furthermore, the effect of ΔR_{core} on the dispersion coefficient is illustrated in Fig. 5. Therefore, by varying of the core radius, the magnitude of dispersion is increased but with increase of core radius, slope of dispersion coefficient is decreased. For explaining of these results, we can note this point, if a core of fiber has a large radius; the internal reflection is occurred. And so this result can affect on dispersion parameters that controlled the total dispersion.

The influence of $N_{\text{Si-Nc}}, R_{\text{Si-Nc}}$ on dispersion coefficient at homogenous doped of Si-Nc at triple clad refractive index fiber is illustrated in this section. The effects of Si-Nc doping radius and concentration of Si-Nc at core of fiber on dispersion coefficient are investigated in Fig. 6, Fig. 7 and Fig. 8. The effects of doping of Si-Nc and Er at the core of fiber are shown in Fig. 6. We have observed that with doping of core by Si-Nc and Er ions has Consequence on dispersion coefficient increasing.

Moreover, the outcomes of Si-Nc and Er ions concentrations on dispersion coefficient are probed in Fig. 7 and Fig. 8. Therefore, the Si-Nc and Er ions doping at core fiber leads to increase of dispersion due to inhomogeneity of radiuses of Si-Nc and SiO_2. Moreover, we can attain zero dispersion at situation of $1.55\,\mu m$ by regulation of the amount of Si-Nc and radius of Si-Nc doping at across of core.

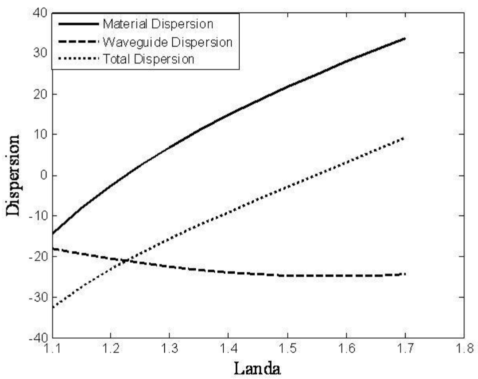

Fig. 3. Dispersion Vs. Landa (wavelength) (μm)
$R_{core} = 2.5\,\mu m, n_1 = 1.5, n_2 = 1.4953$

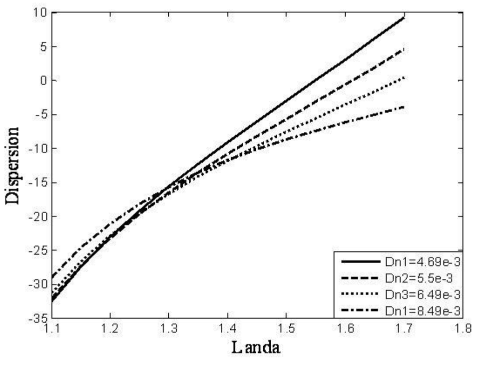

Fig. 4. Dispersion vs. Landa (wavelength) (μm) R_{core}=2.5μm, Dn=n_1-n_2

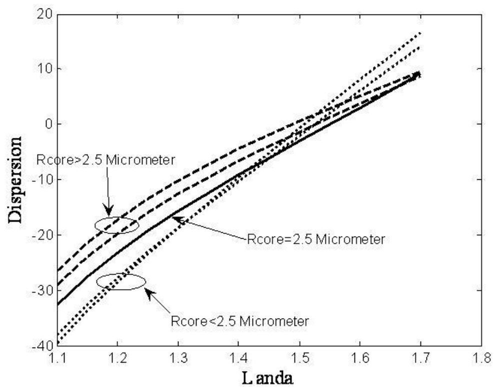

Fig. 5. Dispersion vs. Landa (wavelength) (μm) n_1=1.5, n_2=1.4953

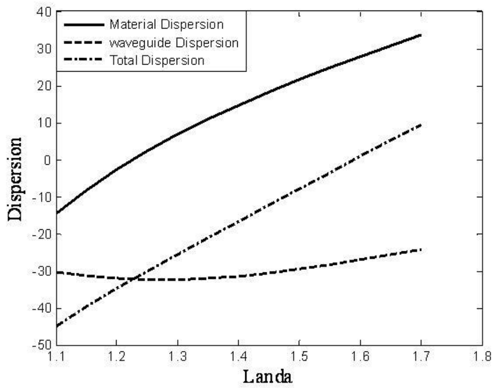

Fig. 6. Dispersion vs. Landa (wavelength) (μm)
n_{11}=1.50034, n_1=1.4936035, n_3=1.4942, n_4=1.4940

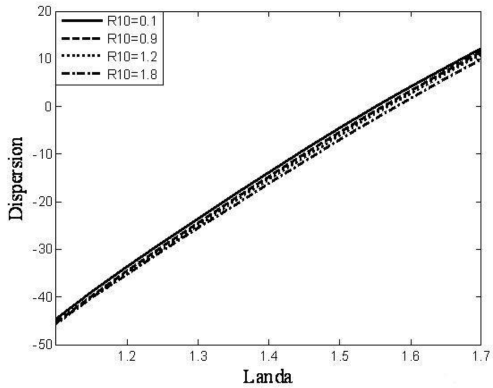

Fig. 7. Dispersion vs. Landa (wavelength) (μm)
n_{11}=1.50034, n_1=1.4936035, n_3=1.4942, n_4=1.4940， R_{10}:Radius of Si-Nc-Er doped

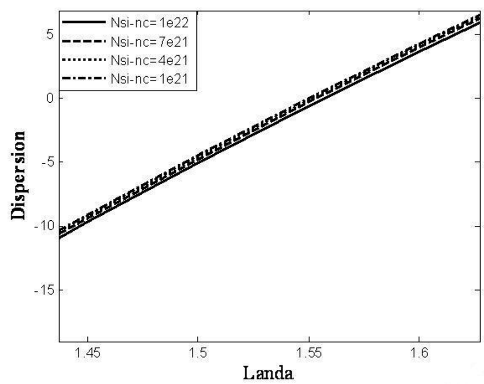

Fig. 8. Dispersion vs. Landa (wavelength) (μm)
n_{11}=1.50034, n_1=1.4936035, n_3=1.4942, n_4=1.4940,

V. Conclusion

The chromatic dispersion coefficient of signal mode traditional fiber and Si-Nc Er-doped optical fiber (homogenous profile) were studied in this paper. It was shown that one can to shift the zero dispersion situations at traditional fibers. This variation is done by changing the Δn and Δr which by variation of those parameters, dispersion coefficient is changed strongly. But when Si-Nc is doped at core fiber, the form of the refractive index of core is varied because of this variation; the situation of zero dispersion is changed. Moreover, when the distribution of Si-Nc on the core of fiber has a homogenous form, we will attain the zero dispersion in $1.55\mu m$ situation, because of the variation of $N_{\text{Si-Nc}}, R_{\text{Si-Nc}}$.

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