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A STUDY ON IMPACT OF INTENSITY DEPENDENT DISPERSION PARAMETER ON THE PICO SECOND PULSE EVOLUTION IN AN OPTICAL FIBER

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Abstract- In modern optical fiber communication systems, dispersion is a very important factor that decreases the communication quality, especially in Group Velocity Dispersion (GVD) and Third Order Dispersion (TOD). This paper presents a comprehensive study on the pulse distortion due to TOD in an optical fiber. TOD causes broadening as well as pulse breaking effects. Using computer simulation, we examine the effect of intensity dependent dispersion parameter on pico second pulses of various pulse widths. Semiconductor Bloch equations are used to determine the Polarization induced in the medium due to incident Gaussian pulse. The analysis of induced polarization is made by Non linear Schrodinger equation. To represent the pulse propagation behavior linear partial differential equation is used. Our results indicate that intensity dependent TOD effects become more prominent for higher intensities and for short pulse width.
Keywords: Group velocity dispersion, pico second pulse, pulse broadening, optical pulse propagation, third order susceptibility, intensity dependent refractive index, Kerr non linearity.

1. INTRODUCTION

The performance of an optical fiber system is highly influenced by dispersion. There are various factors which affects the performance of fiber [1]. GVD is the result of the variation of the group velocity with changes in optical frequency. TOD is generated because of the frequency dependence of the group delay dispersion. The precise evaluation of the higher order dispersion parameter is very important for the correct modeling of experimental observations. Various chirping methods are used to study the dispersion for different input pulses that result due to the dependencies of high order dispersion parameter. [2] The influence of the higher-order dispersion terms on dispersive optical communication systems operating near zero dispersion wavelengths for single mode fiber is studied [3].

The validity of third order dispersion term for dispersive optical communication systems operating near zero dispersion wavelengths for single-mode fiber is studied [4]. Analysis of second and third order dispersion effects in optical fibers is done by Split-Step Fourier method [5]. Comparison between GVD and TOD is done by using various simulation techniques.[6] Compensation of third-order dispersion in a 100 Gb/s single channel system with in-line fibre Bragg gratings.[7] Effects of third-order dispersion on pulse width by using a fem to second Ti:A1203 laser with independently adjustable second- and third-order intracavity dispersion compensation is investigated.

A novel technique for compensating third-order dispersion is demonstrated using Gires-Tournois interferometers that are fabricated monolithically by using multilayer dielectric films. With the addition of intracavity third-order compensation, pulse-width reduction from 45 to 28 fs is achieved. [8] Pulse spreading in a single-mode optical fiber is discussed taking into account the third-order dispersion term of the waveguide when the light source is modulated by a Gaussian pulse. A general expression for the pulse shape is analytically obtained, and an asymptotic approximation is used when the third-order dispersion term is small.

It is observed that the pulse width is no longer proportional to the guide length when the third-order dispersion term becomes large.[9] An arbitrary model is used to study the impact of higher-order dispersion terms in the propagated pulse shape and rms time width.[10]. Group velocity distribution of waveguide modes in the presence of disorder is presented. [13] In this paper pico second pulses of specific pulse width are transmitted through an optical fiber and the pulse behavior is theoretically examined by varying the intensity and pulse width of the input pulse.

2. THEORY

Evolution of the pulse envelope in a moving frame at a propagation distance z and at time T0 is described by the generalized nonlinear Schrodinger equation.

$$i\frac{\partial U}{\partial z} = \frac{1}{2}\beta_2\frac{\partial^2 U}{\partial T^2} + \frac{i}{6}\beta_3\frac{\partial^3 U}{\partial T^3} + i\frac{\alpha}{2}U + \gamma|U|^2 U \qquad \text{..........1}$$

The medium is considered as lossless and only the dispersive effects are considered and restricted our analysis up to TOD. Linear partial differential equation of an optical pulse in terms of normalized amplitude U under the action of GVD and TOD is given by [12]

$$i\frac{\partial U}{\partial Z} = \frac{1}{2}\beta_2\frac{\partial^2 U}{\partial T^2} + \frac{i}{6}\beta_3\frac{\partial^3 U}{\partial T^3} \qquad \text{..........2}$$

T is measured in a frame of reference moving with the pulse at the group velocity vg. β2 is defined as

$$\beta_2 = \frac{\omega}{c}\frac{d^2 n}{d\omega^2} \qquad \text{..........3}$$

Third order dispersion parameter (β3) is expressed as

$$\beta_3 = \frac{\omega}{c}\frac{d^3 n}{d\omega^3} + \frac{1}{c}\frac{d^2 n}{d\omega^2} \qquad \text{..........4}$$

In past studies, β2 and β3 were taken to be frequency dependent terms and no consideration was given to its dependency on optical pulse intensity. While intense optical pulses show considerable effect on β2 and β3. So the inclusion of dependency of intensity is necessary for the accurate analysis of pulse behavior. Using the semiconductor Bloch equations the induced polarization of the medium are derived. After obtaining the induced polarization of the medium, the linear and third-order complex optical susceptibility components have been obtained as [11]

$$\chi_r^{(1)}(\omega) = \frac{-N\mu^2(\omega-\omega_\lambda)}{\varepsilon_0\hbar\left[(\omega-\omega_\lambda)^2+\gamma^2\right]} \qquad \text{..........5}$$

$$\chi_i^{(1)}(\omega) = \frac{-N\mu^2\gamma}{\varepsilon_0\hbar\left[(\omega-\omega_\lambda)^2+\gamma^2\right]} \qquad \text{..........6}$$

$$\chi_r^{(3)}(\omega) = \frac{-4N|\mu|^4\left(\omega^4-\omega^3\omega_\lambda-\omega^2\omega_\lambda^{\,2}-\omega_\lambda^{\,3}\omega-\gamma^2\omega_\lambda\omega-\gamma^2\omega_\lambda^{\,2}-\gamma^4\right)}{\hbar^3\varepsilon_0\omega\left[\left((\omega+\omega_\lambda)^2+\gamma^2\right)\left((\omega-\omega_\lambda)^2+\gamma^2\right)^2\right]} \qquad \text{..........7}$$

$$\chi_i^{(3)}(\omega) = \frac{-4N|\mu|^4\left(2\omega^3\gamma-\omega^2\gamma\omega_\lambda+2\gamma^3\omega-\gamma\omega_\lambda^{\,3}-\gamma^3\omega_\lambda\right)}{\hbar^3\varepsilon_0\omega\left[\left((\omega+\omega_\lambda)^2+\gamma^2\right)\left((\omega-\omega_\lambda)^2+\gamma^2\right)^2\right]} \qquad \text{..........8}$$

The first and third order medium susceptibilities x(1) and x(3)can be determined by solving equations of motion. $\varepsilon_0$is the free-space permittivity, μ= Dipole moment, ħ=Reduced Planck's constant, γ= Dephasing time, ω = Angular frequency, ελ material band gap, N is the excitation density.

The effective intensity dependent GVD parameter β2 (ω, I) is given by:-

$$\beta_2(\omega,I) = \frac{\omega}{c}\frac{d^2}{d\omega^2}\left(n_0+n_2|I|^2\right) \qquad \text{..........9}$$

Third order dispersive parameter β3 (ω,I) is given as

$$\beta_3(\omega,I) = \frac{\omega}{c}\frac{d^3}{d\omega^3}\left(n_0+n_2|I|^2\right) + \frac{1}{c}\frac{d^2}{d\omega^2}\left(n_0+n_2|I|^2\right) \qquad \text{..........10}$$

Here n0 is the background refractive index of the material at frequency ω and defined in terms of first order optical susceptibility as [11]

$$n_0 = \left[1 + \mathrm{Re}\,\chi^{(1)}\right]^{1/2} \quad ....11$$

I is the excitation intensity inside the fiber for electric field E defined as [12]

$$I = \frac{1}{2} n_0 \varepsilon_0 c |E|^2 \quad ....12$$

n2 is the nonlinear refractive index defined as

$$n_2 = \frac{\chi^{(3)}}{\varepsilon_0 \varepsilon_\lambda c} \quad ....13$$

The general solution of equation is given by [12]

$$U(z,T) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \tilde{U}(0,\omega) \exp\left[\frac{i}{2}\beta_2 \omega^2 z + \frac{i}{6}\beta_3 \omega^3 z - i\omega T\right] d\omega \quad ....14$$

$\tilde{U}(0,\omega)$ is the Fourier transform of incident field at z = 0 and is given by U

$$U(0,\omega) = \int_{-\infty}^{+\infty} \tilde{U}(0,T) \exp(i\omega T) d\omega \quad ....15$$

The incident Gaussian field is given by

$$U(0,T) = exp[-\frac{T^2}{2T_0^2}] \quad ....16$$

T0 is the pulse width of incident field. The dispersion lengths LD and LD' corresponding to GVD and TOD respectively are given by

$$L_D = \frac{T_0^2}{|\beta_2|} \quad ....17$$

$$L_D{}' = \frac{T_0^3}{|\beta_3|} \quad ....18$$

3. RESULTS AND DISCUSSIONS

The pulse evolution in the medium is obtained through numerical solution of coupled equations. The effect of intensity on GVD and TOD is calculated for the Gaussian pulse propagating inside silica based optical fiber. For this, the pulse behavior is observed for frequency $2x10^{15}$ Hz. The analysis is done for pulse width ranging from 50 ps to 150 ps. The dipole moment (μ) is $1.865x10^{-29}$ Cm, dephasing time10^{13}sec, material band gap $1.19x10^{-13}$eV. We have examined the variation in the output intensity U (z, T) as a function of dimensionless time parameter T/T0.

The value of β2 and β3 is found to be -6.9 $x10^{-23}$ ps^2 /km and -8.20 $x10^{-37}$ ps^3 /km respectively. Dispersion length LD and LD' for various input pulse width are calculated. The broadening of pulse takes place due to GVD and TOD causes the temporal red shift of the optical pulses from its initial position for the different propagation distances. In Fig. 1, A is the input pulse, B is the pulse evolved at propagation length (z)= 103 cm by considering the effect of β2 only, C is the pulse evolved at the same distance by considering the combined effect of β2 and β3 in the propagation equation. Here we have not taken the effect of intensity on dispersive parameter as done earlier by various authors.

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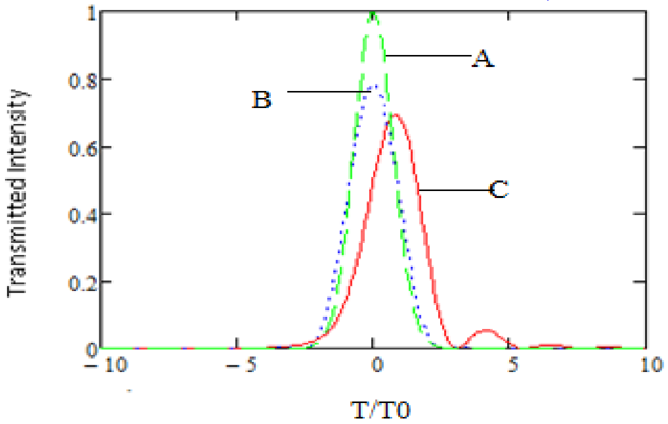

Fig. 1 Pico second pulse evolution with propagation length 103 cm

We now focus our interest to examine the effects of intensity on dispersion parameters. We are restricting our analysis to only third order dispersion parameter only. The values of β2 and β3 are calculated for various pulse widths with various input intensities.

Table 1 represents the variation in dispersion lengths with respect to pulse width when effect of intensity on dispersive parameters have not considered.

Pulse Width (ps)	L_D (cm)	L_D' (cm)
50	36	1.5×10^5
100	144	1.22×10^6
150	325	4.0×10^6

Pulse Width (ps)	Input Optical Intensity (MW/cm^2)	L_D (cm)	L_D' (cm)
50	0.2	0.57	3732
	1.7	0.063	416
	3	0.036	241
	4	0.027	181
	5	0.022	145
	6	0.018	121
	7	0.015	104
100	0.2	2.28	29895
	1.7	0.252	3333
	3	0.146	1935
	4	0.11	1452
	5	0.088	1162
	6	0.073	968
	7	0.063	830
150	0.2	5.13	100777
	1.7	0.568	11249
	3	0.329	6562
	4	.0247	4901
	5	0.198	3921
	6	0.165	3268
	7	.0141	2802

Table represents comparative analysis of dispersion lengths LD and LD'. It is observed from the values of dispersion lengths that when input intensity of the pulse is increased, there is considerable change in dispersion lengths LD and LD' due to change in values of β2 and β3. The values clearly show that dispersion lengths LD and LD' depends on the intensity of the optical pulse as well as its width.

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4. CONCLUSION

It is concluded that while studying the dispersion in an optical fiber, neglect ion of intensity dependent β2 and β3 may not be possible. The effect of GVD and TOD become more significant for the pulse of shorter width and higher intensity.

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