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Equations of Pulse Propagation in Three-Layer Structure of As_2S_3 Chalcogenide Plasmonic Nano-Waveguides

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***Abstract*—**This research aims at obtaining the equations of pulse propagation in nonlinear plasmonic waveguides created with As_2S_3 chalcogenide materials. Via utilizing Helmholtz equation and first-order perturbation theory, two components of electric field are determined within frequency domain. Afterwards, the equations are formulated in time domain. The obtained equations include two coupled differential equations that considers nonlinear dispersion.

***Keywords*—**Nonlinear optics, propagation equation, plasmonic waveguide.

I. Introduction

THE novel plasmonic science, in the late 90s and the beginning of 2000s, started to improve and develop in different and new domains [1], [2]. This field of knowledge lends itself to the electromagnetic fields interacting with free electrons of conductors at the interface of metal-dielectric or plasma-dielectric nanostructures. In general, plasmonics are viewed as the metamaterial elements and nanoscale artificial optical materials [3].

Optical systems that utilize metallic waveguides could be miniaturized as optical element due to surface excitation of plasmon-polariton. Metallic dielectric waveguides accompanied by its exciting features could be utilized for developing sensors and waveguides [4]-[6].

A plasmonic waveguide which is created out of metal and insulator could extend plasmon-polariton in the most explicit case [7]-[9].

Chalcogenide glasses are created from the basic components, e.g. S, Se and Te accompanied with other components including As, Ga and Ge, In, and Sb. Chalcogenides material is found in nature in covalent shape and could be created of a chain, ring or lattice structure. Given to the physical and chemical endurance of such materials, it is proper to use them for making optical fibers and waveguides. Furthermore, chalcogenides have high nonlinear coefficient. The nonlinear optical Kerr coefficient of such materials is estimated almost as 100-1000 times of that silica glasses, and also, the loss in these fibers is scare [10]-[12]. Lately, Yousefi et al. investigated nonlinear signal processing in chalcogenide fiber Bragg gratings [13].

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The sheer goal in this research is to obtain equations that control the pulse propagation in the nonlinear plasmonic waveguides created with the chalcogenide materials. The elements of the electric field, perpendicular and parallel to the direction of propagation for Transverse (TM) mode are derived. The dark and bright solitons propagation also will be studied.

II. Math Equations

The research investigates the equations administering the propagation of nonlinear plasmonic waveguide produced by the chalcogenide materials for the TM mode. In Fig. 1, we consider the structure of metal/insulator/metal (MIM), a plasmonic waveguide made out of a thick layer nonlinear dielectric of thickness 2h and permittivity $\varepsilon_1 \rangle 0$ and installed between two metallic slabs with permittivity $\varepsilon_2 \langle 0$. If we are supposed to have homogeneity in the y direction, all fields and their components are free of y, likewise wave propagate in the z direction. Plasmon-polaritons can be excited only with the TM modes, so we have two transverse E_x and E_z longitudinal components for electric field.

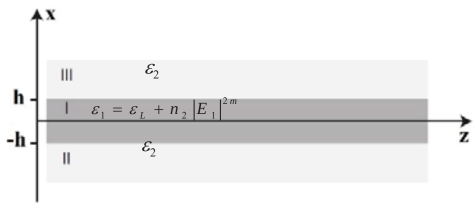

Fig. 1 A three-layer structure in which a dielectric layer is located between the metal layer

Helmholtz equation satisfies each element of electric field when there is no nonlinearity and can be formulated in frequency domain as:

$$\nabla^2 E_x(r,\omega) + \varepsilon(\omega) k_0^2 E_x(r,\omega) = 0 \qquad (1)$$

$$\nabla^2 E_z(r,\omega) + \varepsilon(\omega) k_0^2 E_z(r,\omega) = 0 \qquad (2)$$

in which k_0 is propagation constant of wave in free space at frequency ω and $\varepsilon(\omega)$ is permittivity as a function of frequency. If nonlinear effects are absent, the answer for (1) and (2) are understood as following ansatz:

$$E_x = E_x(x,z)\exp(i\beta z) = AF(x)\exp(i\beta z) \qquad (3)$$

$$E_z = E_z(x,z)\exp(i\beta z) = BG(x)\exp(i\beta z) \qquad (4)$$

in which $F(x)$ and $G(x)$ are transverse distribution of every components of electric field, A and B are constants in the linear and unperturbed condition. β is propagation constant in linear case that can be computed as [5]:

$$\beta = k_0\sqrt{\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2}}\,, \qquad (5)$$

where,

$$\varepsilon_1 = 1-\frac{\omega_p^2}{\omega^2}\,, \qquad (6)$$

ω_p is plasma frequency.

As per nonlinear case, permittivity in (1) and (2) is expressed as:

$$\varepsilon = 1+\tilde{\chi}_{xx}^{(1)}+\varepsilon_{NL}(\omega) \qquad (7)$$

When there are no nonlinear effects that are understood as a perturbation, electric field elements are formulated as:

$$E_x = A(z,\omega-\omega_0)F(x)\exp(i\beta_0 z) \qquad (8)$$

$$E_z = B(z,\omega-\omega_0)G(x)\exp(i\beta_0 z) \qquad (9)$$

in which β_0 is propagation constant of wave in waveguide with frequency ω_0. A tilde over variables signifies that they are formulated in frequency domain. By placing the mentioned solution in the Helmholtz equation, and after a little simplifying and employing slowly changing amplitude A and B we have:

$$\frac{d^2F(x)}{F(x)dx^2}+[2i\beta_0\frac{d\tilde{A}(z)}{dz}-(\beta_0{}^2+\varepsilon(\omega)k_0^2)\tilde{A}(z)]=0 \qquad (10)$$

$$\frac{d^2G(x)}{G(x)dx^2}+[2i\beta_0\frac{d\tilde{B}(z)}{dz}-(\beta_0{}^2+\varepsilon(\omega)k_0^2)\tilde{B}(z)]=0 \qquad (11)$$

By separating variables, four coupled equations are derived as:

$$\frac{d^2F(x)}{dx^2}+F(x)(\varepsilon(\omega)k_0^2-\tilde{\beta}^2)=0 \qquad (12)$$

$$\frac{d^2G(x)}{dx^2}+G(x)(\varepsilon(\omega)k_0^2-\tilde{\beta}^2)=0 \qquad (13)$$

$$2i\beta_0\frac{d\tilde{A}(z)}{dz}-(\tilde{\beta}^2-\varepsilon(\omega)k_0^2)\tilde{A}(z)=0 \qquad (14)$$

$$2i\beta_0\frac{d\tilde{B}(Z)}{dz}-(\tilde{\beta}^2-\varepsilon(\omega)k_0^2)\tilde{B}(Z)=0 \qquad (15)$$

In the event that we consider the nonlinear effect as a perturbation, (12) and (13) can be unraveled by utilizing first-order perturbation theory. Without considering the nonlinear effects and by using first-order perturbation theory [14], we find out $F(x)$ and $G(x)$ which are the solutions of the Helmholtz equation. We also can write the eigenvalue $\tilde{\beta}(\omega)$ that shows the propagation constant in the nonlinear waveguide, as:

$$\tilde{\beta}(\omega)=\beta(\omega)+\Delta\beta(\omega) \qquad (16)$$

where $\beta(\omega)$ and $\Delta\beta(\omega)$ are the propagation constant for linear case and the effect of perturbation, respectively.

The first order perturbation is merely influenced on the propagation constant. This effect varies for each element of electric field as:

$$\Delta\beta_1=\frac{\omega^2 n(\omega)}{c^2\beta(\omega)}\frac{\int_{-\infty}^{+\infty}\Delta n(\omega)\left|F(x)\right|^2dx}{\int_{-\infty}^{+\infty}\left|F(x)\right|^2dx} \qquad (17)$$

$$\Delta\beta_2=\frac{\omega^2 n(\omega)}{c^2\beta(\omega)}\frac{\int_{-\infty}^{+\infty}\Delta n(\omega)\left|G(x)\right|^2dx}{\int_{-\infty}^{+\infty}\left|G(x)\right|^2dx} \qquad (18)$$

where c is the velocity of light in the vacuum. Also, $\Delta\beta_1$ and $\Delta\beta_2$ signify the effect of nonlinear perturbations on the x and z- component of electric field, respectively. Furthermore:

$$\Delta n(\omega)\approx n_2\left|\tilde{E}\right|^2 \qquad (19)$$

$n(\omega)$ in (17) and (18) is estimated by using Sellmeier Equation for As2S3 chalcogenide glass [15]:

$$n^2(\omega)=1+\sum_{j=1}^{m}\frac{\beta_j\omega_j^2}{\omega_j^2-\omega^2} \qquad (20)$$

that, ω_j is the resonance frequency, and β_j is the strength of j^th resonance.

When there is a nonlinear effect, in the direction of propagation, the field amplitudes are not constant, thus the component of electric field in (3) and (4) can be formulated as:

$$\tilde{E}_x = f(\omega)F(x)\tilde{A}(z)\exp(i\beta z) \tag{21}$$

$$\tilde{E}_z = g(\omega)G(x)\tilde{B}(z)\exp(i\beta z) \tag{22}$$

where $f(\omega)$ and $g(\omega)$ are [5]:

$$f(\omega) = C'\frac{\beta}{\omega\varepsilon_0\varepsilon_1}, g(\omega) = -iC'\frac{k_1}{\omega\varepsilon_0\varepsilon_1} \tag{23}$$

$$C' = \frac{\exp(-k_2 h)}{\exp(-k_1 h) + d\exp(-k_1 h)} \tag{24}$$

$$d = \frac{(\frac{k_3}{\varepsilon_3} + \frac{k_1}{\varepsilon_1})}{(\frac{k_1}{\varepsilon_1} - \frac{k_3}{\varepsilon_3})}\exp(2k_1 h) \tag{25}$$

$\left|\tilde{E}\right|^2$ in (19) is:

$$\left|\tilde{E}\right|^2 = \left|\tilde{E}_x\right|^2 + \left|\tilde{E}_z\right|^2 = f(\omega)^2 F(x)^2 \left|\tilde{A}(z)\right|^2 + g(\omega)^2 G(x)^2 \left|\tilde{B}(z)\right|^2 \tag{26}$$

where $F(x)$ and $G(x)$ are the unperturbed linear solutions:

$$F(x) = (\exp(k_1 x) + d\exp(-k_1 x)) \tag{27}$$

$$G(x) = (\exp(k_1 x) - d\exp(-k_1 x)) \tag{28}$$

then, by substituting (19), (20), and (26) in (17) and (18), we have:

$$\Delta\beta_1 = \Delta\beta_{11}\left|\tilde{A}\right|^2 + \Delta\beta_{12}\left|\tilde{B}\right|^2 \tag{29}$$

$$\Delta\beta_2 = \Delta\beta_{21}\left|\tilde{A}\right|^2 + \Delta\beta_{22}\left|\tilde{B}\right|^2 \tag{30}$$

so that

$$\Delta\beta_{11} = \frac{\omega^2 n(\omega)}{c^2\beta(\omega)} n_2 f^2(\omega) \frac{\int_{-\infty}^{+\infty}(\exp(k_1 x) + d\exp(-k_1 x))^4 dx}{\int_{-\infty}^{+\infty}(\exp(k_1 x) + d\exp(-k_1 x))^2 dx} \tag{31}$$

$$\Delta\beta_{12} = \frac{\omega^2 n(\omega)}{c^2\beta(\omega)} n_2 g^2(\omega) \times \frac{\int_{-\infty}^{+\infty}(\exp(k_1 x) + d\exp(-k_1 x))^2(\exp(k_1 x) - d\exp(-k_1 x))^2 dx}{\int_{-\infty}^{+\infty}(\exp(k_1 x) + d\exp(-k_1 x))^2 dx} \tag{32}$$

$$\Delta\beta_{21} = \frac{\omega^2 n(\omega)}{c^2\beta(\omega)} n_2 g^2(\omega) \times \frac{\int_{-\infty}^{+\infty}(\exp(k_1 x) + d\exp(-k_1 x))^2(\exp(k_1 x) - d\exp(-k_1 x))^2 dx}{\int_{-\infty}^{+\infty}(\exp(k_1 x) - d\exp(-k_1 x))^2 dx} \tag{33}$$

$$\Delta\beta_{22} = \frac{\omega^2 n(\omega)}{c^2\beta(\omega)} n_2 g^2(\omega) \frac{\int_{-\infty}^{+\infty}(\exp(k_1 x) - d\exp(-k_1 x))^4 dx}{\int_{-\infty}^{+\infty}(\exp(k_1 x) - d\exp(-k_1 x))^2 dx} \tag{34}$$

Equations (14) and (15) could be formulated as:

$$\frac{\partial\tilde{A}}{\partial z} = i[\beta(\omega) + \Delta\beta_1(\omega) - \beta_0]\tilde{A} \tag{35}$$

$$\frac{\partial\tilde{B}}{\partial z} = i[\beta(\omega) + \Delta\beta_2(\omega) - \beta_0]\tilde{B} \tag{36}$$

The approximation $\beta^2 - \beta_0{}^2 \approx 2\beta_0(\beta - \beta_0)$ was supposed.

$\beta(\omega)$ can be expanded in the shape of Taylor series around ω_0:

$$\beta(\omega) = \beta_0 + (\omega - \omega_0)\beta_1 + \frac{1}{2}(\omega - \omega_0)^2\beta_2 + ... \tag{37}$$

and in similar method, we have:

$$\Delta\beta_{11}(\omega) = \Delta\beta_{11}^{(0)} + (\omega - \omega_0)\Delta\beta_{11}^{(1)} + \frac{1}{2}(\omega - \omega_0)^2\Delta\beta_{11}^{(2)} + ... \tag{38}$$

$$\Delta\beta_{12}(\omega) = \Delta\beta_{12}^{(0)} + (\omega - \omega_0)\Delta\beta_{12}^{(1)} + \frac{1}{2}(\omega - \omega_0)^2\Delta\beta_{12}^{(2)} + ... \tag{39}$$

$$\Delta\beta_{21}(\omega) = \Delta\beta_{21}^{(0)} + (\omega - \omega_0)\Delta\beta_{21}^{(1)} + \frac{1}{2}(\omega - \omega_0)^2\Delta\beta_{21}^{(2)} + ... \tag{40}$$

$$\Delta\beta_{22}(\omega) = \Delta\beta_{22}^{(0)} + (\omega - \omega_0)\Delta\beta_{22}^{(1)} + \frac{1}{2}(\omega - \omega_0)^2\Delta\beta_{22}^{(2)} + ... \tag{41}$$

Using (38)-(41) and Fourier transform from the frequency domain to the time domain, $(\omega - \omega_0)$ is substituted with $i(\partial/\partial t)$, one can find two coupled equations as:

$$\begin{aligned}
&\frac{\partial A}{\partial z}+(\beta_1\frac{\partial A}{\partial t}+i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2}+...)+\\
&(\Delta\beta_{11}{}^{(1)}\frac{\partial}{\partial t}(|A|^2A)+\frac{i}{2}\Delta\beta_{11}{}^{(2)}\frac{\partial^2}{\partial t^2}(|A|^2A)+...)+\\
&(\Delta\beta_{12}{}^{(1)}\frac{\partial}{\partial t}(|B|^2A)+\frac{i}{2}\Delta\beta_{12}{}^{(2)}\frac{\partial^2}{\partial t^2}(|B|^2A)+...)\\
&=i[\Delta\beta_{11}^{(0)}(|A|^2A)+\Delta\beta_{12}^{(0)}(|B|^2A)]
\end{aligned} \tag{42}$$

$$\begin{aligned}
&\frac{\partial B}{\partial z}+(\beta_1\frac{\partial B}{\partial t}+i\frac{\beta_2}{2}\frac{\partial^2 B}{\partial t^2}+...)+\\
&(\Delta\beta_{21}{}^{(1)}\frac{\partial}{\partial t}(|A|^2B)+\frac{i}{2}\Delta\beta_{21}{}^{(2)}\frac{\partial^2}{\partial t^2}(|A|^2B)+...)+\\
&(\Delta\beta_{22}{}^{(1)}\frac{\partial}{\partial t}(|B|^2B)+\frac{i}{2}\Delta\beta_{22}{}^{(2)}\frac{\partial^2}{\partial t^2}(|B|^2B)+...)=\\
&i[\Delta\beta_{21}^{(0)}(|B|^2B)+\Delta\beta_{22}^{(0)}(|A|^2B)]
\end{aligned} \tag{43}$$

By having two dimensionless transverse u and longitudinal v electric field:

$$u(z,\tau)=\frac{A(z,\tau)}{\sqrt{p_0}},v(z,\tau)=\frac{B(z,\tau)}{\sqrt{p_0}} \tag{44}$$

$$\tau=\frac{T}{T_0},\xi=\frac{z}{L_D} \tag{45}$$

where P_0 and T_0 are the peak power and the width of the incident pulse, respectively. Then, we have:

$$\begin{aligned}
&i\frac{\partial A}{\partial\xi}=[\frac{\mathrm{sgn}(\beta_2)}{2}\frac{\partial^2 A}{\partial\tau^2}+\frac{i}{6}\beta_3L_D\frac{\partial^3 A}{T_0^3\partial\tau^3}-iL_D\Delta\beta_{11}^{(1)}\frac{\partial}{T_0\partial\tau}(|A|^2A)+\\
&\frac{1}{2}L_D\Delta\beta_{11}^{(2)}\frac{\partial^2}{T_0^2\partial\tau^2}(|A|^2A)-\frac{i}{6}\Delta\beta_{11}^{(3)}L_D\frac{\partial^3}{T_0^3\partial\tau^3}(|A|^2A)\\
&-iL_D\Delta\beta_{12}^{(1)}\frac{\partial}{T_0\partial\tau}(|B|^2A)+\frac{1}{2}L_D\Delta\beta_{12}^{(2)}\frac{\partial^2}{T_0^2\partial\tau^2}(|B|^2A)\\
&-\frac{i}{6}\Delta\beta_{12}^{(3)}L_D\frac{\partial^3}{T_0^3\partial\tau^3}(|B|^2A)]-\gamma_{11}(\omega_0)L_D|A|^2A-\gamma_{12}(\omega_0)L_D|B|^2A
\end{aligned} \tag{46}$$

$$\begin{aligned}
&i\frac{\partial B}{\partial\xi}=[\frac{\mathrm{sgn}(\beta_2)}{2}\frac{\partial^2 B}{\partial\tau^2}+\frac{i}{6}\beta_3L_D\frac{\partial^3 B}{T_0^3\partial\tau^3}-iL_D\Delta\beta_{21}^{(1)}\frac{\partial}{T_0\partial\tau}(|A|^2B)+\\
&\frac{1}{2}L_D\Delta\beta_{21}^{(2)}\frac{\partial^2}{T_0^2\partial\tau^2}(|A|^2B)-\frac{i}{6}\Delta\beta_{21}^{(3)}L_D\frac{\partial^3}{T_0^3\partial\tau^3}(|A|^2B)\\
&-iL_D\Delta\beta_{21}^{(1)}\frac{\partial}{T_0\partial\tau}(|B|^2B)+\frac{1}{2}L_D\Delta\beta_{22}^{(2)}\frac{\partial^2}{T_0^2\partial\tau^2}(|B|^2B)\\
&-\frac{i}{6}\Delta\beta_{22}^{(3)}L_D\frac{\partial^3}{T_0^3\partial\tau^3}(|B|^2B)]-\gamma_{21}L_D|A|^2B-\gamma_{22}L_D|B|^2B
\end{aligned} \tag{47}$$

and finally

$$\begin{aligned}
&i\frac{\partial U}{\partial\xi}-\frac{\mathrm{sgn}(\beta_2)}{2}\frac{\partial^2 U}{\partial\tau^2}+[\frac{i}{6}M'\frac{\partial^3 U}{\partial\tau^3}+i\frac{\Delta M_{11}^{(1)}}{(N_{11})^2}\frac{\partial}{\partial\tau}(|U|^2U)\\
&-\frac{1}{2}\frac{\Delta M_{11}^{(2)}}{(N_{11})^2}\frac{\partial^2}{\partial\tau^2}(|U|^2U)+\frac{i}{6}\frac{\Delta M_{11}^{(3)}}{(N_{11})^2}\frac{\partial^3}{\partial\tau^3}(|U|^2U)\\
&+i\frac{\Delta M_{21}^{(1)}}{(N_{22})^2}\frac{\partial}{\partial\tau}(|V|^2U)-\frac{1}{2}\frac{\Delta M_{21}^{(2)}}{(N_{22})^2}\frac{\partial^2}{\partial\tau^2}(|V|^2U)\\
&+\frac{i}{6}\frac{\Delta M_{21}^{(3)}}{(N_{22})^2}\frac{\partial^3}{T_0^3\partial\tau^3}(|V|^2U)]+\left(\frac{N_{12}}{N_{22}}\right)^2|V|^2U+|U|^2U=0
\end{aligned} \tag{48}$$

$$\begin{aligned}
&i\frac{\partial V}{\partial\xi}-\frac{\mathrm{sgn}(\beta_2)}{2}\frac{\partial^2 V}{\partial\tau^2}+[\frac{i}{6}M'\frac{\partial^3 V}{\partial\tau^3}+i\frac{\Delta M_{21}^{(1)}}{(N_{11})^2}\frac{\partial}{\partial\tau}(|U|^2V)\\
&-\frac{1}{2}\frac{\Delta M_{21}^{(2)}}{(N_{11})^2}\frac{\partial^2}{\partial\tau^2}(|U|^2V)+\frac{i}{6}\frac{\Delta M_{21}^{(3)}}{(N_{11})^2}\frac{\partial^3}{\partial\tau^3}(|U|^2V)\\
&+i\frac{\Delta M_{22}^{(1)}}{(N_{22})^2}\frac{\partial}{\partial\tau}(|V|^2V)-\frac{1}{2}\frac{\Delta M_{22}^{(2)}}{(N_{22})^2}\frac{\partial^2}{\partial\tau^2}(|V|^2V)\\
&+\frac{i}{6}\frac{\Delta M_{22}^{(3)}}{(N_{22})^2}\frac{\partial^3}{T_0^3\partial\tau^3}(|V|^2V)]+|V|^2V+\left(\frac{N_{21}}{N_{11}}\right)^2|U|^2V=0
\end{aligned} \tag{49}$$

where,

$$L_{NL_{11}}=\frac{1}{\gamma_{11}(\omega_0)P_0},L_{NL_{12}}=\frac{1}{\gamma_{12}(\omega_0)P_0} \tag{50}$$

$$L_{NL_{21}}=\frac{1}{\gamma_{21}(\omega_0)P_0},L_{NL_{22}}=\frac{1}{\gamma_{22}(\omega_0)P_0} \tag{51}$$

$$N_{11}^2=\frac{L_D}{L_{NL_{11}}},N_{12}^2=\frac{L_D}{L_{NL_{12}}} \tag{52}$$

$$N_{21}^2=\frac{L_D}{L_{NL_{21}}},N_{22}^2=\frac{L_D}{L_{NL_{22}}} \tag{53}$$

$$U=N_{11}u,V=N_{22}v \tag{54}$$

Equations (48) and (49), are coupled equations which are written for the pulse propagation in a nonlinear plasmonic waveguide with Kerr nonlinearity.

The values of above parameters specify the behavior of pulse propagation, i.e. dispersion and nonlinear effects studied numerically in the next section.

III. Dispersion

Dispersion and nonlinearity are the essential parameters which impact the state of pulse in time and frequency domain. Plasmonic waveguides by dispersive boundary conditions have indicated substantial dispersion that showed itself by GVD and TOD. Additionally, the waveguide dispersion has significant proportion with respect to material dispersion. In Figs. 2 and 3, we plot the dispersive parameter. In Fig. 2, GVD is plotted versus frequency. It demonstrates that the waveguide dispersion has substantial impact on total dispersion and has negative, zero, and positive quantities. At frequency ω / ω_p =0.107 and 0.234 that is normalized, there is no dispersion. So, by considering the Kerr nonlinearity, this plasmonic waveguide can propagate bright, gray, and dark solitons for negative and positive dispersion individually. In this paper, we consider $\omega_p = 1.36 \times 10^{16} Hz$. In Fig. 3, third request dispersion TOD is plotted versus frequency. TOD for As_2S_3 chalcogenide is positive and negative, yet the impact of waveguide geometry causes to change the manner of TOD; i.e., the sign and estimation of TOD is changed. TOD is one of the essential parameters for designing devices such as plasmonic waveguide.

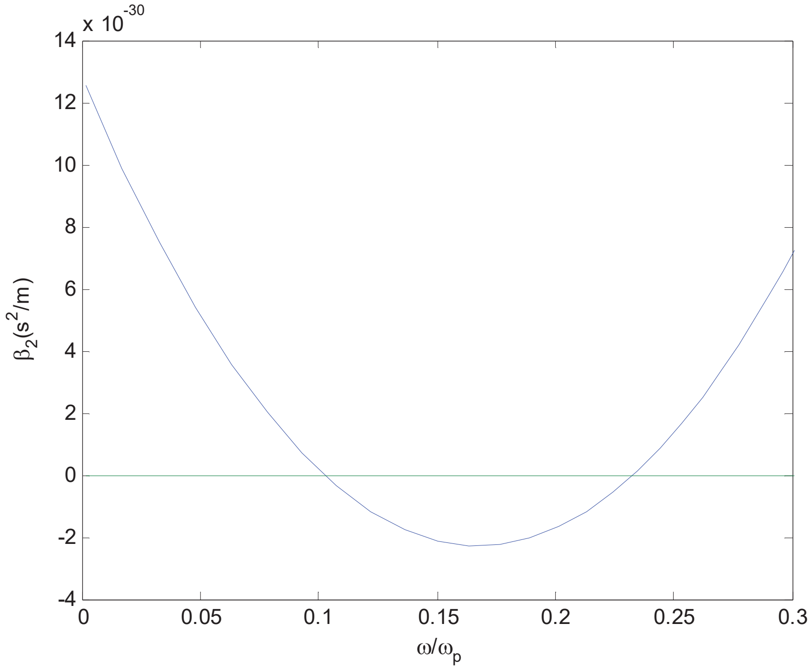

Fig. 2 Second- order dispersion or GVD in three-layer structure of As_2S_3 chalcogenide glass

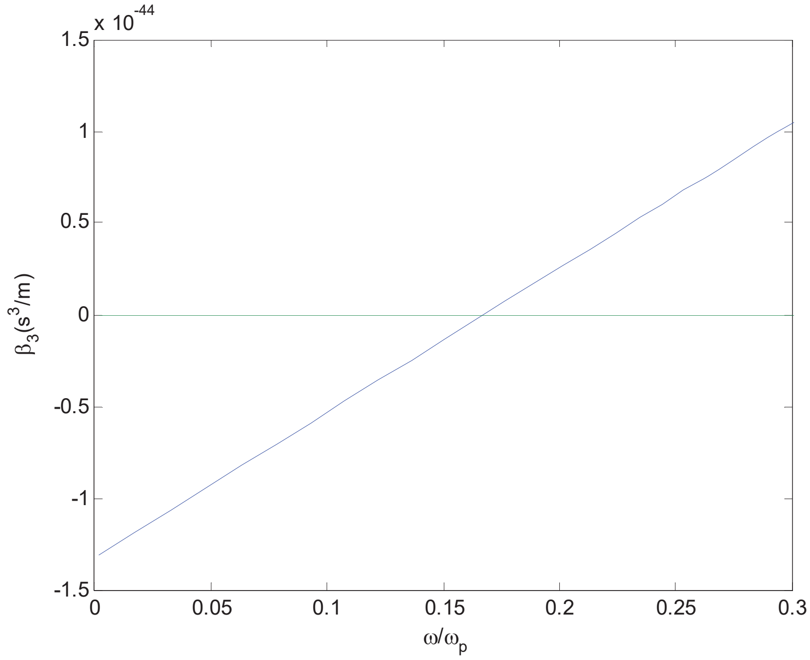

Fig. 3 Third order dispersion or TOD in three-layer structure of As_2S_3 chalcogenide

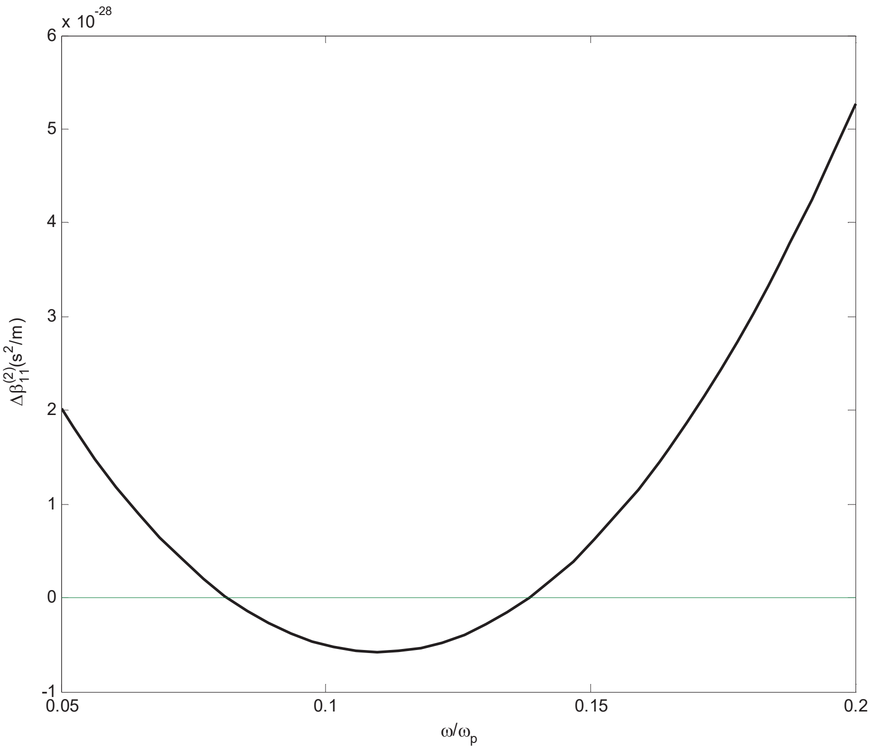

Fig. 4 Nonlinear second- order dispersion of $\Delta\beta_{11}^{(2)}$ in three-layer structure of As_2S_3 chalcogenide

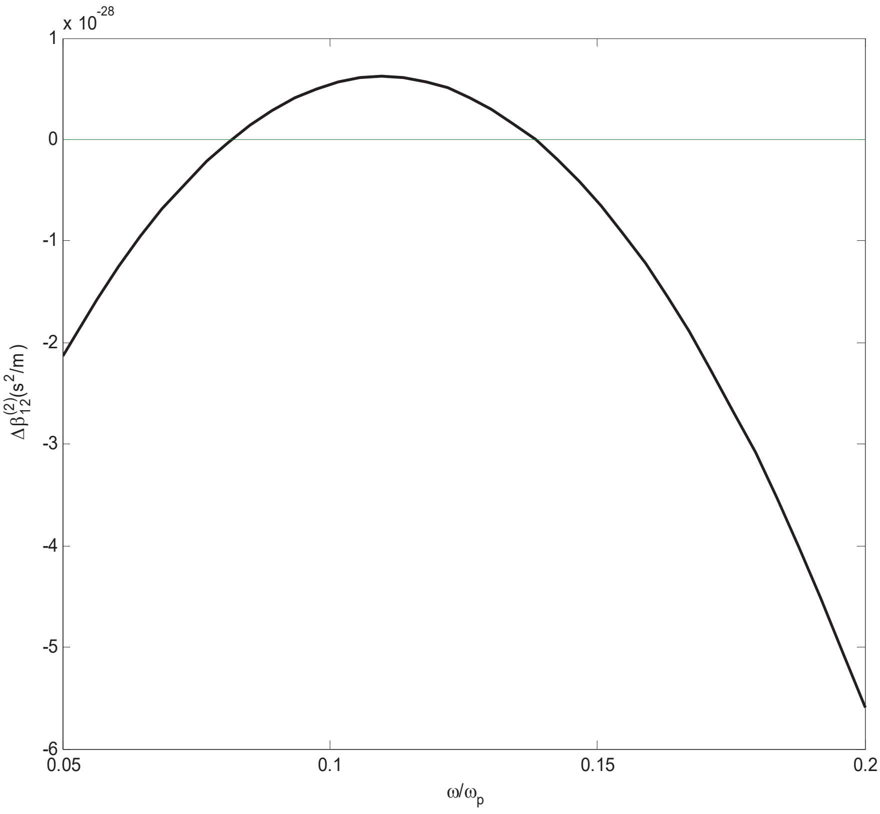

Fig. 5 Nonlinear second- order dispersion of $\Delta\beta_{12}^{(2)}$ in three-layer structure of As_2S_3 chalcogenide

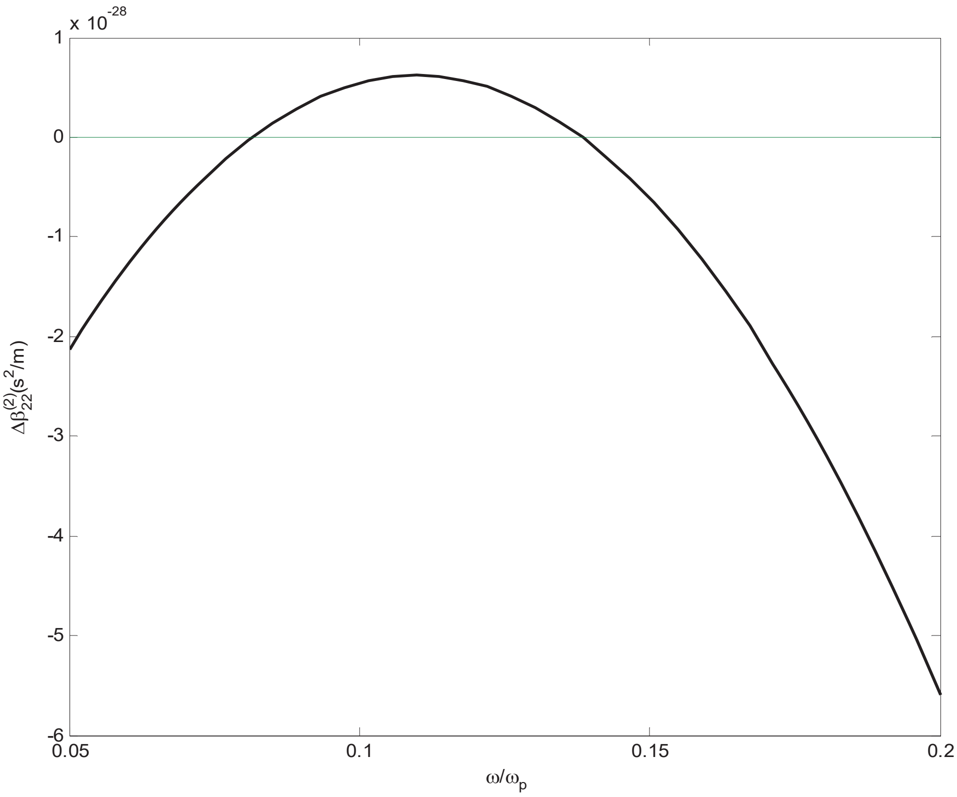

Fig. 6 Nonlinear second- order dispersion of $\Delta\beta_{21}^{(2)}$ in three-layer structure of As_2S_3 chalcogenide

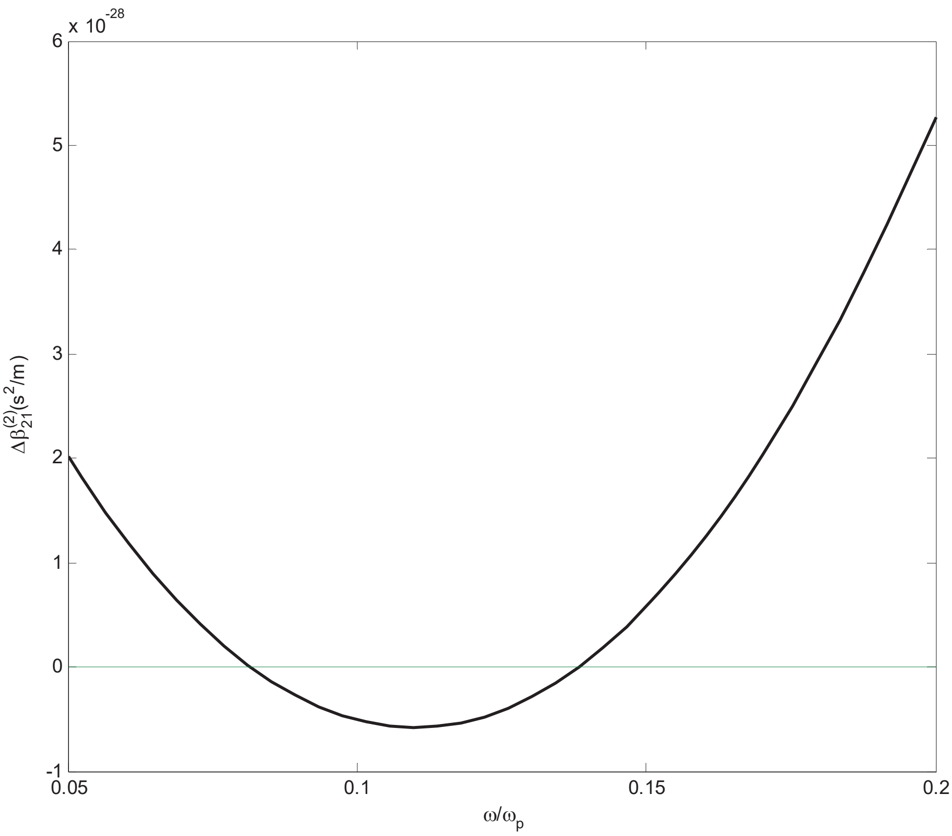

Fig. 7 Nonlinear second- order dispersion of $\Delta\beta_{22}^{(2)}$ in three-layer structure of As_2S_3 chalcogenide

Equations (38)-(41) are acquired by the Taylor series expansion of the coefficient of nonlinear term about ω_0. We name $\Delta\beta_{11}^{(2)}$, self nonlinear group velocity dispersion and $\Delta\beta_{12}^{(2)}$, cross nonlinear group velocity dispersion as SNGVD and XNGVD, respectively. SNGVD and XNGVD are plotted as frequency in Figs. 4-7.

IV. Conclusion

Combination of high nonlinear Kerr index of chalcogenide glasses and high dispersion of plasmonic waveguides that can focus fields in small region, can be a fundamental element to design all optical signal processing and switching. For this aim, we infer equations which represent the pulse propagation in a nonlinear plasmonic waveguides using As2S3 chalcogenide materials. By utilizing the perturbation theory, we determine two parts of electric field in frequency domain, then two coupled equations in time domain are inferred by utilizing Fourier transformation. GVD and TOD are concentrated numerically. We find that there exist a few interims in which GVD is positive, and some others are negative and zero for some points, which is because of dispersive nature of plasmonic waveguides. So, they can outline for bright or dark soliton propagation and procedure.

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