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Space-Time Cloaking based on Reflection, Transmission and Goos-Hänchen Shift

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Abstract: The birefringence characteristics of reflection and transmission of light pulse are explored in chiral medium driving by two probe electric and magnetic fields, while four control fields. The proposed medium show significant birefringence behaviors in reflection/transmission and Goos-Hänchen (GH) shifted beams. The birefringent GH-reflected and GH-transmitted pulses show significant contribution in the space time gap creation for secure communication and invisibility. A space-time gap has been observed in the reflection, transmission and corresponding GH-shifted reflection and transmission birefringent beams. The theoretical results may be useful for noise free secure communication in invisible radar technology.

Key words: Cloaking, Goos-Hänchen Shift, birefringence

I. INTRODUCTION

Cloaking has recently played a significant role in the phenomenon of hiding events using electromagnetic fields. To attain spatial cloaking, the refractive index is controlled to flow light around the object from a probe, such that a "gap" in space is produced, and remains concealed [1–3]. Alternatively a "time cloak" or "temporal cloak" is the one which hide information over a finite period of time. The dispersion of material is manipulating in temporal cloaking to hide the occurrence of an event from the outside source. A new type of electromagnetic cloaking is under consideration, where the events can be hidden rather than objects termed as "Space-time cloaking". Space-time cloak is a means of controlling electromagnetic radiations in space and time in such a way that a collection of events, or happenings is hidden from the distant perceiver [4].

Space time cloaking manipulate and transform data from one to the receiver in secure form and based experimentally on temporal cloaking (TC) [4]. By upgrading time to equal basis with three dimensional space, space-time cloaks, that conceal region of space for a specific window of time can be imagined [4, 5]. Although the full space-time cloak has not yet been implemented. The previous work has really shown pure temporal cloaking for spatially single mode lighting [6]. An event taking place in the gap is cloaked from the sensors and only a particular observer can be reached to the original information of light. This phenomenon leads to new successive possibilities in the field of quantum optics [7], such as it operates commonly for increasing or decreasing the speed of light without deviation or realignment of light [8]. Recent work on time cloaking observed a gripping approach to hide temporal events from an applied light field and also study intensity gaps in a probe beam. Experimental results show temporal cloaking of non-linear relation and large-speed optical data [9]. TC like phenomenon had also been reported in the last decade regarding conductivity problems [1]. Soon after origination, a lot of cloaking devices were carried out using electromagnetic meta-materials from microwave [2] to optical frequency range [3]. In a few years the field has reached to a high level of maturity due to its practical applications [10]. The idea of TC came out with the intention of hiding events rather than matter [11]. Firstly TC presentation was revealed in fiber optics setup [12]. Four-wave mixing was applied to impress a non-continuous linear frequency chirrup on a known segment of a monochromatic laser signal [13]. In addition, the acoustic cloaking, where an object can be hidden and transformed acoustically, is a practical application based on acoustic meta-materials [14].

In 1947 Goos and Hänchen showed experimentally the phenomenon of GH-Shift for the first time [15]. When an infinite plane wave is incident on the interface of two mediums, there occur a small shift between the incident and reflected wave called GH Shift [16] and is proportional to the depth of penetration comparable to the wavelength of the light [15, 17]. This tiny shift occurs under the process of total internal reflection [18]. GH effect is studied theoretically and experimentally for different mediums having different refractive indices, and is observed in the case of electron [19, 20] and neutron [5, 21]. Allan and John [23] presented an easy derivation for total internal reflection

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grounded on energy considerations and Fresnel's equation. On the basis of these considerations GH-shift is observed at the interface of two semi-infinite dielectric media due to which this energy flows through the dielectric boundaries. GH effect can also be obtained by using energy flux conservation [24]. GH-Shift has a variety of applications in different fields such as acoustics, quantum mechanics, photonics, plasma physics, micro optics and nano-optics [25], i.e. optical wave-guide switches [26], ultra-layered structures [27], displacement sensors [28] and many more.

A large number of research work has been published on temporal, space and event cloaking using different techniques and formalism. In my knowledge no work is available in literature on space-time cloaking, in which five level atomic system having electric and magnetic probe fields and four control fields are involved to modify space-time cloaking based on reflection/transmission and corresponding GH-shifted beams. In this work we use the above formalism to modify event or space time cloaking for noise free secure communication to protect information hacking.

FIG. 1: Figure of five level atomic system.

II. DYNAMICS OF THE SYSTEM

A five level chiral atomic system is under consideration for controlling space-time cloaking through GH-shifted beams as shown in the Fig.1. The lower energy level $|1\rangle$ is coupled to energy levels $|2\rangle$ and $|4\rangle$ with control fields $E_{1,2}$ having Rabi frequencies $\Omega_{1,2}$ respectively. The level $|1\rangle$ is also coupled to energy level $|3\rangle$ with magnetic field B having Rabi frequency Ω_m . Likewise the energy levels $|2\rangle$ and $|4\rangle$ are coupled to level $|5\rangle$ with controlled fields $E_{3,4}$ having Rabi frequencies $\Omega_{3,4}$. The level $|3\rangle$ is coupled to level $|5\rangle$ with probe field E_p having Rabi frequency Ω_p . The decay rates γ_{ij} between two states and detuning of driving fields Δ_i are shown in the figure. To discuss the system dynamics the following interaction picture Hamiltonian is used

$$\begin{aligned}
 H_I = & -\frac{\hbar}{2}\Omega_1 e^{-i\Delta_1 t} |1\rangle \langle 2| - \frac{\hbar}{2}\Omega_m e^{-i\Delta_m t} |1\rangle \langle 3| \\
 & -\frac{\hbar}{2}\Omega_2 e^{-i\Delta_2 t} |1\rangle \langle 4| - \frac{\hbar}{2}\Omega_3 e^{-i\Delta_3 t} |2\rangle \langle 5| \\
 & -\frac{\hbar}{2}\Omega_p e^{-i\Delta_p t} |3\rangle \langle 5| - \frac{\hbar}{2}\Omega_4 e^{-i\Delta_4 t} |4\rangle \langle 5| + H.c.
 \end{aligned}$$

FIG. 2: Group refractive index $n_g^{(\pm)}$ vs probe field detuning Δ_p/γ and control field Rabi frequencies $|\Omega_{1,2}|/\gamma$, such that (a) $\Omega_1 = 2\gamma, 4\gamma, 6\gamma, 8\gamma$ (b) $\Omega_2 = 2\gamma, 4\gamma, 6\gamma, 8\gamma$.

FIG. 3: Transmission and corresponding GH-shift in transmission of birefringent beam vs controlled field of Rabi frequency as $|\Omega_{1,2}|/\gamma$, such that (a) and (c) show the transmission at different phases while (b) and (d) shows GH-shifts. in transmission

The external fields are tuned to their angular frequencies and atomic state resonance frequencies as: $\Delta_1 = \omega_{12} - \omega_1$, $\Delta_2 = \omega_{14} - \omega_2$, $\Delta_p = \omega_{35} - \omega_p$ and $\Delta_m = \omega_{13} - \omega_m$ of the system. The following Von-Neumann equation of density matrix is to measure coherence between two states [29–31]:

$$\dot{\rho} = -\frac{i}{\hbar}[\rho, H_I] - \frac{1}{2}\Gamma_{ij} \sum (\delta^\dagger \delta \rho + \rho \delta^\dagger \delta - 2\delta \rho \delta^\dagger) \quad (1)$$

where δ and $\delta^\dagger$ are the lowering and raising operator respectively for the atomic decay $\Gamma_{j=1,2,3,4,p,m}$. By putting $\rho_{nm} = \tilde{\rho}_{nm} \exp[-i(\Delta_{j=1,2,3,4,p,m})t]$.

After large algebraic manipulation the following coupled rate equations are obtained

$$\dot{\tilde{\rho}}_{35} = (i\Delta_p - \frac{1}{2}\gamma_p)\tilde{\rho}_{35} + \frac{i}{2}(\Omega_3\tilde{\rho}_{32} + \Omega_p\tilde{\rho}_{33} + \Omega_4\tilde{\rho}_{34} - \Omega_m^*\tilde{\rho}_{15} - \Omega_p\tilde{\rho}_{55}) \quad (2)$$

$$\dot{\tilde{\rho}}_{34} = (i(\Delta_p - \Delta_4) - \frac{1}{2}(\gamma_p + \gamma_4))\tilde{\rho}_{34} + \frac{i}{2}(\Omega_2\tilde{\rho}_{31} + \Omega_4^*\tilde{\rho}_{35} - \Omega_m^*\tilde{\rho}_{14} - \Omega_p\tilde{\rho}_{54}) \quad (3)$$

FIG. 4: Reflection and corresponding GH-shift in reflection of birefringent beam vs controlled field of Rabi frequency as $|\Omega_{1,2}|/\gamma$. The graph (a) and (c) shows the reflection at different phases while graphs (b) and (d) are their corresponding shifted reflections.

$$\dot{\tilde{\rho}}_{32} = (i(\Delta_p - \Delta_3) - \frac{1}{2}(\gamma_3 + \gamma_p))\tilde{\rho}_{32} + \frac{i}{2}(\Omega_1\tilde{\rho}_{31} + \Omega_3^*\tilde{\rho}_{35} - \Omega_m^*\tilde{\rho}_{12} - \Omega_p\tilde{\rho}_{52}) \quad (4)$$

$$\dot{\tilde{\rho}}_{31} = (-i\Delta_m - \frac{1}{2}(\gamma_1 + \gamma_m + \gamma_2 + \gamma_p))\tilde{\rho}_{31} + \frac{i}{2}(\Omega_m^*\tilde{\rho}_{33} + \Omega_1^*\tilde{\rho}_{32} + \Omega_2^*\tilde{\rho}_{34} - \Omega_m^*\tilde{\rho}_{11} - \Omega_p\tilde{\rho}_{51}) \quad (5)$$

Initially the state $|1\rangle$, $|2\rangle$, $|3\rangle$, and $|4\rangle$, are taken in superposition state as

$$|\psi\rangle = \beta_1|1\rangle + \beta_2|2\rangle + \beta_3|3\rangle + \beta_4|4\rangle \quad (6)$$

The zero order density matrix is

$$\rho^{(0)} = |\psi\rangle\langle\psi| \quad (7)$$

In the above mentioned equations Ω_m and Ω_p are taken in first order perturbation, while Ω_1 , Ω_2 , Ω_3 and Ω_4 are taken in all orders. From superposition states, $\tilde{\rho}_{11}^{(0)} = |\beta_1|^2$, $\tilde{\rho}_{33}^{(0)} = |\beta_3|^2$, $\tilde{\rho}_{12}^{(0)} = \beta_1\beta_2^*$, $\tilde{\rho}_{14}^{(0)} = \beta_3\beta_4^*$, $\tilde{\rho}_{15}^{(0)} = \tilde{\rho}_{54}^{(0)} = \tilde{\rho}_{52}^{(0)} = 0$, We can use the following relation to solve coupled rate equation [32, 33]:

$$Z(t) = \int_{-\infty}^t e^{-A(t-t')} B dt' = A^{-1}B \quad (8)$$

where $Z(t)$ and B denotes column matrices, and A denotes 4x4 matrix. Using eq.8 the coherence $\tilde{\rho}_{35}$ and $\tilde{\rho}_{31}$ are obtained in the following forms:

$$\rho_{35} = T_1\Omega_p + T_2\Omega_m \quad (9)$$

$$\rho_{31} = T_3\Omega_p + T_4\Omega_m \quad (10)$$

The polarization and magnetization equation can be written from coherence $P = N\sigma_{35}\rho_{35}$ and $M = \mu_{31}N\rho_{31}$. Plugging $B = \mu_0(H + M)$, $\Omega_m = \mu_{31}B/\hbar$ and $\Omega_p = \rho_{35}E/\hbar$ in polarization as well as magnetization equation we obtain the following.

$$P = N\sigma_{35}(T_1\Omega_p + T_2\Omega_m) \quad (11)$$

$$M = N\mu_{31}(T_3\Omega_p + T_4\Omega_m) \quad (12)$$

where T_{1-4} , A_{1-4} , x_{1-4} , G_{1-2} , M_{1-2} , w_{1-2} , α_5 and Q are given in appendix. The polarization and magnetization in the form of electric and magnetic susceptibility and chiral condiments are available in literature as:

$$P = \epsilon_0\chi_e E + \frac{\xi_{EH}H}{c} \quad (13)$$

$$M = \frac{\xi_{HE}E}{\mu_0 c} + \chi_m H \quad (14)$$

Comparing eqs.11 and eqs.13, while eqs.12 and eqs.14 the following electric and magnetic susceptibilities and chiral coefficients are obtained:

$$\xi_{EH} = c\left(\frac{N\sigma_{35}\mu_{31}T_2\mu_0}{\hbar} + \frac{N^2\sigma_{35}\mu_{31}^3T_2T_4\mu_0^2}{\hbar(\hbar - N\mu_{31}^2T_4\mu_0)}\right) \quad (15)$$

$$\xi_{HE} = \mu_0 c\left(\frac{N\mu_{31}\sigma_{35}T_3}{\hbar - N\mu_{31}^2T_4\mu_0}\right) \quad (16)$$

$$\chi_m = \frac{N\mu_{31}^2T_4\mu_0}{\hbar - N\mu_{31}^2T_4\mu_0} \quad (17)$$

$$\chi_e = \frac{1}{\epsilon_0}\left(\frac{N\sigma_{35}^2T_1}{\hbar} + \frac{N^2\sigma_{35}^2\mu_{31}^2T_2T_3\mu_0}{\hbar(\hbar - N\mu_{31}^2T_4\mu_0)}\right) \quad (18)$$

The complex refractive index of chiral medium is calculated from eqs.(15-18) and can be written as:

$$n_r^{(\pm)} = Re\left[\sqrt{(1 + \chi_e)(1 + \chi_m) - \frac{(\xi_{EH} - \xi_{HE})^2}{4}} \pm \frac{i}{2}(\xi_{EH} + \xi_{HE})\right] \quad (19)$$

The chiral coefficient contribute additional terms ξ_{EH} and ξ_{HE} to refractive index. If $\xi_{HE, EH} = 0$ the medium will be left handed or right handed. It is dependent on $\epsilon_r = 1 + \chi_e$ and $\mu_r = 1 + \chi_m$. If both ϵ_r and μ_r are positive the refractive index will be positive. This medium is called positive refracted medium or conventional medium or right handed medium. If both ϵ_r and μ_r are negative the refractive index will be negative. This medium is called negative refracted medium or left handed medium. If $\xi_{HE, EH} \neq 0$ the medium is chiral. It may be conventional or negative refracted medium with the need of positive and negative ϵ_r and μ_r . These terms show circular birefringence in the medium having refractive index $n_r^{(+)}$ and $n_r^{(-)}$. The birefringent reflection and transmission are written as:

$$R^{(+)} = \frac{\cos[G_1](x_1^2 - x_2^2)x_2x_3\sin[2\alpha_5] + M_1\sin[G_1]}{x_2x_3\cos[G_1]G_3 + w_1\sin[G_1]} \quad (20)$$

$$R^{(-)} = \frac{\cos[G_2](x_1^2 - x_2^2)x_2x_4\sin[2\alpha_5] + M_2\sin[G_2]}{x_2x_4\cos[G_2]G_3 + w_2\sin[G_2]} \quad (21)$$

$$T^{(+)} = \frac{2ix_1x_3x_2^2}{x_2x_3\cos[G_1]G_3 + w_1\sin[G_1]} \quad (22)$$

$$T^{(-)} = \frac{2ix_1x_4x_2^2}{x_2x_4\cos[G_2]G_3 + w_2\sin[G_2]} \quad (23)$$

The corresponding left and right circularly polarized GH-shifts in reflection and in transmission beams are written below:

$$S_R^{(+)} = -\frac{\lambda}{2\pi|(R^{(+)})|^2} [Re(R^{(+)}) \frac{\partial}{\partial\theta} Im(R^{(+)}) - Im(R^{(+)}) \frac{\partial}{\partial\theta} Re(R^{(+)})] \quad (24)$$

$$S_R^{(-)} = -\frac{\lambda}{2\pi|(R^{(-)})|^2} [Re(R^{(-)}) \frac{\partial}{\partial\theta} Im(R^{(-)}) - Im(R^{(-)}) \frac{\partial}{\partial\theta} Re(R^{(-)})] \quad (25)$$

$$S_T^{(+)} = -\frac{\lambda}{2\pi|(T^{(+)})|^2} [Re(T^{(+)}) \frac{\partial}{\partial\theta} Im(T^{(+)}) - Im(T^{(+)}) \frac{\partial}{\partial\theta} Re(T^{(+)})] \quad (26)$$

$$S_T^{(-)} = -\frac{\lambda}{2\pi|(T^{(-)})|^2} [Re(T^{(-)}) \frac{\partial}{\partial\theta} Im(T^{(-)}) - Im(T^{(-)}) \frac{\partial}{\partial\theta} Re(T^{(-)})] \quad (27)$$

The input pulse is taken in the Gaussian form as:

$$S_i(x, t)|_{z=0} = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} A(k_x, \omega_p) e^{i(k_z z + k_x x)} e^{-i(\omega_p - \omega_0)t} dk_x d\omega_p \quad (28)$$

where

$$A(k_x, \omega_p) = \frac{W_x}{\sqrt{2\pi_0}} e^{-\frac{W_x^2(k_x - k_{x0})^2}{4}} e^{-\frac{\tau_0^2(\omega_p - \omega_0)^2}{4}} \quad (29)$$

The reflection and transmission birefringent pulses are written as:

$$S_T^{\pm}(x, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} T^{(\pm)} A(k_x, \omega_p) e^{i(k_z(z-L) + k_x x)} e^{-i(\omega_p - \omega_0)(t - t^{(\pm)})} dk_x d\omega_p \quad (30)$$

$$S_R^{\pm}(x, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} R^{(\pm)} A(k_x, \omega_p) e^{i(-k_z z + k_x x)} e^{-i(\omega_p - \omega_0)(t - t^{(\pm)})} dk_x d\omega_p \quad (31)$$

The GH-shifted birefringent pulses are written as:

$$S_{GHT}^{\pm}(x, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} S_T^{(\pm)} A(k_x, \omega_p) e^{i(k_z(z-L) + k_x x)} e^{-i(\omega_p - \omega_0)(t - t^{(\pm)})} dk_x d\omega_p \quad (32)$$

$$S_{GHR}^{\pm}(x, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} S_R^{(\pm)} A(k_x, \omega_p) e^{i(-k_z z + k_x x)} e^{-i(\omega_p - \omega_0)(t - t^{(\pm)})} dk_x d\omega_p \quad (33)$$

III. RESULTS AND DISCUSSIONS

In this section we present and explain our main outcomes. The parameter γ is considered to be $36.1GHz$ and other parameters are scaled to this γ . In our numerical simulations atomic units are used, while $\hbar, \mu_0$ and ϵ_0 are considered to be unity. Those parameters which are same for all the plots are: $\Omega_{3,4} = 1\gamma$, $\gamma_{1,2,3} = 1\gamma$, $\gamma_4 = 0.2\gamma$, $\gamma_m = 0.01\gamma$, $\gamma_p = 2\gamma$, $\Delta_{1,3,4,m} = 0\gamma$, $\varphi_1 = \pi/3$, $\varphi_2 = \pi/4$, $\varphi_{3,4} = 0$, $\phi_{1,3} = \pi/6$, $\phi_{2,4} = 0$, $\phi_5 = \pi/4$, $\theta = \pi/3$, $\alpha_1 = 0.4$, $\alpha_2 = 0.1$, $\alpha_3 = 0.2$, $\alpha_4 = 0.3$, $L = 1m$, $N = 10^{16} atoms/cm^3$, $d_1 = 1.5$, $d_2 = 2.5$ $k = 2\pi/\lambda$. The width of pulses are $\tau_0 = 1.5\mu s$, $w = 30\lambda_p$, $\lambda_p = 2\pi c/\omega$, $\omega = 10^2\gamma$

In FIG.2 the plots are traced for birefringent group indices vs probe detuning Δ_p/γ and control field Rabi frequencies $|\Omega_{1,2}|/\gamma$. The birefringent group indices are the function of probe detuning Δ_p and control field Rabi frequency $|\Omega_2|$. The right circularly polarized (red) beam have positive group index and left circularly polarized (green) beam show

FIG. 5: The birefringent pulses beam vs time and space coordinates normalized to pulse width τ_0 and W such that the plots shows intensities of pulses (a) incident, (b) reflection and (c) transmission.

negative group index as $\Delta_p > 0\gamma$. Further as $|\Omega_1|$ is increased from 2γ to 4γ , 6γ and then to 8γ , consequently the value of positive and negative group index of right and left circularly polarized beam decreases. The maximum value of positive group index of right circularly polarized is $n_g^{(+)} = 1000$ and negative group index of left circularly polarized beam is $n_g^{(-)} = -2000$. The corresponding group velocity of the beams are $v_g^{(+)} = c/1000$ and $v_g^{(-)} = c/-2000$ as shown in FIG.2a. The birefringent group indices are also a function of probe detuning Δ_p and control field Rabi frequency $|\Omega_1|$. In this case the group indices are value of -500 and corresponding group velocities are $v_g^{(\pm)} = \pm c/500$. The control field Rabi frequency varies from $|\Omega_2| = 2\gamma$, $|\Omega_2| = 4\gamma$, $|\Omega_2| = 6\gamma$ and then to $|\Omega_2| = 8\gamma$ enhances the birefringent group indices as shown in FIG.2b.

In FIG.3 the graphs are traced for transmission and corresponding GH-shift in transmission of birefringent beam under controlled field of Rabi frequencies $|\Omega_{1,2}|/\gamma$. The right and left circularly polarized beams having fluctuations at small values of $|\Omega_{1,2}|$ and then becomes constant at high values while keeping the incident angle $\theta_i = \pi/6$. Increasing intensity of $|\Omega_1|$ and keeping $|\Omega_2| < 4\gamma$, the transmission beam fluctuates between -0.5 and 1.00 . Similarly increasing intensity of $|\Omega_2|$ and keeping $|\Omega_1| < 2\gamma$, the transmission beam fluctuates between -0.5 and 1.00 as shown in FIG.3a.

The corresponding GH-shift in left and right circular polarized beams at the same incident angle fluctuates between the values of -3 to 1 at lower value of $|\Omega_{1,2}|/\gamma$. The left and right circularly polarized beams show both positive and negative GH-shifts due to normal and anomalous dispersion. The same condition is imposed on the GH-shifted beams. Increasing intensity of $|\Omega_1|$ and keeping $|\Omega_2| < 4\gamma$, the GH-shifts in transmission beam fluctuates between -3 and 1.00 . Similarly increasing intensity of $|\Omega_2|$ and keeping $|\Omega_1| < 2\gamma$, the GH-shift in transmission beam fluctuating between -3 and 1.00 . At certain values of $|\Omega_{1,2}|/\gamma$, the right circularly polarized shifted beam has greater value than left circularly polarized beam and at another values of $|\Omega_{1,2}|/\gamma$, the contrast behavior is true as shown in FIG.3b. Both circularly polarized beams having fluctuations at small values of $|\Omega_{1,2}|$ and then becomes constant at high values, keeping the incident angle $\theta_i = \pi/3$. When the intensity of $|\Omega_1|$ is increased while keeping $|\Omega_2| < 4\gamma$, then the transmission beam fluctuates between -0.5 and 1.00 . Similarly by increasing the intensity of $|\Omega_2|$ and keeping $|\Omega_1| < 2\gamma$, the transmission beam fluctuates between -0.5 and 1.00 as shown in FIG.3c. Likewise the GH-shifted beams for the incident angle $\theta_i = \pi/3$, the left and right circular polarized beams fluctuate at smaller values of $|\Omega_{1,2}|$ and remain constant for higher values. In this case the fluctuation varies between -1 and 0.5 , such that for values of $|\Omega_1| > 1$ and for values of $|\Omega_2| \leq 4$, the fluctuations are continuously increasing and decreasing while at values greater than 5.5 , the right circularly polarized beam's fluctuation increases and beyond this value the left beam's fluctuation becomes constant as shown in FIG.3d.

In FIG.4 the graphs are traced for reflection and corresponding GH-shift in reflection of birefringent beam under controlled field of Rabi frequencies $|\Omega_{1,2}|/\gamma$. The reflection beams oscillate between the value of -1 to 1 at incident angle

FIG. 6: The plots (a,c) show reflections and (b, d) show transmission intensities in the birefringent medium. In all these plots cloaking is being observed, the right sided peaks show the intensities of the Right circular polarized beams while the left sided peaks show the intensities of left circular polarized beams .

$\theta_i = \pi/6$. The left circularly polarized beam fluctuates between -0.5 and 0.5 with $|\Omega_1|$ in the range of $0 \leq |\Omega_2| \leq 4\gamma$. Again the left circularly polarized beam fluctuates between -0.5 and 0.5 with $|\Omega_2|$ in the range of $0 \leq |\Omega_1| \leq 2\gamma$. At $|\Omega_1| > 2\gamma$ and $|\Omega_2| > 4\gamma$, the left circularly polarized beam gradually decreases to the value of -0.5 and right circularly polarized beam gradually decreases from 1 to 0.5 . At higher values of $|\Omega_{1,2}|/\gamma$, both the beams become saturated as shown in the FIG.4a. The corresponding GH-shift in left circularly polarized reflected beam is nearly equal to zero, while right circularly polarized beam fluctuates from zero to 1 at the same incident angle $\theta = \pi/6$. The fluctuation gradually decrease for $|\Omega_1| > 2\gamma$ and $|\Omega_2| > 4\gamma$ as shown in FIG.4b. Both beams having same behavior as that of FIG.4a but show maximum splitting for $|\Omega_1| > 2\gamma$ and $|\Omega_2| > 4\gamma$ at incident angle $\theta = \pi/3$ as shown in FIG.4c. The corresponding GH-shift in right circularly polarized beam is negative for $|\Omega_{1,2}| < 6\gamma$, while the GH-shift is positive for $|\Omega_{1,2}| > 6\gamma$. There is no GH-shift in left circularly polarized beam as shown in FIG.4d.

In FIG.5 the plots are traced for incident reflected and transmitted beams vs time and space coordinates normalized to pulse width τ_0 and W . The incident pulse is taken in Gaussian form, it's intensity varies from zero to 0.4 in arbitrary units. The pulses have soliton like behavior having uniform distribution about origin of space time coordinates as shown in FIG.5a. The reflected pulse is splitted through the medium into uniform soliton like Gaussian pulses intensities. The intensities of these pulses vary from zero to 0.2 in arbitrary units. The two reflected beams have zero intensity near the origin. The space time gap (event gap) is appeared between the two intensities, where pulse amplitude is zero. Thus in this space time gap the information and object is not detectable. The object is invisible and information is hidden from the outside hackers and obsessors through birefringent reflected beams as shown FIG.5b. The birefringent transmitted pulses have also unequal intensity distribution and have space time gap creation. The intensity of transmitted birefringent pulses is very less than reflected pulses. In this case information and object can be hidden from outside detectors through a gap created in birefringent transmitted pulses as shown in FIG.5c. If an external event of $S_E(x, t)$ interacts with birefringent reflected and transmitted pulses in this gap then $S_E(x, t)S_T^\pm(x, t) = 0$ as well as $S_E(x, t)S_R^\pm(x, t) = 0$. Thus no information can be hacked by external event propagating through the space time gaps.

In FIG.6 the graphs are traced for reflection and transmission beams vs time and space coordinates normalized to pulse width τ_0 and W . The incident angle is supposed here $\theta_i = \pi/3$. In this case the intensity varies from zero to 0.2 in arbitrary units. Both birefringent reflected beams have different intensities. The intensity of the pulses within the gap is zero and no external event interacts it as shown in FIG.6a. The birefringent transmission pulses intensities having the same event gap as shown in FIG.6b, where the intensities are in the range of 0 and 0.00002 . The first peak

FIG. 7: Birefringent intensities of GH-shifts in the reflection are shown in plots (a,c) and transmission in (b,d)

shows the intensity of transmission with greater amplitude while the second one shows the transmission with very less amplitude. Once again the effect is observed with comparable intensity peak for reflection of the birefringent beams having the same intensities range and space time gap as that of FIG.6a. The incident angle is supposed here $\theta_i = \pi/6$ as shown in FIG.6c. In FIG.6d the birefringent transmitted beam have intensities from 0 to 0.0001, which having less intensity as compared to the reflected beams of FIG.6c. In all these cases no amplitude of pulses is occurred in the space time gaps. Beside this $|\Omega_1|$ and $|\Omega_2|$ are taken 5γ and 8γ for all the plots respectively.

In FIG.7 the graphs are traced for birefringent GH-reflection and GH-transmission pulses intensities vs time and space coordinates normalized to pulse width τ_0 and W . The birefringent GH-reflected pulses have different intensities. The intensity of right peak is maximum while the intensity of the left peak is very less at incident angle $\theta_i = \pi/6$. There occurs a space time gap, where the event can be hidden from the outside sources as shown in the FIG.7a. The birefringent GH-transmitted pulses intensities with the same parameters are shown in FIG.7b. Both the plots (a,b) have the same intensity range i.e. from zero to 0.4. The reflected pulse is splitted through the medium into two intensities, where the intensity of one peak is greater than the other at incident angle $\theta_i = \pi/3$ and the intensity range is from zero to 1 as shown in FIG.7c. In the same manner the birefringent GH-transmitted beams with broaden peaks, having minimum left pulse and maximum intensity ranges from 0 to 0.1 as shown in the FIG.7d. $|\Omega_1|$ and $|\Omega_2|$ taken 8γ and 5γ for all plots of this figure respectively.

IV. CONCLUSIONS

The birefringent characteristics of reflection and transmission of light pulse are explored in a five-level chiral atomic medium. Two probe electric and magnetic fields, while four control driving fields are considered in the system to modify the birefringent response of the medium. The proposed medium shows significant birefringence behaviors in the reflection/transmission and GH-shifted beams. The birefringence behavior of the beams is controlled and modified with intensities of control fields, probe and control field detunings, the phases variation of control fields and phases of superposition states. The birefringent GH-reflection and GH-transmission pulses intensities are controlled for space time gaps. A space-time gap has been observed in reflection, transition and corresponding GH-shifted reflection and transmission birefringent beams. The amplitude or intensity of the electromagnetic pulse is zero in this space-time gap where an external event remain undetected. The space time gap is important for secure communication between different systems and invisibility objects. The theoretical results may be useful for noise free secure communication in an invisible radar technology.

V. APPENDIX

$$A_1 = i\Delta_p - \frac{1}{2}\gamma_p$$

$$A_2 = i(\Delta_p - \Delta_4) - \frac{1}{2}(\gamma_p + \gamma_4)$$

$$A_3 = i(\Delta_p - \Delta_3) - \frac{1}{2}(\gamma_3 + \gamma_p)$$

$$A_4 = -i\Delta_m - \frac{1}{2}(\gamma_1 + \gamma_m + \gamma_2 + \gamma_p)$$

where

$$T_1 = \frac{ie^{2i\phi_5}(4A_2A_3A_4 + A_2\Omega_1^2 + A_3\Omega_2^2)\alpha_3^2}{4Q}$$

$$T_2 = \frac{e^{i\phi_1-i\phi_2}(-4A_2A_4\Omega_3e^{i\varphi_3} - \Omega_2^2\Omega_3e^{i\varphi_3} + \Omega_1\Omega_2\Omega_4e^{-i\varphi_1+i\varphi_2+i\varphi_4})\alpha_1\alpha_2}{8Q}$$

$$- \frac{2i(A_2\Omega_1\Omega_3e^{i\varphi_1+i\varphi_3} + A_3\Omega_2\Omega_4e^{i\varphi_2+i\varphi_4})(-\alpha_1e^{i\phi_1} + \alpha_3e^{i\phi_5})(\alpha_1e^{i\phi_1} + \alpha_3e^{i\phi_5})}{8Q}$$

$$+ \frac{e^{-i\phi_4+i\phi_5}(\Omega_1\Omega_2\Omega_3e^{i\varphi_1-i\varphi_2+i\varphi_3} - 4A_3A_4\Omega_4e^{i\varphi_4} - \Omega_1^2\Omega_4e^{i\varphi_4})\alpha_3\alpha_4}{8Q}$$

$$T_3 = -\frac{ie^{2i\phi_5}(A_2\Omega_1\Omega_3e^{-i\varphi_1-i\varphi_3} + A_3\Omega_2\Omega_4e^{-i\varphi_2-i\varphi_4})\alpha_3^2}{4Q}$$

$$T_4 = \frac{e^{i\phi_1-i\phi_2}(\Omega_2\Omega_3\Omega_4e^{-i\varphi_2+i\varphi_3-i\varphi_4} - \Omega_1(4A_1A_2 + \Omega_4^2)e^{-i\varphi_1})\alpha_1\alpha_2}{8Q}$$

$$+ \frac{2i(4A_1A_2A_3 + A_2\Omega_3^2 + A_3\Omega_4^2)(-\alpha_1e^{i\phi_1} + \alpha_3e^{i\phi_5})(\alpha_1e^{i\phi_1} + \alpha_3e^{i\phi_5})}{8Q}$$

$$+ \frac{e^{-i\phi_4+i\phi_5}(-\Omega_2e^{-i\phi_2}(4A_1A_3 + \Omega_3^2) + \Omega_1\Omega_3\Omega_4e^{-i\varphi_1-i\varphi_3+i\varphi_4})\alpha_3\alpha_4}{8Q}$$

where

$$Q = \frac{(4A_2A_4 + \Omega_2^2)(4A_1A_3 + \Omega_3^2) + \Omega_4(-\Omega_1\Omega_2\Omega_3e^{i\varphi_1-i\varphi_2+i\varphi_3} + 4A_3A_4\Omega_4e^{i\varphi_4})e^{-i\varphi_4}}{8}$$

$$+ \frac{\Omega_1e^{-i\varphi_1}(4A_1A_2\Omega_1e^{i\varphi_1} - \Omega_2\Omega_3\Omega_4e^{i\varphi_2-i\varphi_3+i\varphi_4} + R_1\Omega_4^2e^{i\varphi_1})}{8}$$

$$x_1 = \sqrt{\epsilon_0 - (\sin\theta)^2}$$

$$x_2 = \sqrt{\epsilon_1 - (\sin\theta)^2}$$

$$x_3 = \sqrt{(n_r^+)^2 - (\sin\theta)^2}$$

$$x_4 = \sqrt{(n_r^-)^2 - (\sin\theta)^2}$$

$$d = 2d_1 + d_2$$

$$G_1 = d_2 k \sqrt{(n_r^+)^2 - (\sin\theta)^2}$$

$$G_2 = d_2 k \sqrt{(n_r^-)^2 - (\sin\theta)^2}$$

$$\alpha_5 = d_1 k \sqrt{\epsilon_1 - (\sin\theta)^2}$$

$$M_1 = x_2^2(x_1^2 - x_3^2)(\cos\alpha_5)^2 + (x_2^4 - x_1^2 x_3^2)(\sin\alpha_5)^2$$

$$M_2 = x_2^2(x_1^2 - x_4^2)(\cos\alpha_5)^2 + (x_2^4 - x_1^2 x_4^2)(\sin\alpha_5)^2$$

$$G_3 = 2ix_1 x_2 \cos[2\alpha_5] + (x_1^2 + x_2^2) \sin 2\alpha_5$$

$$w_1 = x_2^2(x_1^2 + x_3^2)(\cos\alpha_5)^2 - (x_2^4 - x_1^2 x_3^2)(\sin\alpha_5)^2 - ix_1 x_2 (x_2^2 + x_3^2) \sin 2\alpha_5$$

$$w_2 = x_2^2(x_1^2 + x_4^2)(\cos\alpha_5)^2 - (x_2^4 - x_1^2 x_4^2)(\sin\alpha_5)^2 - ix_1 x_2 (x_2^2 + x_4^2) \sin 2\alpha_5$$

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Figures

Figure 1

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Figure 2

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Figure 7

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