Terahertz Electromagnetically Induced Transparency in Cesium Atoms

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Abstract: We outline a proposal to realize Electromagnetically Induced Transparency (EIT) with the potential to store Terahertz (THz) optical pulses in Cesium atoms. Such a system, when experimentally realized, has a potential to make Quantum Communication possible with THz signals.

1. Introduction

Terahertz (THz) (0.1 – 10 THz) signals suffer less attenuation and scintillation effects caused by fog, dust, and airborne particles in comparison to Infrared (IR) signals [1, 2]. At the same time, the high level of directionality associated with THz signals reduces the vulnerability to eavesdropping [2]. Additionally, THz signals are compatible with superconducting based quantum computers. Taken together, these factors make THz frequencies an attractive regime for communication purposes and there are several groups conducting research in this field. However, THz quantum communication has not been fully investigated [3, 4]. Here, we present a study in which an ensemble of Cesium atoms is shown to have the potential to store THz signals via Electromagnetically Induced Transparency (EIT). In this scheme, the Cesium atoms are excited to the Rydberg energy levels and EIT occurs within the Rydberg manifold. These energy levels have been chosen because the transition frequencies between the Rydberg levels are of the order of THz and this suggests it is possible to realize EIT based quantum memory for THz signals. We present the theoretical model and simulation results of this scheme.

2. Theoretical Model

The energy level diagram of our model is shown in Fig.1. The ground level (represented as $|g\rangle$) atoms are excited to the Rydberg level $30P_{1/2}$ (represented as $|1\rangle$) by a very strong pulsed Ultraviolet (UV) light at 320 nm and with a repetition rate of GHz order [5]. $|1\rangle$ - $|3\rangle$ and $|2\rangle$ - $|3\rangle$ are the probe and control transitions respectively. The decay from the energy levels $|1\rangle$, $|2\rangle$, and $|3\rangle$ and all other intermediate levels to $|g\rangle$ is compensated by a very strong 320 nm laser which pumps almost all the atoms to $|1\rangle$. Therefore, the four-level system effectively becomes the three-level system shown in Fig.1, which can be used for EIT.

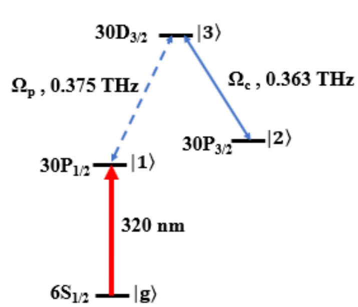
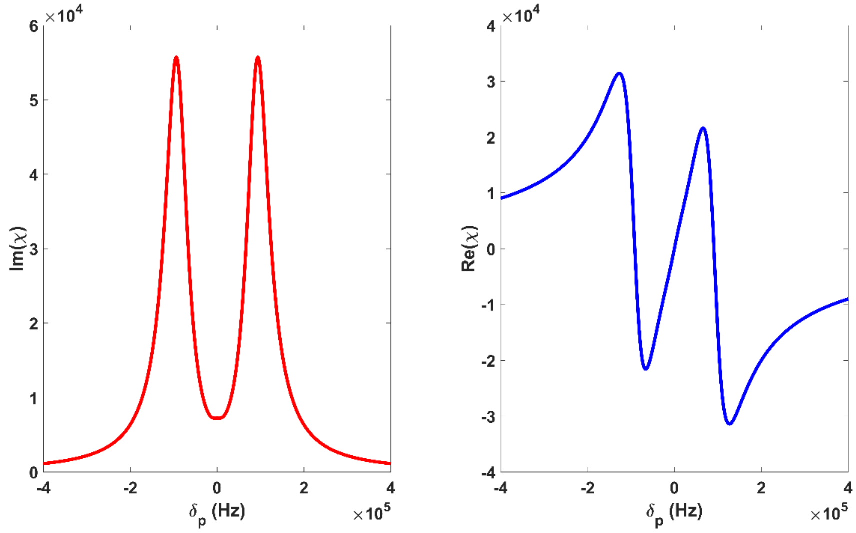


Fig.1 Simplified Cs energy level diagram for our model. Ω_p and Ω_c are the Rabi frequencies of probe and control fields respectively.

The susceptibility of the three-level light-matter system can be written as [6]

$$\chi = i\frac{Nd^2}{\varepsilon_0\hbar}\frac{1}{\left[\frac{(\Omega_c/2)^2}{\gamma_d - i(\delta_p-\delta_c)} + (\gamma_p - i\delta_p)\right]}$$

where N is the atomic number density, d is the dipole moment associated with probe transition, γ_d is the decoherence rate between $|1\rangle$ and $|2\rangle$, γ_p is the probe decay rate, δ_p (δ_c) is the detuning of probe (control) from its corresponding transition, ε_0 is the permittivity of free space, and ħ is $h/2\pi$ where h is the Planck's constant. The real and imaginary parts of the above equation have been plotted as a function of δ_p as shown in Fig. 2



(a) (b)

Fig.2 (a) The imaginary part of the susceptibility and (b) the real part of susceptibility both plotted as a function of δ_p. The values of the other equation parameters are: $N = 10^{15}$ atoms/m^3, $d = 5.69 \times 10^{-26}$ C.m, γ_p = 0.046 MHz, γ_d = 0.018 MHz, δ_c = 0, and $\Omega_c = 4\gamma_p$. The typical EIT features are clearly visible.

The values of various parameters written in the caption of Fig.2 have been either taken from or calculated from the relevant formula given in Ref. [7, 8]. The signal pulse can be spatially compressed inside the atomic ensemble due to the reduction of the probe's group velocity. Note that this reduction in the group velocity is evident from the steep slope around $\delta_p = 0$ in Fig. 2(b). After the signal enters the medium, one can adiabatically turn off the control field and the quantum state of the signals will be mapped on the atomic spin wave. When needed, the signal can be retrieved by turning on the control field. As mentioned above, this system is effectively three levels, hence the readout of the stored pulse will be the same as in a usual three level lambda type EIT based quantum memory. Such a scheme would be useful for quantum memory using THz signals.

3. References

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