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Phase control of the temporal envelope of an ultrashort pulse propagating in an strongly driven atomic medium

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Abstract. We consider a double two-level system in which each single two-level system is driven by a strong linearly polarized pulse. The system is probed by a weak pulse orthogonally polarized. We study the distortion experienced by the probe temporal envelope when the relative phase between the pump and the probe is varied. We show that pulse behavior oscillates between two regimes that corresponds to transparency and amplification respectively. Interpretation of this effect is given within adiabatic representation.

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Key words: coherent control, propagation effects, light shifts

1 Introduction

The control of physical processes through manipulation of the relative phase between exciting fields represents the basic scheme of coherent control [1]. Several mechanisms in this regard have been explored. The combination of a fundamental frequency and its harmonics [2] and excitation by time delayed coherent pulses [3] are some examples. The control comes from the relative optical phase difference between different excitation fields. The attractive aspect in these experiments is the ease and the versatility in the control of this latter parameter. For example, for a sequence of pulses, it can be realized by modifying the relative delay between the pulses [4]. If strong pulses are used, light-shifts are induced in the medium and strong modification occurs in the atomic structure. Light shifts are the basis for many spectacular phenomena in atomic and molecular physics (rapid adiabatic passage, stimulated Raman adiabatic passage, Stark-chirped adiabatic passage, light induced potential etc. [5,6]). However, only little work deals with the control of these light shifts. An original situation

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arises in a double two-level system where each single two-level sub-system is driven by a strong pulse. We have shown in a series of papers [7–9] that coherent control ideas can be applied to the control of light-shifts induced by the strong field. An efficient control of the amplification of a weak pulse that probes the driven system is obtained. The scope of present paper is to investigate the temporal behavior of the probe pulse and observe its dependence with the phase and the intensity of the pump pulse. We demonstrate both experimentally and theoretically that depending on the relative phase between the pulses the probe pulse can be restored with little distortion (transparency regime) or with strong reshaping effects (amplification regime). We connect these features to the modification of the light shifts in the atomic sample for corresponding values of the relative phase.

2 Maxwell Bloch equations

We consider the situation of a duplicated two-level system $\{|1\rangle,|1'\rangle,|2\rangle,|2'\rangle\}$ (Fig. 1a) excited resonantly by two time delayed pulses. Pulse (1) strongly couples the parallel states while pulse (2) which is weak couples resonantly the crossed states. In practice, this situation can be realized by exciting the atomic rubidium with a pair of π- and σ-polarized pulses acting on the $S_{1/2} \to P_{1/2}$ transition. The electric fields of the pulses that propagate along the $\hat{y}$ axis are expressed as $\vec{E}_1(y,t) = \vec{e}_z(\epsilon_{01} f_1(y,t) e^{-i\omega t} + cc)$ and $\vec{E}_2(y,t) = \vec{e}_x(\epsilon_{02} f_2(y,t) e^{i\phi} e^{-i\omega t} + cc)$ with $f_1(y=0,t) = \pi^{-1/2} e^{-(t/\tau_0)^2}$, $f_2(y=0,t) = f_1(y=0,t-\tau)$, $\phi = \omega\tau$ is the relative phase between the pulses at the entrance of the medium, t represents the local time $(t = t_{lab} - y/c)$, τ is the delay and $|\epsilon_{02}/\epsilon_{01}| \ll 1$. Initially, the atoms are statistically equally distributed between the two ground states $|1\rangle$ and $|1'\rangle$. From symmetry arguments, we can consider the evolution of only those in state $|1\rangle$.

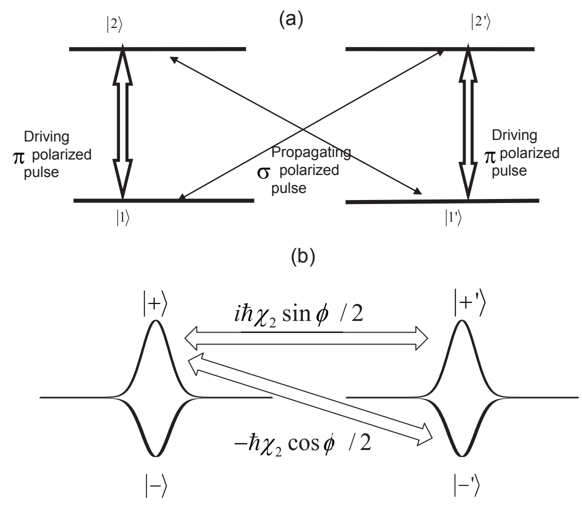

Figure 1: (a) Energy levels and optical transitions involved in our system. (b) Adiabatic representation (we represent only transitions connecting state $|+\rangle$).