Gain from cross talk among optical transitions

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We analyze the probe absorption spectra of a strongly driven Λ system with arbitrary spacing between the two lower levels. Under the condition that the spacing between the two lower levels is of the order of a strong-pump-field Rabi frequency, important interference effects are observed due to same-field coupling with both the transitions. We report the possibility of a significant gain from the cross talk among optical transitions, and a strong dependence of gain and absorption on the relative polarizations of the pump and probe beams. We present an analysis based on dressed states to explain our numerical results. [S1050-2947(99)01801-6]

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I. INTRODUCTION

The very early work of Mollow [1] on a coherently driven two-level atom demonstrated the possibility of gain without inversion in bare states. Mollow’s work led to a variety of experimental [2] and theoretical [3] activity on gain in driven systems. Various features of gain in driven two-level systems are now understood [4–6] both in terms of inversion in a dressed basis or in terms of coherence in the new basis. In the last decade the work on gain in driven systems became especially important with the work of Harris [7] and Kucharovskaya and Khanin [8] on lasing without population inversion (LWI). Harris in particular emphasized how the interference effects can make the absorption and emission profiles asymmetric, leading to the possibility of gain without inversion. Many different models for LWI have been proposed [9–13], and several experiments [14–16] were also performed to test these ideas. Gain can be understood to be arising either from inversion between dressed states or from coherence between such states. For the model of Ref. [9], coherence plays a very important role [17].

In connection with LWI models, one usually considers the interaction of a strong coherent drive and a weak probe with different transitions of a system, i.e., the pump and probe act on different transitions. There are, however, situations when one has to relax the above assumption. Consider for example the hyperfine levels of potassium, the excited level 4P_{1/2}(F = 1) and the two ground levels 4S_{1/2}(F = 2) and 4S_{1/2}(F = 1) (Λ system), where the ground-level splitting is of the order of 462 MHz for 39K, and 254 MHz for 41K. In such a case a single field can couple with more than one transition, and unlike driven two-level where doublets of dressed levels appear around bare levels, now multiple dressed levels appear [18–20], giving rise to many additional features. Along with this, for a probe field scanning such a system, interference effects become inevitable due to the strong coherence between the two closely spaced ground levels. This coherence is created due to the cross talk among optical transitions.

It may be noted that such common coupling of levels in a Λ system was studied in the context of optical bistability [21] and two-photon gain [22]. Xia et al. demonstrated the possibility of electromagnetically induced transparency [23] in the presence of common coupling among hyperfine levels of 207Pb. In this paper, we present the effects of such common coupling on probe response in a driven system with closely spaced ground levels, particularly when ground levels have a separation of the order of driving field Rabi frequency.

The organization of this paper is as follows: In Sec. II we study the absorption and gain spectra of a strongly driven three-level atom, and show the possibility of significant gain in such a medium. We include the effect of cross talk among optical transitions. In Sec. III we analyze the spectra by identifying strong interference effects, which gives rise to more pronounced gain when spacing between the two ground levels is of the order of one-half the pump Rabi frequency. In Sec. IV we present the dressed-state analysis to understand the numerical results. We show the existence of gain features due to inversion in dressed states, and transparency at certain probe frequencies due to weak coupling among dressed states.

II. MODEL SYSTEM

We select a Λ system with one excited state |1⟩, and two ground levels |2⟩ and |3⟩ (see Fig. 1) with arbitrary spacing Ω between them. Such a configuration of levels with two fields has been well studied by assuming that a given field is driving only one transition. This can be achieved either by selecting levels with large spacing Ω or by suitable arrange-

![FIG. 1. Schematic diagram of a three-level Λ system with arbitrary spacing Ω between the two ground levels. The pump (coupling strengths F and G) and probe fields (coupling strengths g and f) act on both the transitions.](image)