Manifestation of an electric dipole order induced by optical near fields

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Owing to the recent progress in fine processing technology it becomes possible to investigate the interaction via optical near fields among materials in nano meter scale [1]. Since one of the remarkable characters of optical near fields is non-propagating property, it is more suitable to use localized functions as a basis set than to use plane waves to describe optical near fields. We present a phenomenological model of a near field photon-matter system using such a localized function to describe optical near fields. We suppose quantum dots chain as a matter system and model it as one-dimensional N two-level system (in other words, excitons) with a periodic boundary condition. A localized photon is described as a harmonic oscillator localized in each site, and only allowed to hop to the nearest neighbor sites. As a result of the interaction, quantum dots emit and absorb localized photons. A Hamiltonian of the system consists of three parts as follows:

$$H = (H_a + H_b) + H_{\text{int}}$$

Here H_a describes localized photons, H_b describes excitons, and H_{int} represents the localized photon-exciton interaction. Each Hamiltonian can be expressed as

$$H_a = \varepsilon \sum_{n=1}^{N} a_n^{+} a_n + V \sum_{n=1}^{N} (a_{n+1}^{+} a_n + a_n^{+} a_{n+1}),$$

$$H_b = E \sum_{n=1}^{N} b_n^{+} b_n ,$$

$$H_{\text{int}} = U \sum_{n=1}^{N} (a_n^{+} b_n + b_n^{+} a_n),$$

where n indicates the site number, and a_n (a_n^{+}) and b_n (b_n^{+}) represent annihilation (creation) operators of a localized photon and an exciton, respectively.

We investigate dynamical properties of the system driven by the Hamiltonian. As shown in Fig. 1, we predict a coherent oscillation of dipoles of the whole system started from an initial condition, and show that we can classify each dipole oscillation of the system into four groups depending on the parameters of the Hamiltonian.

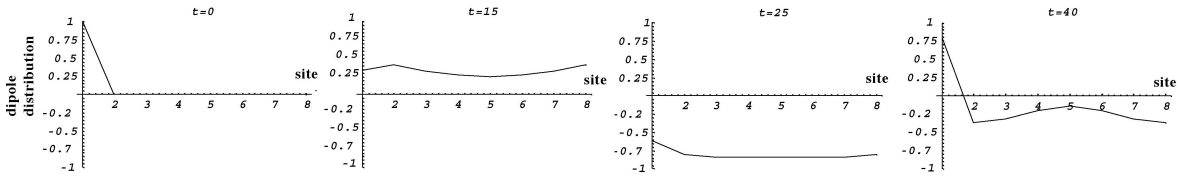

Figure 1: Time evolution of the dipole moment distribution. The vertical and horizontal axes represent the dipole moment and the site number of quantum dots.

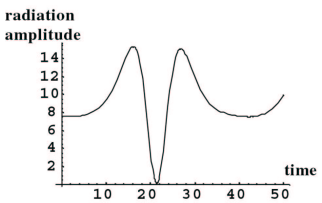

Figure 2: Time evolution of the radiation amplitude. The super-radiatiant state has the value of 20 as the radiation amplitude.

Moreover radiation probability of each state is examined in Fig. 2. It indicates that the state with the coherent oscillation is close to the Dicke's superradiant state. We will discuss the ordering mechanism in detail.

Reference

[1] M. Ohtsu, K. Kobayashi, H. Ito, and G. H. Lee, *Proc. IEEE* **88**, 1499(2000).