# Resonant Transfer of Excitons and Quantum Computation

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Resonant energy (Förster-Dexter) transfer mechanisms [1, 2] have been observed in the sensitized luminescence of solids, in quantum dots and in molecular nanostructures, and they also play a central role in light harvesting processes in photosynthetic organisms. Here we give various methods for creating entangled quantum states in quantum dots which use the two electrostatic interactions that act between them: the Förster-Dexter interaction and the direct biexciton coupling. We use the envelope function and effective mass approximations to calculate the magnitude of these two electrostatic interactions as a function of dot size and shape, interdot separation, material composition, confinement potential and applied electric field in a two-cuboid dot molecule (see Fig. 1 (a)). The Schrödinger equation is solved by a direct expansion in the analytical eigenstates of a closely related potential. The Förster interaction results from a dipole coupling of the exciton states to the virtual photon field, and its strength is therefore proportional to the overlap integral of the electron and hole envelope functions. Hence, we find that the Förster interaction is suppressed by an applied electric field, which moves the electron and hole apart, resulting in a smaller overlap (see Fig. 2). By contrast, the biexcitonic energy is increased by applying a field, since it induces an excitonic polarization and a direct electric dipole-dipole coupling between the dots (see Fig. 1 (b) and (c)).

In our first quantum logic implementation, we show that it is desirable to suppress the Förster coupling and to create entanglement by manipulating the biexciton energy alone [3]. When the interaction Hamiltonian is written as a matrix in the computational basis, the biexciton binding appears as a diagonal term. In this case, quantum logic is most easily performed by using laser pulses, tuned to the appropriate excitation frequencies of the coupled system. We show that through careful selection of materials parameters high fidelity logic can be achieved. The second implementation proposes generating quantum entanglement by modulating the off-diagonal Förster interaction itself. This may be achieved by using a pulsed field to change the magnitude of the interaction, or by altering the single exciton energies of the two dots by controlling their AC Stark shifts. We also show that the energy transfer can be fast enough in certain dot structures that switching can occur on a timescale which is much less than the typical decoherence times.

Refs. [4–6] have demonstrated that single dot decoherence times become dominated by recombination processes at low temperatures (2 K-25 K), with a negligible contribution from pure dephasing. We account for these mechanisms by introducing the optical master equation of single or interacting dots coupled to an environment of harmonic oscillator modes. We show that the decay rates in the system are directly related to the off-diagonal interdot interaction strength and can hence be modified in a similar way. We identify parameter ranges, for both quantum logic implementations, in which the ratio of decoherence time to gate operation time is optimal.

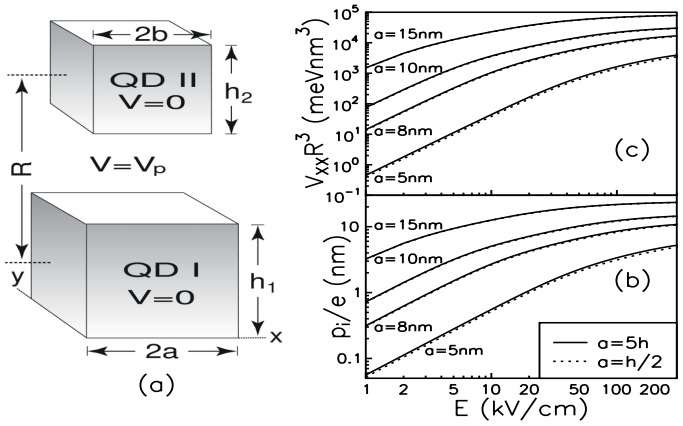


FIG. 1: (a) Schematic diagram of the cuboidal dot model. The potential inside the cuboids is set to zero, that outside is determined by the band offsets of the conduction and valence bands within the heterostructure. (b) Exciton dipole moment $p_i$ as a function of the dot size and applied electric field $E$ for two dot shapes. The dot parameters $m_e = 0.06$, $m_h = 0.6$, $V_e = V_h = 500$ meV. (c) Exciton-exciton binding energy ($V_{\rm XX}$) for $a = b$ and sequence of dot shapes, size and field strength as in (b).

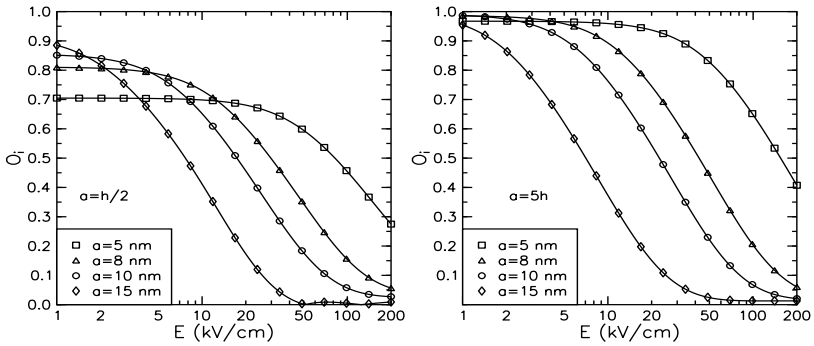


FIG. 2: The electron-hole envelope function overlap integral $O_{\rm i}$ as a function of $E$ for a range of dot sizes. The left-hand figure shows the dependence for a cubic dot ($a = h/2$), and the right-hand figure shows the dependence for a flatter cuboidal dot ($a = 5h$). Note that the overlap integral, and so also the Förster interaction, is suppressed at large field as the electron and hole are forced apart.


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