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HYBRID MODEL FOR SIMULATION OF MAGNETO-OPTICAL RESPONSE OF LAYERS OF TRIPLE QUANTUM DOT MOLECULES

O. Voskoboynikov

National Chiao Tung University
1001 Ta Hsueh Rd., Hsinchu
Taiwan
vam@faculty.nctu.edu.tw

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ABSTRACT

Modern nano-structured semiconductor meta-materials potentially can manipulate electromagnetic fields in very wide diapason, which is particularly beneficial for potential applications and devices, as well as for new basic science. Those new materials are constructed from very small semiconductor nano-objects. In recent years the knowledge of the physical properties of semiconductor nano-sized objects, like quantum dots, nano-rings, and quantum dot molecules, with respect to their transport, magnetic and optical behavior has increased considerably (see for instance [1] and references therein).

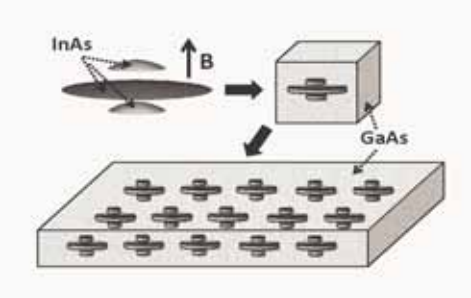

Figure 1. Schematic of the building of a layer of *InAs* triple quantum dot molecules embedded in *GaAs* matrix.

In this theoretical study we consider the impact of the coherent manipulation of electronic states in triple quantum dot molecules (combined from dots of sufficiently different sizes) on the collective magneto-optical response from layers of those nano-objects embedded in a semiconductor matrix (Figure 1). Our theoretical and computational approach is based on a hierarchical (multi-physical) modeling. In the hybrid discrete-continuum method [2] each embedded nano-object gets represented by a single discrete dipole, characterized by a bare excess polarizability. This polarizability includes the screening by the surrounding medium. The influence of the magnetic field **B** enters through the excess polarizability.

The bare polarizability (α_B) and dressed polarizability (α_D) are connected by [2,3]:

$$\mathrm{p} = \vec{\alpha}_{\mathbf{D}}\mathrm{E}_{\mathbf{L}} = \vec{\alpha}_{\mathbf{B}}\left[\mathrm{E}_{\mathbf{L}} + \vec{\mathrm{t}}\mathrm{p}\right],$$

where $\mathbf{E}_L$ is the classical local field, which equals the external field $\mathbf{E}_X$ for the case of a single nano-object, **p** is the dipole strength and **t** is the intracellular transfer tensor, accounting for electromagnetic self-interaction. The dynamical (frequency dependent) contribution $\Delta\alpha(\omega)$, as derived before in [2,3], we add to the bare polarizability α_B [3]:

$$\alpha_{\mathbf{BE}}(\omega) = \alpha_{\mathbf{BE}} + \Delta\alpha(\omega)$$

For the embedded dressed static polarizability α_{BE} we solve the potential $\Phi(\mathbf{r})$ from the Poisson equation for the embedded *InAs*/*GaAs* quantum dot molecule (upper cube in Figure 1).

For the dynamic part of the polarizability we use the approach formulated in our previous publications (see for instance [2]), where we have shown that for photon frequencies near the energy gap of the semiconductor the object is made from, this part can be treated theoretically using an effective Hamiltonian with position dependent electronic and hole effective masses. It was found that experimentally relevant simulations of the behavior of nano-object can only be obtained with three-dimensional models using the experimentally determined shape, strain and composition of the object.

For the layer of embedded quantum dot molecules we have solved the system of equations:

$$\vec{\alpha}_{BEi}^{-1}\mathrm{p}_i - \frac{1}{\varepsilon_{GaAs}}\sum_{i\neq j}\vec{\mathrm{t}}_{ij}\mathrm{p}_j = \mathrm{E}_X\,,$$

where $\mathbf{t}_{ij}$ is the frequency dependent vacuum intercellular transfer tensor, screened by ε_{GaAs}. The optical response of the layer can be calculated using the Vliger's expressions for reflection and transmission coefficients r_{ss} and r_{pp}.

We vary the magnetic field strength and distance between the three quantum dots in the layer and show that through the hybrid model all relevant changes in the quantum mechanics of the dots can be carried through to outer experimentally observable quantities like the reflectance, transmittance and absorbance of the system. They also can be converted into changes in the ellipsometric angles Ψ and Δ of the system.

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