Transmission through Multiple Nanoscale AB-Rings with Zeeman-split Quantum Dots

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Electron transmission through nanoscale ring structures with quantum dots (QD's) embedded in each arm have been the focus of theoretical and experimental research [1]. The phase coherence of the electrons is maintained during their passage through the ring and QD's, leading to possibility of studying interference and resonance effects, including Breit-Wigner and Fano type resonances.

The application of external magnetic fields to the structure can produce a combination of Aharonov-Bohm (AB) and Zeeman effects, which also introduce novel transmission resonances which facilitate spin-filtering [2]. Further, our recently investigated results on sharpened AB oscillations [3], and reversal of spin polarization due a small Zeeman splitting [4] for parallel double QD's in resonance suggest the applicability of such structures in the growing field of spintronics [5].

In this communication, we study spin-polarized transmission through a series of asymmetric AB-ring interferometers; each with QD's embedded in the arms. We do this by incorporating the electron spin into a tight-binding Hamiltonian. We also assume that the spin degeneracy of the electrons is lifted by the Zeeman effects via application of an external, in-plane magnetic field.

A schematic of the model used in this work is shown in Fig. 1, which illustrates the spin-split QD's in each arm of a ring. The ring is coupled to semi-infinite leads which are assumed to be spin-neutral, which can be accomplished, for example, by using materials for which the g-factor of the leads is much lower than for the QD's [6,7].

The tight-binding approximation to the Schrödinger equation is used to computationally evaluate the transmission through the multiple-ring structure. The inter-QD coupling integrals are set to $V_n=0.1$, and the couplings between sites in the 1-d leads are all set to $V_o=1.0$, which we use throughout the discussion as a unit of energy. The electron energy window is $-2V_o \leq E \leq 2V_o$, as set by the tight-binding dispersion relation for the uniform leads. All upper site energies are set to $\varepsilon_n=0.1$, all lower sites to $\varepsilon_n= -0.1$, and all other sites to $\varepsilon_n=0$.

Typically, in a one ring system, two resonant peaks will appear, each located approximately at a value corresponding to the energy of a QD. Additional pairs of peaks appear for each supplemental ring added (Fig. 2). The new peaks are also symmetrically placed around zero energy, with their positions filling in a conduction band extending away from the QD site energy value. The conduction band formed by these resonant peaks is bound approximately by the energy window $-0.4V_o \leq E \leq 0.4V_o$, with the band becoming more of a continuum as more rings are added and individual resonant peaks narrow.

In each system, the number of rings determines how well defined the band gap is, with more rings providing higher definition of the band edges (Fig. 2). Measuring the location of the band gap edges for systems with high ring number reveals that the edges sit at energy values very close to that of the quantum dots. The band gap widens as Zeeman splitting of the energy levels is introduced, creating additional conduction bands within the band gap (Fig. 3).

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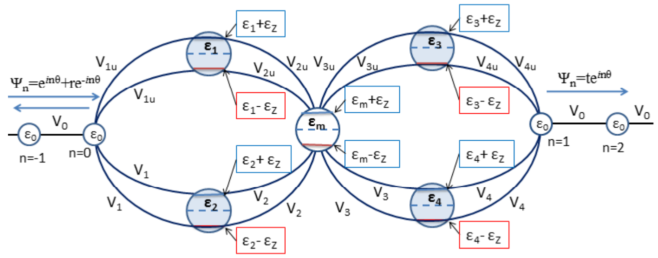

Fig. 1. Sample schematic of a two ring system. Each ring consists of an A-B ring with embedded quantum dots in each arm. Identical leads act as a source and drain for the system. A magnetic field, parallel to the plane of the rings, induces Zeeman splitting of the quantum dot energy levels. The incident and reflected wavefunctions are shown on the left, the transmitted on the right. Additional rings may be added in series.

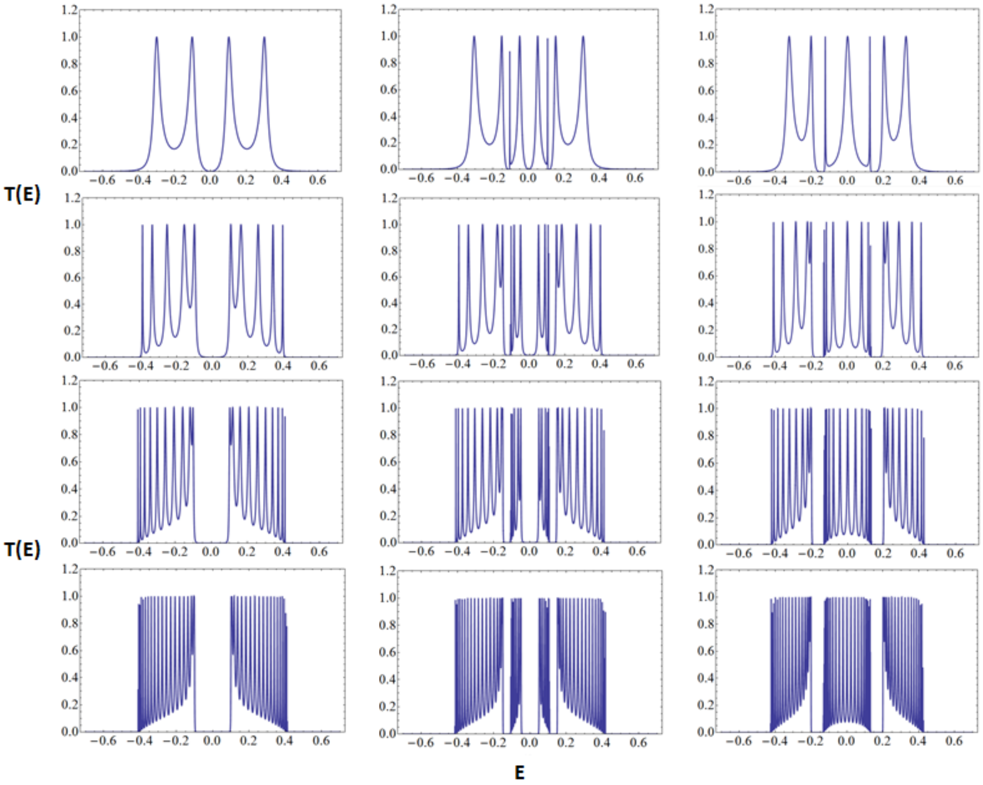

Fig. 2. Transmission through multi-ring systems for two (a-c), five (d-f), ten (g-i), and twenty (j-l) ring structures. The leftmost graphs show no Zeeman splitting in the field. The central graphs are for a Zeeman split energy of 0.05, and the right most 0.1.

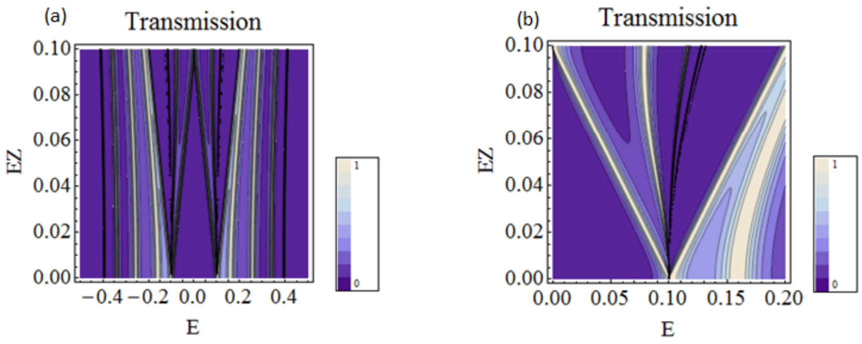

Fig. 3. Contour plots for the five ring structure. Transmission is plotted versus the Fermi energy (E) of the system and the value of Zeeman splitting (EZ) energy in the QD's in the arms of each ring. Additional resonances appear with Zeeman splitting.