Simulation and Optimization of Spin-Qubit Quantum Dot Circuit with Integrated Quantum Point Contact Read-Out

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We use computer simulation to study a novel laterally coupled quantum dot (LCQD) circuit with integrated quantum point contact (QPC) for charge read-out. The prototype of the device is shown in Fig. 1 [1] with the SEM view of the top gate patterns in the xy direction [Fig.1(a)]. The two circles indicate the location of the two dots. Figure 1(b) shows the simulated layer structure in the z direction. In order to obtain the electron density inside the LCQD, we solve self-consistently three-dimensional (3D) Poisson and Kohn-Sham equations within the local spin density approximation (LSDA), while outside the LCQD, we use the Thomas-Fermi approximation to compute the charge densities. The above differential equations are discretized on a non-uniform 3D mesh using realistic doping profiles and boundary conditions [2]. Figure 2 displays the self-consistent potential profile in the 2DEG plane, and along the z direction on the dot with the inset of Fig. 2(b) illustrating the ground state wavefunction along the z direction [3]. Electronic states and eigenenergy spectra reflecting the particular LCQD confinement are obtained as a function of the external gate biases. The conditions for charging the dots with successive electrons, as a function of the applied gate biases, are determined by the Slater's rule, by which we derive the stability diagram for the system in the few-electron regime (Fig. 3) [3]. We investigate the detector sensitivity of different QPC gate geometries to the first electron charging in the quantum dot [4]. For this purpose, we obtain the variation of the potential energy saddle point in the constriction at the first electron charging as a function of different QPC gate biases [Fig. 4(a)]. We then use the Büttiker formula [5] to compute the relative change of the conductance ($\Delta G/G$) over the specified QPC gate bias range [Fig. 4(b)]. Our results indicate that constrictions with dented designs give more sensitive detectors than conventional QPC geometries.

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Figures

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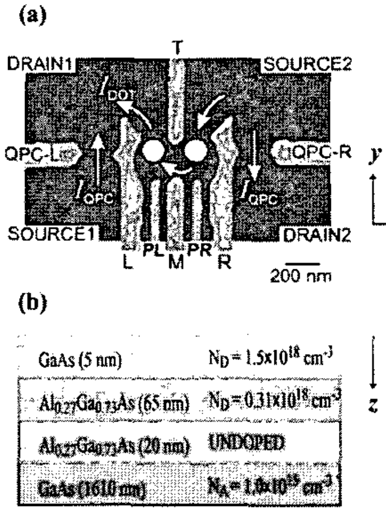

Figure 1: (a) SEM view of the top gates of the LCQD-QPC quantum circuit (Light gray areas show the gate pattern for the LCQD and the QPC's; circles show the dots; curved arrows show the possible charging current paths; and straight arrows show the QPC currents). (b) Layers of the heterostructure (not to scale). The 2DEG is 90 nm below the top surface, after Elzerman et al. [1].

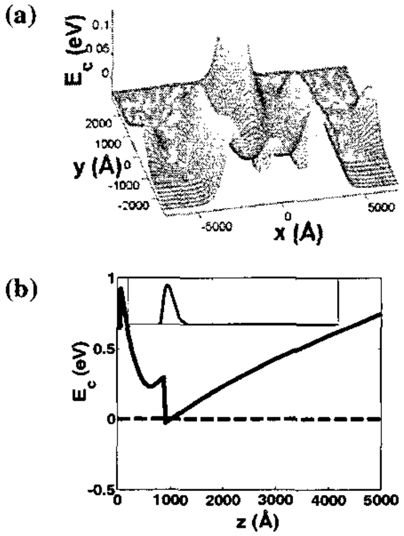

Figure 2: Potential energy profile (a) in the *xy* plane at the 2DEG interface (b) along the *z* direction with the inset showing the ground state wavefunction under bias condition $V_L=V_R=V_{QPC\text{-}L}=V_{QPC\text{-}R}=V_M=V_T=-0.585$ V, $V_{PL}=V_{PR}=-0.15$ V.

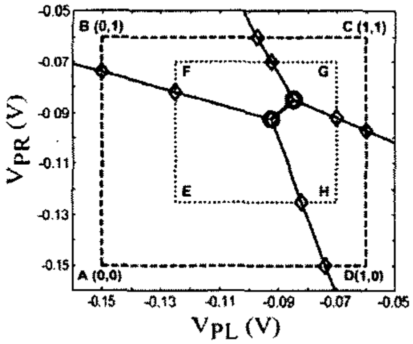

Figure 3: Stability diagram for the first two charging electrons characterizing the double-triple points (shown by circles).

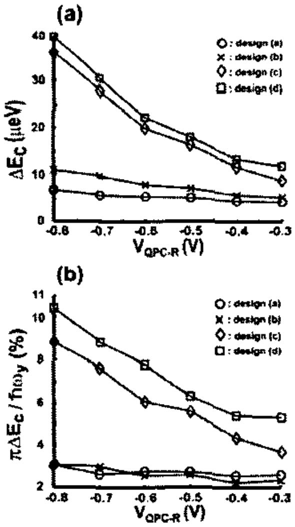

Figure 4: (a) Discontinuity of the saddle point of the potential energy in the confinement of the QPC ΔEc as a function of QPC gate bias $V_{QPC\text{-}R}$ for four QPC designs. (b) QPC sensitivity as a function of $V_{QPC\text{-}R}$. Designs (c) and (d) are dented geometries while designs (a) and (b) are conventional geometries.

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