Numerical simulations of the Coulomb blockade microscopy experiments: probing the local properties of the planar quantum dots using the scanning gate technique

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Scanning gate microscopy (SGM) is relatively new technique for probing the quantum transport properties [1, 2]. The electrical transport of the nanodevice is probed with a metalized tip of the atomic force microscope used as a floating gate electrode. It scans the nanostructure and couples capacitively to the sample. The tip-induced electrostatic potential perturbs locally the two-dimensional electron gas (2DEG) buried shallow beneath the semiconductor surface. The perturbation modifies the potential landscape seen by the electrons at the Fermi surface and thus the conductance of the system can be changed.

The conductance monitored as a function of the tip position by the SGM technique allows to obtain some important experimental data on the charge transport properties through the nanodevices, including conditions of the current flow through the quantum dots [3-5]. The current flows only in the conditions of the transport window, i.e. lifting the Coulomb blockade.

We simulate the phenomena that occur during the current transport measurements in the semiconductor heterostructures containing quantum dots defined within the two-dimensional electron gas with the perturbation introduced by the metalized tip of the atomic force microscope. Our numerical models are based on the exact diagonalization for the confinement potential and also the DFT calculations to simulate the screening effect of the tip-induced potential by 2DEG. The effect is crucial for describing the scanning gate experiments. We show how this phenomenon decreases the range of the tip-induced potential, which becomes short-ranged effectively.

We determine the considered system properties by inspecting the maps of the current versus the position of the tip and the energy shifts of the confined particles caused by the tip. The mentioned properties include, for example, the unperturbed charge density in the dot and the form of the effective tip-induced potential seen by the electrons in the nanostructure.

[1] D. K. Ferry, A. M. Burke, R. Akis, R. Brunner, T. E. Day, R. Meisels, F. Kuchar, J. P. Bird, B. R. Bennet, *Semicond. Sci. Technol.* **26**, 043001 (2011).
[2] H. Sellier, B. Hackens, M. G. Pala, F. Martins, S. Baltazar, X. Wallart, L. Desplanque, V. Bayot, S. Huant, *Semicond. Sci. Technol.* **26**, 064008 (2011).
[3] M. Huefner, B. Kueng, S. Schnez, K. Ensslin, T. Ihn, M. Reinwald, W. Wegscheider, *Phys. Rev. B* **83**, 235326 (2011).
[4] A. E. Gildemeister, T. Ihn, M. Sigrist, K. Ensslin, D. C. Driscoll, and A. C. Gossard, *Phys. Rev. B* **75**, 195338 (2007).
[5] P. Fallahi, A. C. Bleszynski, R. M. Westervelt, J. Huang, J. D. Walls, E. J. Heller, M. Hanson, A. C. Gossard, *Nano Lett.* **5**, 223 (2005).