Journal of ELECTRONIC MATERIALS, Vol. 42, No. 1, 2013
DOI: 10.1007/s11664-012-2315-z

Modeling of a Room-Temperature Silicon Quantum Dot-Based Single-Electron Transistor and the Effect of Energy-Level Broadening on Its Performance

M. MIRALAIE,[1] M. LEILAEIOUN,[1] and K. ABBASIAN[1,2]

1.—School of Engineering Emerging Technologies, University of Tabriz, 51664 Tabriz, Iran.
2.—e-mail: k_abbasian@tabrizu.ac.ir

In this work, we have modeled silicon quantum dot (QD)-based single-electron transistors (SETs) operating at room temperature and investigated the effect of the QD's energy-level broadening on the performance of the SET. First we obtained the energy levels and corresponding wave functions for spherical Si QDs by solving the coupled Schrödinger–Poisson equations in three dimensions. Then, we demonstrated different tunneling current rates for separated energy levels by considering nonequal energy-level broadenings. Accordingly, an expression for the corresponding tunneling rates in the quantum Coulomb blockade regime was derived. In the next step, the transconductance characteristics of the Si QD SET device with Coulomb oscillations were simulated, and their differences from previously investigated metal-based SETs were demonstrated. Finally, by applying different bias voltages, we determined the effect of temperature variations on the transconductance characteristics.

Key words: Single-electron transistor (SET), Si QD energy-level broadening, transconductance characteristics, Coulomb blockade regime

INTRODUCTION: BASIC PHYSICS

Single-electron transistors (SETs), which are the ultimate limit of switching devices, have been intensively studied recently because of their unique multifunctionality with ultralow power and scalability down to the subnanometer regime.[1] However, the reliability of room-temperature operation and requirement for complementary metal–oxide–semiconductor (CMOS)-compatible processes have been significant obstacles to the implementation of practical device applications.[2–5] Rapid progress in the fabrication and study of SEDs based on quantum objects [such as small grains, quantum dots (QDs), and molecules] capable of operating at temperatures close to 300 K calls for an adequate theoretical description of the fundamental properties of such SEDs. The known models for electron tunnel transport in a system can be divided into two classes. The first approach is to calculate the charge transport by the microscopic self-consistent method. This method is a charging model based on the Poisson equation. It creates a good single-electron picture by using the mean-field approximation, known as the Hartree approximation, for the model of electron–electron interactions. However, it is generally recognized that it tends to overestimate exchange and correlation effects and may need correction. A detailed review of this method can be found in Ref. 6. The second method is also a charging model but is based on the statistical theory of the Coulomb blockade or single-electron charging regime. In contrast to the Hartree approximation, this second approach can affect the model of current flow even in a simple one-level device. The use of the latter approach for systems based on small metallic granules and QDs has been described in Refs. 7 and 8.

The structure of a SET includes metallic source and drain electrodes bridged by an island (metallic, semiconductive or a molecule) plus a gate electrode. As in the Coulomb blockade regime, the electron is carried by sequential tunneling through the island between the source and drain, where tunnel junctions

(Received April 17, 2012; accepted October 1, 2012; published online November 8, 2012)