# Thermoelectric properties of Si-based Single-electron Transistors

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### Abstract

The thermoelectric properties of Single Electron Transistors (SETs) in sequential transport regime are investigated. By including the effect of energy level broadening, we assess the potentiality of semiconducting SETs in view of application in nanoscale thermoelectric metrology.

### Introduction

Specific properties of nanostructures have generated a recent revival of interest in thermoelectric devices [1,2]. Thanks to their delta-like density of states, devices based on quantum dots are expected to exhibit high Seebeck coefficient, nearly zero electronic thermal conductance and ultra-low phononic thermal conductance if embedded in an oxide matrix, but to the price of low electronic conductance. The single-electron tunneling across discrete levels in the QD occurring in such devices behaves as a quasi-ideal energy filter providing these incomparable thermoelectric properties [3,4]. Moreover, the Seebeck coefficient in a single electron transistor (SET) thanks to its material-independent characteristics has been proposed as a reference in nanoscale metrology [5].

### Model

In this work, we perform self-consistent 3D Poisson/Schrödinger simulation within the Hartree approximation, which captures the details of charging and tunneling effects in semiconductor quantum dots [6]. From the computation of tunneling rates within the Bardeen's formalism, we use a Monte-Carlo algorithm to solve a master equation and to extract the current-voltage characteristics for different temperature gradients applied between the source/drain electrodes of the device schematized in Fig. 1. Fig. 2 shows typical diamond stability diagram that are commonly obtained in SETs due to the effect of Coulomb blockade. The effect of collisional broadening of energy levels is accounted by introducing a Lorentzian function for the spectral function of the level instead of the Dirac function commonly used to describe unperturbed states. The width of the Lorentzian function can be obtained from the calculation of the self energy of the electron-phonon interaction [7].

### Results

The influence of a temperature gradient applied to the SET on its current-voltage characteristics (Fig. 3) allows us to check that the linear approximation may be used to study the SET as a thermoelectric generator.

We plot in Fig. 4 the evolution of the Seebeck coefficient, the electronic conductance and the thermoelectric power factor resulting from a temperature gradient for SETs with both spherical and cubic quantum dot. It is shown that the power factor of such SET can reach the value of about 1 kW/m$^2$ at $T = 77$ K with small $\Delta T = 10$°K.When including realistic energy level broadening $H$ at 77 K $(\text{i.e.}\, H \leq 0.1kT)$, the evolution of the Seebeck coefficient remains very close to its ideal material-independent value. This demonstrates the good potential of semiconducting SETs for nanoscale thermoelectric metrology.

### References

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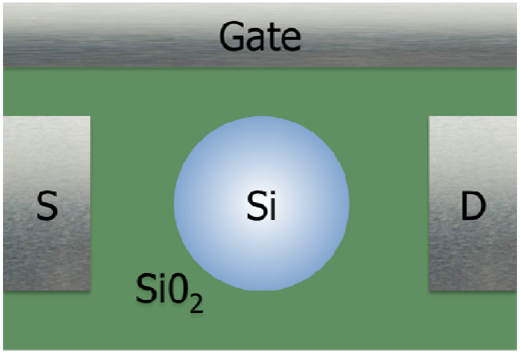


Fig. 1. Schematic cross-section of simulated Single Electron Transistors.

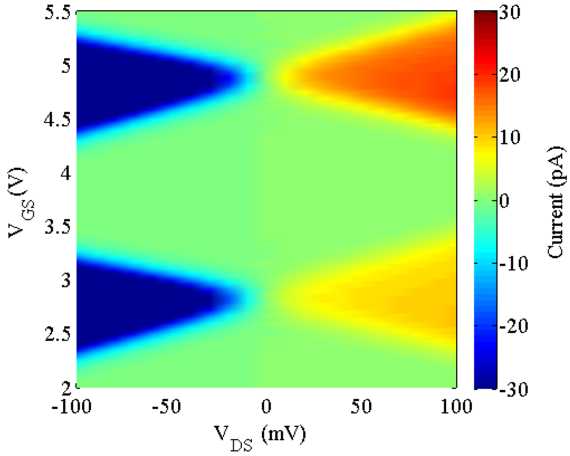


Fig. 2. Drain current stability diagram of the cubic SET at $T = 77$ K.

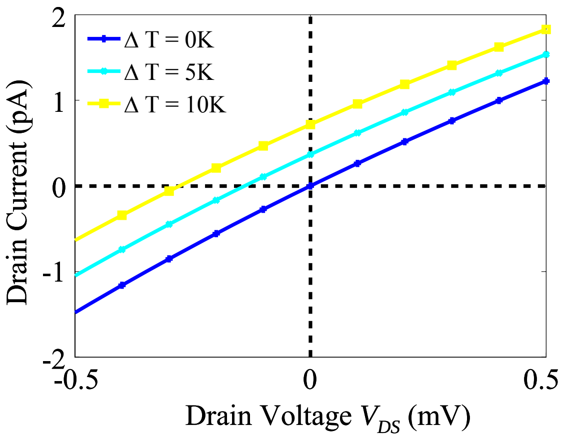


Fig. 3. Drain current-bias voltage characteristics for different temperature gradients around $T = 77$ K at $V_G = 3.4$ V.

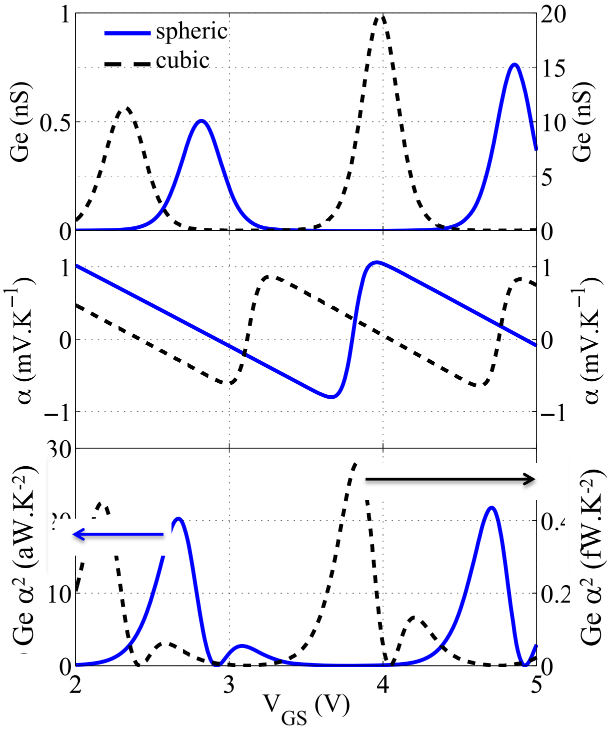


Fig. 4. Electronic conductance, Seebeck coefficient and power factor as a function of gate voltage, for the spherical-dot and cubic-dot SETs.

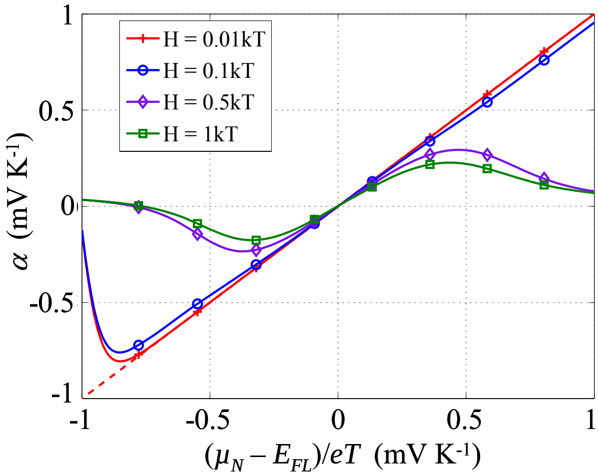


Fig. 5. Evolution of the Seebeck coefficient for different energy level broadenings H and comparison with the ideal linear function $\alpha_{ideal} = (\mu_N - E_{FL})/eT$ (dashed line)