Temperature-Induced Revolving Effect of Electron Flow in Semiconductor Heterostructures

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Thermoelectric devices consist in converting heat into electricity or vice versa. Those devices are based on the diffusive phonon and electron transport, and operate in close to equilibrium regime, where their produced power is obviously limited. The scenario is significantly different in nanostructures where carrier transport can be assumed as strongly ballistic. In this non-equilibrium regime, electron temperature may significantly differ from the lattice one, raising the opportunity to obtain devices with better performances than conventional thermoelectric structures. We recently demonstrated that an GaAs/AlGaAs asymmetric double-barrier heterostructure can efficiently act on both the electronic and phononic bath's refrigeration when applied a bias between the emitter and collector contacts [1,2].

Here, we theoretically focus on the opposite effect, *i.e.* when a temperature gradient is applied between the collector and the emitter (Fig. 1-a)), and we study the induced electrical current properties. We demonstrate that electrons are subject to an unexpected *revolving* effect. Depending on the lattice temperature increase/decrease, electrons respectively absorb/emit a phonon and subsequently go back to the reservoir from which they have been injected (Fig. 1-b)). Our simulation code, which self-consistently solves the non-equilibrium Green's function framework and the heat equation, is capable to calculate the electron temperature and electrochemical potential inside the device. By investigating those non-equilibrium thermodynamic quantities, we show that the boomerang effect is due to the sign inversion of the local electron distribution [3].

We will investigate this effect by varying the phonon energy, the access region's doping (i.e. Fermi level) and the electron-phonon coupling. We will also show that current-voltage characteristics of resonant tunneling diodes under different temperature gradients should be a relevant approach to experimentally verify this effect. This latter should be more important than the Seebeck effect in well-designed nanostructures.

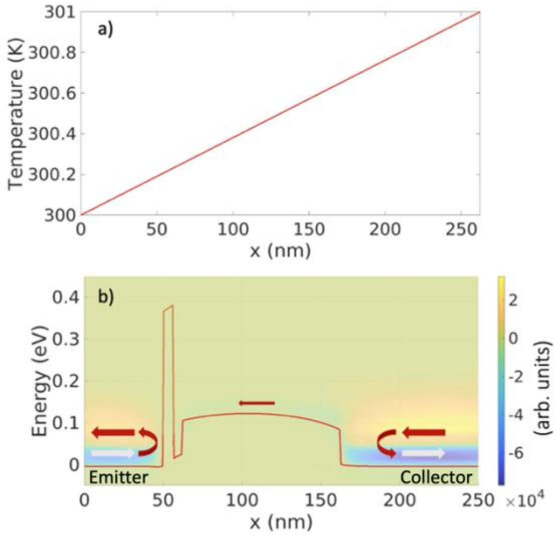

Fig. 1. a) Lattice temperature gradient along the device shown in Fig. 1. A temperature gradient of 1 K is applied between the emitter (T_{emit}=300 K) and collector (T_{coll}=301 K) reservoirs; b) Corresponding electron current spectrum. The solid red line represents the energy potential profile, while red and white arrows indicate the electron flow and reflection on the potential barrier. The smaller red arrow in the central region represents the total electron flow, going from right to left. No potential bias is applied (V=0 V).

References

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