傾斜ポテンシャル障壁を有する熱電子放出ヘテロ構造中の電子と格子の冷却効果

Electron and lattice cooling in thermionic emission heterostructures with tilted barriers

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The understanding and control of cooling properties at the nanoscale represent major scientific and industrial issues. In that context, thermoelectricity appears to be a relevant solution as a "green" approach operating at small scales. However, since electrical cooling power is clearly limited near thermodynamic equilibrium, we propose to investigate nanostructures whose working principle applies far from it. This is the field of thermionic cooling. In this work, we first investigate both experimentally and theoretically the semiconductor thermionic cooling structure based on an asymmetric AlGaAs/GaAs double barrier heterostructure shown in Fig.1-a). In this structure, "cold" electrons are injected from the emitter into the GaAs quantum well (QW) *via* a resonant tunneling effect through a potential barrier. "Hot" electrons are extracted from the QW through a thermionic process above the thick AlGaAs alloy.

The sample structure was grown by MBE and electron temperatures, T_e, in the QW and in the electrodes, were determined by photoluminescence (PL) spectroscopy. We found that T_e in the QW decreases with increasing the applied bias voltage (V) and reaches 250 K around the resonant tunneling condition. In contrast, T_e in the electrodes remains unchanged, equal to 300 K (Fig.1-b)).

To shed light on this behavior, we have developed an “in-house” code based on the non-equilibrium Green's Function formalism, in which the electrical and thermal transport equations are self-consistently resolved [1]. The results also predict a significant drop in T_e (~ 50 K) in the QW, which is in good agreement with experiment (Fig.1-b)). Such cooling effect results from the evaporation of the electrons in the QW. Indeed, due to the thick collector barrier only electrons whose kinetic energy is larger than the height of the collector barrier are removed by thermionic emission. This effect leads to the cutoff of the high-energy tail of the distribution function of electrons in the QW, which thermalize themselves into a new quasi-equilibrium state at a lower temperature [2].

However, quantum simulations show that tunneling current across the collector barrier is detrimental for the cooling performances. We then propose a new structure with a "tilted" potential profile in the collector barrier to reduce this effect (Fig.1-c)). Simulations indicate that such a structure leads to an improvement of the coefficient of performance over the entire applied bias range by at least 60 % [3]. Therefore, the present low-energy-injection/high-energy-extraction device coupled with a tilted potential profile can lead to thermionic devices of crucial technological interest, providing a higher efficiency and a larger cooling power.

a) b) c)

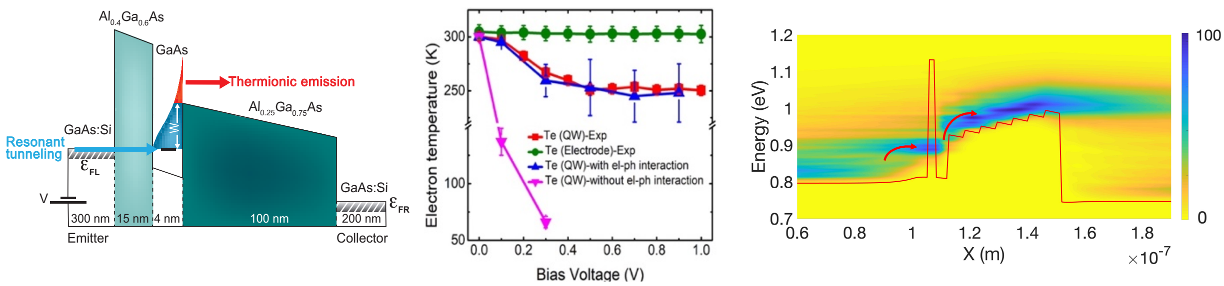

Figure 1: a) Band diagram of the asymmetric double-barrier heterostructure; b) The electron temperatures in the QW (red squares) and electrode (green circles) determined from PL measurements on the device of Fig.1-a); c) Current spectrum (arb. unit.) of the tilted structure at V =0.05 V. The aluminum concentration in the collector barrier varies from 0.15 to 0.3 every 5 nm, which prevents from the tunneling current. Red solid line represents the potential profile.

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