熱電子放出ヘテロ構造を用いた電子と格子の冷却効果

Electron and lattice cooling based on thermionic heterostructures

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In this work, we 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 developed an “in-house” code based on the non-equilibrium Green's Function formalism. By adopting a full-quantum approach, we have self-consistently resolved the electrical and thermal transport equations [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)). According to our interpretation, 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 thermalized into a new quasi-equilibrium state at a lower temperature [2]. Collector barrier impact on electron temperature has been also theoretically investigated.

Finally, simulations indicate that the heterostructure studied here achieves a coefficient of performance larger than 25%, clearly demonstrating the relevance of the architecture to provide high performance nano-refrigerators. This study then shows a significant step towards a new generation of cooling devices.

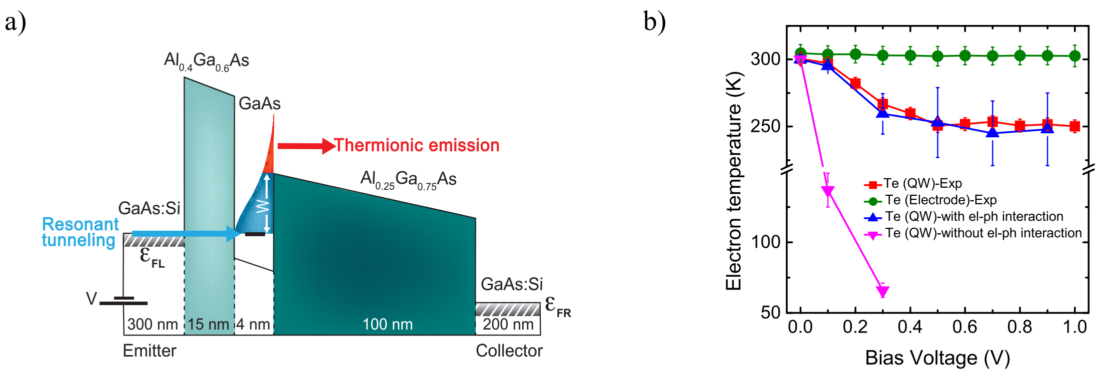

Figure 1: a) Band diagram of the asymmetric double-barrier heterostructure. Electron transport mechanisms, *i.e.*, resonant tunneling through the thinner barrier (blue arrow) and thermionic emission above the thicker barrier (red arrow), are schematically shown; b) Electron temperatures in the QW (red squares) and the electrode (green circles) determined from PL measurements as a function of the bias voltage. Blue triangles denote the electron temperature calculated from quantum simulations, showing a good agreement with experiment.

[1] M. Bescond, D. Logoteta, F. Michelini, N. Cavassilas, T. Yan, A. Yangui, M. Lannoo, K. Hirakawa, J. Phys.: Condens. Matter **30**, 064005 (2018).
[2] A. Yangui, M. Bescond, T. Yan, N. Nagai, and K. Hirakawa, Nature Commun. **10**, 4504 (2019).