半導体ヘテロ構造熱電子放出冷却構造中の活性化型伝導電流

Thermal activation behavior of current in semiconductor thermionic cooling heterostructures

東大生研・ナノ量子機構[1]、LIMMS-CNRS[2]、エコールノルマルスーペリア[3]
○朱　翔宇[1]、ベスコン・マーク[2]、バスタード・ジェラルド[3]、長井奈緒美[1]、平川一彦[1,2]
IIS/INQIE, Univ. of Tokyo[1], LIMMS-CNRS[2], Ecole Normale Superieure[3]
°Zhu Xiangyu[1], Marc Bescond[2], Gerald Bastard[3], Naomi Nagai[1], Kazuhiko Hirakawa[1,2]
E-mail: zxy@iis.u-tokyo.ac.jp

Managing rapid increase in thermal power densities associated with device miniaturization is a major technological challenge. Development of new efficient cooling technologies is therefore urgently required for future progress in electronics. Solid-state cooling devices can be one answer owing to their high efficiency and possibility of integration. To achieve such an efficient cooling, we have been working on semiconductor double barrier heterostructures to utilize the thermionic cooling effect.

We fabricate an asymmetric AlGaAs/GaAs double barrier heterostructure [1], as shown in Fig. 1(a). In the present heterostructure, cold electrons are first injected into the quantum well (QW) by resonant tunneling through the thin barrier (emitter barrier). Subsequently, hot electrons are removed by thermionic emission over the second thick barrier (collector barrier). This sequential two-step conduction process is essential for the cooling effect. Therefore, quantitative understanding on the conduction process is necessary. In this work, we have developed an analytical theory to calculate the two-step current and compared it with experiment.

To clarify the transport mechanism, we have systematically measured *I-V* curves at various temperatures and also performed theoretical calculations on the sample structure shown in Fig. 1(a). Figure 1(b) plots the temperature-dependence of the current density measured at 0.1V (green dots), which shows a thermal activation behavior. In the theory, we use two different description for the thermionic emission process. The one is the standard three-dimensional (3D) Richardson theory (blue). The other is a more rigorous theory which takes into account the thermionic emission process from the two-dimensional (2D) QW to the continuum assisted by LO phonon scattering (red). The major difference between the two theories is that the thermal activation energy for the LO phonon-assisted process (red) is smaller than that for the 3D theory (blue) by $\hbar\omega_{LO}$. As seen in Fig. 1(b), the agreement between theory and experiment is very reasonable and, furthermore, the activation energy determined from experiment agrees with that for the LO assisted process. We will discuss more detail at the conference.

References [1] A. Yangui, M. Bescond, T. Yan, N. Nagai, K. Hirakawa, Nature Commun. **10,** 4504 (2019).

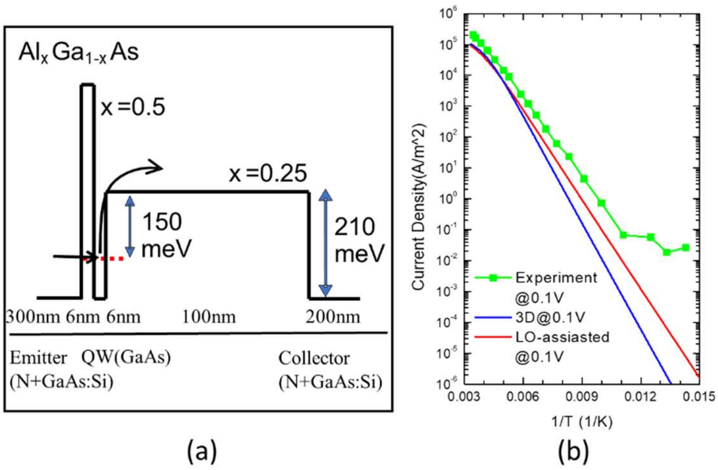

Fig. 1 (a) Band diagram of the sample, (b) temperature-dependence of the current density measured at V = 0.1 V.