二重量子カスケード冷却構造中の電子温度（Ⅱ）

Electron emperature in double well quantum cascade cooling structures (II)

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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 compatibility for integration. To achieve efficient cooling, we have been working on semiconductor double barrier heterostructures to utilize the thermionic cooling effect [1,2].

In this work, we have studied a double quantum well (QW) structure as a model for the quantum cascade cooling (QCC) structure. The structure consists of two 5 nm-thick $Al_xGa_{1-x}As$ QWs with different Al compositions (x = 0.1 for QW1 and x = 0.2 for QW2) sandwiched by $Al_{0.35}Ga_{0.65}As$ or $Al_{0.7}Ga_{0.3}As$ barriers (see Fig. 1(a), (c)). As an electron cascades through the double QW structure, it can absorb multiple phonons, which can improve the cooling efficiency, when compared with single QW structure.

The first QCC structure we investigate is shown in Fig. 1(a) (QCC-A). To clarify the electron cooling behavior, we measured voltage (*V*)-dependent photoluminescence (PL) of the sample. PL spectra from bulk n-GaAs, QW1, and QW2 were analyzed and electron temperatures in the respective layers were determined as a function of *V* (see Fig. 1(b)). We observed that electrons in QW1 are cooled, while electrons in QW2 are significantly heated. From NEGF calculations, this unexpected electron heating in QW2 comes from the hot electrons generated by direct thermionic emission from the emitter electrode.

In order to block this hot electron population above the barrier, we have increased the barriers and investigated a new structure (see Fig. 1(c); QCC-B). When positive voltage is applied, we observe electron cooling effect in both QWs, as shown in Fig. 1(d), from which we confirm that the observed electron heating in QCC-A arises from hot carrier distribution due to direct thermionic emission from the emitter. By adjusting the barrier profile, we ensure that the sequential thermionic emission process is dominant, which improves the electron cooling effect in QCC-B.

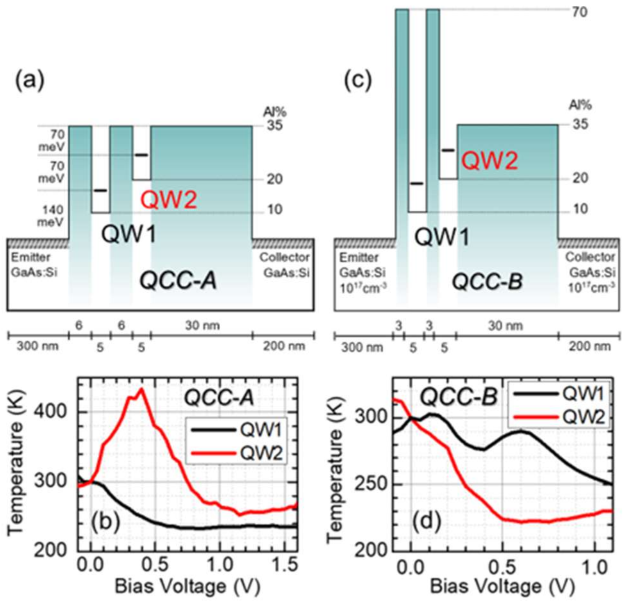

Fig. 1 (a) Band diagram of the QCC structure A,
(b) Electron temperatures in QW1 and QW2 of QCC-A,
(c) Band diagram of the QCC structure B,
(d) Electron temperatures in QW1 and QW2 of QCC-B.

References

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[2] X. Zhu, M. Bescond, G. Bastard, K. Hirakawa, et al., Phys. Rev. Appl. 16, 064017 (2021).