GaN 系 THz 量子カスケードレーザーの導波路設計

Waveguide design for GaN/AlGaN terahertz quantum cascade lasers

理研 光量子，テラヘルツ量子素子研究チーム ○王 科，林 宗澤，寺嶋 亘、平山 秀樹

RIKEN, THz quantum device labotory, RAP °Ke Wang, Tsung-Tse Lin, Wataru Terashima, Hideki Hirayama

E-mail: ke.wang@riken.jp

III-nitrides which have much larger phonon energies (91meV in GaN) can in principle allow for terahertz quantum cascade lasers (THz QCLs) to operate at higher temperatures than GaAs based THz QCLs[1-2], in which the thermally activated phonon scattering depopulation and backfilling are limiting THz lasing at <200 K. GaN THz-QCLs would be key coherent sources in the unexplored terahertz frequency range of 5–12 THz, at which GaAs THz-QCLs are not able to work due to the Reststrahlen band.

Although our group has reported stimulated emission from GaN THz QCL structures recently [3] , it is still very challenging for such devices. The residual electron density in unintentionally doped GaN epilayers is also high, ~10^{16} /cm^3, which would undoubtedly result in strong free carrier absorption in THz range, as shown in Fig 1(a). Since the free carrier absorption is strong and results in waveguide loss, we should remove the buffer GaN or AlGaN layers, which is typically 2-4 μm thick, on foreign substrates (sapphire or Si). Then a metal metal waveguide becomes possible. The free carrier absorption in such designed waveguide will be much reduced and the confinement factor is nearly 1.0, as shown in Fig 1(b) . We investigate the influence of the free carrier absorption, doped contacting layers, and active layer thickness on the waveguide loss for GaN/AlGaN THz QCLs with metal-metal waveguides. If free carrier absorption is completely ignored, the lowest loss is obtained, which is ~15 cm^{-1} for a 10 μm active layer. However, if we assume an average electron density of 5e16 cm^{-3}, which is reasonable for a typical growth and includes both unintentional residual e- density and Si doping for GaN QCL, the waveguide loss increases to 31 cm^{-1} at 10 THz. The electrode contacting layers would further increase the loss.

Keeping the current growth technologies in mind, to control the waveguide loss as low as possible for a GaN/AlGaN QCL, we must ensure that: the growth conditions are optimized to achieve the lowest background electron density; the contacting layers should be as thin as possible; and the higher frequency range is preferable since free carrier absorption is lower.

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[2] E. Bellotti, K. Driscoll, T. D. Moustakas, and R. Paiella, Appl. Phys. Lett. 92, 101112 (2008).
[3] H. Hirayama, W. Terashima, S. Toyoda and N. Kamata, Proc. SPIE Photonics, (2016).

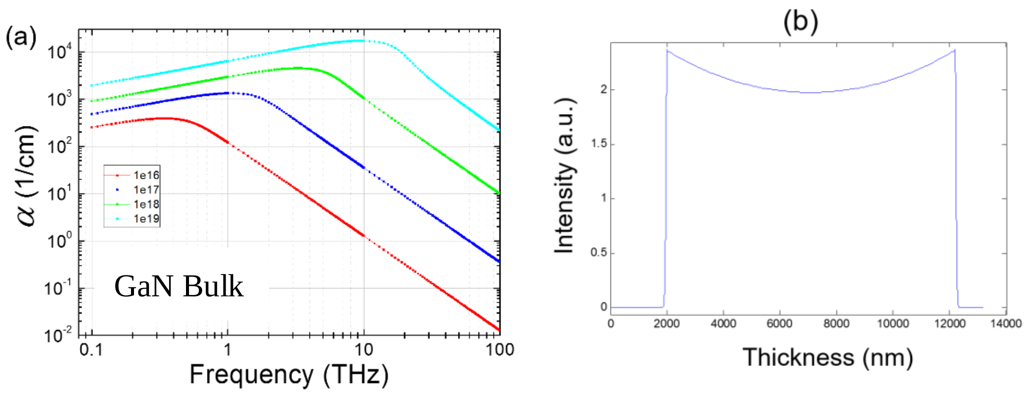

Fig. 1. (a) GaN bulk free carrier absorption loss for several electron densities using 77 K Drude scattering times obtained from measured mobilities. (b) Mode profile for an Au-Au metallic waveguide at 10 THz.