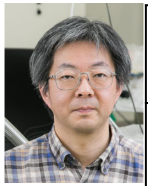
【Grant-in-Aid for Scientific Research (S)】

A Study on realizing unexplored frequency and room temperature operation THz-QCL through innovation of inter-subband transition mechanism



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Purpose and Background of the Research

●Outline of the Research

Terahertz quantum-cascade lasers (THz-QCLs), which are small size high power THz laser, are expected to be applied in a variety of fields, including non-destructive and transparent inspection, automotive lidar, and light sources for next-generation communications. However, THz-QCL only operates at low temperatures and has a limited frequency range. The purpose of this research is to achieve room-temperature (RT) operation and expand the frequency range of QCLs. In order to achieve RT operation, we reviewed the inter-subband transition (ISBT) mechanism of the QCL active layer and introduced an "isolated three-level" mechanism that completely blocks multiple electron leakage channels. Furthermore, we will introduce nitride semiconductors to realize the unexplored frequency band of 5 to 12 THz and wavelengths shorter than 3 μm. By conducting highly precise crystal-growth of GaAs- and GaN-based structures, we achieve RT operation and unexplored frequency QCLs.

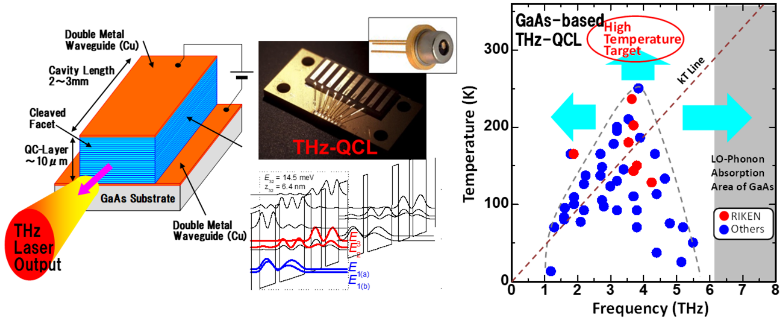

Figure 1. Schematic image of THz-QCL and new operating region of THz-QCL aimed at in this research

●QCL in "unexplored frequency range" using nitride semiconductors)

GaN (gallium nitride)-based semiconductors, which are wide-gap semiconductors, have three times larger LO phonon energy than that of GaAs-based semiconductors, and the conduction-band discontinuity is also more than three times larger than that of GaAs. Therefor, GaN is possible to achieve 5 to 12 THz, and 0.8 to 6.5 μm QCL, which were previously unexplored areas.

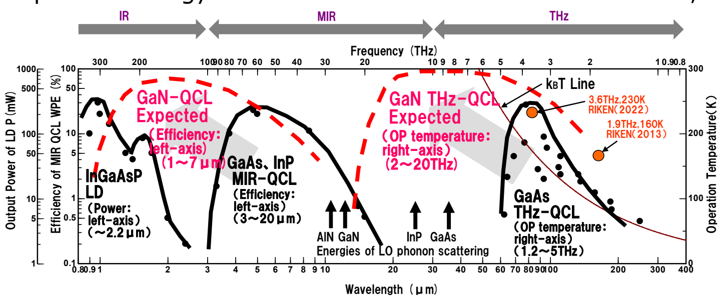

Figure 2. THz and IR-QCL operating range expected by introducing GaN semiconductors

●THz-QCL mechanism achieving room temperature (RT) operation

Three mechanisms are adopted to enable RT laser operation of THz-QCL. First, "indirect injection using LO phonon scattering" is introduced to obtain selective injection of electrons into the upper lasing level. Also we block horizontal electron leakage from the upper lasing level and jump-up leakage due to LO phonon absorption via thermally activated electrons. In addition, LO phonon scattering via thermally activated electrons is reduced, by spatially separation of the wave functions between lasing levels, allowing population inversion to be formed even at up to 340K.

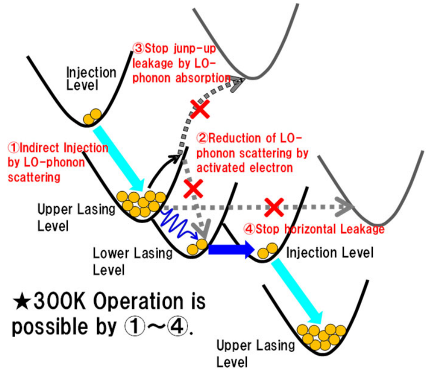

Figure 3. "Isolated 3-level mechanism" enables RT operation of THz-QCL

Expected Research Achievements

●Realization of room temperature (RT) operation of GaAs-based THz-QCL

We will design a quantum structure that realizes an "isolated three-level mechanism" that enables RT operation. We will fabricate a device through crystal growth of a GaAs-based QCL superlattice structure using molecular beam epitaxy (MBE), wafer bonding, lift-off, electrode processing, and cavity creation, and attempt laser operation. By incorporating an isolated three-level quantum structure, we aim to achieved RT operation of THz-QCL.

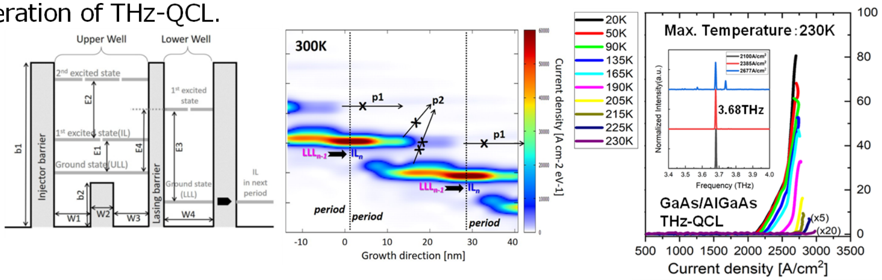

Figure 4. A "modified two quantum well" THz-QCL structure, predicted to have a *maximum operating* temperature of 340K, and lasing operation at 230K obtained by fabricating the same structure.

●Realization of lasing operation of GaN-based THz-QCL

We analyzed the optical gain of GaN/AlGaN THz and infrared QCL, and predicted that RT lasing would be possible from 1.5 to 15.5 THz and 0.8 to 6.5 μm. We aim to create a GaN-based QCL using a SiC (silicon carbide) substrate that does not absorb terahertz light and can perform optical confinement with low refractive index of SiC.

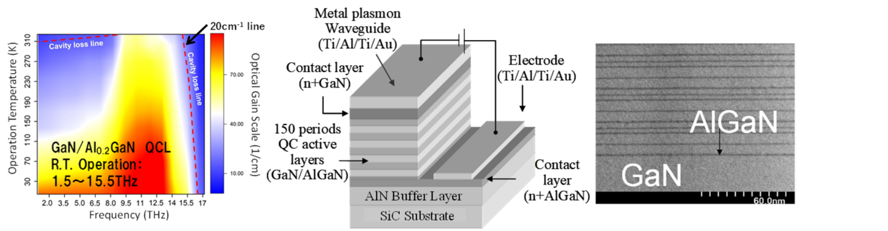

Figure 5. Optical gain mapping analyzed for GaN/AlGaN THz-QCL and structure aiming for lasing operation

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