NEGF 法を用いた GaN 系 THz 量子カスケードレーザーの光利得解析

Simulation of optical gain for GaN terahertz quantum cascade lasers by using non-equilibrium Green's function method

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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 5.4~12 THz, at which GaAs THz-QCLs are not able to work due to the Reststrahlen band.

Although our group has reported very narrow emission from GaN THz QCL structures recently [3] , it is still very challenging for such devices. We have adopted the self-consistent Non-Equilibrium Green's Function method (NEGF) to simulate the carrier transportation and optical processes in GaN THz QCL structures. Inelastic scattering due to optical and acoustic phonons, as well as elastic scattering due to charged impurities, interface roughness, and alloy disorder are taken into account within the self-consistent Born approximation. Electron-electron interaction is treated within the first order, Hartree approximation. The gain is calculated in a self-consistent way within the linear response theory. We are studying various designs for GaN THz QCLs based on resonant phonon scheme.

Fig 1 shows an example, pure 3 levels design, **2.0**/6.6/**1.2**/3.1 nm, two barriers ($Al_{0.15}Ga_{0.85}N$, bold) and two GaN wells in each period. The photon emission is diagonal transition between the upper and lower lasing levels. Depopulation is through the fast LO-phonon scattering in the wide well. Then the carriers are accumulated in this wide well, which is the next upper lasing level. Fig 1(left) shows the conduction band profile and the envelop functions of Wannier-Stark states. The calculated peak gain at 10 K is 153 cm^{-1} for photon energy of 26 meV (6.4 THz), and it remains 42/cm at 300 K which is still above the calculated waveguide loss.

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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. (left) Conduction band diagram and wave functions of a GaN THz QCL structure under a bias of 120mV/period (pure 3 levels design, **2.0**/6.6/**1.2**/3.1 nm). (right) Calculated optical gain at various temperatures. RT lasing is possible.