New design of GaAs based THz-QCL for obtaining high optical gain by indirect-injecting asymmetric-wells superlattice structure

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THz-QCLs has been attracted huge attentions since their first realization. However, the operating temperature until now is still below 200K [1]. It is quite significant to find new device designs to achieve room temperature lasing, at least, to be up to the thermoelectric cooling 230K. Compared to the designs using resonant tunneling (RT) and LO phonon depopulation which realizes the world record operating temperature of 199.5K (Fig.1a), we proposed a new design and simulated it by NEGF method: 1. It is the GaAs/AlGaAs superlattice with asymmetric wells. The upper lasing well is Al0.06Ga0.94As. The lower lasing well is GaAs and very narrow to avoid the multi-periods current leakage raised from the high energy levels in this well (Fig.1b); 2. Injecting process is realized by the inter-well LO phonon scattering in the upper lasing well (also we call it as indirect injecting process). 3. One period only consists of two wells and the efficient extraction (e) of electrons from lower lasing levels (l) is by resonant tunneling. In Fig.2c, it is clear that in this new design the electrons mainly stay at the upper lasing levels (u), which results in a better population inversion ($u \rightarrow l$). Such electrons distribution is also benefit to avoid the formation of negative differential conductivity (NDC) which can make the electric field inhomogeneous. As compared, in the world-record design with RT and LO phonon depopulation (Fig.2d), many electrons are retarded at injecting level(i). From the I-V and optical gain in Fig. 3, it can be found that the new design results in an improved maximum gain of 74cm^{-1} at the operating bias per period (54mV) where the world-record design is 59cm^{-1}, and its threshold current is also quite small (∽700A/cm^2) and also the lasing dynamic range is much larger (700→1305A/cm^2). The corresponding values of the world record designs are 1060A/cm^2 and 1060→1200A/cm^2, respectively.

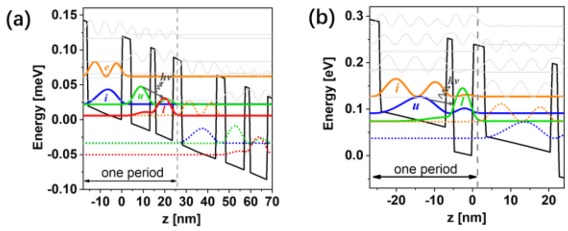

Fig.1 Absolute square of the Wannier states of QCL with tight bonding at resonance tunneling barrier. (a) RT LO- phonon depopulation scheme (world record [1]); (b) New design in this paper.

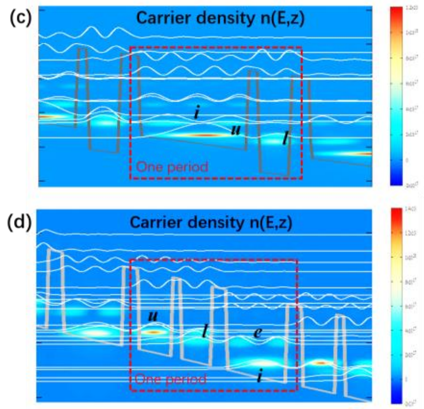

Fig.2 Electron density distribution at lattice temperature of 200K under operating bias. (c)RT LO-phonon depopulation at 58mV bias per period; (d)New design at 54mV bias per period.

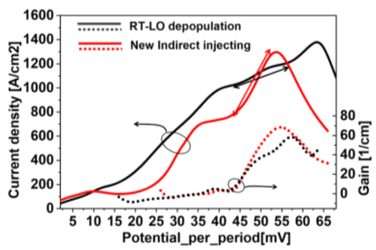

Fig.3 Current and optical gain of both designs at lattice temperature of 200K with different bias.

References

[1] S. Fathololoumi,et.al, Optics Express (2012)3866.

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