Terahertz quantum cascade lasers approaching room-temperature operation: Design by non-equilibrium Green's functions and the experiments

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Terahertz (THz) wave has been treated as important wavelength range for specific applications, such as chemical, biological, astrophysical areas. However, the promising of THz wave generator based on quantum cascade lasers(QCL), an integrated semiconductor device , suffers from the limit of operation temperature. That is, THz-QCL only operates below room-temperature with specific cooling component. After its first realized 20 years ago, the till-recent breakthrough of 250K indeed set a milestone of possible cryostat-free QCL for THz-wave [1]. To approach the final aim of room-temperature operation, the thermally degradation in this kind of laser still left as a tough task, and therefore calls for new design with specific suppression strategy.

Two-well direct-phonon scheme is used for the recent breakthrough more than 200K. It employs resonant-tunneling once only in electrons injection process. So, the real growth is easier to reprint the design and made it reliable. This scheme demonstrates a simple 3-level system, and the depopulation of lower lasing subband (LLS) by vertical electron and LO-phonon down-scattering is very efficient, both make the population inversion be much higher. However, in lower well, the feature of energy separation of ground states(injection subband, IS) and first excited state(LLS) is close to 36meV, the high-lying subbands(HLS) in this well are also low in energy. As a result, thermally activated leakage channels will be formed which origin from IS and upper lasing subband(ULS) to those HLS, *via* up-scatterings. Furthermore, the narrow period length of two-well structure is with sharp potential profile. The direct-tunneling leakages across neighbor periods are also serious. This kind of leakage is due to alignment of destined subband (mainly IS, ULS) with the HLS in downstream period. Actually, the design freedom in two-well direct-phonon scheme is quite limited. In this work, we propose a new design, in which it creates isolated three-subbands by using ministep located in the center of lower well, to push up the HLS high in energy. Due to tunability in this ministep, the design freedom can be large. Parasitic channels, not only the thermally-escape *via* up-scattering but also the interperiods direct-tunneling leakages, are efficiently suppressed (as shown in Fig.1). We initially observe lasing close 200K in the on-going experiments.

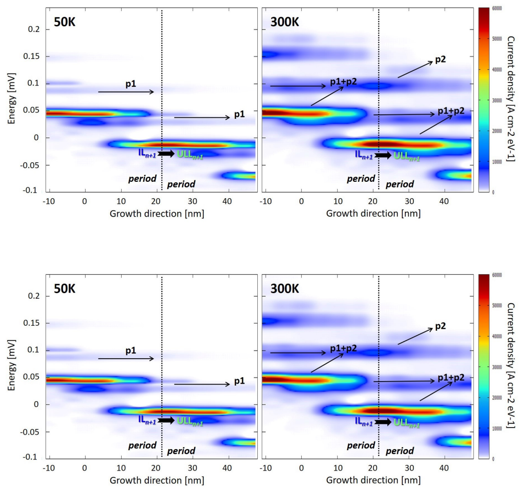

Fig. 1 Current mappings of conventional two-well direct-phonon and this design at low (50K) and high(300K) temperatures (top/bottom)

[1]. A.Khanlatpour, A.K. Paulsen, C. Deimert, Z.R. Wasilewski and Q. Hu "High-power portable terahertz laser systems," *Nature.Photonics,* 15, pp. 16-20, 2021.