High-Power Mid-IR Quantum Cascade Lasers grown by MOCVD

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The MOCVD growth of high performance QCLs requires an understanding of the influence of growth conditions on the interfacial properties if the superlattice (SL) active region. Such structures are sensitive to small deviations from the design thicknesses and compositions in the active-core region, which can alter the emission wavelength through changes in the electron wavefunctions in the conduction band. Furthermore, the interfaces between quantum wells and barriers within the active region are not atomically abrupt, but exhibit characteristic roughness and compositionally graded regions of finite thickness at each interface. These structural 'non-idealities' have significant consequences for QCL-device performance. We have employed atomic probe tomography to elucidate the interfacial properties of the SL active region, and are developing models to incorporate these observed properties into QCL design software.

At present, the InP substrate is still the most prominent platform for high-power quantum cascade lasers (QCLs). Challenges remain to integrate InP-based QCLs onto mismatched substrates, such as GaAs and Si, without severe degradation in performance. Direct growth on mismatched substrates often employs metamorphic buffer layers (MBLs) as an intermediate substrate to adjust the lattice constant accordingly. One primary challenge is that, during the mechanical stress caused by relaxation originating from the lattice mismatch between InP and GaAs (~3.8%) or Si (~8.1%), defects including stacking faults and misfit/threading dislocations are formed in high-density levels. While III/V-semiconductor MBLs have been studied extensively for solar cells and diode lasers, until recently little has been reported regarding their application to intersubband-transition devices such as QCLs. We have developed the MOCVD growth of QCLs on mismatched substrates (GaAs), which addresses strain considerations, and reveals the impact of residual threading dislocations on device performance.

Scaling the coherent power of mid-IR-emitting quantum cascade lasers (QCLs) to the multi-watt power range remains a significant challenge due to strong self-heating under CW operation. The strong device heating stems primarily from two attributes of QCLs: (a) relatively low wall-plug efficiencies compared to those of high-power near-IR diode lasers, and (b) poor thermal conductivities of the constituent materials forming the device structure. Self-heating in QCLs leads to a significant reduction in CW output power (e.g., via thermal rollover) relative to that achievable under short-pulse operation, as well as to degradation of the beam quality due to thermally induced index variations. Furthermore, the maximum output CW powers of QCLs are limited by reliability issues associated with Catastrophic Mirror Damage (CMD) occurring at the emitting facets. To address QCL power scaling, we have been developing novel design concepts that will significantly increase the active volume in order to dramatically increase the power over those currently achievable from single-element QCLs, while maintaining a stable-beam, single-mode output to the highest possible drive levels. However, challenges remain as far as reducing self-heating in such large-aperture devices, in order to mitigate thermally induced performance degradation and maximize the reliable output power.