n-type Si/SiGe quantum cascade structures

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The quantum cascade laser (QCL) has proved extremely successful in III-V materials systems. As intersubband rather than interband optical transitions are employed and the emission energies depend primarily on the widths of the layers, the indirect bandgap of silicon is no longer an obstacle to achieving optical emission. The use of Si/SiGe heterostructures would enable integration with conventional CMOS technology and potentially reduce QCL fabrication costs. Whilst most efforts to date have focussed on intersubband transitions in the valence band,[1], [2] there are some disadvantages to this approach. The large non-parabolicity of the valence band leads to linewidth broadening, whilst the possibility of light-hole to heavy-hole optical transitions adds complexity to devices.

n-type devices have six almost parabolic conduction band Δ-minima located near the X-points, and intersubband transitions yield much lower energy dispersion with respect to small shifts in wavevector. Electroluminescence linewidths are therefore expected to be smaller than in p-type structures. Designing devices for optical transitions far from the Γ-point raises several interesting challenges. The lattice mismatch between heterolayers causes a strain-induced splitting of the degeneracy between the Δ-valleys, resulting in two distinct sets — a Δ_z set with wavevectors perpendicular to the growth plane and a Δ_{xy} set for the parallel case. f-type phonon scattering mechanisms can cause carriers to drain into orthogonal valley states and prevent optical emission. We show however, within a one-band effective mass/envelope function model that it is possible to strain the quantum wells sufficiently to separate the two sets of states. Quantum confinement induced splitting of the Δ_z-valley states is also taken into consideration.[3]

Electron-phonon, interface-roughness and alloy disorder scattering mechanisms are used to investigate populations of states in a quantum cascade structure, whilst considering realistic Ge interdiffusion and dopant segregation. Taking all these effects into account, a design is presented for population inversion and intersubband optical emission from n-Si/SiGe heterostructures.

References

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