This is the author's version of a Proceedings Paper presented at **UK Semiconductors 2013**

Ivanov, P, Valavanis, A, Ikonic, Z and Kelsall, RW (2013) *Design and Simulation of SiGe/Ge Structures for Optically Pumped THz Lasers;* Institute of Physics

Design and Simulation of SiGe/Ge Structures for Optically Pumped THz Lasers

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Quantum Cascade Lasers (QCLs) are efficient mid-infra-red and THz sources, however, most THz QCLs are GaAs-based devices with maximum operation temperatures below 200 K. Silicon-based SiGe/Ge QCLs may have higher operating temperatures because silicon has a higher thermal conductivity than GaAs and polar optical phonon scattering is absent in Si and Ge. Moreover, silicon-based QCLs offer the prospect of integration with silicon microelectronics.

To date, no working SiGe/Ge QCL has been demonstrated. The standard QCL heterostructure designs are extremely complex, and the sensitivity of the device to minor variations in layer thicknesses presents substantial challenges for SiGe epitaxy. In this work we investigate an alternative approach to generating THz radiation from intersubband transitions in SiGe/Ge quantum well (QW) structures, by using external optical excitation.

Four types of optically-pumped QW periodic SiGe/Ge structures have been designed and investigated: asymmetric double QWs, asymmetric triple QWs, stepped QWs, and symmetric multiple QW structures. All structures were designed to be grown on a virtual substrate with a $Si_{0.22}Ge_{0.78}$ buffer layer [1] and excited with a CO_2 laser at a wavelength of 9.6 μm. The structures are n-type doped to provide a source of carriers, which are excited by the pump laser from the lowest subband of the structure to high-energy bound states. Attainment of population inversion between subbands is dependent on engineering the intersubband scattering rates. The THz gain in each structure has been simulated using a multi-subband rate-equation model [2] which includes electron-phonon, electron-electron, ionized impurity, alloy disorder and interface roughness scattering processes.

The designs were optimized via an extensive parameter search. The layer widths in all structures, the QW alloy composition in the stepped QW structure, and the number of wells in the symmetric multiple QW structure were all varied to identify designs with the highest predicted gain. Symmetric multiple QW structures with 5 QWs per period demonstrated the best predicted performance.

References

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