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n-type Si/SiGe Quantum Cascade Lasers

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The Quantum Cascade Laser (QCL) is an epitaxially grown periodic multiple quantum well heterostructure. By engineering an appropriate bandstructure in the device, a cascade of intersubband transitions occurs, producing several photons for each carrier, allowing high power output. Emission energies are determined primarily by the widths of quantum wells rather than by the material bandgap, meaning that previously unavailable wavelengths may be achieved, even with conventional semiconductors such as the Si/SiGe materials systems. QCLs are ideal sources of terahertz (THz) radiation and thus will see wide-ranging applications including medical imaging, spectroscopy and security screening.

Remarkable results have been achieved for III-V materials, with recent demonstrations of 4.3μm continuous wave (CW) output of 1.34W at 80K, and 166mW at room temperature (298K) [1]. The use of silicon based materials is desirable as the required growth technology is well established and the cost is substantially lower than that of traditional semiconductor optoelectronic materials. There is scope for the integration of optical components with controlling electronics on a single chip. Work on silicon based QCLs has so far focussed on p-type material [2], [3]. In contrast, an n-type silicon based QCL with transitions in the conduction band, would present several advantages. In silicon, the conduction band edge has a higher degree of parabolicity than the valence band edge. Also, the design complexity caused by optical transitions between light-hole (LH) and heavy-hole (HH) states in p-type materials would be removed. Silicon is an indirect bandgap material with the conduction band minimum located in the Δ direction, near the X points for germanium concentrations below 85% [4]. However, optical intersubband transitions may be observed far from the Γ point. The excitation spectrum for unstrained arsenic doped silicon shows several clear regions which may be exploited for these transitions.

In Si/SiGe systems, a potentially large mismatch exists between the lattice constants in each layer. Strain balancing by selection of an appropriate strain relaxed virtual substrate is therefore essential to prevent misfit dislocations. Surface segregation of the arsenic dopant in n-type Si/SiGe heterostructures causes smoothing of interfaces in the doping profile. The development of simulation software to model the optical transitions at the conduction band edge is presented, along with preliminary designs for electroluminescence devices.

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