Crystal orientation and waveguide geometry effects in n-type Si/SiGe quantum cascade lasers

Alex Valavanis,* L. Lever, C. A. Evans, Z. Ikonić, and R. W. Kelsall

Institute of Microwaves and Photonics,

School of Electronic and Electrical Engineering,

University of Leeds, Leeds LS2 9JT, United Kingdom

(Dated: 24th April 2008)

The quantum cascade laser (QCL) was first demonstrated in 1994 as a compact source of mid-infrared radiation,[1] but remains restricted to III-V compound semiconductors. There are however, many potential advantages associated with Si/SiGe alloys, and electroluminescence has been demonstrated in (001) oriented p-type cascade structures.[2]

Mature Si processing technology may reduce costs and offer a route to photonic integrated circuits. The absence of polar LO-phonon interactions may also allow higher temperature operation. The Δ valleys in the conduction band of Si rich systems provide an alternative to p-type systems, and we have demonstrated theoretically that net gain is achievable.[3]

We determine the active region gain for an n-type bound-to-continuum QCL in both the (001) and (111) crystal orientations, using a rate equation/energy balance approach. We show that the (111) orientation offers larger usable band offsets and lower effective mass than the (001) orientation, and hence larger active region gain. We compare the maximum operating temperature and net gain for single and double metal waveguides of varying thicknesses and predict that the highest temperature operation is achievable with a double-metal waveguide and a 15 μm thick active region.

---

[1] J. Faist, F. Capasso, D. L. Sivco, C. Sirtori, *et al.* Science **264**, 553 (1994).

[2] G. Dehlinger, L. Diehl, U. Gennser, H. Sigg, *et al.* Science **290**, 2277 (2000).

[3] L. Lever, A. Valavanis, Z. Ikonić, and R. W. Kelsall. Appl. Phys. Lett. **92**(2), 021124 (2008).

*Electronic address: a.valavanis05@leeds.ac.uk