On the formation of periodic electric field domains in p-Si/SiGe quantum cascade structures

Z. Ikonic, P. Harrison, and R. W. Kelsall
School of Electronic and Electrical Engineering,
University of Leeds, Leeds LS2 9JT, UK

email: r.w.kelsall@leeds.ac.uk

Biased semiconductor quantum well cascade structures, as are nowadays used in intersubband infrared photodetectors and lasers, are well known to be susceptible to the formation of electric field domains. The homogeneous electric field in a structure is broken, due to charge redistribution over individual wells and the appearance of the associated space-charge contribution to the potential. The effect is related to the existence of negative differential resistivity of the cascade, usually ascribed to resonant tunneling between quantized states in subsequent wells. Although the problem of domain formation has been addressed by several authors, e.g. [1-3], there is no straightforward numerical approach, since the conditions under which domains occur depend on the assumed contact boundary conditions, as well as the specific device geometry and electronic properties.

All previous treatments have been for electron transport within the one-band effective mass approximation. In this work we consider the formation of stationary periodic domains in p-type Si/SiGe cascade structures. Hole transport is described via scattering between quantized subbands in subsequent wells, as calculated using the 6x6 **k.p** method which accounts for the full anisotropy of heavy hole and light hole subbands. The scattering mechanisms taken into account are deformation potential (acoustic and optical phonons), alloy disorder, and carrier-carrier scattering. In order to find the possibility of domain formation the hole scattering rates between all pairs of states in subsequent wells in a homogeneous cascade are calculated, as a function of the electric field, taking the carrier heating (thermal self-consistency) into account. These are then used (via interpolation) to solve a system of rate equations for the subband populations in each quantum well, coupled with the discretized Poisson equation. In order to avoid use of contact boundary conditions, for which no experimental data is presently available, we use periodic boundary conditions, in which the electric field distribution in a long homogeneous cascade is assumed to break into an arbitrary number of periodic segments. This is a generalization of the period-doubling model described in [3].

Our simulations show that formation of larger domains is more likely. Results are presented for p-Si/SiGe superlattice cascades, and the conditions (doping density and temperature) under which domain formation occurs are calculated.

This work is supported by DARPA/ USAF contract No. F19628-99-C-0074. The authors thank R.A. Soref (Hanscom AFB) for useful discussions.

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A full journal publication of this work will be published in the Journal of Computational Electronics.