Design of a MIR QCL based on Intervley Electron Transfer: A Monte Carlo Approach

G. Milovanovic¹, O. Baumgartner¹, H. Kosina¹

¹Institute for Microelectronics, TU Wien, Gusshausstrasse 27-29, 1040 Wien, Austria

Over the past several years, Quantum Cascade Lasers (QCLs) have proved to be very promising candidates for practical sources of radiation, particularly in the midinfrared (MIR) region [1]. MIR QCLs are rapidly acquiring new applications such as free-space telecommunications or chemical spectroscopy in medical applications [2].

To investigate charge transport and the performance in general, we developed a Monte Carlo simulator which includes the relevant scattering mechanisms like electron-longitudinal optical phonon, acoustic and optical deformation potential, and intervalley scattering. The electron states corresponding to a single QCL stage are evaluated within a self consistent Schrödinger-Poisson solver. Given such carrier states, we consider the multi quantum well structure as a repetition of this periodicity region. The carrier transport is simulated over the central stage and every time a carrier proceeds an interstage scattering process, the electron is reinjected into the central region and the corresponding electron charge contributes to the current [3].

The simulator has been used to simulate a GaAs/AlGaAs MIR QCL structure [4] and investigate the role of $\Gamma$-$X$ intervalley scattering as a mechanism for the depopulation of the lower laser level, since recently a lot of interest arose for intervalley electron transfer in quantum well structures [5].

We propose to modify the Al content and the width of the collection barrier of the given QCL design in order to increase the overlap between the upper X-state of the next stage and the lower $\Gamma$-state of the central one. Our results indicate a significant increase in current density when considering $\Gamma$-$X$ intervalley scattering for the modified structure B, whereas structure A shows negligible deviations. Thus our calculations demonstrate the possibility of achieving better performance through $\Gamma$-$X$ electron transfer. Furthermore, our simulation highlights the importance of intervalley charge transport for QCL design considerations.

Acknowledgement: This work has been supported by the Austrian Science Fund, special research program IR-ON (F2509).


* Corresponding author: email: milovanovic@iue.tuwien.ac.at
Fig. 1. Overlap between the lower $\Gamma$-state of the central stage and the upper X-state of the next stage at an electric field of 40 kV/cm in dependence on the Al content.

Fig. 2. Electron population in $\Gamma$ and X valleys in dependence on electric field.

Fig. 3. Current density as a function of electric field for structure A and structure B, with and without X-valley transport.