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

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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 Schroedinger-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 Γ-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 Γ-state of the central one. Our results indicate a significant increase in current density when considering Γ-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 Γ-X electron transfer. Furthermore, our simulation highlights the importance of intervalley charge transport for QCL design considerations.

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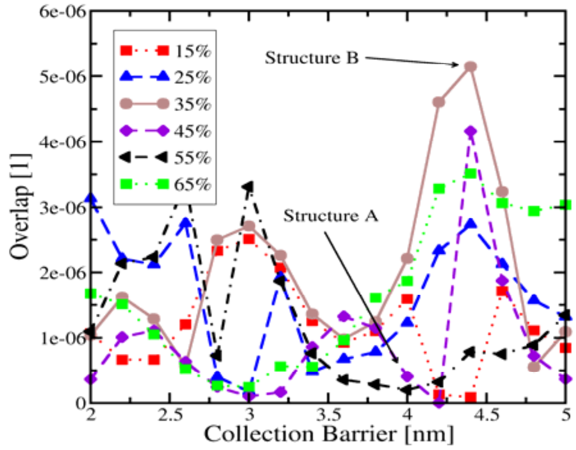

Fig. 1. Overlap between the lower Γ-state of the central stage and the upper X-state of the next stage at an electric field of 40 kV/cm in dependence on the Al content.

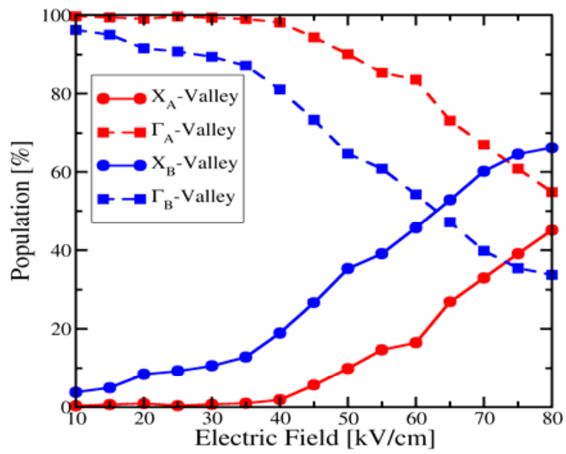

Fig. 2. Electron population in Γ and X valleys in dependence on electric field.

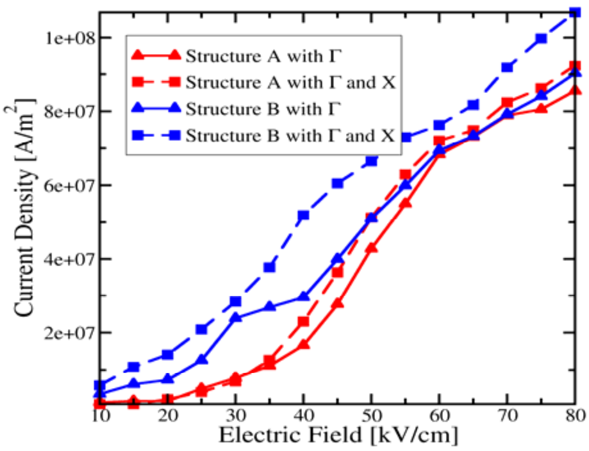

Fig. 3. Current density as a function of electric field for structure A and structure B, with and without X-valley transport.