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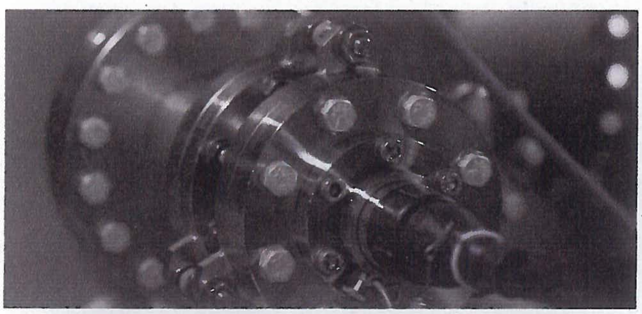

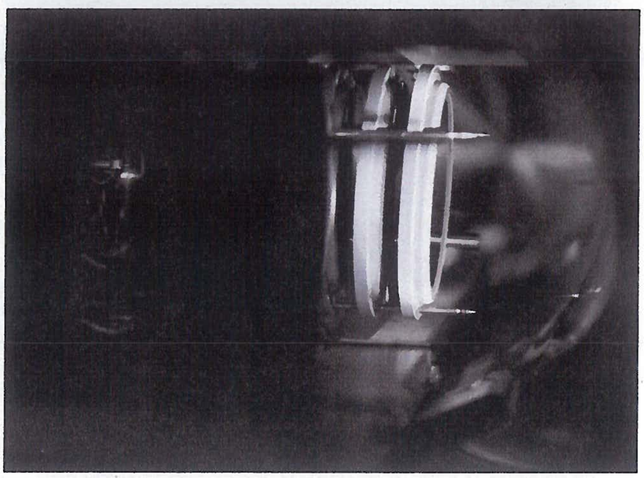

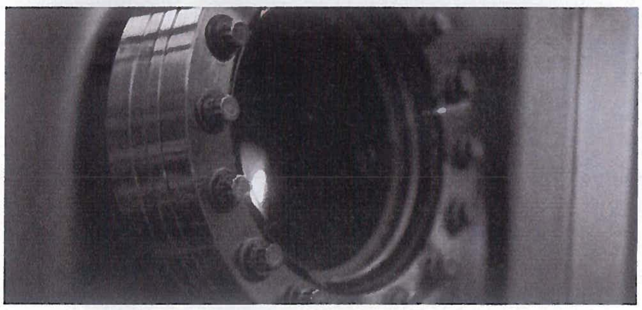

Asymmetry study for high performance InGaAs/InAlAs terahertz quantum cascade lasers

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Quantum cascade lasers (QCLs) are powerful sources of coherent radiation covering the frequency range from mid-infrared to terahertz. In the terahertz frequency range the active region is normally realized using a GaAs/$Al_xGa_{1-x}As$ semiconductor heterostructure. This material system enables a variable conduction band offset by changing the Al-content in the barrier layers without introducing a significant lattice mismatch between the barrier and well material. In comparison to the standard GaAs-based material system, active regions based on material systems with a lower effective electron mass are highly beneficial for the design of terahertz QCLs as the optical gain increases for a lower effective electron mass [1]. Promising material systems are based on InGaAs or InAs with an effective electron mass of 0.043 and 0.023, respectively, compared to that of GaAs (0.067) [2, 3].

In this work we present a systematic study of growth related asymmetries for terahertz QCLs based on the InGaAs/InAlAs material system lattice matched on InP [4]. A nominally symmetric active region enables the comparison of the positive and negative bias direction of the very same device. With such bias dependent performance measurements asymmetries like dopant migration and interface roughness, which play a crucial role in this material system, are studied and result in a preferred electron flow in growth direction. A structure based on a three well optical phonon depletion scheme is optimized for this bias direction. Depending on the doping concentration the performance of the QCLs shows a trade-off between maximum

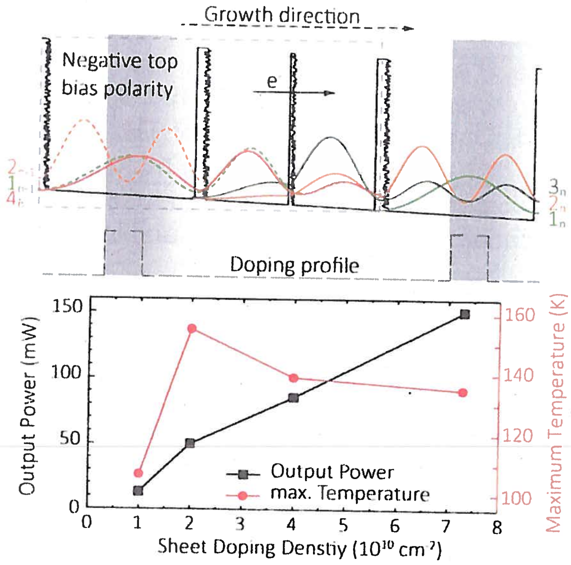

Fig. 1: Bandstructure of the symmetric active region and laser performance for different sheet doping densities.

operating temperatures and high output powers. While a peak output power of 151 mW is achieved for a sheet doping density of 7.3 x 10^{10} cm^{-2}, the highest operation temperature of 155 K is found for 2 x 10^{10} cm^{-2}.

By further attaching a hyperhemispherical GaAs lens to a laser facet, the peak output power could be improved and reaches a record output power for double metal waveguide terahertz QCLs of almost 600 mW.

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