Low Effective Electron Mass InGaAs/InAlAs for High Power 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. A nominally symmetric active region enables the comparison of the positive and negative bias direction of the very same device [4]. 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 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.

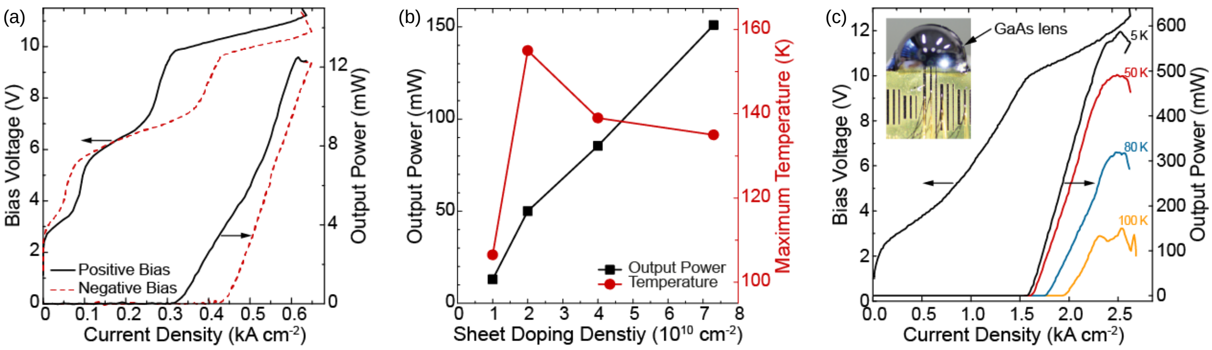

Fig. 1 (a) Light-current-voltage measurement at 5 K for both bias directions of the symmetric active region design showing a higher slope efficiency for the negative bias polarity. (b) Trade-off between high output powers and the maximum operation temperature as a function of the sheet doping density. (c) Improved out-coupling efficiency with an attached hyperhemispherical GaAs lens yields a record output power of 587 mW for double metal waveguide terahertz QCLs.

References

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