Inverse Bandstructure Engineering of Alternative Barrier Materials for InGaAs-based Terahertz Quantum Cascade Lasers

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Quantum cascade lasers (QCLs) are compact and powerful sources that cover a wide spectral range from infrared to terahertz (THz) radiation. The emission characteristics of QCLs depend on design parameters such as layer thickness, material composition and doping. Therefore, the material system has to be chosen accurately. Most commonly used material systems for THz QCLs are GaAs/AlGaAs and InGaAs/InAlAs. The latter requires very thin layers of InAlAs and is therefore difficult to manufacture epitaxially [1]. One solution to overcome this issue, while still making use of the benefits provided by InGaAs, namely lower effective electron mass ($m^{*}= 0.043m_0$) which leads to a higher optical gain, is the usage of different barrier materials such as the ternary GaAsSb [2] and the quaternary InAlGaAs [3]. Crucial for the barrier thickness is the conduction band offset (CBO) of the material system. The common notion is to employ barrier materials having lower CBOs and therefore thicker barriers.
We implemented an inverse quantum engineering algorithm [4] to investigate the influence of the barrier material on the lasing performance and characteristics of THz active regions. Starting from an original design, barrier materials are exchanged while the wave functions are kept constant. A systematic comparison between material systems such as InGaAs/InAlAs, InGaAs/GaAsSb and InGaAs/InAlGaAs was performed with focus on quantum transport and optical gain. Fig. 1 shows the quantum design with the wave functions, the electrical and the optical properties of two InGaAs-based devices, one of which is employs ternary InAlAs barriers, whereas the other device employs quaternary InAlGaAs barriers. As designed, the algorithm leads to almost identical wave functions for different barrier thickness due to the different CBOs of the investigated materials. We find that thin barrier devices employing ternary barrier materials such as InAlAs show the highest optical gain. Consequently the InGaAs/InAlAs material system, which is already commonly used for mid-infrared QCLs, is also very well suited for high performance THz QCLs.

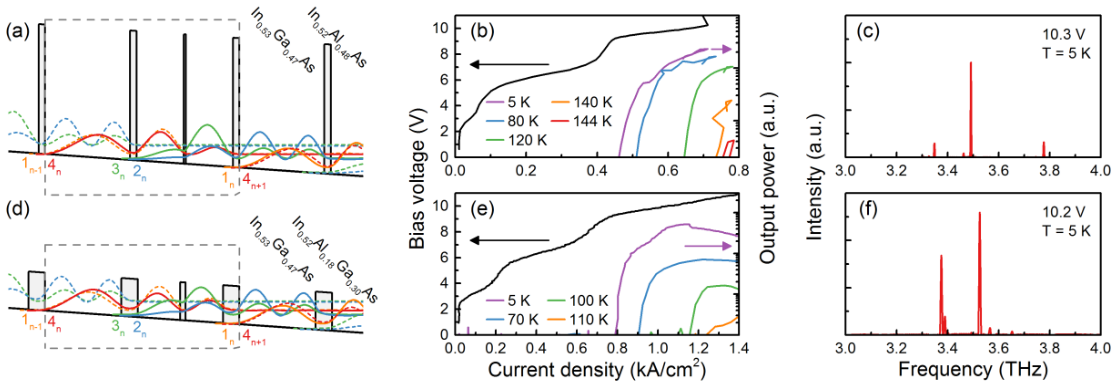

Fig. 1 Scaling of a resonant-phonon active region from ternary (a-c) InAlAs to quaternary (d-f) InAlGaAs barriers, while the wave functions stay almost identical. In contrast the electrical and optical properties alter remarkably.

References

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