Various Barrier Materials for Terahertz Quantum Cascade Lasers

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1. Introduction

Since their invention in 1993, quantum cascade lasers (QCLs) have proven to be reliable and highly customizable coherent light sources, which allow for the design of devices emitting in the mid-infrared (MIR) as well as in the terahertz (THz) regime. Despite their great success in the MIR regime, QCLs operating at THz frequencies still require cryogenic cooling techniques. Advanced band structure design recently pushed the maximum operation temperature of THz QCLs to 200 K [1]. Moreover, the use of symmetric active regions has shown the potential to measure the effects of both interface roughness and dopant migration on the performance of this device [2,3]. Room temperature operation, however, is still out of reach to this date.

A second approach to further improve the performance of THz QCLs is to use other material systems. While the highest pulsed operation temperature so far has been measured from devices fabricated in the GaAs/GaAs material system, there is evidence that the use of new materials with a lower effective mass can improve the performance. Candidates for well materials featuring an effective mass lower than that of GaAs are InGaAs lattice matched to InAlAs as well as InAs. Recently, the highest THz laser emission from devices using InAs as a well and AlAsSb as a barrier material was shown [5], despite the very low effective mass, no laser operation was reported.

In the group of materials lattice matched to InAlAs laser operation in the THz regime has been shown for three different material combinations so far. The two ternary materials AlInAs and GaAsSb have shown THz laser operation up to 145 K and 143 K respectively [6]. The quaternary AlInGaAs material, being the most recently developed one among them, showed operation up to 130 K [7]. The fact that many different materials, all having unique features, can be used as barrier material with the same well material makes this group of materials interesting to gauge the influence of the barrier material on the performance of THz QCLs.

2. Results

In this work, we show our first results of THz QCLs using the quaternary AlInGaAs material and report on our latest findings when comparing them to devices using different materials. The lasers have been grown in a Vecco MBE 11 MBE system on InP substrates. Aluminum mole fractions of 15% and 19% have been used. The lasers have been processed into ridges using double-metal waveguides.

Both devices show laser emission at 3.6 THz, a maximum operation temperature of 110 K and a threshold current density of 800 A/cm².

References


Figure 1: Band structure of a Al0.5Ga0.5As/InGaAs THz QCL at a bias of 10 kV/cm

Figure 2: J-V of a Al0.5Ga0.5As/InGaAs THz QCL. At 5 K a threshold current density of 300 A/cm² was found. Operation was possible up to 110 K.