Quantum Cascade Lasers and Their Applications in Gas Sensing and Biomedical Fields

L. Ozyuzer
Department of Physics, Izmir Institute of Technology, Urla, Izmir, Turkiye
Teknoma Technological Materials Industrial and Trading Inc., Urla, Izmir, Turkiye.
e-mail:ozyuzer@iyte.edu.tr

Quantum Cascade Lasers (QCLs) are semiconductor lasers that operate in the mid- and long-wave infrared (IR) and terahertz regions [1], enabling a broad spectrum of applications such as industrial gas detection, standoff explosive detection, infrared imaging, health monitoring, and advanced spectroscopy [2-3]. QCLs are compact, portable, capable of room-temperature operation, and deliver high optical power in both pulsed and continuous wave modes. Their ability across the 3–13 μm wavelength range coincides with the principal absorption bands of many atmospheric gases (e.g., CO_2, CO, NO, NO_2, SO_2, NH_3, CH_4) and biological species making them highly effective for sensitive and selective gas sensing. In this study, three distinct laser systems are being developed for: (i) greenhouse gas detection, (ii) biosensing spectroscopy of urea in blood, and (iii) directional infrared countermeasures (DIRCM). The active region of laser was designed by the Nextnano program for three wavelenghts. The superlattice structures were grown by using the MOCVD method on InP (100). The active region structure consisted of a periodically layered InGaAs/InAlAs quantum wells. The fabrication of quantum cascade lasers began with the formation of mesa structures on InP wafers using conventional lithography and chemical etching techniques. To ensure electrical insulation between the mesa top, its sidewalls, and the substrate, a thin film of SiO_2 was applied as a passivation layer, which was critical for stable laser operation. To enhance electrical contact and facilitate heat dissipation during laser emission, a thick gold layer was added to the laser bars, serving as heat sinks. Due to the high operating voltages and large threshold currents, significant heat was generated in the QCL's active region. These devices were typically cooled from the bottom of the substrate; thus, reducing the distance between the active core and the substrate base was essential for efficient thermal management. Accordingly, the QCL substrates were thinned. After thinning, the bottom of the substrate was coated with a thin titanium (Ti) layer as a buffer, followed by approximately 200 nm of Au. The progress of the ongoing project about the fabrication steps, the characterization and the characteristics of QCL chips will be discussed in detail.

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