Abstract

Topic: Development of MOVPE-grown InP-based layerstacks for resonant tunneling diodes

For applications in communications, spectroscopy, and radar technology, powerful and high-frequency sources and receivers are required [1,2]. On the electronic side, the resonant tunneling diode (RTD), with measured frequencies up to 1.98 THz, is one of the most promising devices [1]. The highest-frequency RTDs are grown in the InP material system and consist of a quantum well made of indium gallium arsenide (InGaAs) with aluminum arsenide (AlAs) barriers. The complete epitaxial layer structure is schematically illustrated in Figure 1. When a voltage is applied, this structure exhibits a region of negative differential resistance (NDR), which acts as an amplification element in an oscillator circuit, enabling high-frequency oscillations.

This work focuses on the growth of RTDs using metalorganic vapor phase epitaxy (MOVPE), which, compared to the traditionally used molecular beam epitaxy (MBE), offers a significantly higher throughput and thus holds substantial industrial relevance.

To achieve high current densities—essential for high-frequency RTDs requiring a large gain—the barriers must consist of only a few atomic layers (<2 nm), posing a significant challenge for epitaxial growth. Furthermore, the grown layers must be defect-free and exhibit sharp interfaces.

During the course of this work, IV characteristics of RTDs with various layer stacks were first simulated. The barrier thickness emerged as a key parameter influencing high current densities. During the growth process, an exponential dependence of the current density on the growth time of the barrier layer was observed (see Figure 2). However, the barrier thickness could not be reduced arbitrarily, as devices grown with excessively short growth times no longer exhibited NDR, indicating the presence of defects in the barrier. Atomic force microscopy (AFM) revealed that the RTD layers exhibited surface roughness on the order of the barrier thickness.

To optimize the layer quality, individual layers were characterized using X-ray diffraction (XRD) and AFM, and various sources of surface roughness were investigated. In particular, n-doped InGaAs was identified as a major contributor to surface roughness. By optimizing the growth parameters—such as temperature, growth rate, III/V ratio, and reactor pressure—the morphology of the layers was significantly improved. Subsequently, a fully optimized RTD layer stack was grown, exhibiting enhanced surface quality with a maximum height difference of ~1 nm over a $3 \times 3\ \mu m^2$ scan area (Figure 3), and demonstrating current densities exceeding 400 kA/cm^2 in subsequent electrical measurements.

[1] M. Asada and S. Suzuki, “Terahertz Emitter Using Resonant-Tunneling Diode and Applications,” Sensors, vol. 21, no. 4, p. 1384, Feb. 2021, doi: 10.3390/s21041384.

[2] D. Cimbri, J. Wang, A. Al-Khalidi, and E. Wasige, “Resonant Tunneling Diodes High-Speed Terahertz Wireless Communications - A Review,” IEEE Trans. THz Sci. Technol., vol. 12, no. 3, pp. 226–244, May 2022, doi: 10.1109/TTHZ.2022.3142965.

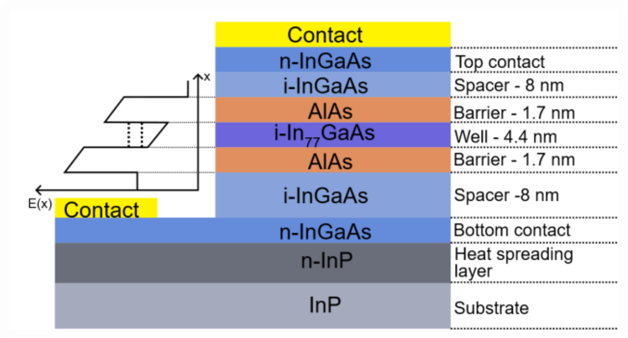

Figure 2: Schematic cross-section of the RTD layer stack

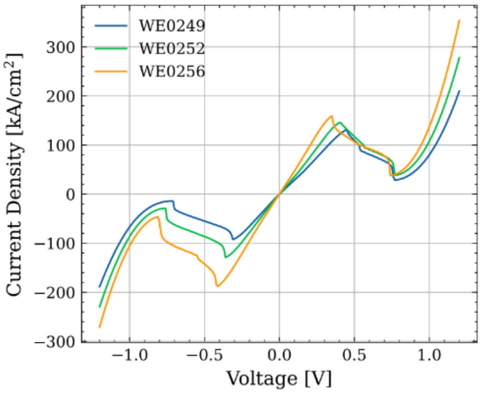

Figure 2: IV characteristics of various grown RTDs with different thicknesses of the upper barrier. Sample WE0249 with ~1.8 nm, WE0252 with ~1.65 nm, and WE0256 with ~1.5 nm.

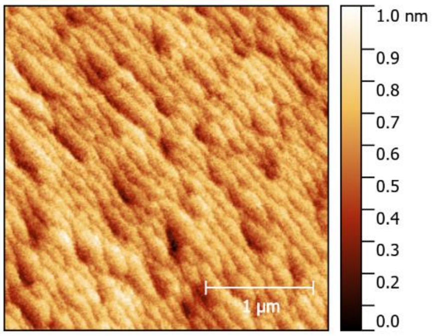

Figure 3: AFM scan of the RTD surface under optimized growth conditions