ZnO-based Resonant Tunneling Diode Structures

B. Hinkov[1,*], **H. T. Hoang**[1], **D. Winter**[1], **A. Alsalhi**[1], **W. Schrenk**[1], **M. Hugues**[2], **J.-M. Chauveau**[2], **and G. Strasser**[1]

[1]*Institute of Solid State Electronics and Center for Micro- and Nano-Structures, TU Wien, Floragasse 7, A-1040 Wien, Austria*

[2] *Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Centre national de la Recherche Scientifique (CRHEA-CNRS), Rue B. Gregory, F-06560 Valbonne, France*

[*]*Corresponding Author: borislav.hinkov@tuwien.ac.at*

1. Introduction

The terahertz (THz) spectral region ranging between 30µm – 300µm covers various relevant and significant real-world applications like spectral imaging [1], medical diagnostics [2] and trace gas spectroscopy [3]. Unfortunately, due to the lack of high-performance laser sources, it is also referred to as the "THz-gap" in the electromagnetic spectrum. Therefore, a crucial step is to close this gap by realizing room temperature emitting THz laser sources.

To date, GaAs-based quantum cascade lasers (QCLs) [4] are the most promising devices but they lack significant improvements within recent years concerning their maximum operating temperature and are still limited to operation at cryogenic temperatures (~200K). They are fundamentally limited by the parasitic, non-optical LO-phonon transitions (36meV in GaAs), being on the same order as the thermal energy at room temperature (kT = 26meV). Promising alternative semiconductors to solve this problem include new material systems like ZnO or GaN with their larger LO-phonon energy ($E_{LO,ZnO}$ = 72meV, $E_{LO,GaN}$ = 91meV). While GaN has already been extensively investigated in the past without final breakthrough concerning GaN-based QC devices, ZnO is new to this field of application.

To master the fabrication of ZnO-based QC structures, a high quality epitaxial growth is crucial combined with a well-controlled fabrication process including (selective) Zn(Mg)O etching, and the deposition of low resistance ohmic contacts.

2. Results

The devices we investigated are grown on m-plane [10-10] ZnO-substrate by molecular beam epitaxy (MBE). Their core typically consists of a ZnO quantum well, sandwiched between two ZnMgO barriers, while above and below highly doped ZnO-layers ensure good electrical contacts. They are patterned by (dry) plasma etching in a CH_4-based chemistry into square MESAs (see Fig. 2). The CH_4-process protects the mask by an amorphous carbon-layer increasing the selectivity of the etching [4].

Resonant tunneling diode structures are investigated in this geometry and are presented including different barrier- and well-configurations (see Fig. 3 for a typical RTD current-voltage characteristic). We extract contact resistances of ~mid 10^{-5} Ω cm^2 to ~mid 10^{-4} Ω cm^2 for the top and bottom contact, respectively, for not annealed Ti/Au contacts and an electron mobility of above 130cm^2/Vs. Those values are in good agreement with typical values from literature. Demonstrating resonant electron tunneling in Zn(Mg)O structures is a crucial prerequisite for future QCL and QCD devices.

[1] M. I. Amanti, G. Scalari, M. Beck, and J. Faist, "Stand-alone system for high-resolution, real-time terahertz imaging", Opt. Express 20, 3 (2012).

[2] S. M. Kim, F. Hatami, J. S. Harris, A. W. Kurian, J. Ford, D. King, G. Scalari, M. Giovannini, N. Hoyer, J. Faist, and G. Harris, "Biomedical terahertz imaging with a quantum cascade laser", Appl. Phys. Lett. 88, 1 (2016).

[3] S. Bartalini, L. Consolino, P. Cancio, P. De Natale, P. Bartolini, A. Taschin, M. De Pas, H. Beere, D. Ritchie, M. S. Vitiello, and R. Torre, "Frequency-Comb-Assisted Terahertz Quantum Cascade Laser Spectroscopy", Phys. Rev. X 4, 021006 (2014).

[4] R. Köhler, A. Tredicucci, F. Beltram, H. E. Beere, E. H. Linfield, A. G. Davies, D. A. Ritchie, R. C. Lotti, and F. Rossi, "Terahertz semiconductor-laser", Nature 417, 156-159 (2002).

[5] S.-W. Na, M. H. Shin, Y. M. Chung, J. G. Han, and N.-E. Lee, "Investigation of process window during dry etching of ZnO", J. Vac. Sci. Technol. A 23, 898 (2005).

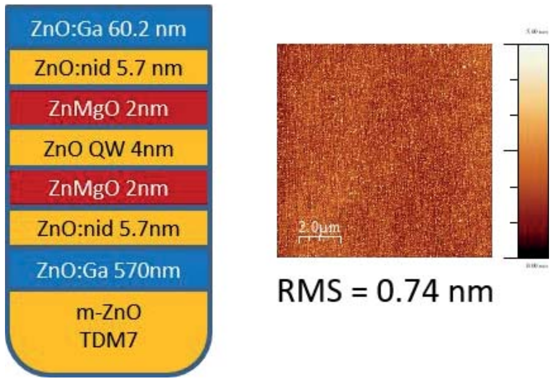

Fig. 1: (Left): Layer-sequence of a typical RTD-structure. (Right): AFM measurement of the same MBE-grown structure, showing the low surface roughness (RMS = 0.74 nm).

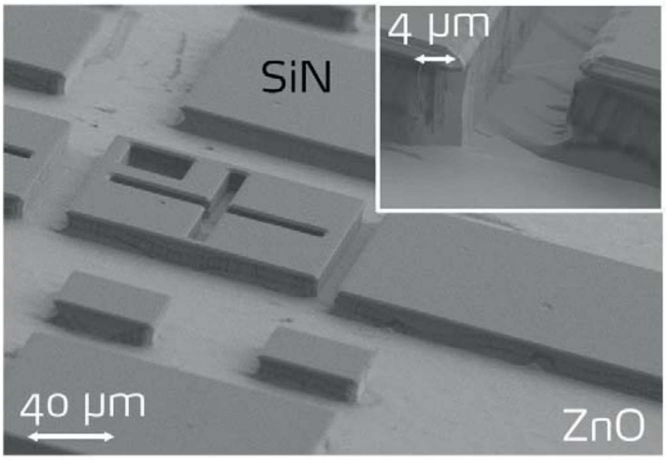

Fig. 2: Typical ZnO-based MESA RTD structures after ICP-RIE dry and additional H_3PO_4 wet etching. The inset shows the vertical and smooth sidewalls.

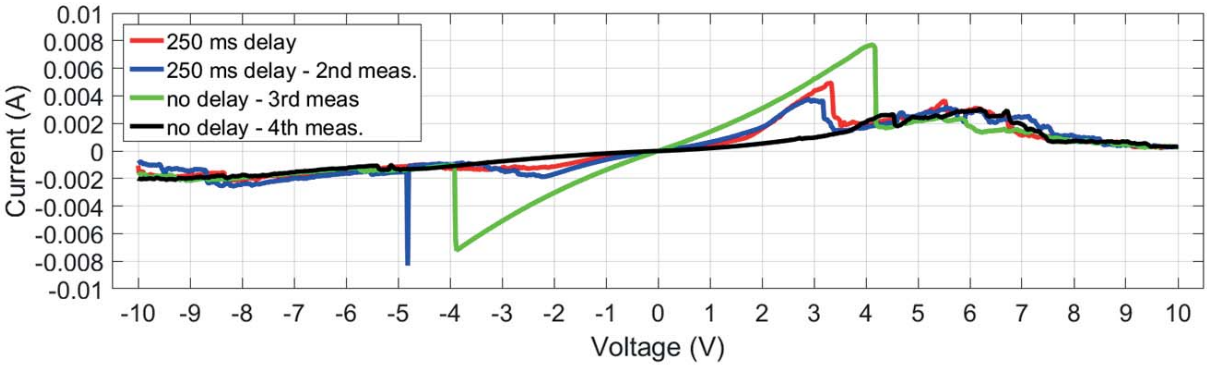

Fig. 3: Comparison of exemplary IV-curves of a 75 µm MESA RTD structure at room temperature with (250 ms) and without additional delay for each measurement point (resolution: 0.01 V).