Dislocation-Free GaN/AlGaN Double-Barrier Diodes Grown on Bulk GaN

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Introduction

Integrated resonant tunneling diodes (RTDs) are interesting devices for a number of applications, such as ultrafast switches or as components in HF oscillators. The last might be particularly interesting in the GaN/AlGaN system due to its high power handling capability and availability of well performing GaN HEMTs at elevated temperature.

While AlGaN quantum cascade electro-optic devices recently received particular interest, the behavior of such vertical devices is not well understood and their performance greatly lags behind that of horizontal devices. The RTD is a benchmark for any such quantum cascade/intersubband (ISB) device. While epitaxial quality of InGaN/AlGaN could be improved so far that blue laser diodes became possible, the fabrication of RTDs still suffers from instabilities that relate to the large defect density near such heterostructures.

Other ISB devices such as detectors could be realized already. A clear relationship between energetic levels of QW states and the continuum was established by ISB absorption and photovoltage [1] experiments. At the same time results obtained for resonant tunneling [2] are still very scarce and controversial [3]. The observed current-voltage (IV) characteristics exhibited a negative differential resistance (NDR), but only on one-sided and not reproducible. This is likely to be at least partly due to conduction over dislocations [4]. However the recent availability of high pressure grown bulk samples [5] makes fabrication of dislocation free RTDs possible [6].

Experimental

Dislocation free mesas were achieved with the low dislocation density ($10^2\,\mathrm{cm}^{-2}$) of bulk substrates and fabrication of single diodes of 6 µm diameter, which is much smaller than in previous studies (40 µm Ref. [2] and 100 µm Ref. [3])

The epitaxial structure was grown by plasma assisted molecular beam epitaxy (PAMBE). On top of a template overgrown by 1 µm of a metal organic chemical vapor deposition (MOVPE) GaN:Si layer the following structure was deposited (starting at substrate): GaN:Si – $Al_{0.7}Ga_{0.3}N$ – GaN - $Al_{0.7}Ga_{0.3}N$ –GaN:Si. Layer thicknesses were 150 – 2 – 2 – 2 – 100 nm respectively. Calculating this structure with a self-consistent Schrödinger-Poisson solver, not taking into account transport, the QW ground state is 0.6 eV above the Fermi level.

Mesas (Fig. 1) were defined by standard UV contact lithography. The irregular and small shape of the bulk samples was overcome by spray coating of 2 µm photoresist. Mesas were then etched in an inductively coupled plasma reactive ion etcher (ICP-RIE) with $SiCl_4$ chemistry. SiN_x (300 nm) was deposited with 300°C plasma enhanced chemical vapor deposition (PECVD) and opened with SF_6 RIE. Evaporated Ti – Al – Ni

– Au (10 – 150 – 35 – 200 nm) annealed at 580°C for 30 s serves as the top contact. Annealing was limited by the thermal resistance/adhesion of the SiN_x.

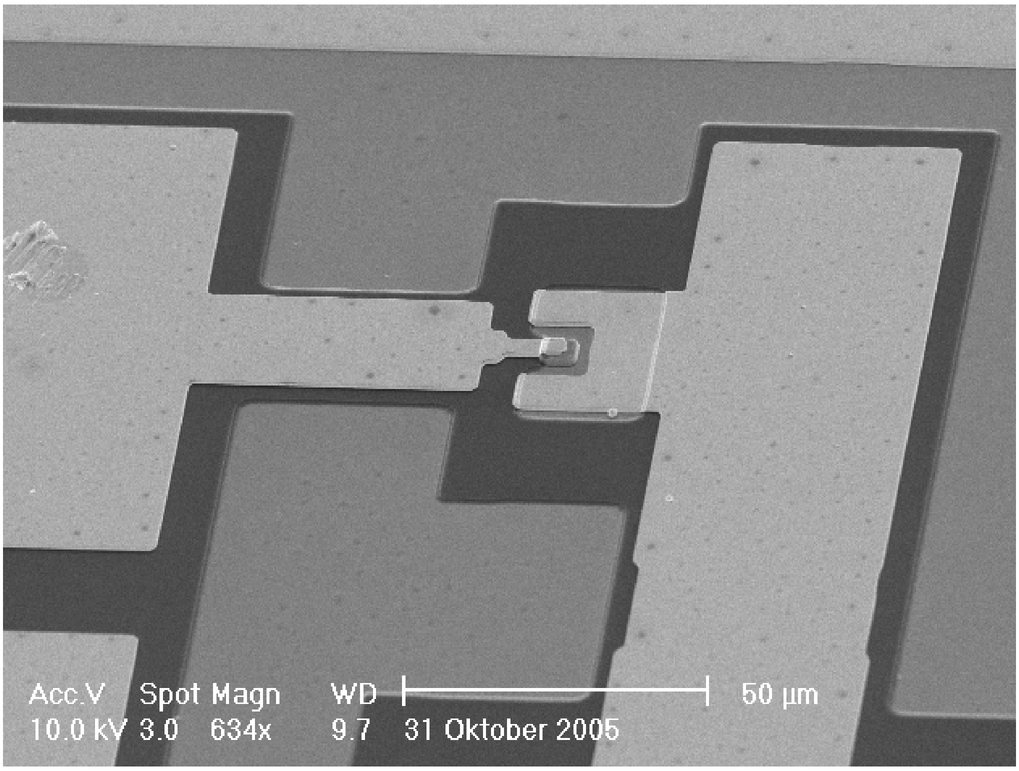

Fig. 1: SEM image of fully processed device with 6 µm diameter and separate bottom contact

Results

Like in studies published earlier [2] we see a fundamental and abrupt change in the IV curve between the first trace on a virgin mesa and the subsequent retrace or any further trace leaving only the exponential background. Contrary, the NDR (seen in 20% of all devices) our IVs consist of multiple data points. The asymmetry in the IVs (voltage applied to top contact) stems partially from the internal polarization fields and partly from the difference between a good ohmic back contact and a Schottky-like top contact. No direct relationship between measurement conditions and shape/position of the NDR has been observed. However, position of the NDR varies randomly between different devices within limits (Fig. 2). The ‘hysteresis’ that causes this decay is described in more detail in [6].

While in principle a degradation or breakdown of the material could be responsible for such decay, especially concerning the high peak current density in the 10 kA/cm2 range, the same observations in pulsed mode with low duty cycle contradict that assumption.

The position and magnitude of NDR depends mainly on the greatest (previously) applied voltage. After decay the NDR can be restored partly (Fig. 3) by thermal treatment. Such behavior can be explained by a combination of tunneling and electron trapping effects.

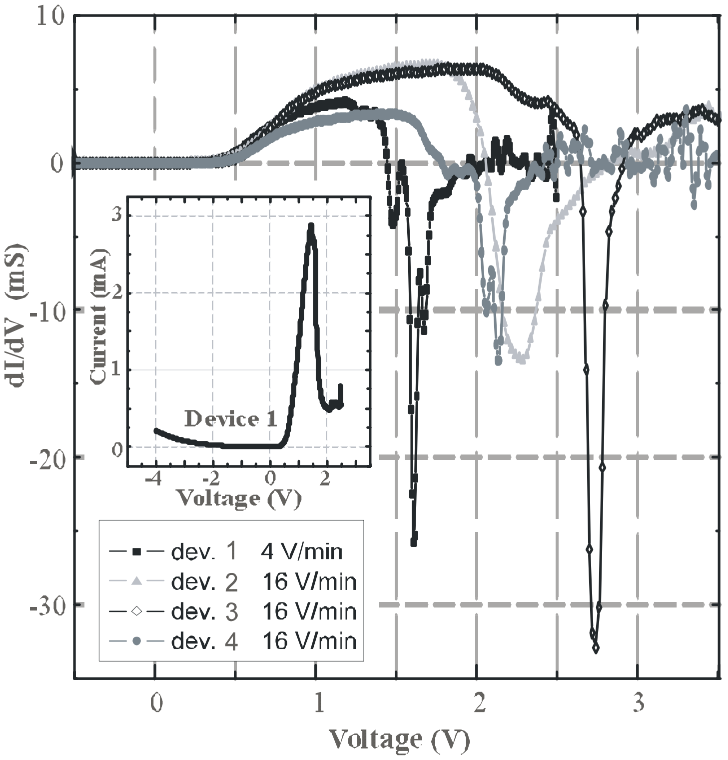

Fig. 2: Differential conductivity dI/dV of four devices all with 6 µm diameter measured at RT. *Inset:* Original IV of device 1.

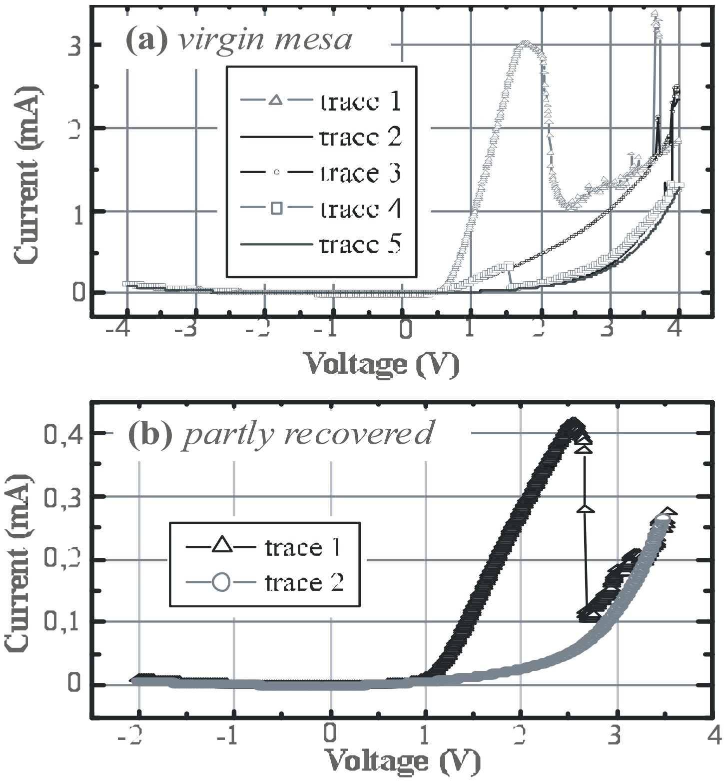

Fig. 3: IV characteristic of a device with d = 6 µm (a) before and (b) after annealing at 350°C in a RTA oven under N_2 atmosphere.

Conclusion

We have shown smooth IVs exhibiting NDR in a voltage interval of ~0.3 V, located in the range 1.2…2.8 V of a GaN based RTD. Decay of this NDR feature after a first measurement and possible recovery by thermal treatment were related to deep electron traps and consequent deformation of the conduction band profile in the double barrier region.

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