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# High frequency ($f = 2.37$ GHz) room temperature operation of 1.55 μm AlN/GaN-based intersubband detector

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The fabrication and high frequency operation of a room temperature 1.55 μm intersubband detector based on a regular AlN/GaN superlattice is reported. This photovoltaic device was capable of detecting a sinusoidally modulated laser beam at high frequencies of up to 2.37 GHz.

*Introduction:* The AlN/GaN material system, with its large conduction band discontinuity of 1.9 eV, attracts increasing attention for intersubband (ISB) devices operating at the technologically interesting wavelength range around 1.55 μm. The true application potential of this material, however, is most likely related to its ultra-short ISB scattering times of the order of 370 fs [1]. Consequently, ISB absorption [2, 3], pump-probe measurements [4] and, more recently, photovoltaic experiments [5, 6] have been performed using III-nitride superlattices (SLs). Unfortunately, none of the presently available electro-optical devices have revealed high frequency behaviour which satisfies the ambitious prognostics derived from the short ISB scattering time [7]. This is partly because most researchers active in detector development have adopted a device architecture known from photoconductive quantum well infrared photodetectors (QWIPs). In the case of III-nitride materials, this design presents serious limitations owing to large vertical leakage currents. In this Letter, we therefore focus attention on the photovoltaic operation principle, which partly circumvents the problem of vertical transport and leads to a greatly simplified device architecture. The final detectors have successfully been tested at room temperature and demonstrated high frequency operation up to 2.37 GHz.

*Growth and sample preparation:* The photovoltaic QWIP structure was grown by plasma assisted molecular beam epitaxy. Its active region consists of a regular 40 period SL with GaN wells and AlN barriers; both wells and barriers have a nominal thickness of 1.5 nm and the wells are n-doped to $1 \times 10^{20}$ cm$^{-3}$. This active region is sandwiched between a 1.1 μm-thick AlN buffer layer deposited on c-sapphire and a 50 nm AlN cap. High-resolution X-ray diffraction studies of the SL have been performed. The $\omega - 2\theta$ scan of the (0002) reflection (presented in Fig. 1) confirms an SL period of 3.1 nm. The asymmetry of the SL peaks in Fig. 1 points out a partial relaxation of the SL. From the analysis of the reciprocal space map of the (10–15) reflection we have measured an average compressive in-plain strain $\epsilon_{xx} = 0.24\%$ in the SL, corresponding to an average relaxation of about 80%.

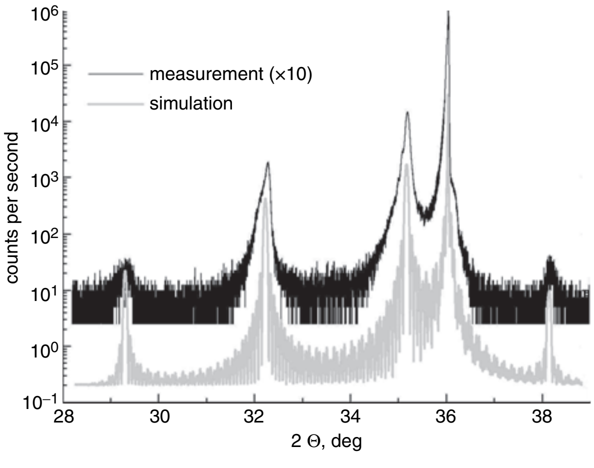


**Fig. 1** *High-resolution $\omega - 2\theta$ scan of (0002) X-ray reflection of GaN/AlN superlattice*

Slight asymmetry of superlattice peaks due to partial relaxation

After growth, the sample was polished as a standard multi-pass waveguide with two parallel 45° wedges. As shown in the schematic top view (inset of Fig. 2), we then evaporated a pair of square-shaped Ti/Au contacts with side lengths of 200 and 300 μm as well as a pair of 800 μm-wide and 3 mm-long contact stripes directly on the cap layer. The separation is 2 mm between the mesas and 2 mm between the stripes. One contact of each pair served as ground (to remain dark) whereas the other became the signal (to be illuminated). To perform the optical response experiments, the sample was mounted on a copper platelet and its stripes were wire-bonded to large ceramic contact pads. Since this mounting technique results in large parasitic capacitances, we chose a different experimental configuration for the subsequent high frequency measurements. In this more sophisticated setup, the sample was soldered directly onto a BNC connector. Its signal contact with side length of 200 μm was directly wire-bonded to the central pin of the connector; while the 300 μm sized reference contact was bonded to the ground contact of the connector.

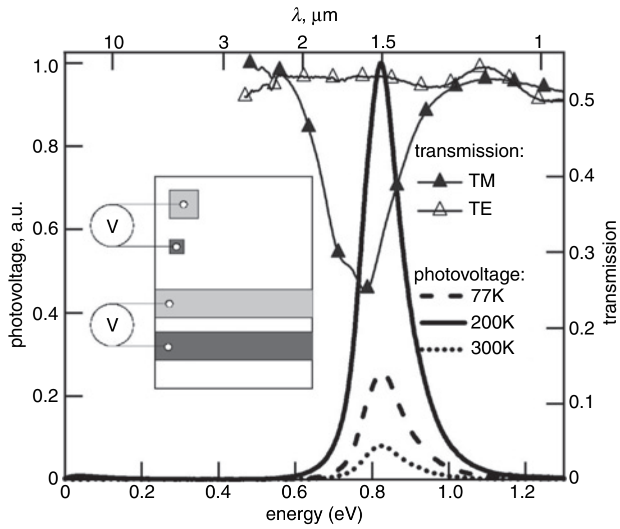


**Fig. 2** *ISB absorption for TM and TE polarisation and PV at 77, 200, 300 K measured with FTIR*

Inset: Schematic top view of sample
Reference contacts shown in light grey, signal contacts dark grey

*Measurements:* Room temperature ISB absorption measurements were performed using both the white light source and the HgCdTe detector of a Fourier transform infrared spectrometer (FTIR). In this experiment, the light passed the active region 10 times in an optical zigzag path. Fig. 2 shows the resulting transmission measurements of the sample for both TE and TM polarisation. We observe an absorption peak at 785 meV (1.58 μm), with a full width at half maximum (FWHM) of 216 meV. As expected for an ISB signal, it is entirely TM polarised, which is an indicator for the excellent material quality.

For measuring the photovoltage (PV), the sample was mounted in a liquid He flow cryostat; this allowed testing at different temperatures. Under back illumination of only one stripe contact, a PV occurred between the dark (ground) and the illuminated contact (see inset in Fig. 2). As shown in Fig. 2, the PV signal was strongest around 200 K and dropped roughly by a factor of 12 at room temperature. As seen in earlier experiments, the PV is slightly blue shifted relative to the ISB absorption, peaks at an energy of 825 meV, with a FWHM of 119 meV at 200 K.

For high frequency testing of this detector, a 1.55 μm NEL NLK1554STB DFB laser diode was sinusoidally modulated through a bias-Tee. The emitted radiation with an average power of 1 mW was fed into a 35 m-long optical singlemode fibre, and focused onto the sample exactly behind the signal contact. A Faraday cage around the modulation equipment and the physical distance between laser and detector of nearly 25 m guaranteed minimal electrical cross-talk. The PV signal was amplified by a 38 dB SONOMA317 amplifier and an additional 26 dB MITEQ AFS5-001-02000-30-10P-4 low noise preamplifier. Acquisition was performed with an Agilent E4403B spectrum analyser. Fig. 3 shows the obtained frequency response of the sample at room temperature. The signal shows a local maximum at 10 MHz and then drops with a slope of 20 dB/decade. As illustrated in the inset of Fig. 3, the maximum frequency at which a reasonably high signal could be detected was 2.37 GHz. The overall frequency response can be fitted by a first-order highpass and two first-order lowpass filters, with corner frequencies of 1.3, 3.9, 43 MHz, respectively. Comparison between different experimental configurations led us to the conclusion that the geometry of the contacts plays a major role in the exact shape of the roll-off; thereby masking the intrinsic speed limiting mechanism.

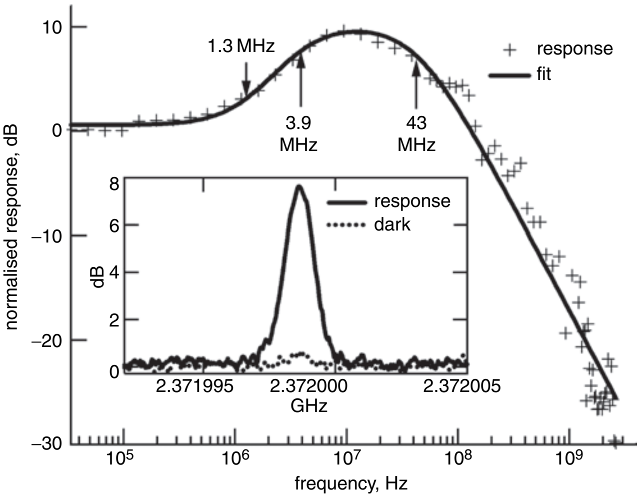


**Fig. 3** *Measured room temperature frequency response together with fit consisting of one highpass and two lowpasses*

Inset: Spectrum analyser trace at 2.37 GHz

Finally, to obtain a rough estimate for device responsivity, a reference measurement was carried out using a Keithley 2410 sourcemeter, yielding a DC PV signal of 10 μV under DC laser illumination. Using a calibrated thermopile detector, a DC laser power of 3 mW was measured, resulting in a PV responsivity of approximately 3 mV/W.

*Conclusion:* We have measured the high frequency response of a photovoltaic 1.55 μm ISB detector fabricated from a regular AlN/GaN SL. The device worked at 300 K and could be operated up to a maximum frequency of 2.37 GHz. This result demonstrates the potential of III-nitride heterostructures in high frequency devices of future telecommunication applications.


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