Unpolarized Intersubband Photocurrent in Te Doped GaInAsN/GaAlAs Quantum Well Infrared Photodetector

Asaf Albo, Dan Fekete and Gad Bahir

We report observation of unpolarized intersubband photocurrent (PC) in quantum-well infrared photodetector (QWIP) based on Te doped GaInAsN/AlGaAs multiple-quantum well structures (MQWs). The unpolraized photocurrent spectrum is peaked at 2.4 μm for front and wedge waveguide configuration illumination. Clear PC signal is observed at room temperature. The observed intersubband transitions PC peaks are in good agreement with calculations based on an empirical model.

Index Terms— **Dilute Nitrides, GaInAsN, Intersubband Transition, Photo-Current, Polarization, Selection Rules And Quantum Well Infrared Photodetector.**

Nitrogen containing III-V alloys have been a subject of considerable research interests due to their very unique physical properties. In particular, the incorporation of small amounts (less than 3%) of nitrogen into GaAs based III-V semiconductors strongly reduces the fundamental band gap. Intersubband devices could potentially take advantage of this property in order to obtain much higher conduction band offset for shorter wavelengths design and improve their high temperature performance. In addition to the giant bowing in the band gap energy, other properties induced by the nitrogen incorporation such as E^+ and E^- subbands in the conduction band and the significant increase of effective electron mass with increasing nitrogen contents could affect the performance of QWIPs. Unlike the widely explored fundamental optical transitions in the dilute nitrides, the intersubband transitions in this unique materials family has been given less attention until recently [1-6]. Recent works, dealing with intersubband absorption in dilute nitrides, report on contradicting selection rules for these transitions, i.e. TM or TE dominant polarization induced transition, and insensitivity to QW width [1-4]. Here we report on a new experimental evidence of an unpolarized intersubband photocurrent measured in Te doped GaInAsN/GaAlAs quantum well photodetector.

The samples were grown by metal organic chemical vapor deposition (MOCVD) on semi-insulating GaAs substrates. Nitrogen was provided by dimethylhydrazine (DMHyN). Te doped GaInAsN QWs were grown at 500 ºC and undoped barriers of GaAlAs layers were grown at 750 °C. The first sample (S1) consists of 10 periods of 75 Å Te doped $GaIn_{0.28}As_{0.98}N_{0.02}$ QWs and 350 Å undoped $Ga_{0.74}Al_{0.26}As$ barriers. GaAs contact layers, 5000 Å thick, n-doped with Te at concentration of 10^{18} cm^{-3}, were grown at 650 °C on the top and bottom of the MQWs structure. The second sample, S2, similar to S1 but with QWs width of 52 Å and barriers width of 330 Å. A reference sample, S3, consisting of 10 periods of Te doped 45 Å $GaIn_{0.28}As$ QWs and 370 Å undoped $Ga_{0.74}Al_{0.26}As$ barrier was grown at the same conditions as the first two samples. The photo-detectors were implemented as square mesa structures, 200 μm wide, using standard photolithography and wet etching techniques.

High resolution x ray diffraction (HRXRD), secondary ion mass spectroscopy (SIMS), scanning tunneling electron microscopy (STEM) cross-section and low temperature photoluminescence (PL) were employed to characterize the MQWs compositions, structures and quality. For intersubband absorption and photocurrent measurements, 45° edges were polished on the sample sides to implement a multipass waveguide. Photo-induced absorption and photocurrent, for front and wedge configurations, were measured using a Fourier-transform infrared (FTIR, Bruker-Equinox 55) spectrometer.

The QWs and barriers thicknesses were extracted from STEM cross section measurements. Fig. 1 shows an example of such cross section image for MQW sample S1.

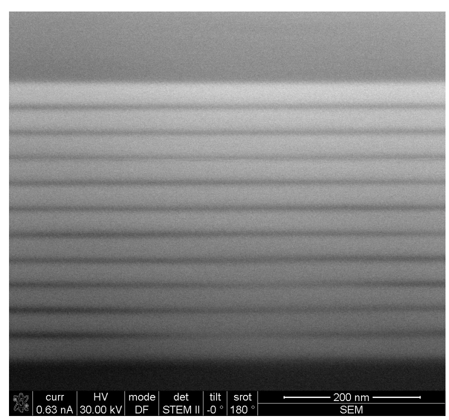

Fig. 1: STEM cross-section image of sample S1 showing 10 periods of 75 Å GaInAsN QWs and 300 Å GaAlAs barriers.

From the measured HRXRD spectra, well defined periodic satellite peaks were identified for the three samples. Figure 2 shows the measured HRXRD of sample to S1.

Asaf Albo and Gad Bahir are with the Department of Electrical Engineering, Dan Fekete is with the Department of Physics, Technion-Israel Institute of Technology, Haifa 32000 Israel (phone: 972-4-8293598; fax: 972-4-8235107, e-mail: bahir@ee.technion.ac.il).

The PL emission energy, at 77 K, peaked at 1.35, 1.23 and 0.9 μm for samples S1, S2, S3 respectively. Using the STEM, SIMS and PL data with HRXRD simulations enabled us to determine the well and barrier compositions.

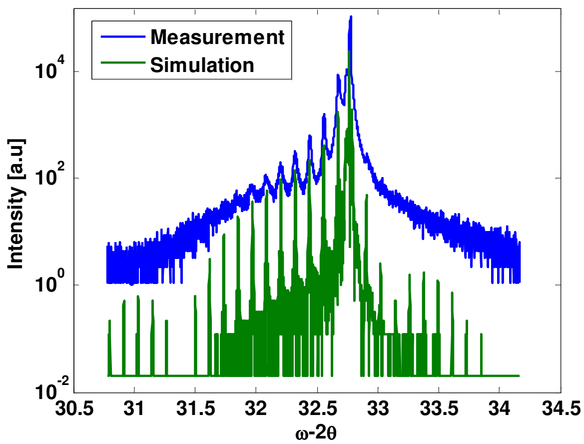

Fig. 2: Experimental (blue) and simulated (green) HRXRD spectra of 10 quantum wells GaInAsN/AlGaAs MQW structure.

The most unexpected characteristics are shown in the spectral response in Figs. 3 and 4. The intersubband transitions are insensitive to illumination polarization and to the QW well widths. The intersubband PC spectra of a QWIP fabricated from sample S1 are shown in Fig. 3. The intersubband PC signal peaked at 2.4 μm and does not show any polarization dependence. Lower wavelength peaks at 1.05 μm and 1.35 μm, observed in this figure, are attributed to valence to conduction band transitions e1-hh1 (electron-heavy holes) and el-hl1 (electron-light holes).

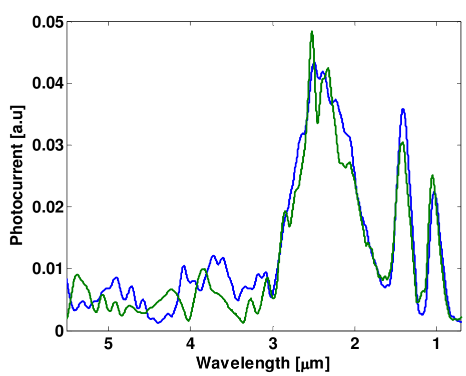

Fig. 3: 120 K spectral response of S1 QWIP in wedge configuration under 5 V bias. Green line - S-polarization; blue line - P polarization.

Front and wedge illuminations PC spectra of a QWIP fabricated from sample S2 (52 Å InGaAsN MQWs) are shown in Fig. 4. The normalized unpolarized intersubband PC signals peaked at 2.4 μm, similar to the PC peak in sample S1 which has a with different QW width. Fig. 5 shows intersubband PC spectral response for a reference sample S3 (GaInAs/GaAlAs MQWs structure) not containing any nitrogen. 3 PC spectra were measured; unpolraized and at P and S illumination polarizations. The lower energy of the intersubband peak transition (5.7 μm) is expected since the InGaAs/GaAlAs QW is shallower than the InGaAsN one. Photo-induced absorption and PC spectra measured at room temperature will be shown at the conference.

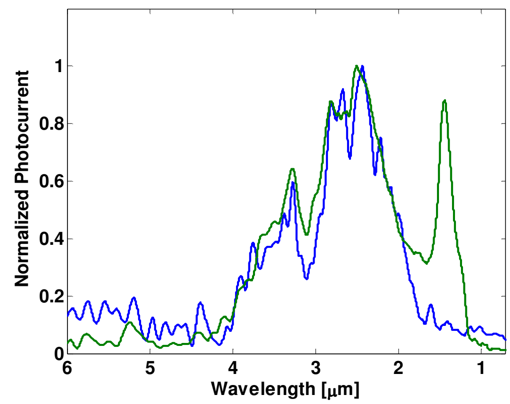

Fig. 4: 120 K normalized PC spectra of S2 QWIP in wedge (green) and front (blue) illumination configurations, measured at 1 V bias. Front illumination PC spectrum was taken with a 1.67 μm high pass filter cutting lower wavelengths interband transition signal.

These observations indicate that the intersubband PC signal in sample S1 and S2 containing 2% nitrogen is unpolarized, which is contrary to the P polarized absorption observed in the conventional III-V MQWs and also in the reference sample S3 that does not contain nitrogen.

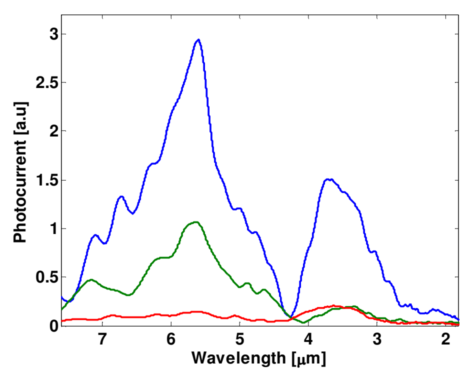

Fig. 5: QWIP S3 reference sample photocurrent spectra at 120 K for wedge illumination, at bias of 0.2V: without polarizer (blue), P polarization (green) and S polarization (red). The dip at 4.25 μm is due to CO_2 absorption.

To interpret the results we carried out, as first approximation, an experimental single band effective mass model calculation. Using this model we ascribed the 2.4 PC peak to e2 to continuum transition in the InGaAsN QW in samples S1 and S2. A more sophisticated model, which reflects the nitrogen bands and its effect on absorption selection rule will be presented at the conference.

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