Quantum cascade NIR-detection at room temperature in GaN\AlN heterostructure

A. Vardi and G. Bahir

Solid State Institute and Department of Electrical Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel

F. Guillot , C. Bougerol and E. Monroy

Equipe mixte CEA-CNRS "Nanophysique et Semiconducteurs", 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

S. E. Schacham

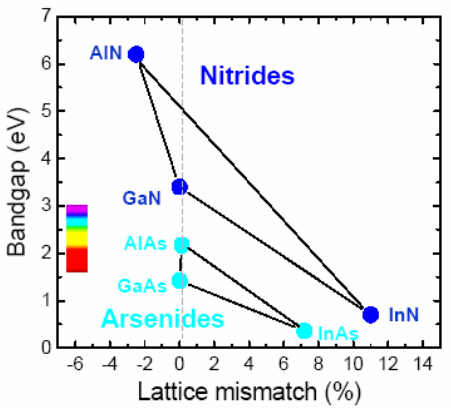
Department of Electrical and Electronic Engineering, Ariel University Center, Ariel 40700, Israel

Outline

- Introduction
- Model
- Structure Growth and characterization
- Device
- Summary

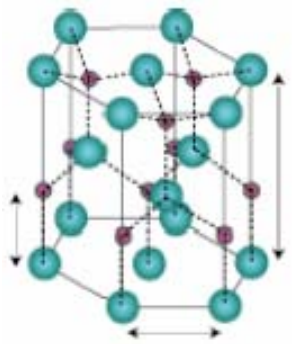
AlN – GaN Heterostructures

Eg Vs. Lattice mismatch



Material properties:

- wide bandgap (3.5-6.2 eV)
- Large conduction band-offset (~2eV)
- Large internal field (5-7MV/cm)
- AlN defects – barrier leakage
- Large lattice mismatch (~2.5%)

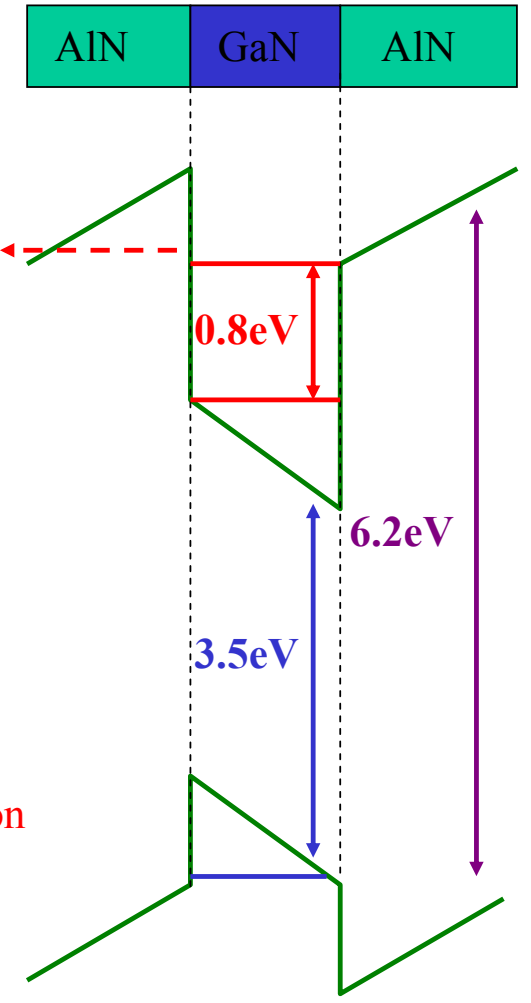


Wurtzite Structure

ISB Devices:

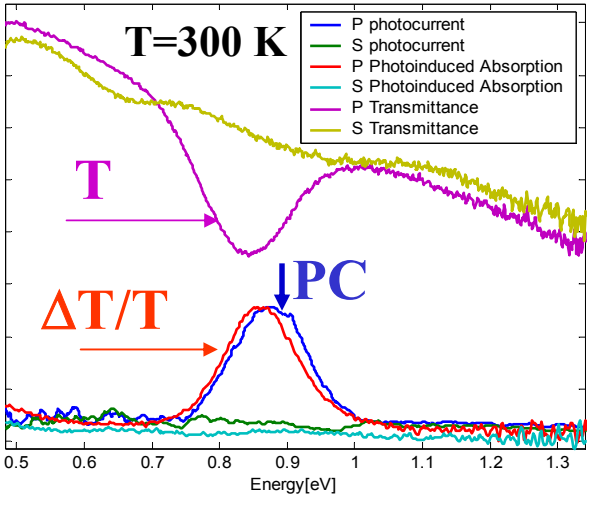
- Cover the NIR spectral range
- Strong electron-LO phonon interaction
- Operating at room temperature

Schematic band structure

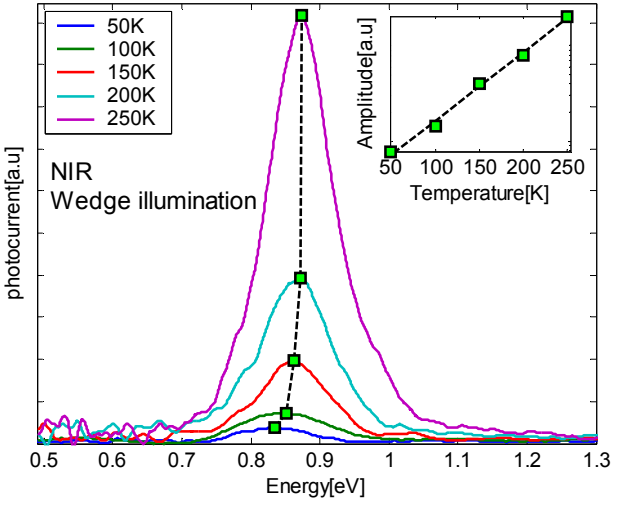


GaN Lateral Detectors

NIR absorption and photocurrent (PC)

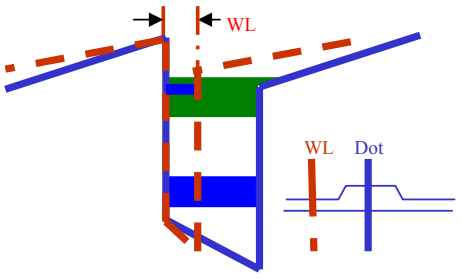


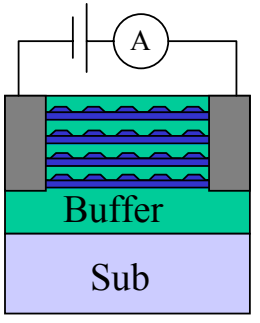
PC Temperature dependence



Extraction of carriers to quasi continuum (Wetting layer)

- Good Responsivity (~10-50mA/W)
- Operates at Room Temperature
- Low Frequency (~KHz).

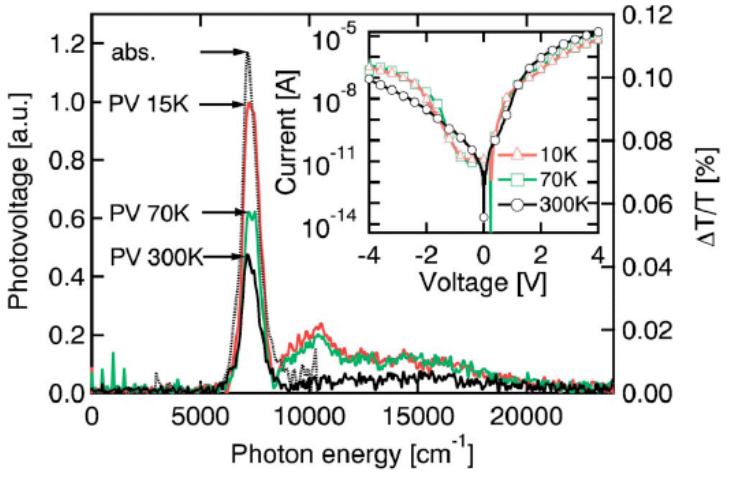




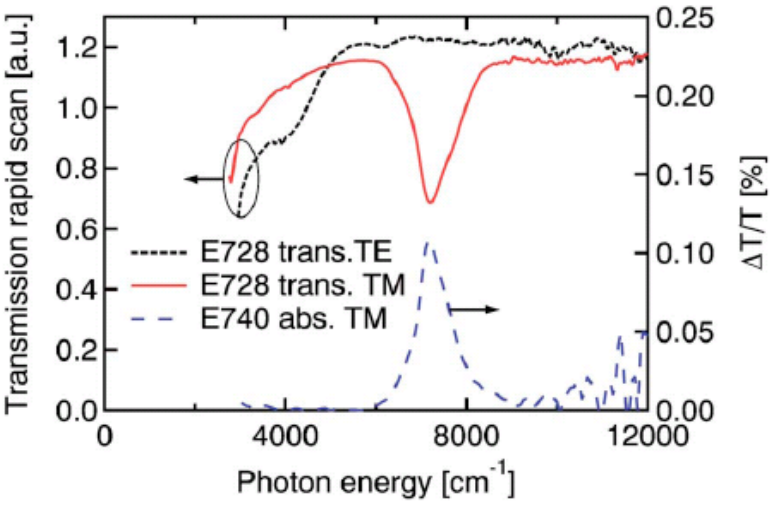
Vardi et al. APL 88, 143101 (2006)

GaN Photovoltaic Detectors

NIR PV response

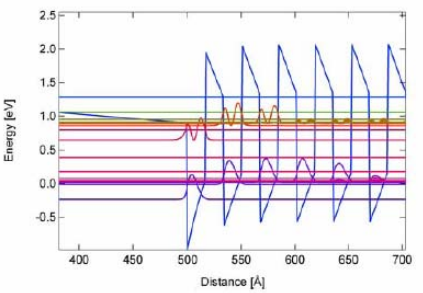


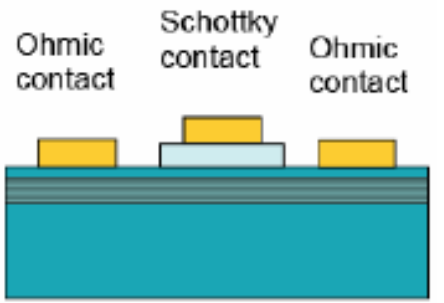
NIR absorption



- PV effect in a Schottky contact
- High speed (2.5GHz)
- Transport in minibands
- Low responsivity (10 μV/W)

Hofstetter et al. APL 88, 121112 (2006)





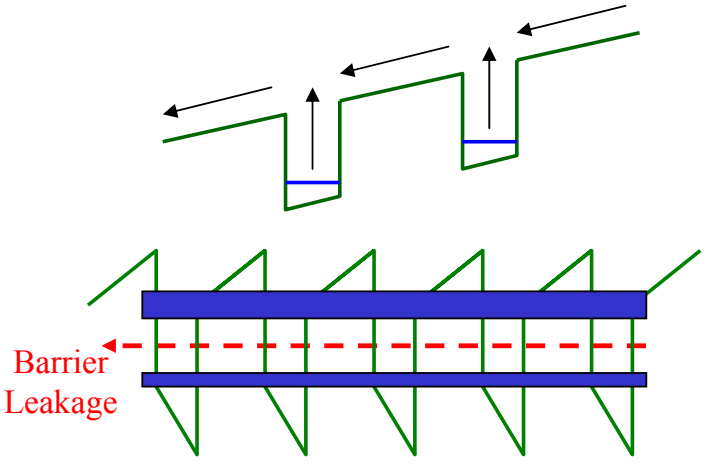
Photoconductive vs. Photovoltaic QWIPs

Photoconductive QWIPs

• Require external bias – dark current ► low operating temperature.

• Thin barriers required in AlN\GaN system ►barrier leakage, miniband transport ►responsivity quenching.

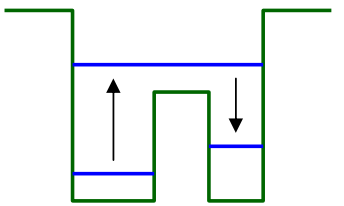
• Solutions: thick AlGaN barriers, photovoltaic detectors



Photovoltaic QWIPs

• Operate at zero bias ► no dark current ► high temperature, long wavelengths.

• NIN structure – high V_{oc} ► working with high impedance amplifier ► no terminal current ► high f_{max}

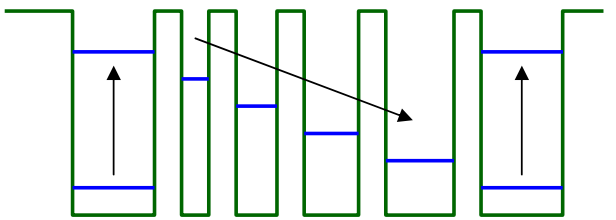


Quantum Cascade Detectors (Gendron APL (2004))

• Based on electron-LO phonon interaction.

• thin barriers

• Relatively easy for optimization – only 2D wave functions are involved

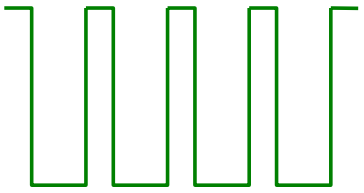


Unique QCD design in polar nitrides

- Typically, the energy slope in a QCD structure is accomplished by increasing well width along the stage.
- In order to increase the detection efficiency, the energy levels are designed to form a phonon ladder.
- In our novel design the well width is constant and the saw-tooth structure relies on the strong polarization field in the nitride material system in order to create the phonon ladder.

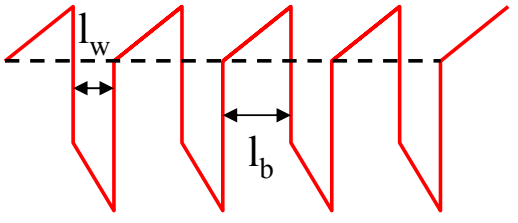
Internal Field Considerations

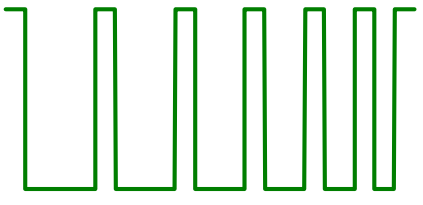
$$\nabla\cdot\vec{D}=0, \quad B.C.: \sum_i V_i = 0$$



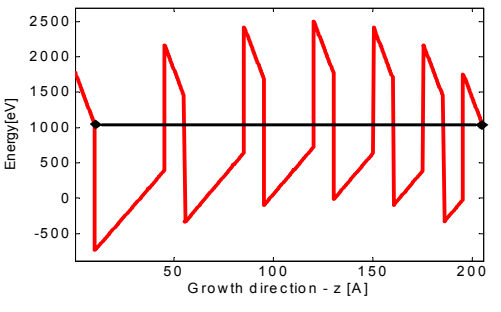
$$E_b = \frac{\Delta P}{\varepsilon_0}\cdot\frac{l_b}{\varepsilon_w l_w + \varepsilon_b l_b}$$

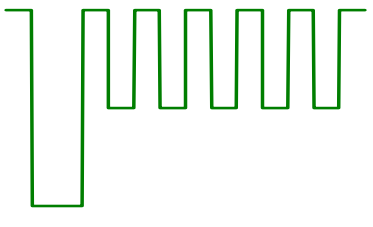
$$E_w = -\frac{\Delta P}{\varepsilon_0}\cdot\frac{l_w}{\varepsilon_w l_w + \varepsilon_b l_b}$$

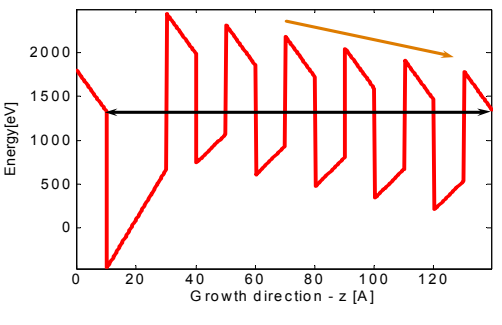




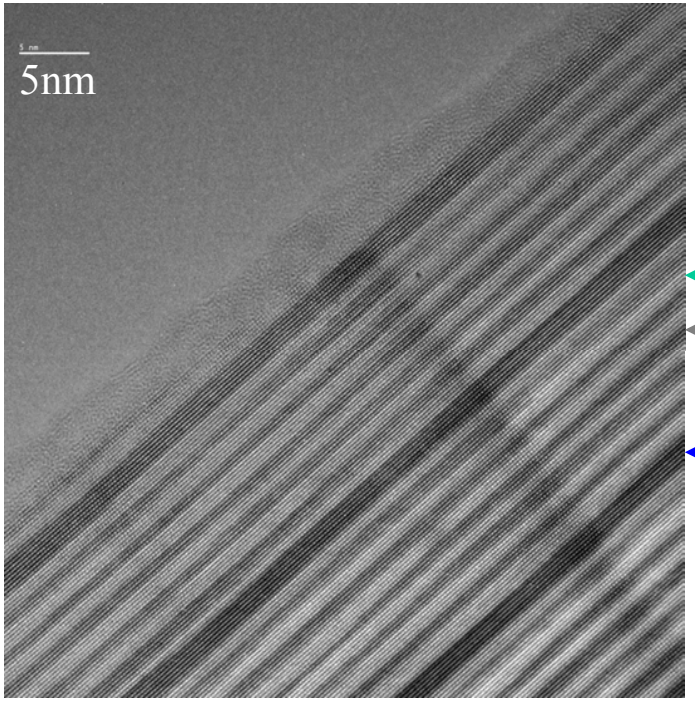
$$E_j = \frac{\sum_k \left(P_k - P_j\right)\frac{l_k}{\varepsilon_k}}{\varepsilon_j \sum_k \frac{l_k}{\varepsilon_k}}$$







Structure Design and Growth

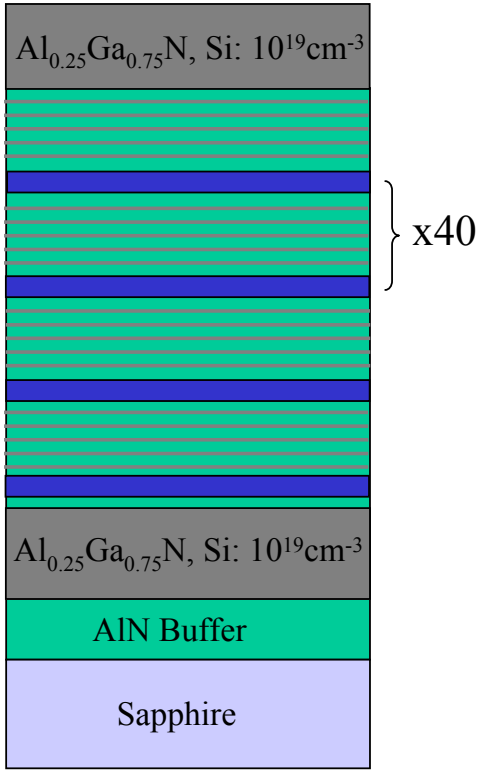


Interface roughness
~1ML

AlN (4ML)

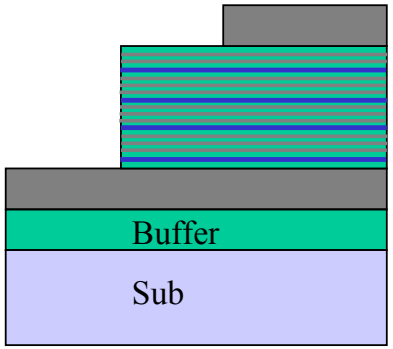
$Al_{0.25}Ga_{0.75}N$ (4ML)

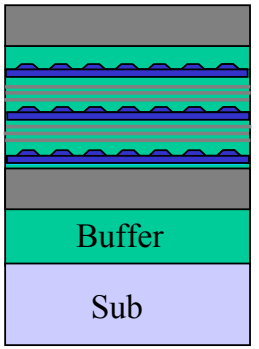
GaN (6ML)

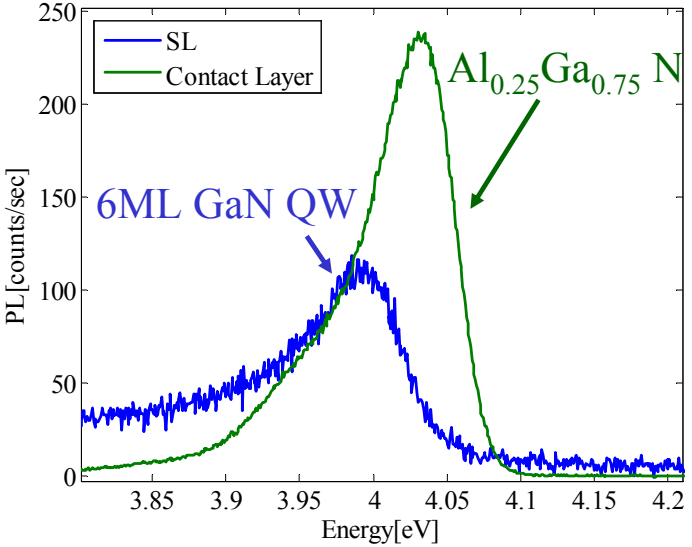


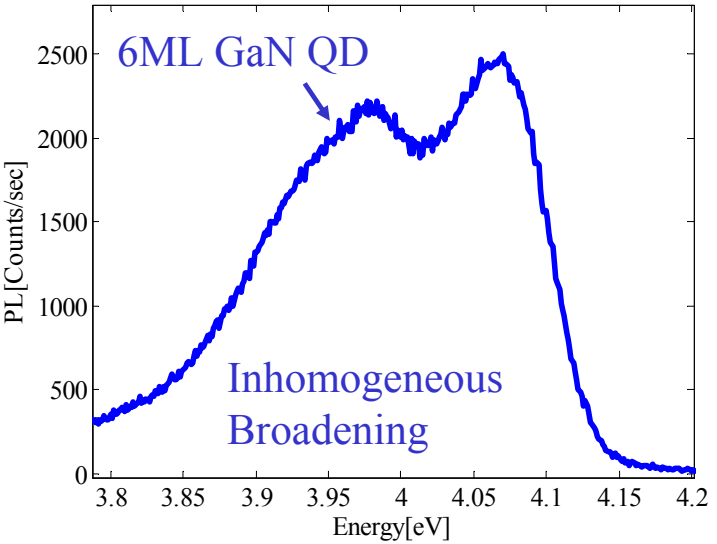
The structure consists of 40 periods of a 6-monolayer-thick (6 ML) GaN quantum well followed by a short period superlattice consisting of 5 periods of AlN\$Al_{0.25}$ $Ga_{0.75}N$ (4 ML \ 4 ML)

Photoluminescence



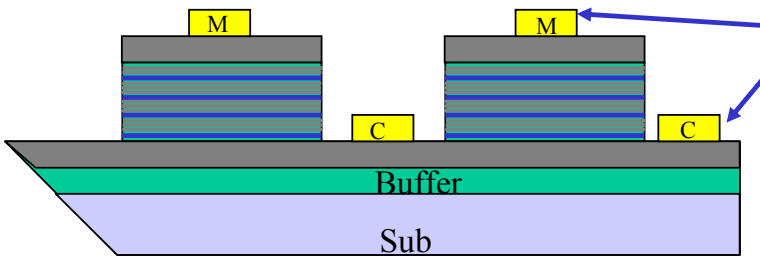






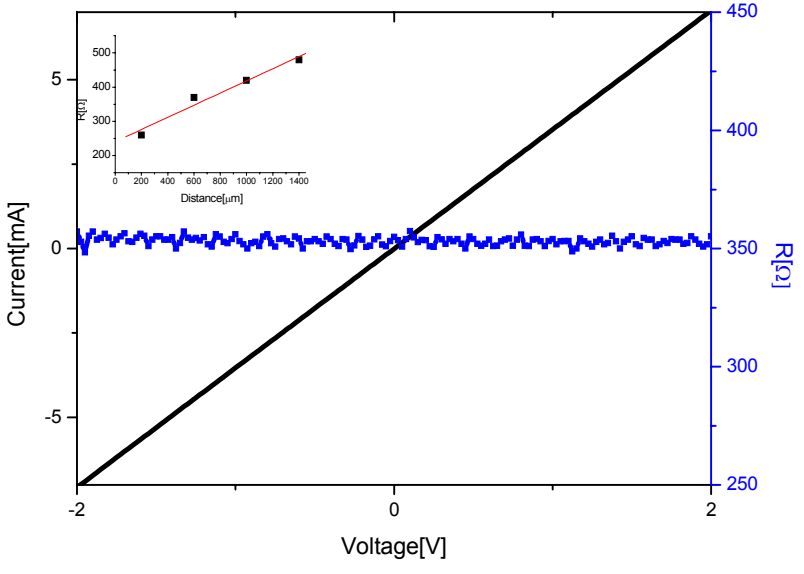
Measured at 15K, using Xenon lamp light, dispersed by 0.25m monochromator. Excitation wavelength: 280nm.

Device Fabrication

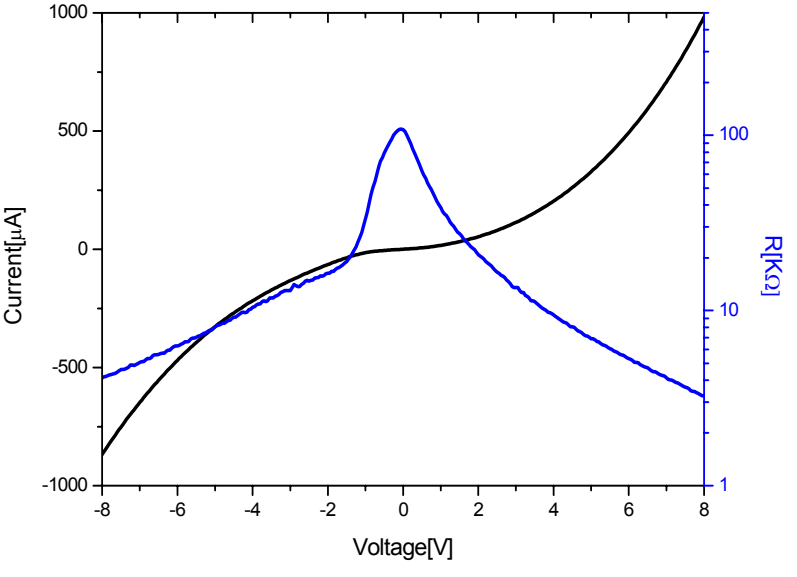


Ohmic Contacts
Ti\Al\Ti\Au

Current-Voltages curves



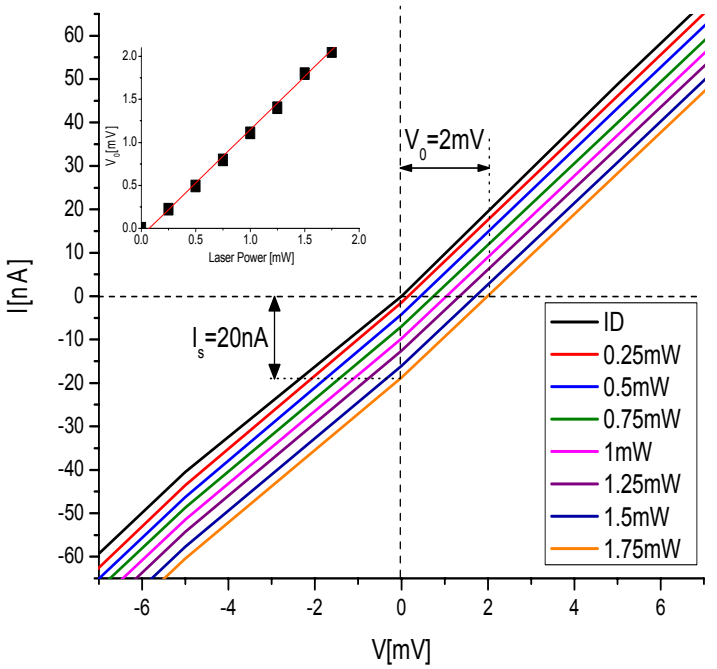
Measured between
two C contacts



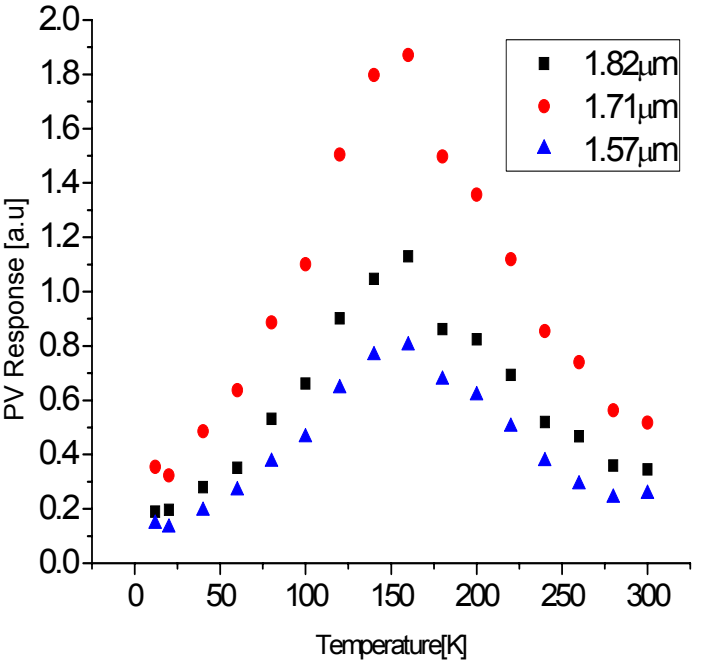
Measured between
M and C contacts

Device – Photovoltaic Response

Current-Voltage curves under illumination of 1.55μm Laser



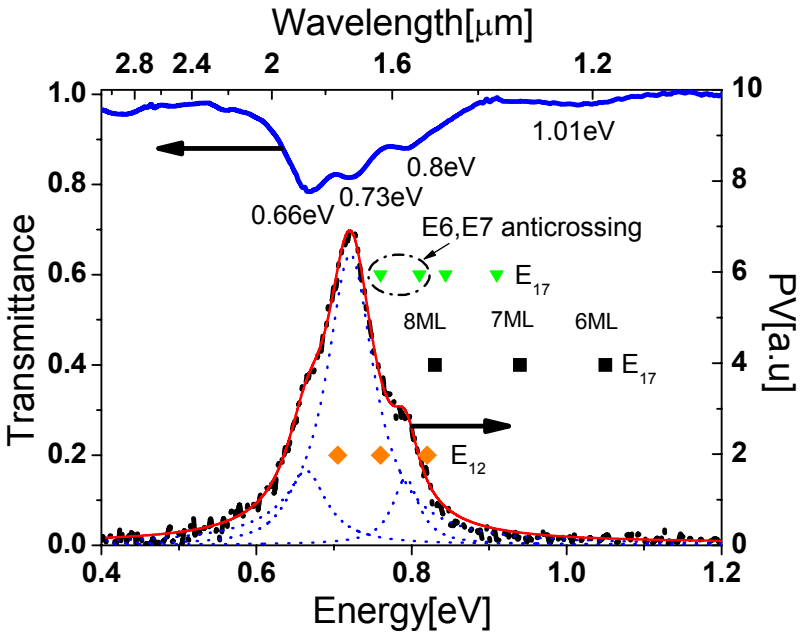
Temperature dependence of the PV response at different wavelengths



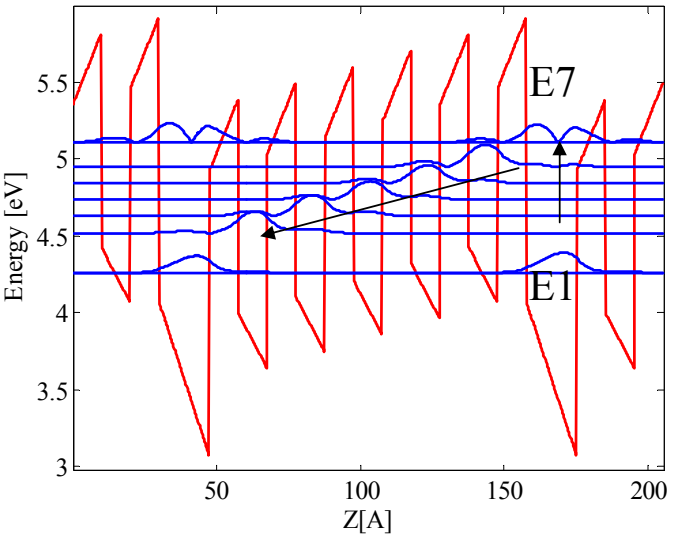
Peak Responsivity at Room Temperature ~10mA/W

Device – Photovoltaic Response

Photovoltaic response



8x8KP model

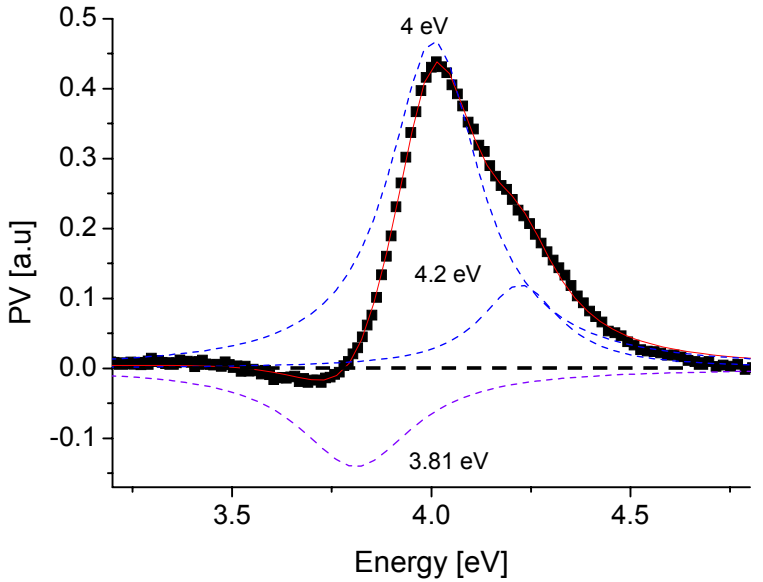


▼ 8x8 KP ■ Single band ◆ M. Tchernycheva et al. PRB 73, 125347 (2006)

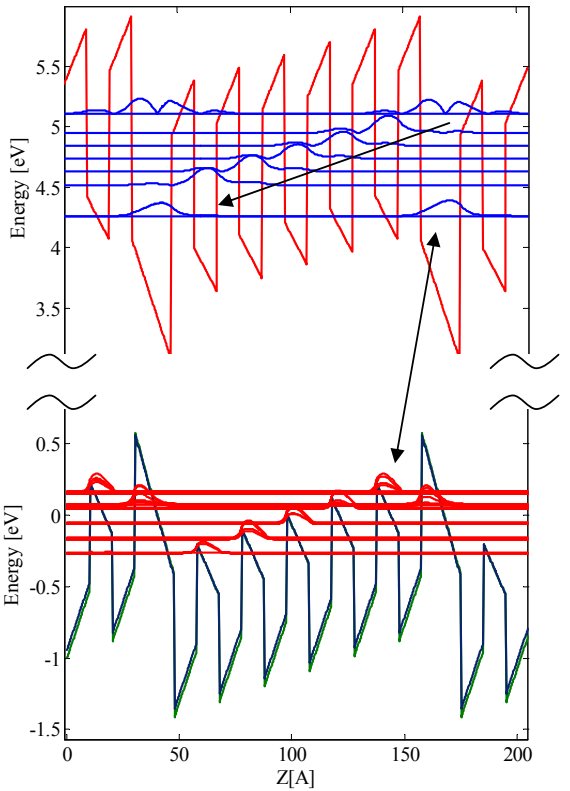
Measured at room temperature, using FTIR and Tungsten-Halogen source

Device – Photovoltaic Response at UV

Photovoltaic response at UV

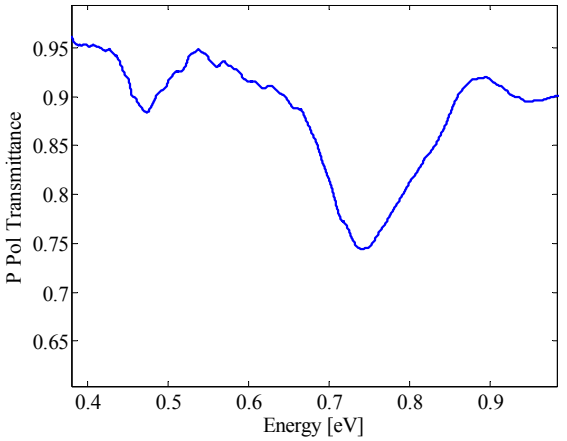


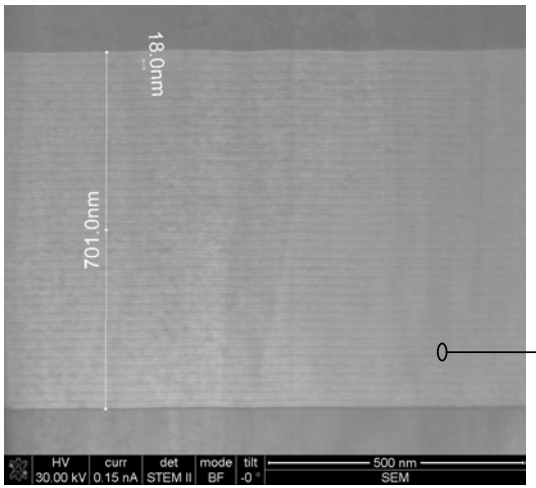
8x8KP model

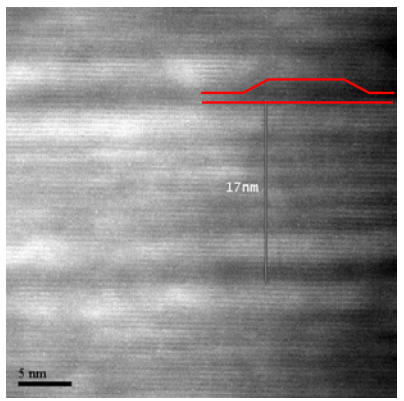


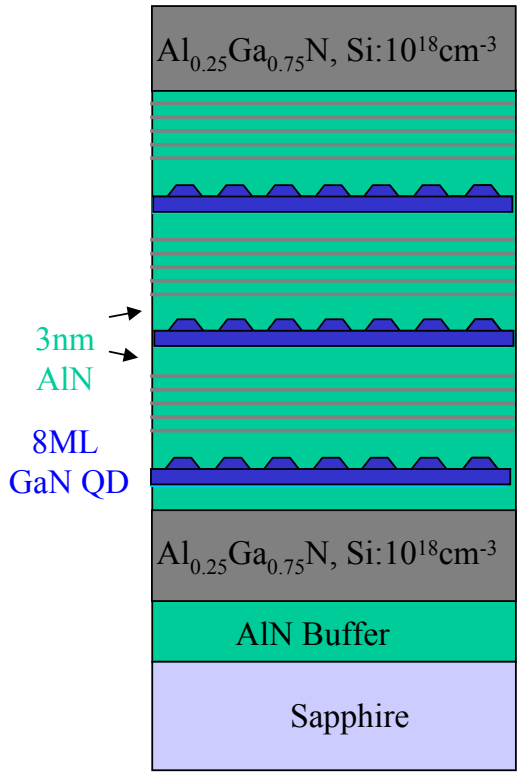
QD embedded structure

No PV response !









3nm AlN Barriers !

Summary

- A novel structure of QCD was demonstrated
- PV operation at RT
- High responsivity in optimized structure
- High frequency response (soon)…

Thank you for your attention