# Recent Progress in Non-Cesiated III-Nitride Photocathodes

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1st Workshop on Photocathodes: 300nm-500nm
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# Introduction

3x Directorate: **Engineering and Science**
Division 38: **Instruments and Science Data Systems**
Section 389: **Instrument Electronics and Sensors**

Group 389E: Advanced Detector & Nanoscience Technologies
Shouleh Nikzad (Supervisor)
Doug Bell
Jordana Blacksberg
Frank Greer
Blake Jacquot
Todd Jones

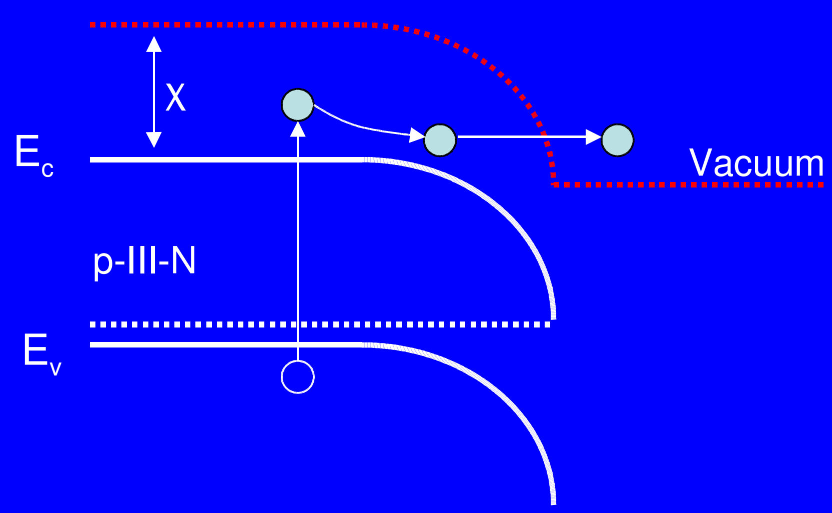
The group works on advanced device concepts (mostly detector), including new materials.

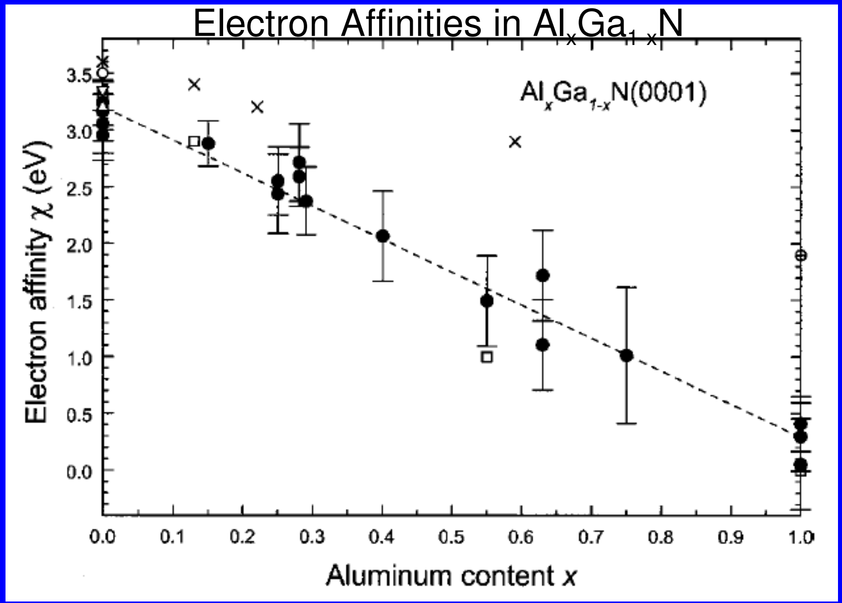
# Topics

- Motivation for III-N Photocathodes
- Delta-doping
- Progress in delta-doping for non-cesiated photocathodes
- AlGaN versus GaN
- Summary

# Why III-Nitrides for Photocathodes?

- Low electron affinities in the $Al_xGa_{1-x}N$ system.
- High chemical stability.
- Low inherent surface state charge.
- Tailorable UV response and solar blindness.
- Current UV photocathodes suffer from low QE and instability in the response

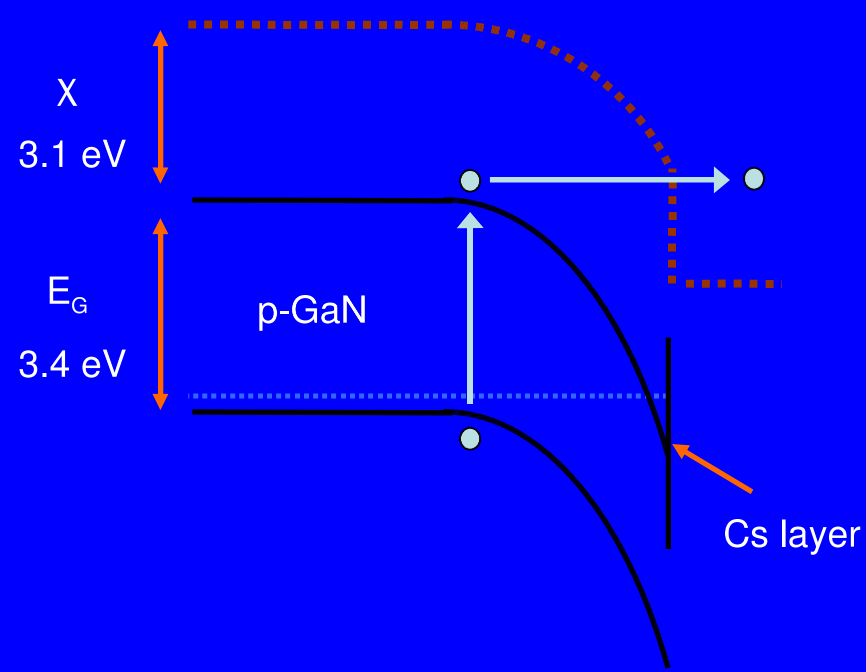



Grabowski *et al*, Appl. Phys. Lett. 78, No. 17 (2001)

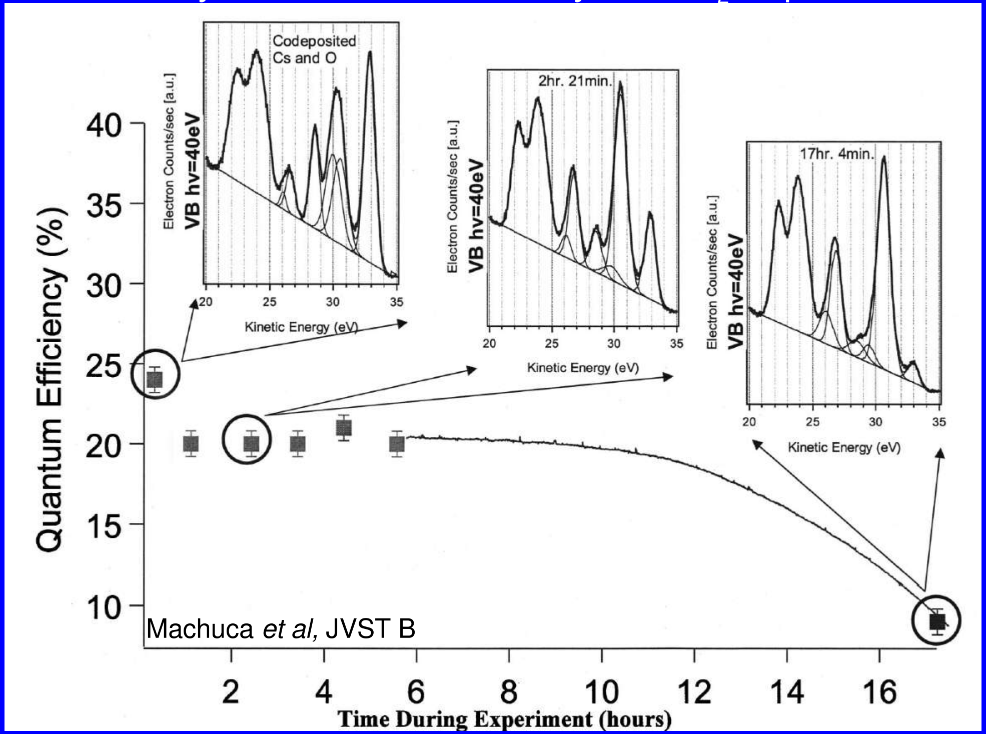
# Photocathode Activation with Cesiation

Cesiated Photocathode




(1) Machuca, et al. (2) Wu and Kahn (3) Shahedipour, et al. , (4)Siegumund

Decay in Quantum Efficiency from $O_2$ Exposure




- **Quantum efficiency degrades rapidly under minute exposure to $O_2$ Degradation linked to oxidation of Cs.**
- **Cesiated AlGaN photocathodes are only appropriate for UHV environments.**

# Approach

Goal: Demonstrate a non-cesiated III-N based photocathode

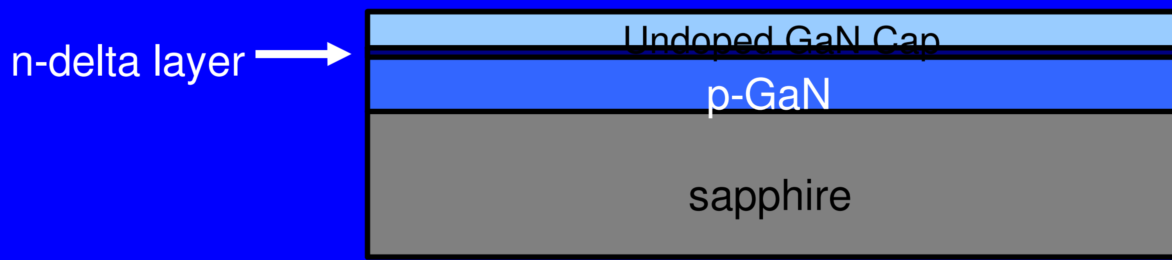
Cesiation alters surface band structure using low-work function metal

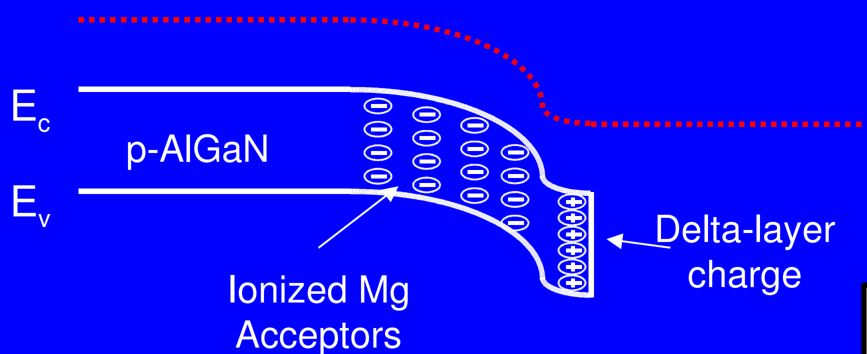
Our approach is based on experience with other devices and materials*

- Piezoelectrically Enhanced Photocathode (PEPC)
- Delta doped Enhanced Photocathode (DDEPC)
- Take advantage of lower work function of AlGaN

*Hoenk, et al., Nikzad et al., Blacksberg, et al., Delta doped CCDs

# Delta-doped Photocathode

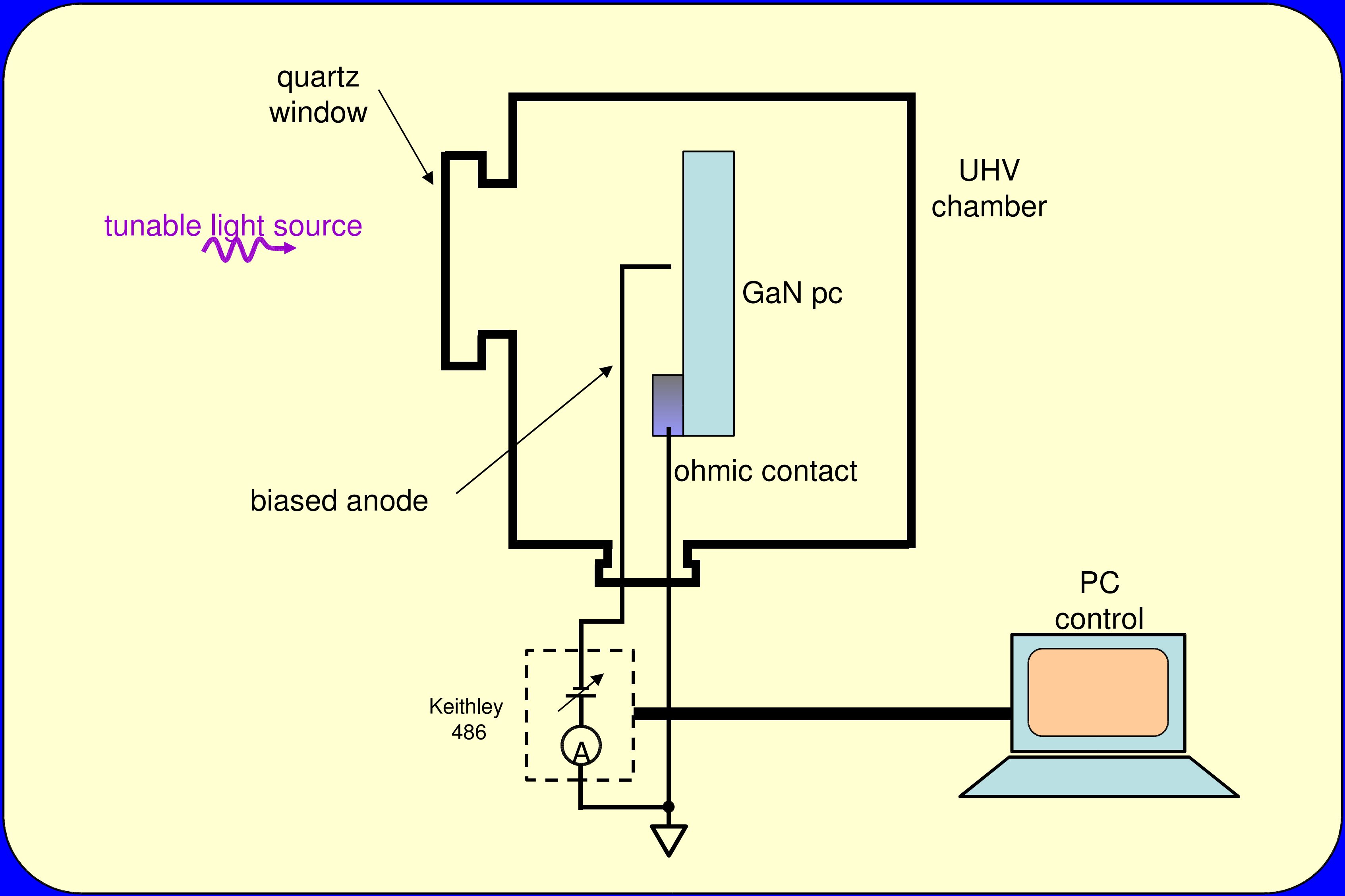


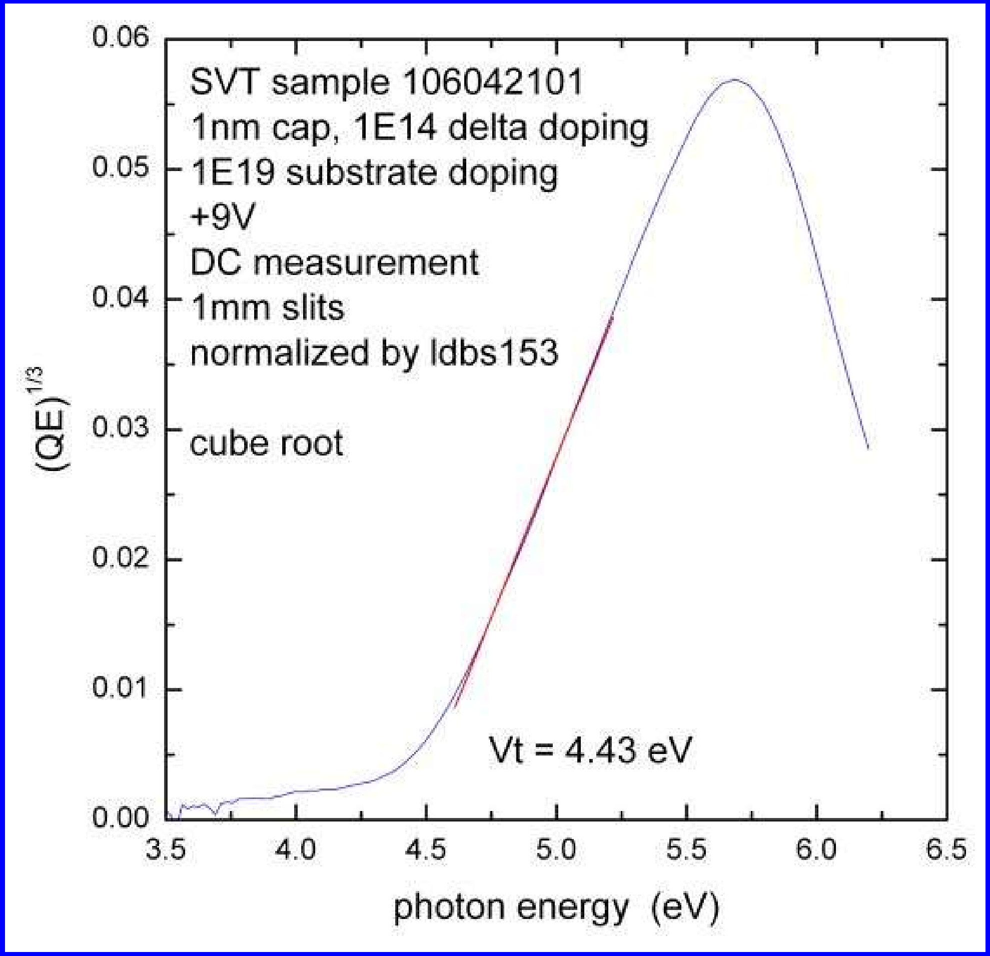

Band bending and QE depend on:

Cap thickness
Delta-layer n-doping density
GaN layer p-doping density

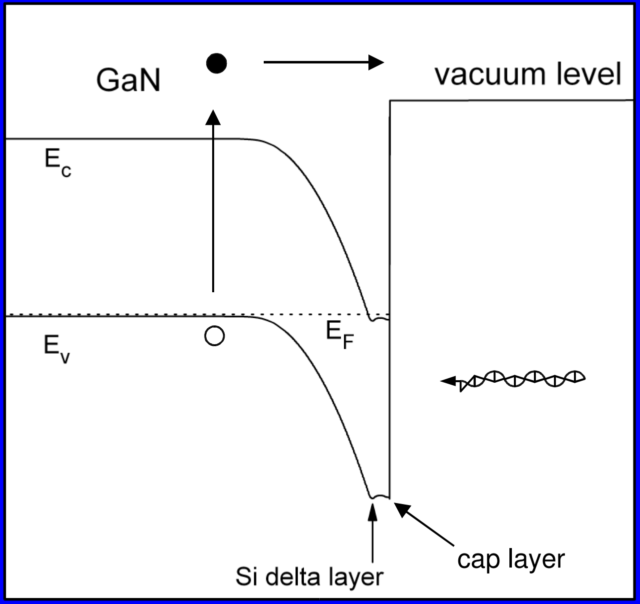
# Schematic of Emission Measurement



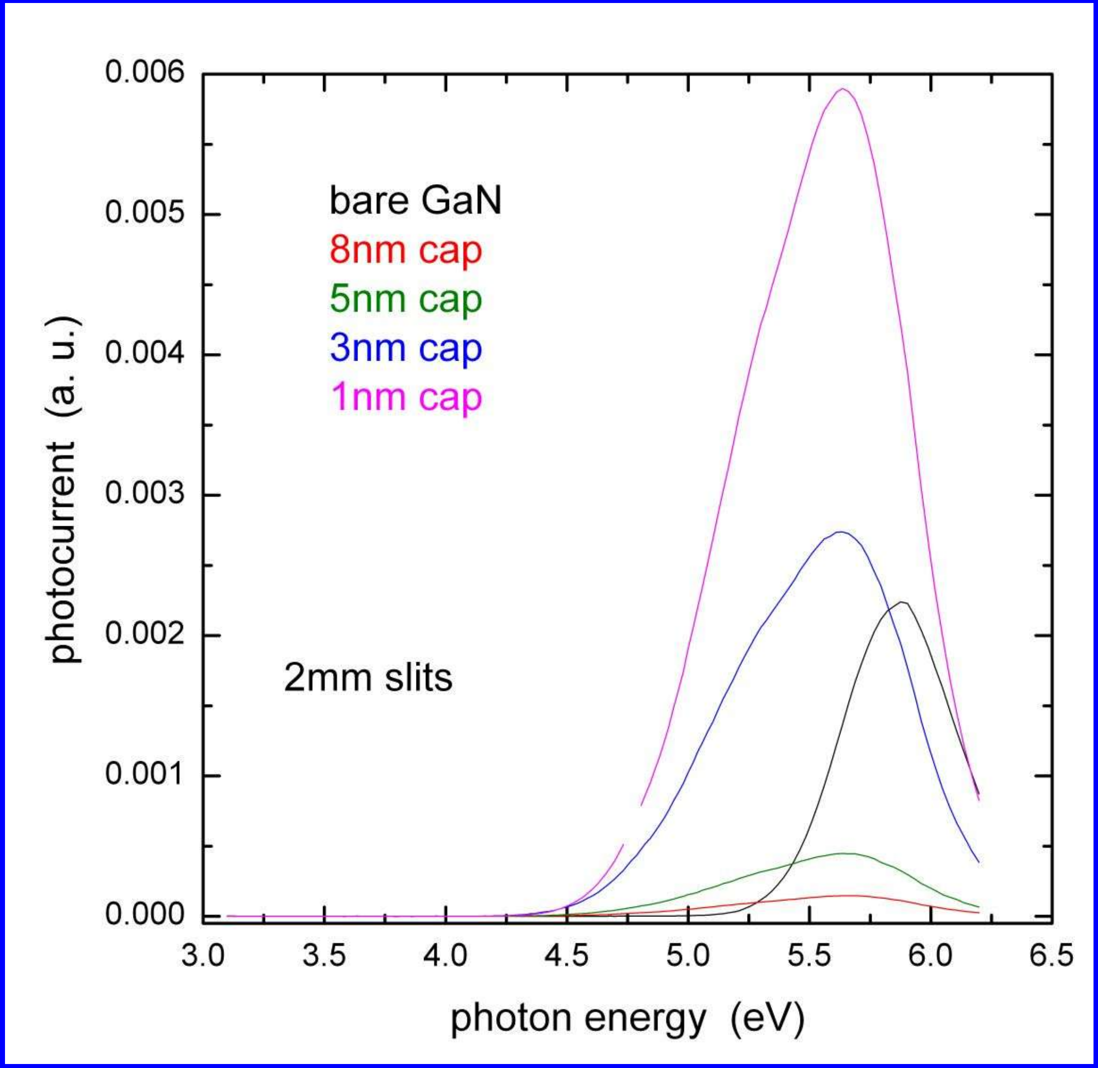
# IPE Spectrum for GaN / δ-Si / p-GaN




IPE spectrum for delta-doped GaN photocathode. The power-law threshold allows simple extraction of the emission threshold.

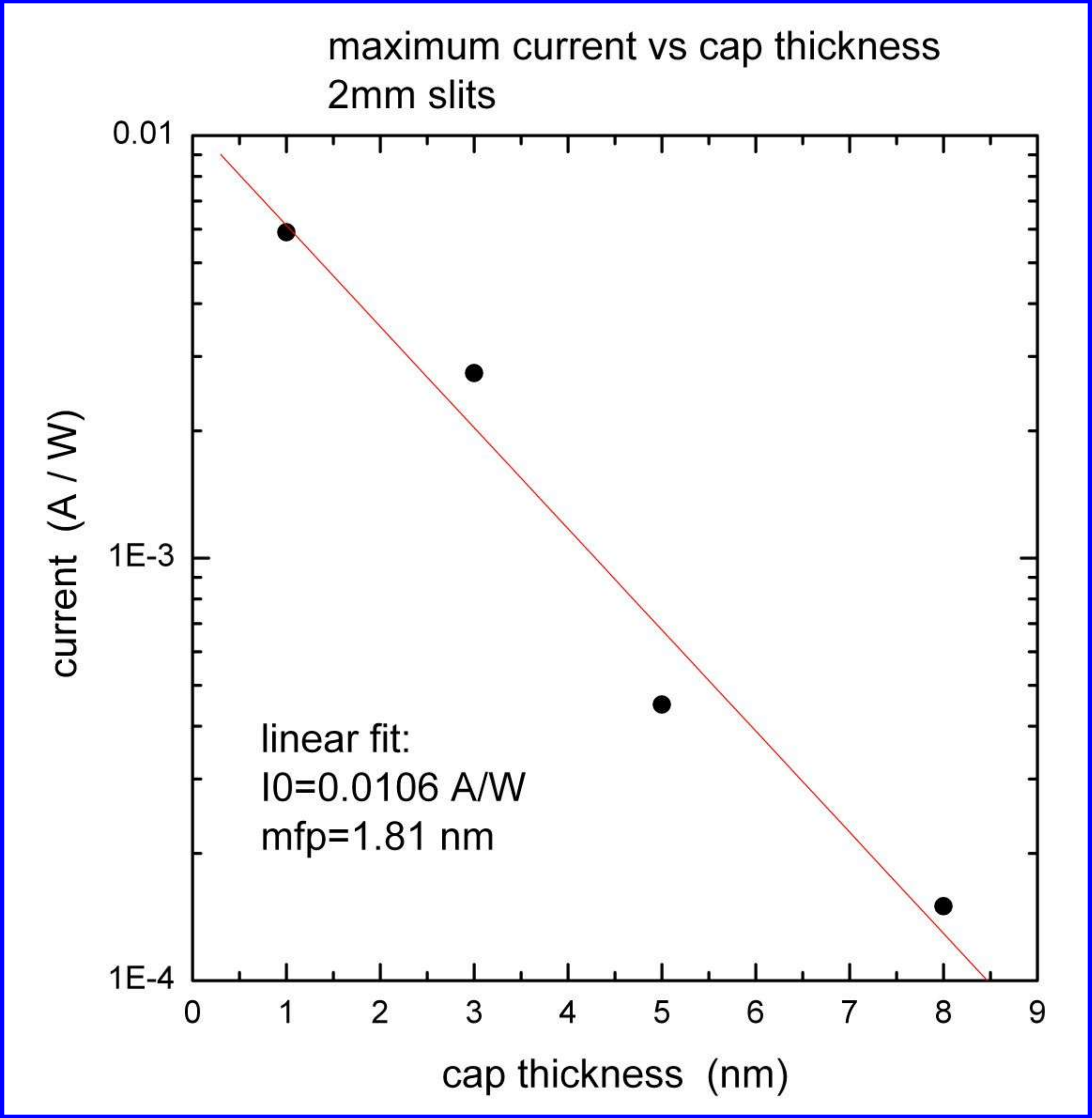


# Effect of Delta-layer Cap Thickness on Emission Intensity



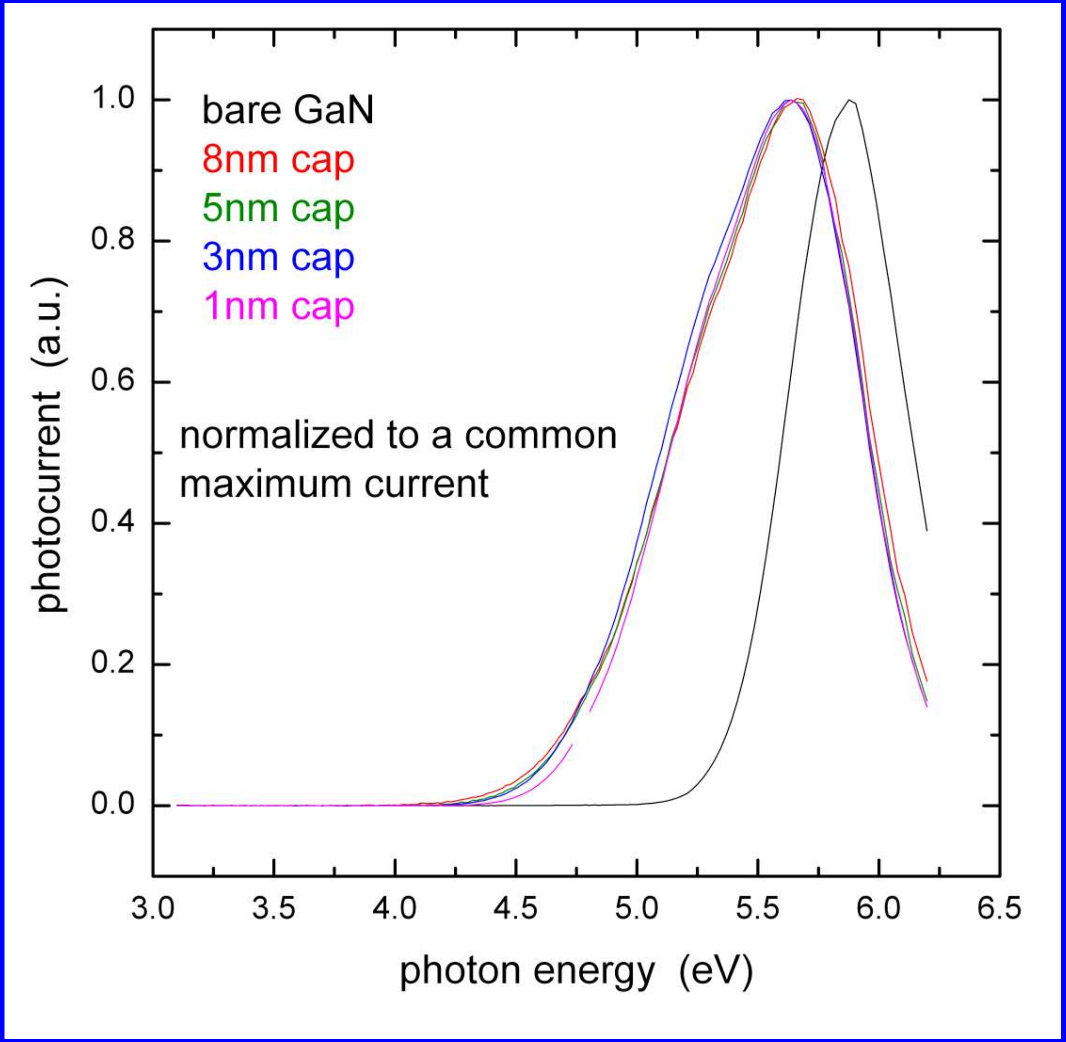

Thinner GaN cap layers produce an increase in emission intensity, due to decreased hot-electron scattering.

# Effect of Delta-layer Cap Thickness on Emission Intensity



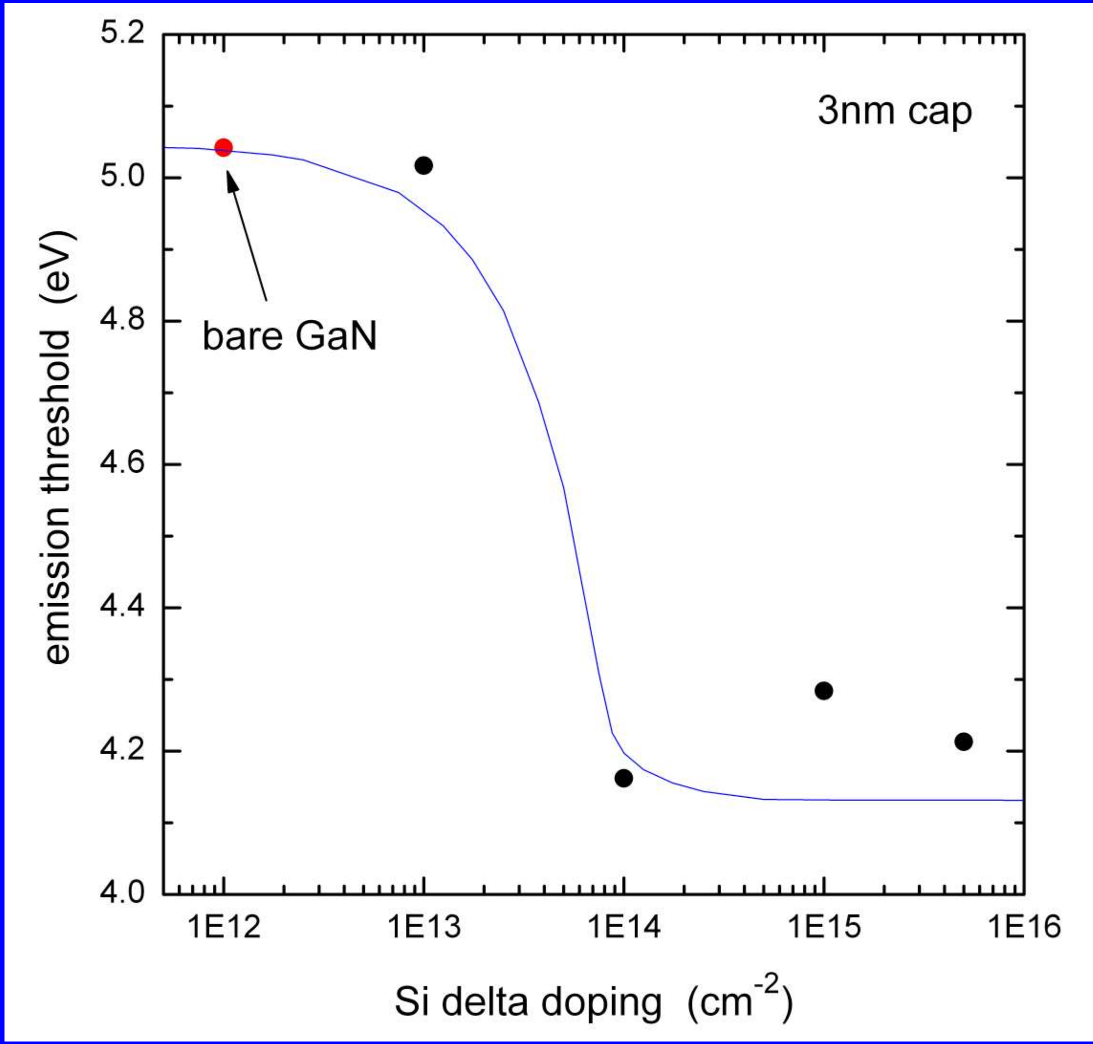

Very short attenuation length for the cap layer indicates strong scattering. Improvement in cap quality is essential.

# Effect of Delta-layer Cap Thickness on Emission Threshold



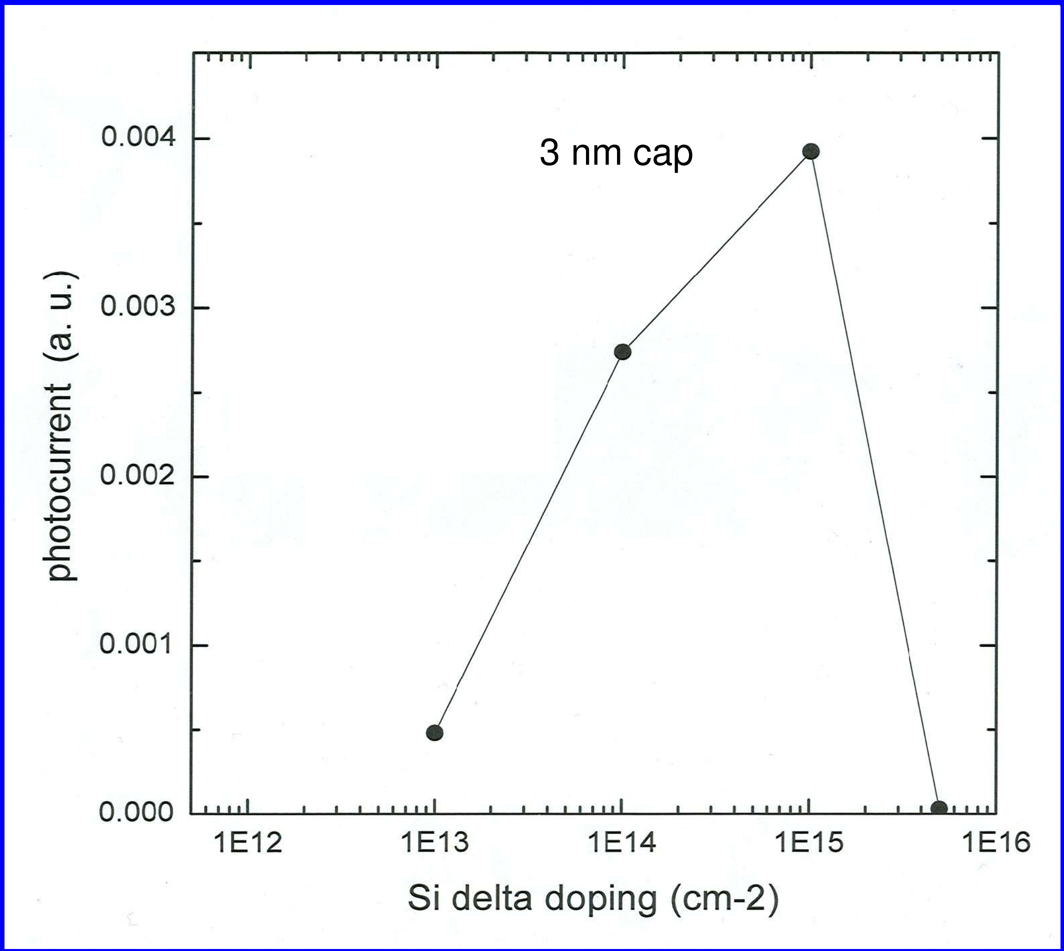

Only a weak dependence of emission threshold on GaN cap layer thickness observed.

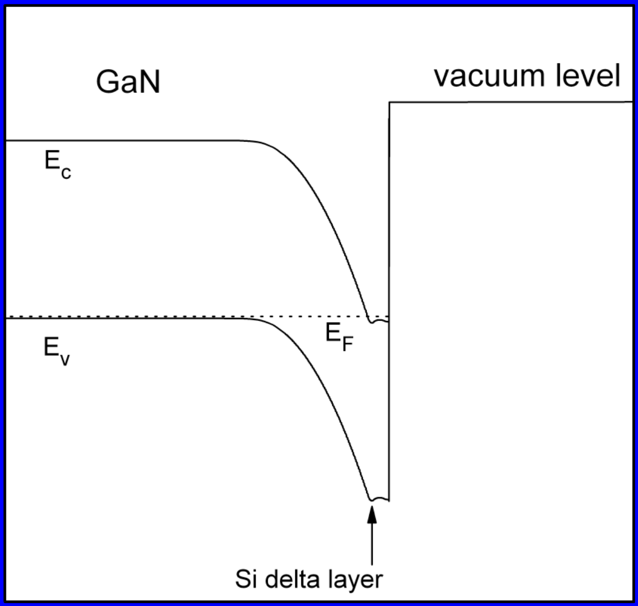
# Effect of Si Delta-doping Density on Emission Threshold



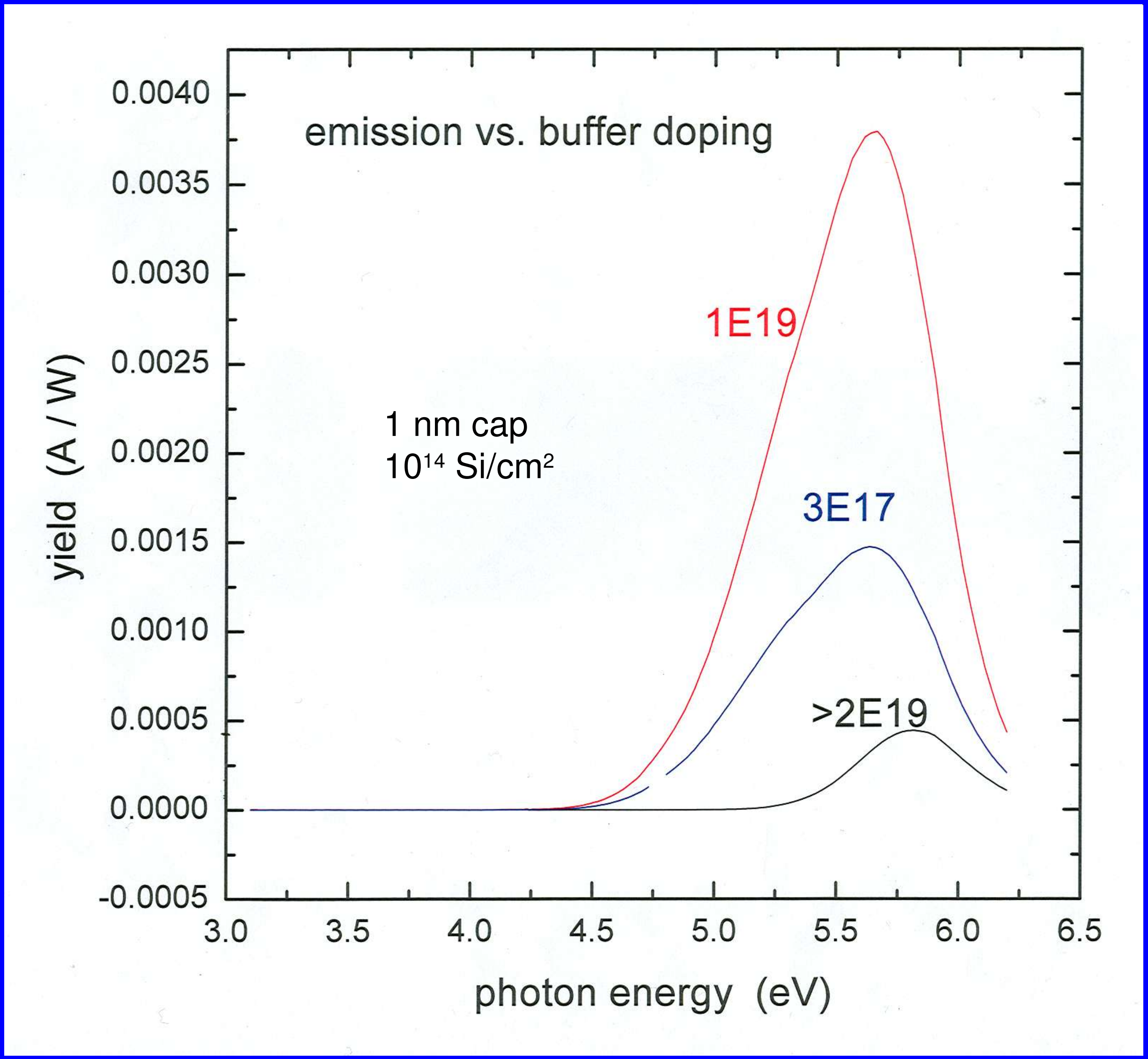

Bare GaN has a high emission threshold. Si delta-doping produces a rapid reduction of threshold until the conduction band edge reaches the Fermi level.

# Effect of Delta Layer Doping Density on Emission Intensity



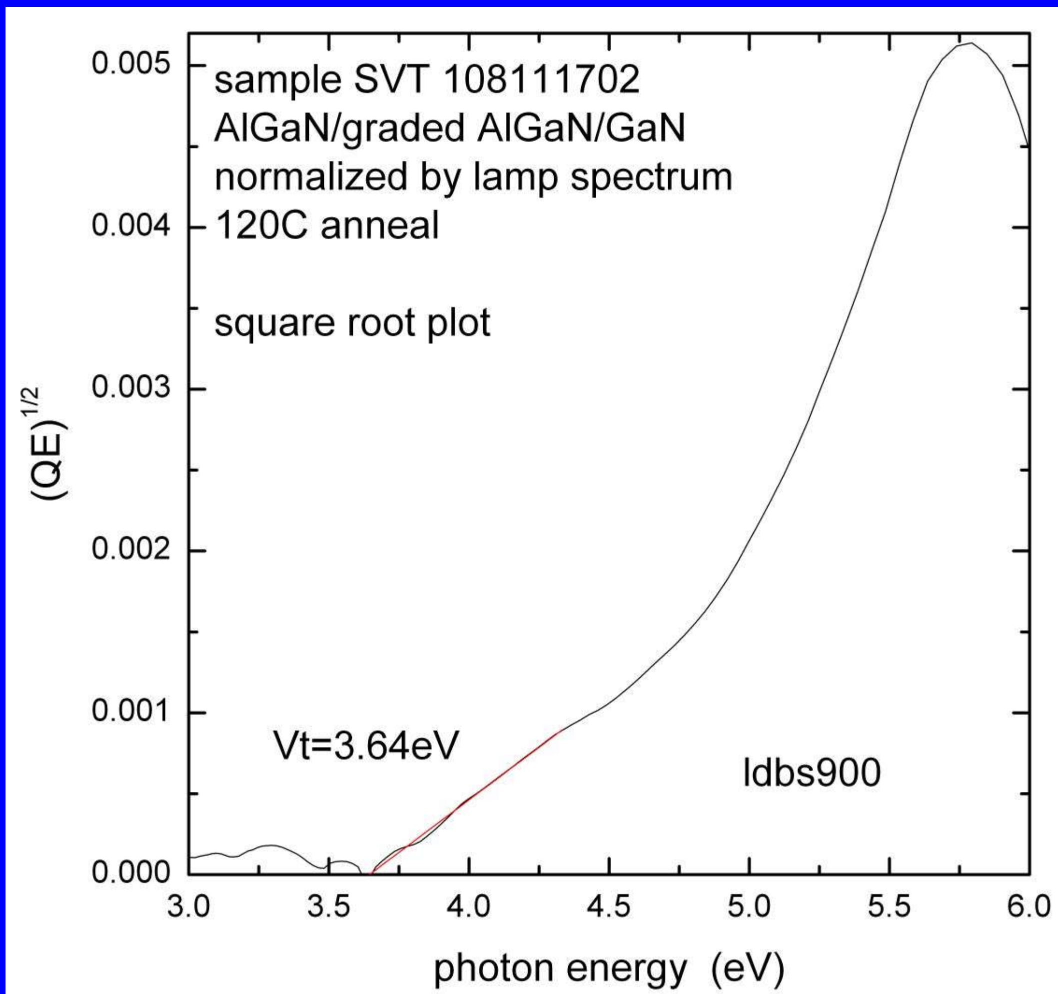



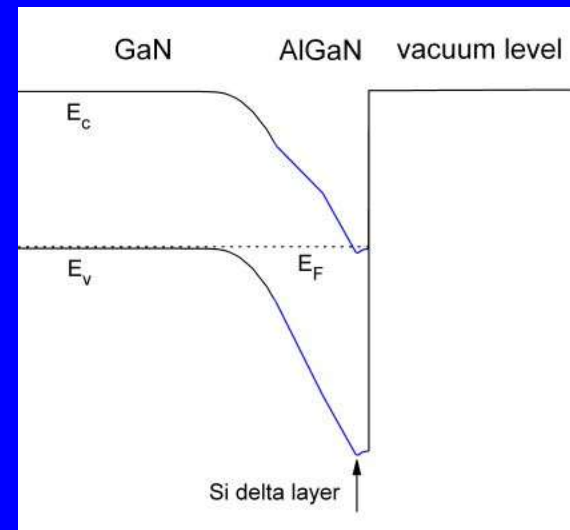
# Effect of Bulk p-Doping on Emission Intensity




Increased p-doping of the bulk GaN reduces the width of the surface well, thus decreasing scattering losses during well traversal.

# IPE Spectrum for AlGaN / δ-Si / p-GaN




The lower electron affinity of AlGaN reduces the emission threshold, but delta-doping of the AlGaN layer is required.

# Summary

III-N photocathode activation is investigated without use of cesiation

These techniques offer the advantage of stable response even with exposure to air

GaN samples grown on sapphire were examined as delta doped enhanced photocathodes

Effect of cap layer, dopant density in the bulk, and dopant density in the delta layer were determined and optimized

Work is underway to integrate other effects to achieve true NEA without cesiation