Advanced Photo-Cathode Materials

(Wide-band-gap Nitride Semiconductor Heterostructures)

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Outline

- Nitride Semiconductor Material Properties
- Device Applications
- MBE Growth
- Materials Characterization
- Surface Activation and Quantum Efficiency
- External Bias and Intrinsic Gain
- Tube Sealing

Semiconducting Nitrides

Materials Properties of GaN, InN, AlN and alloys

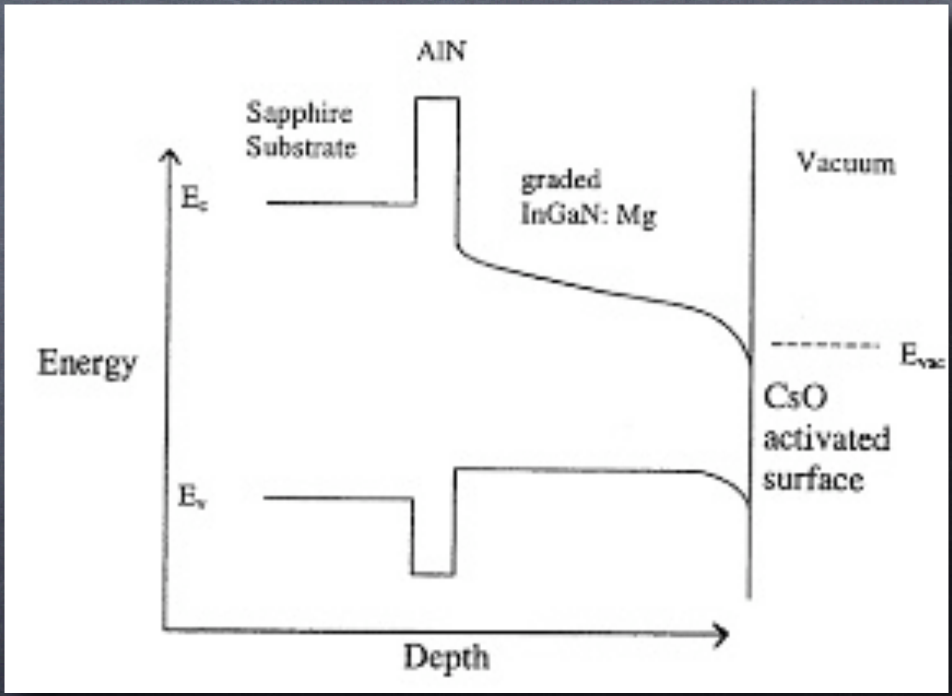
- Crystal structure - hexagonal or cubic
- Band gap energy - ranges from 0.8 to 6.2 eV
- Epitaxial growth on sapphire window substrates (other substrates such as AlN, GaAs and Si are possible)
- n-type carrier conductivity - intrinsic and doping with Si
- p-type carrier conductivity - doping with Mg
- Negative electron affinity surface with Cs activation (intrinsic NEA possible with AlN)
- Amorphous GaN predicted to have a ``clean gap''

Nitride Semiconductor Applications

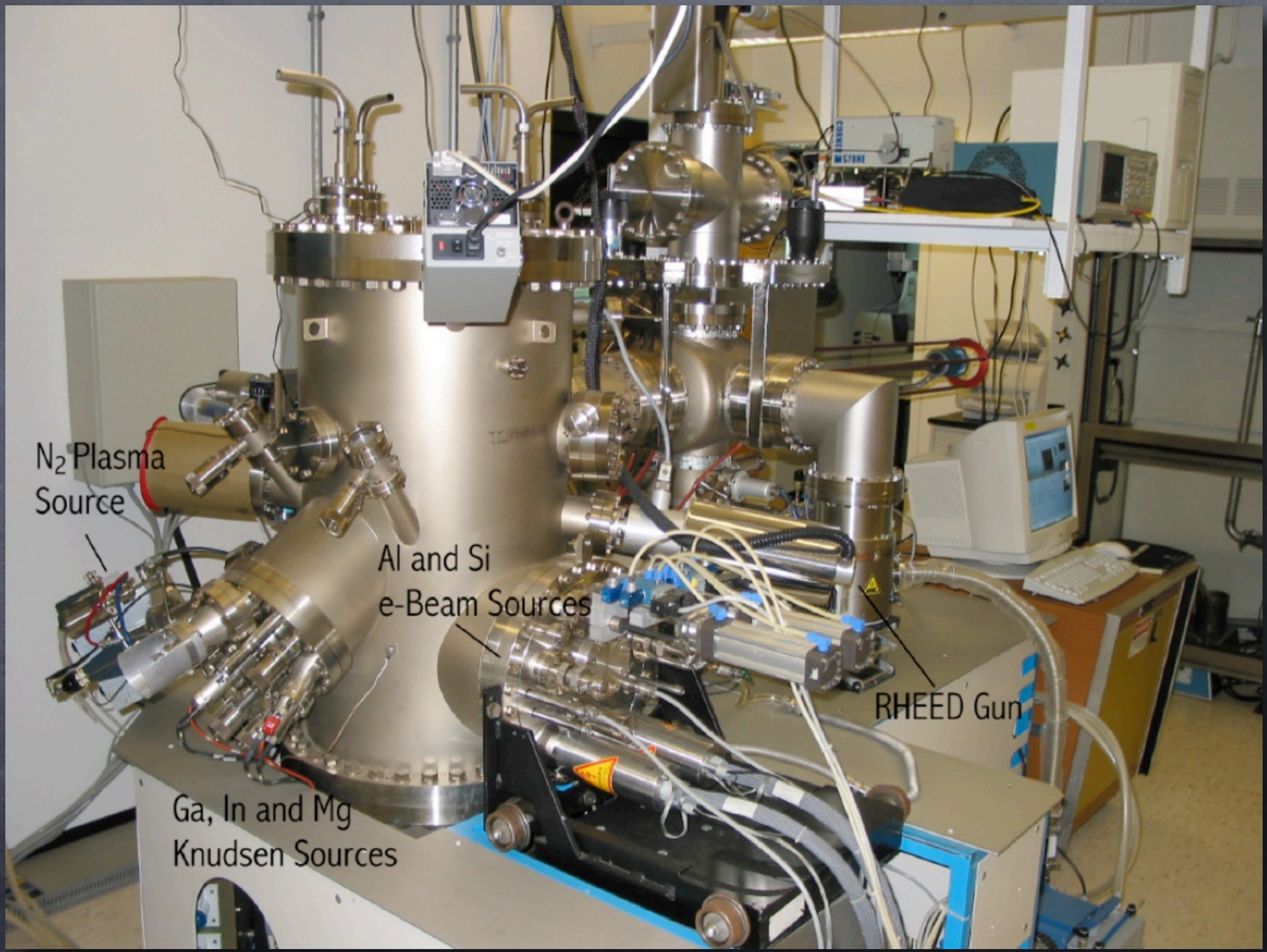
- Detectors (UV/visible)
- LED's and lasers
- High power electronics
- Spintronics

Energy Band Profile

- Our approach is to use MBE for heteroepitaxial growth of nitride semiconductors with a band structure tailored to promote efficient transport of photoelectrons to the photoemissive surface.

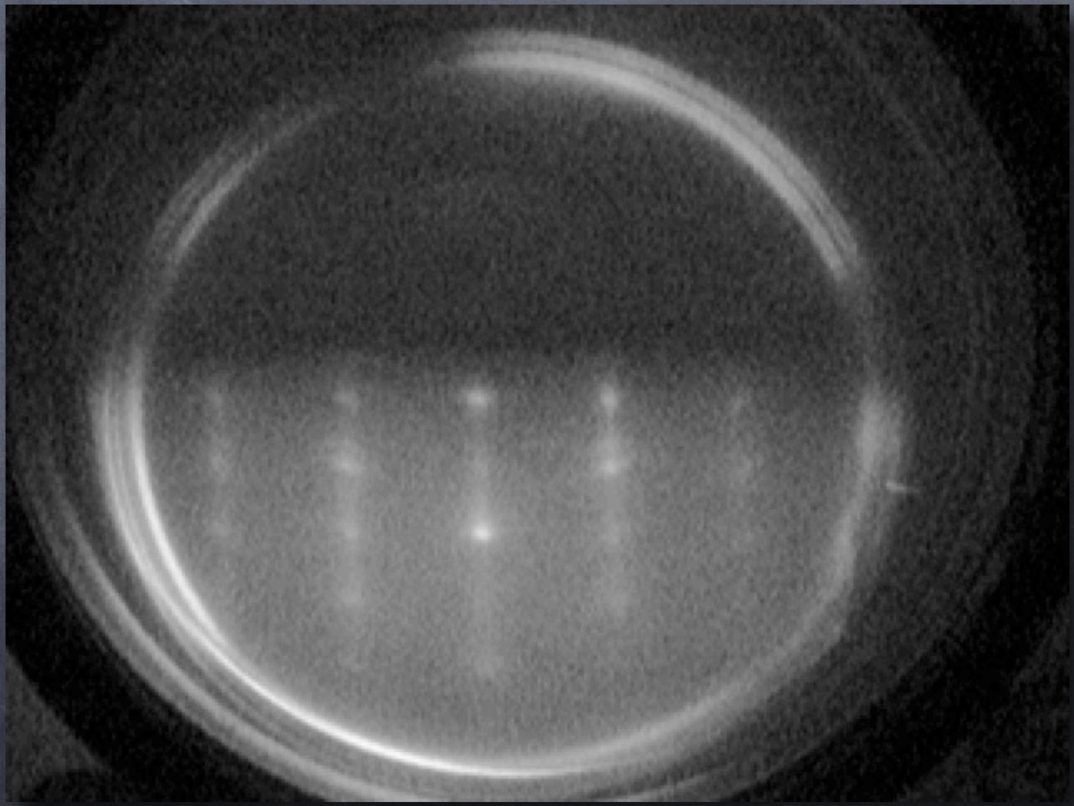


MBE Growth of Photocathode Layers

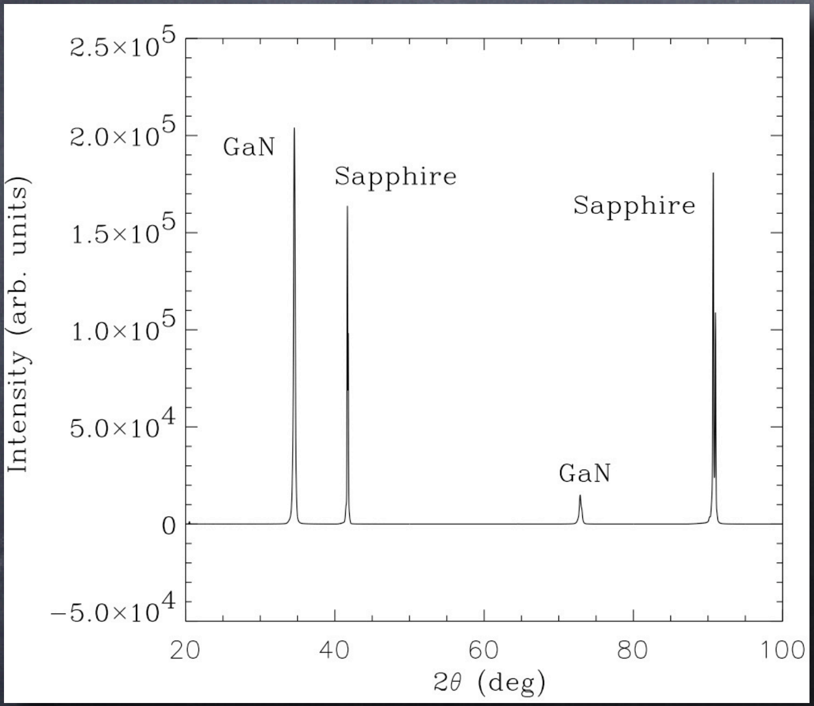


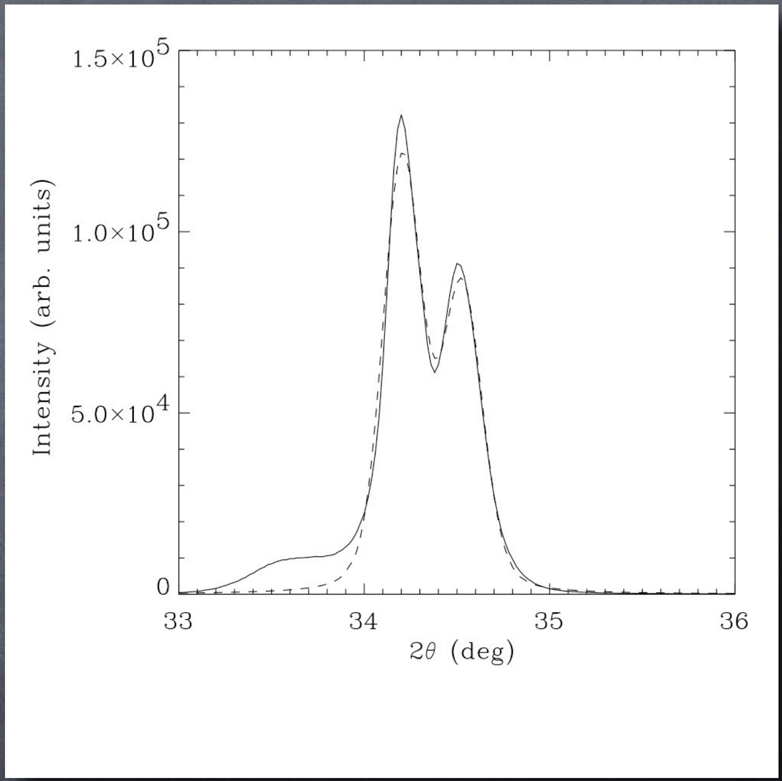
Electron Diffraction

- During growth, Reflection High-Energy Electron Diffraction (RHEED) is used to monitor growth surfaces

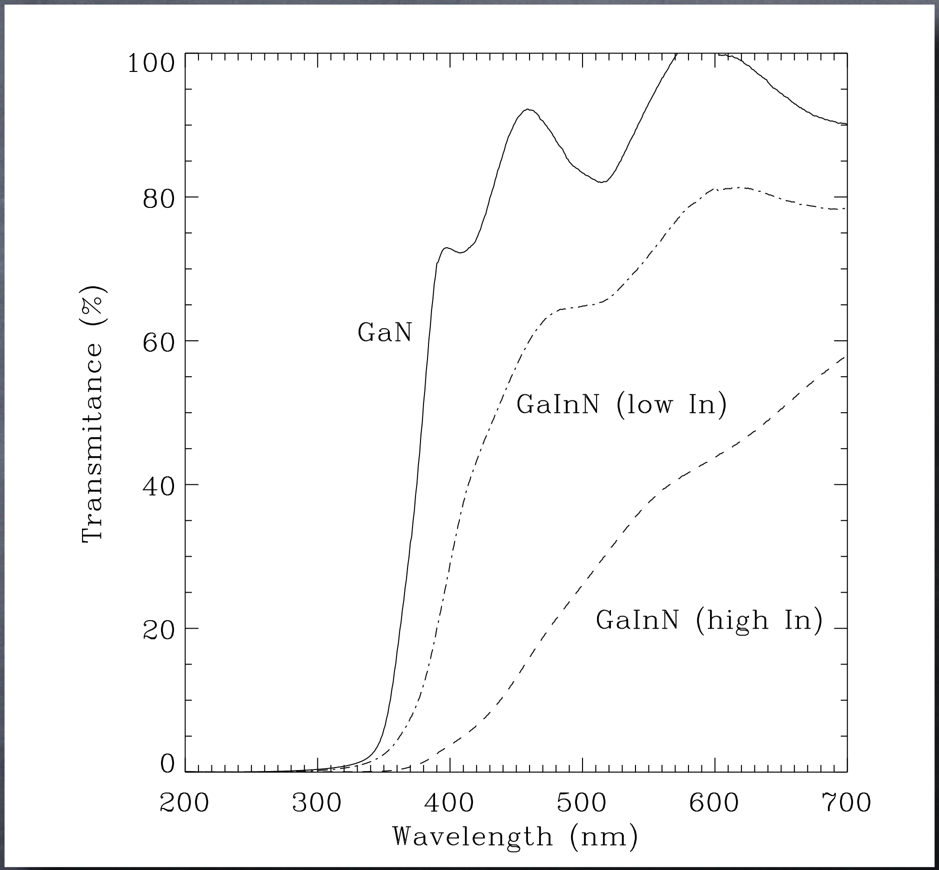


X-ray Diffraction



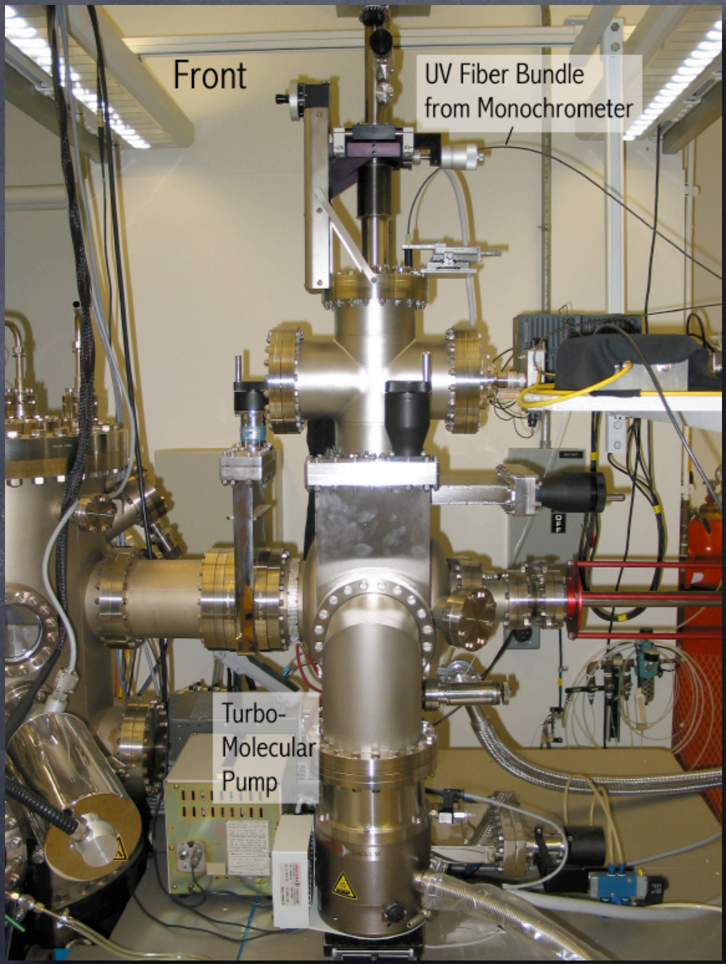


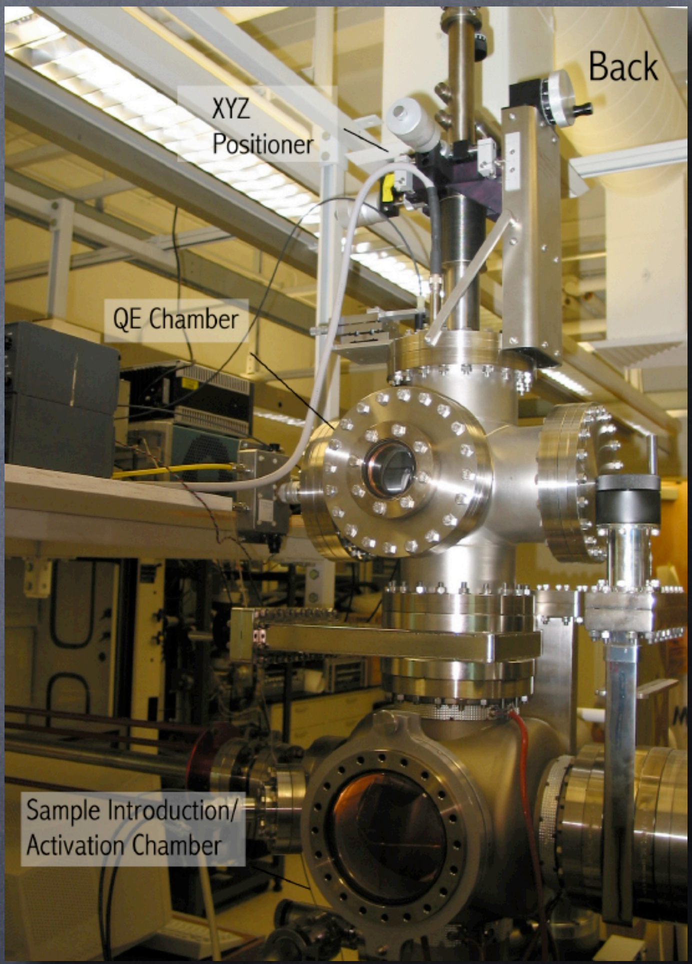
Optical Transmission



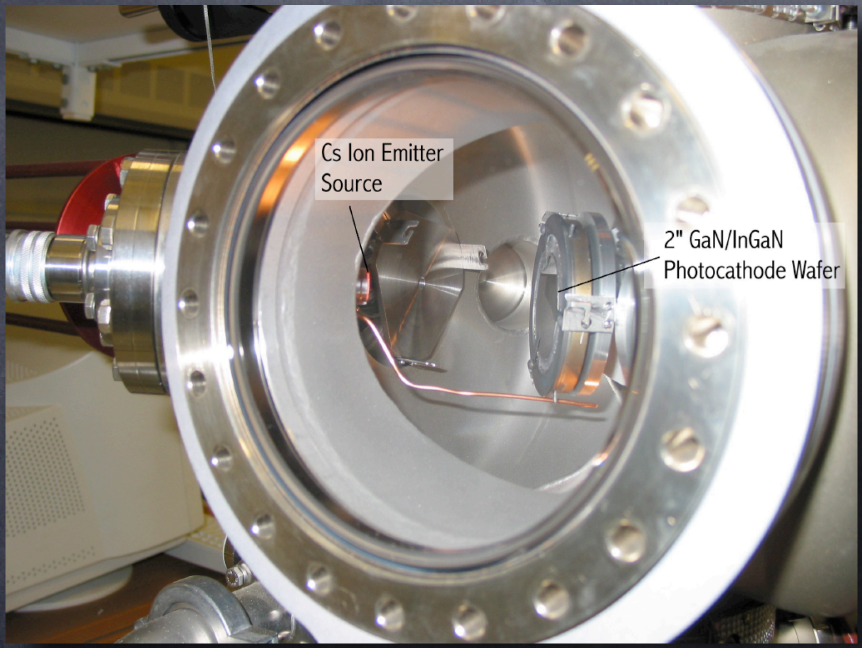
- Alloying with In shows a shift to larger wavelengths (smaller bandgap)

QE Measurement System

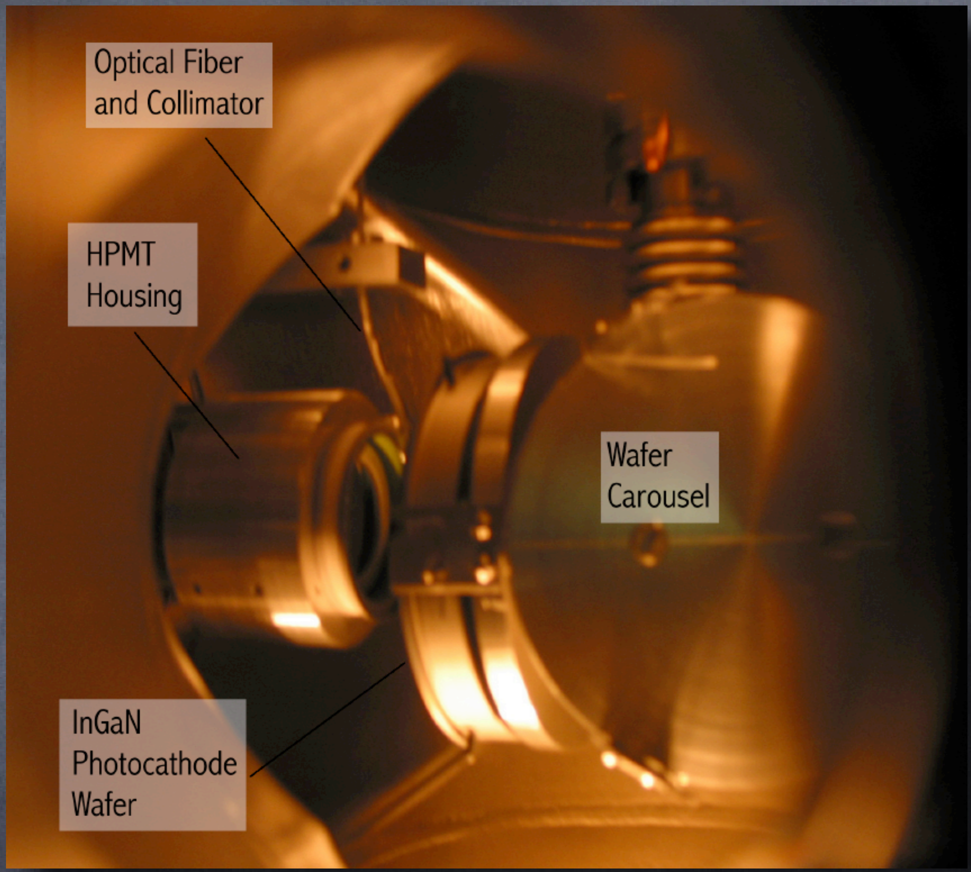




Cesium Activation

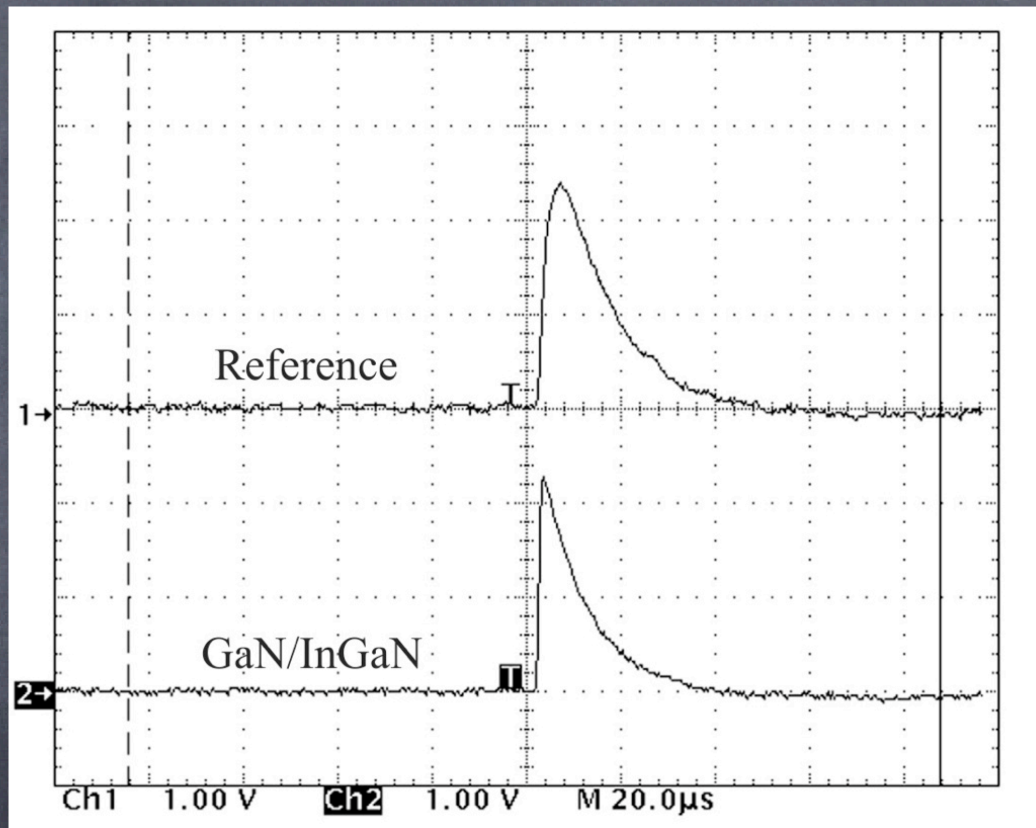


QE Measurement System



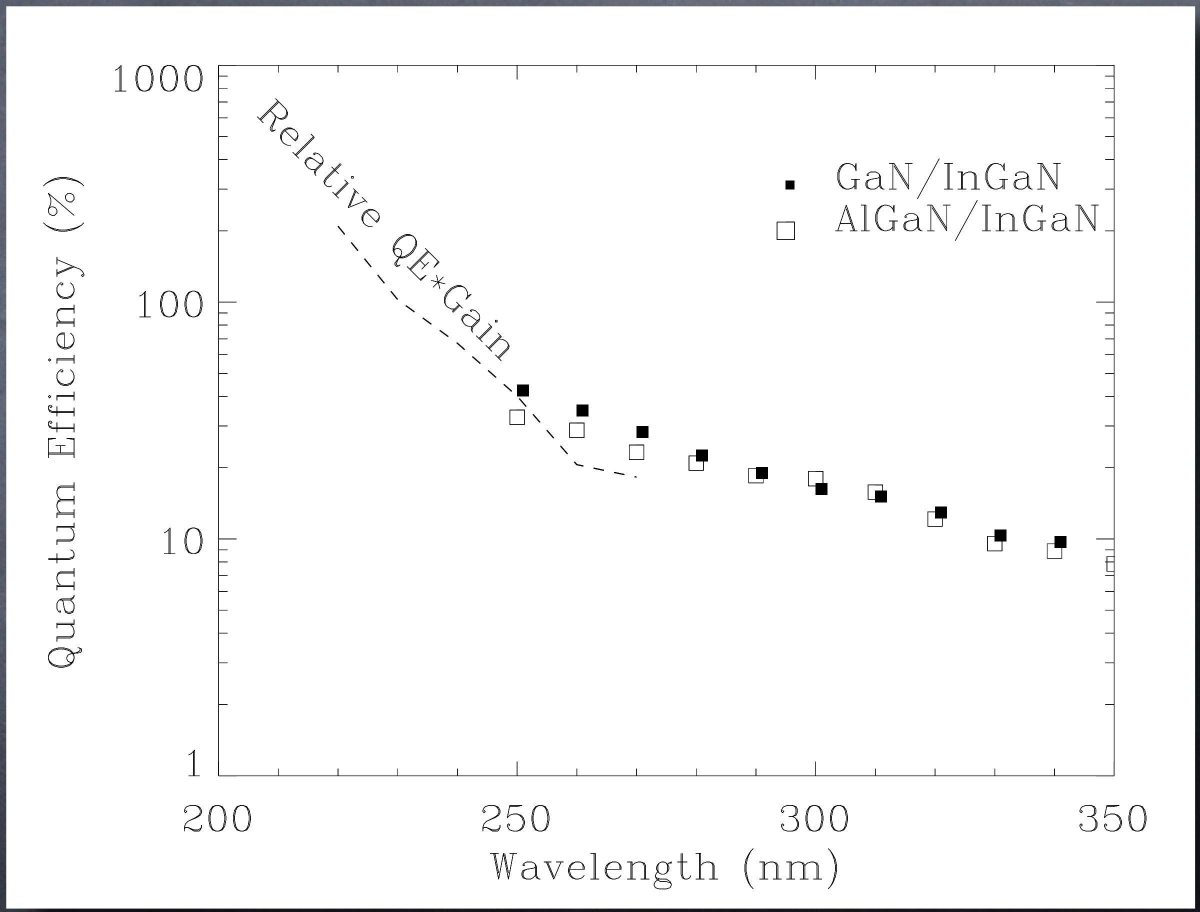
- Hybrid phototube with 7-pin photodiode array, and two independent HVs for gain and cathode bias
- UV-fiber coupled signal from monochromatic pulsed light source

Quantum Efficiency

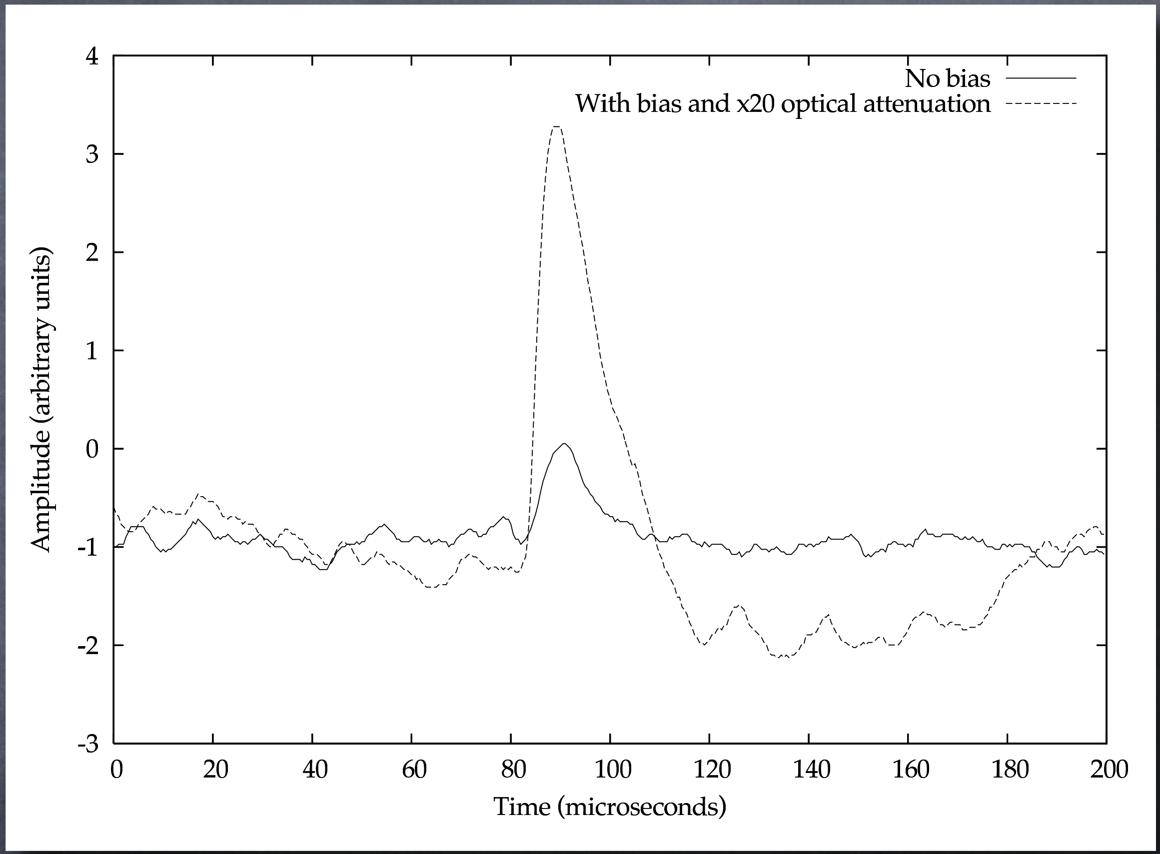


- Electronic pulses from HPMT pin diode and reference photodiode registered by low-noise-amplifier electronics.

QE Wavelength Dependence

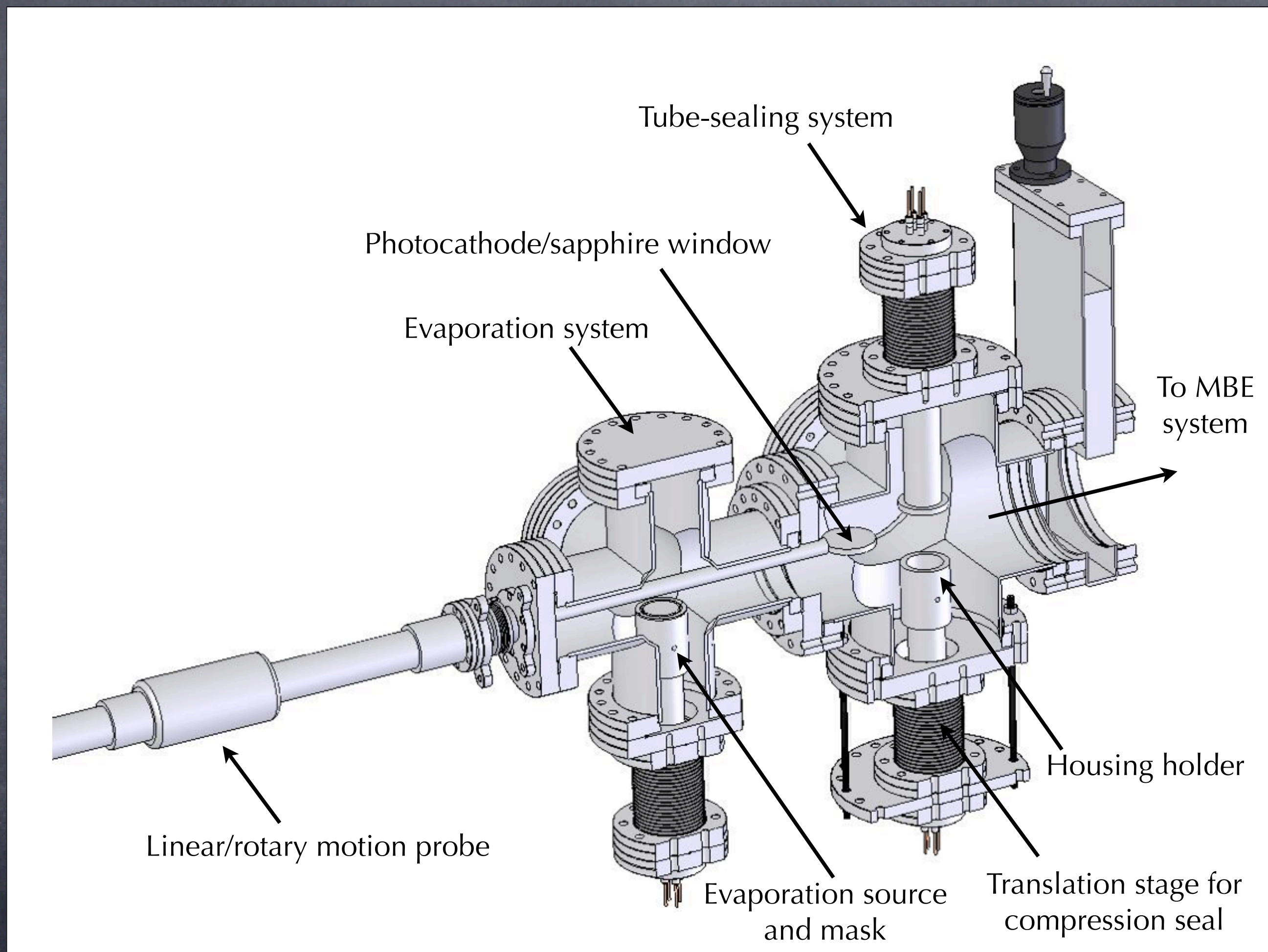


Voltage Bias

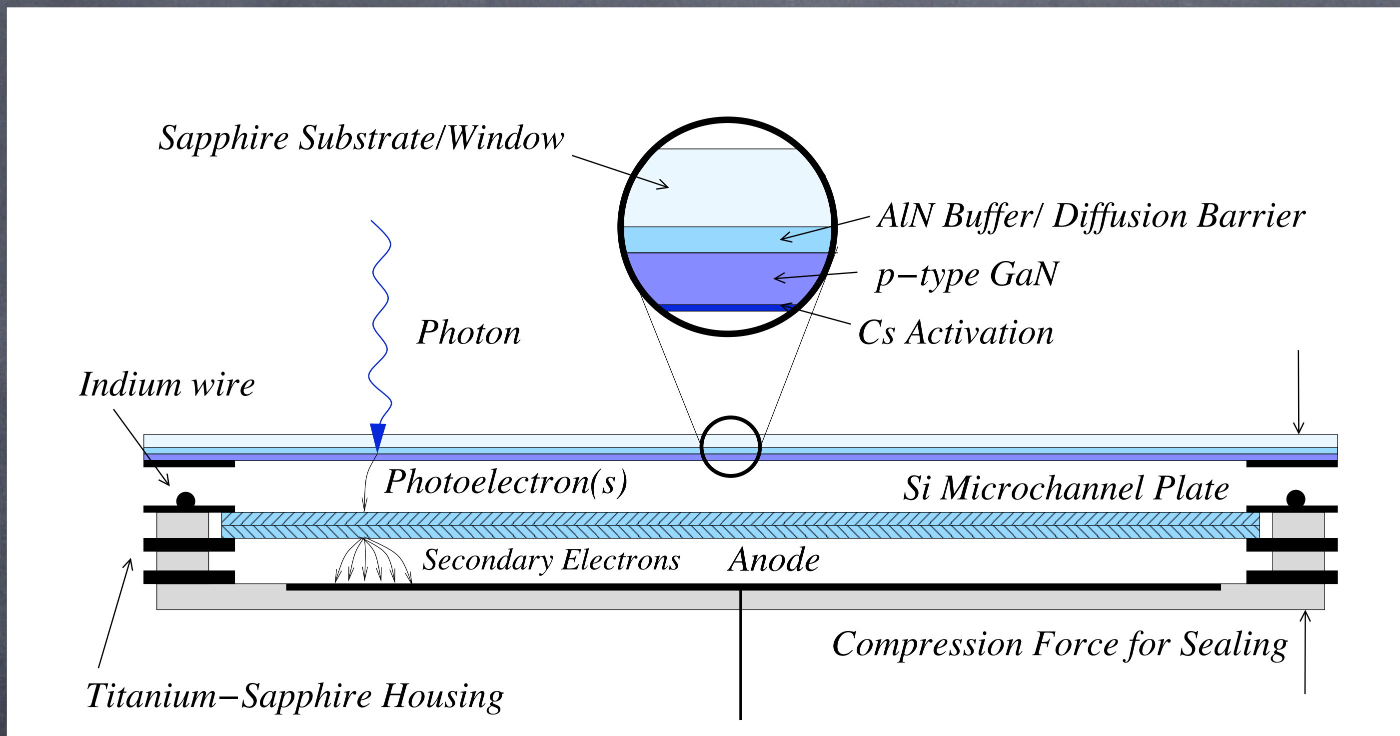


- Pulse signal with and without electrical bias applied across cathode surface.
- Applied voltage gain to aged surface results in a dramatic improvement in the gain-QE product.

Tube-Sealing System

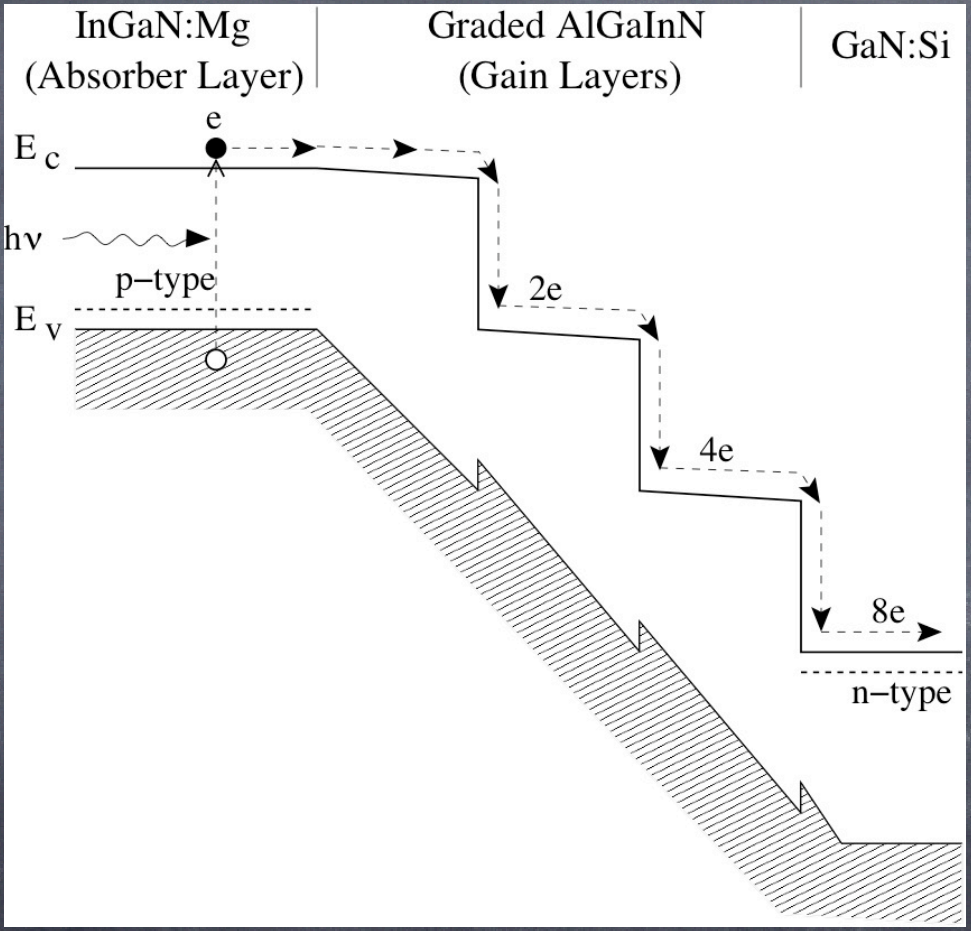


MCP PMT Concept



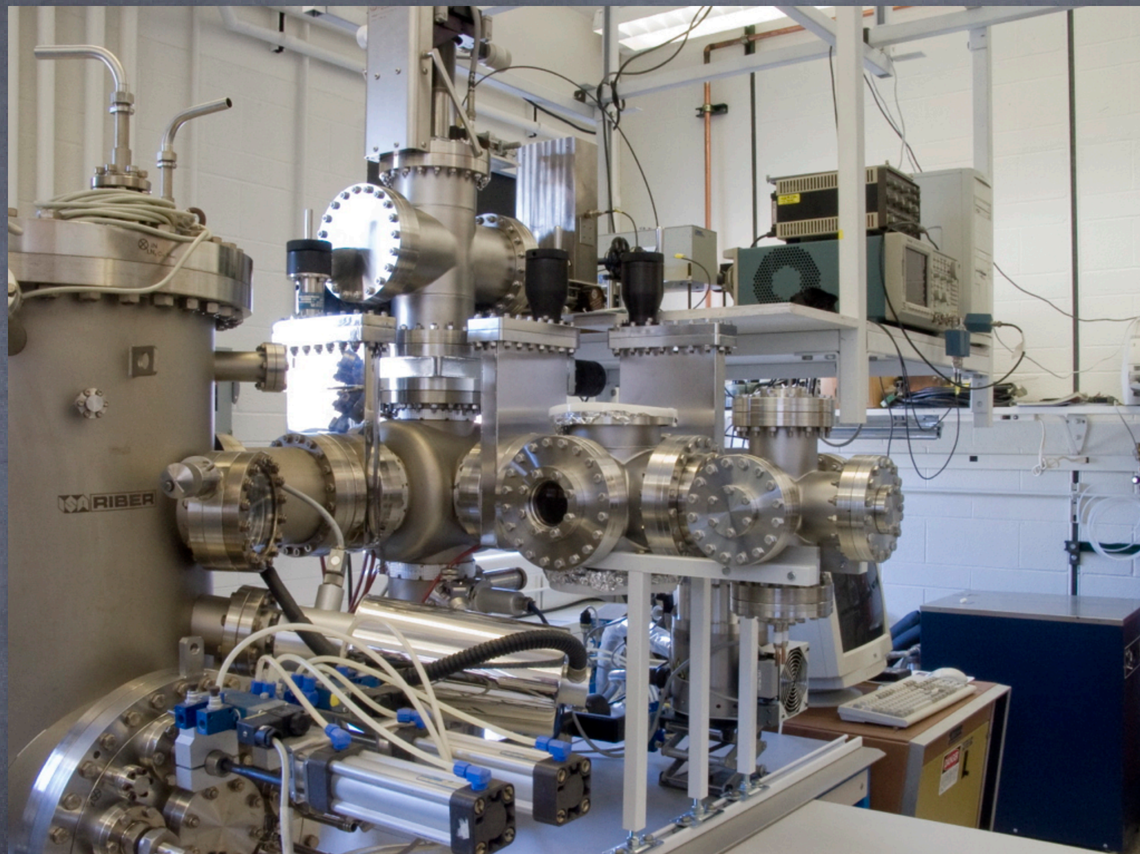
- Working with Yale and Fairfield U. groups, working on novel devices incorporating Si MCPs and high-QE cathodes.

Internal-Gain Device Concept



- Energy band-edge profile of photocathode heterostructure with discrete gain stages

Status



- Construction of tube-sealing system
- Developing methods for in-situ VUV calibration
- New methods for cathode transfer (restoring aged surfaces)

Summary

- Semiconductor nitride heterostructures look very promising as photocathodes specifically tailored in the UV/blue wavelength range.
- Possiblity exists for devices with internal gain.
- Hard UV quantum efficiency can be extended with AlN alloying

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