III-V Cathodes and Sealing

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Overview

- Background of InGaN photocathode development.
- Facilities for device growth and evaluation.
- Experimental Results:
  - Epitaxial Cathodes.
  - Amorphous Cathodes.
  - Transfer/cleaning techniques.
  - Direct deposition on MCPs.
- Upgrades for tube sealing, VUV measurement.
- Future plans.

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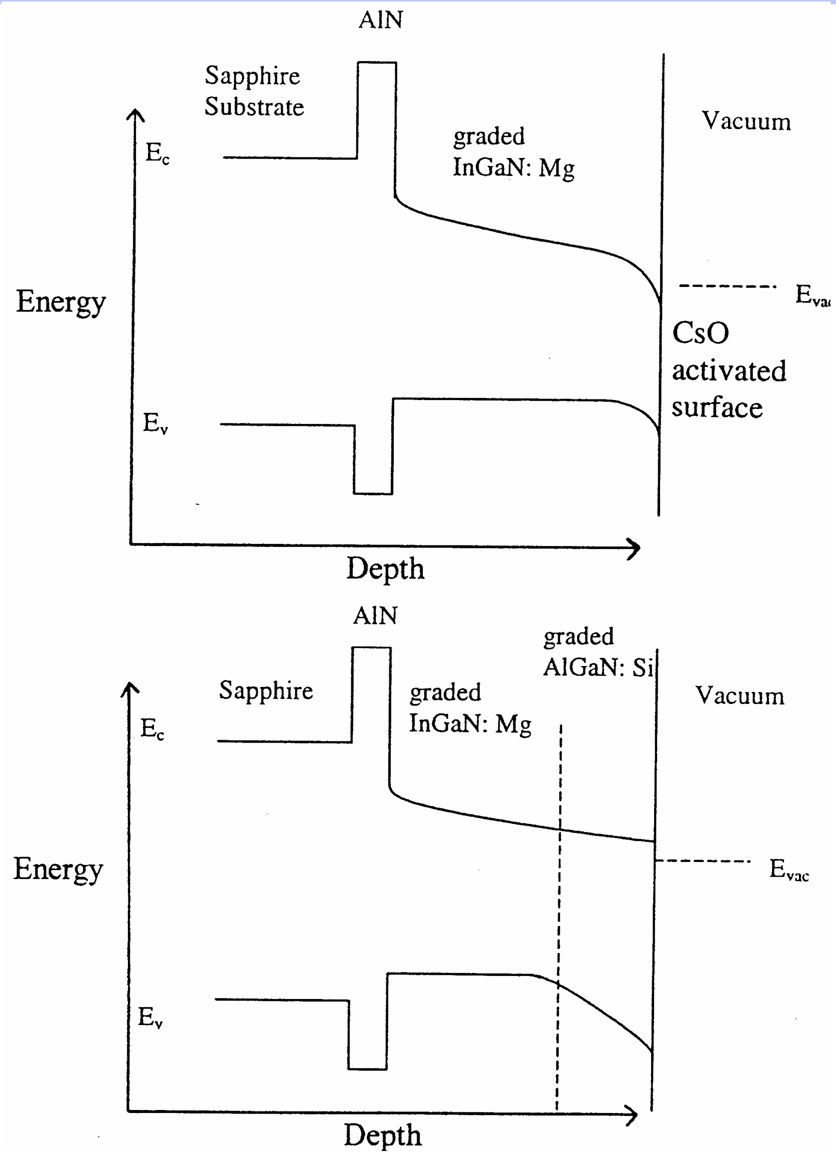
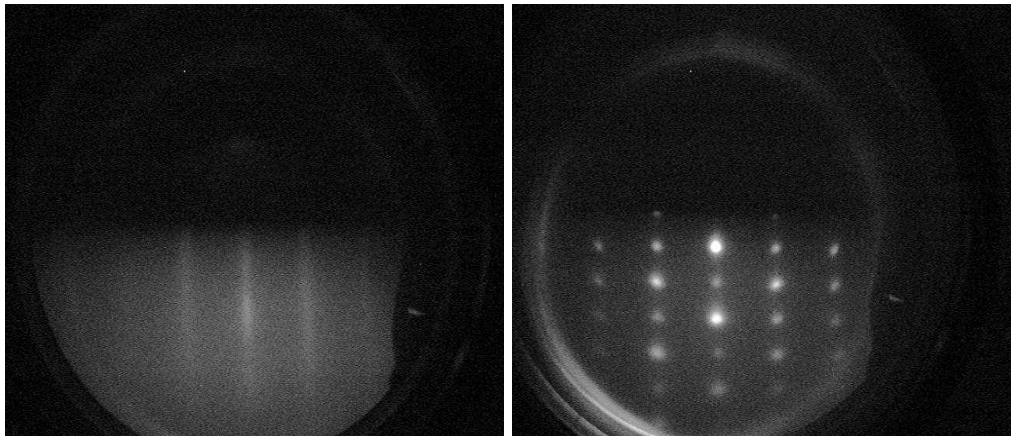
  - NMR studies show local-disorder-mode “motion” typical of glassy materials

Design Concept and Results

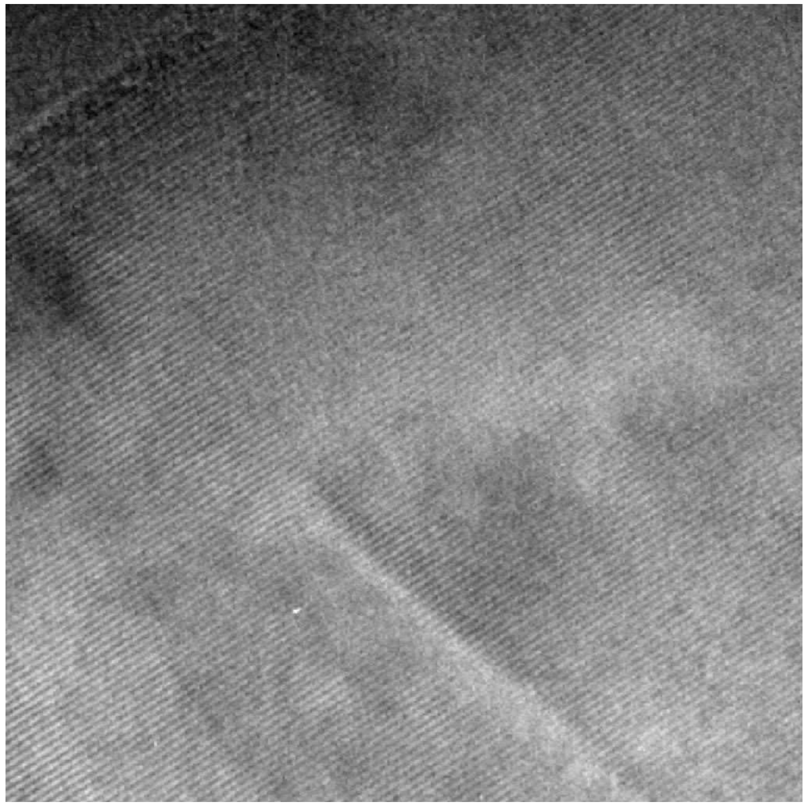
- Original design concept (1) epitaxial growth on a UV-transparent window substrate (no etch-stop and transfer as for GaAsP), (2) use of an *AlN buffer layer* for lattice matching, refractive index matching and a *reflection barrier for electrons* keeping them from defects at the wall (3) *graded composition for an internal field* to aid mobility, (4) *in-situ* Cesation (5) alloying with *Indium to reduce bandgap*



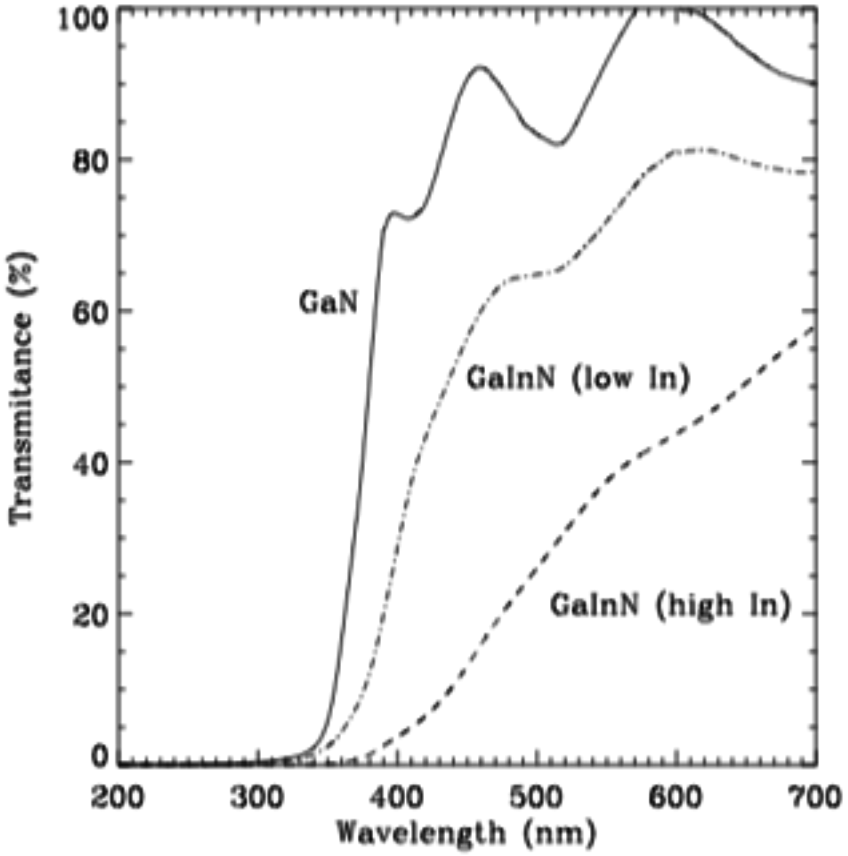
Band structure concept for 1998 Proposal



RHEED images from growth optimization



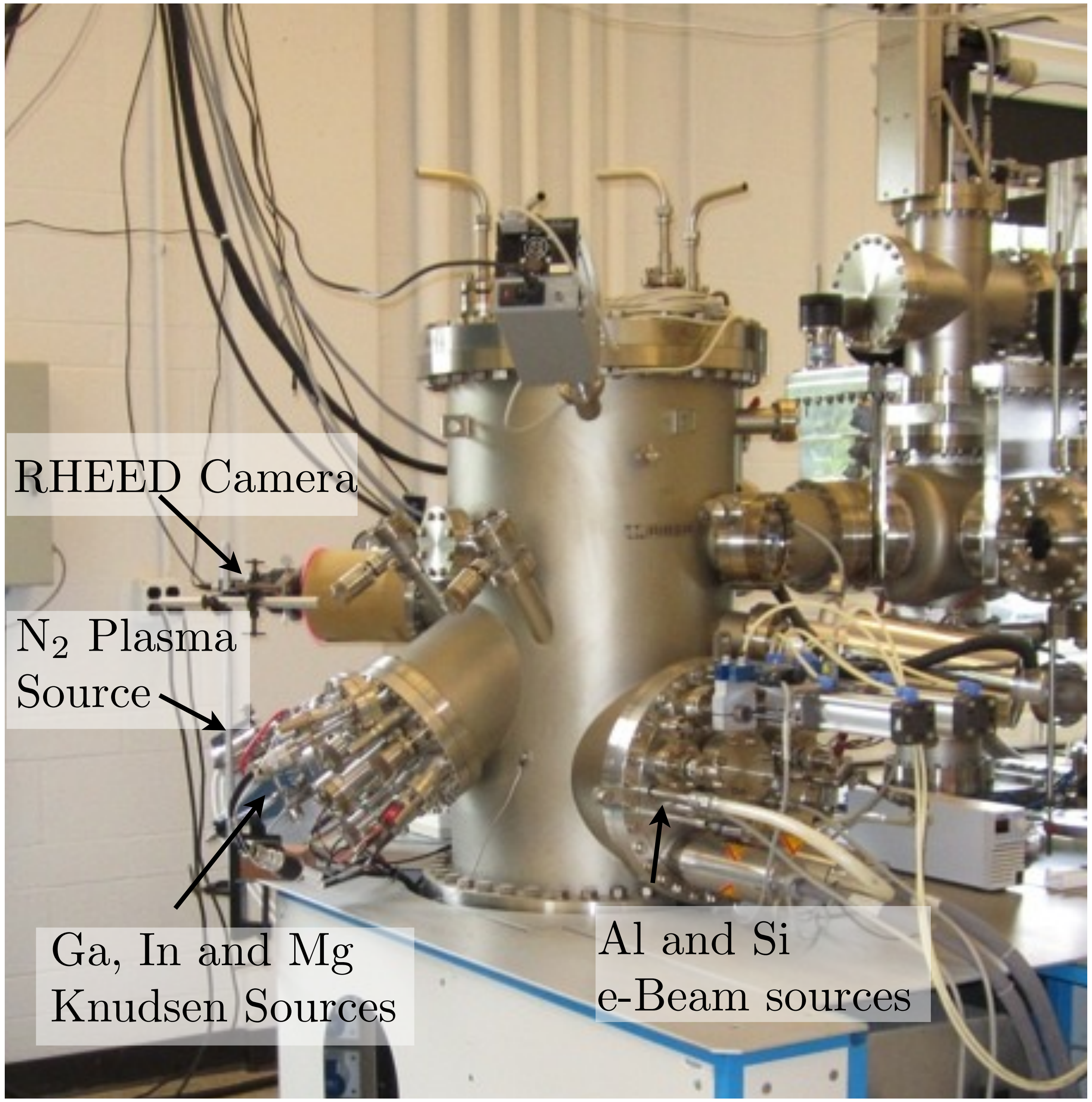
TEM image of WU GaN/InGaN structure grown on c-plane sapphire



Demonstration of shift in band structure by alloying with In

MBE Growth System

- MBE utilizes a UHV growth chamber with a rotating, heated substrate and shuttered effusion sources (Ga, In and Al) as well as a Nitrogen plasma source for epitaxial growth of InGaAlN.



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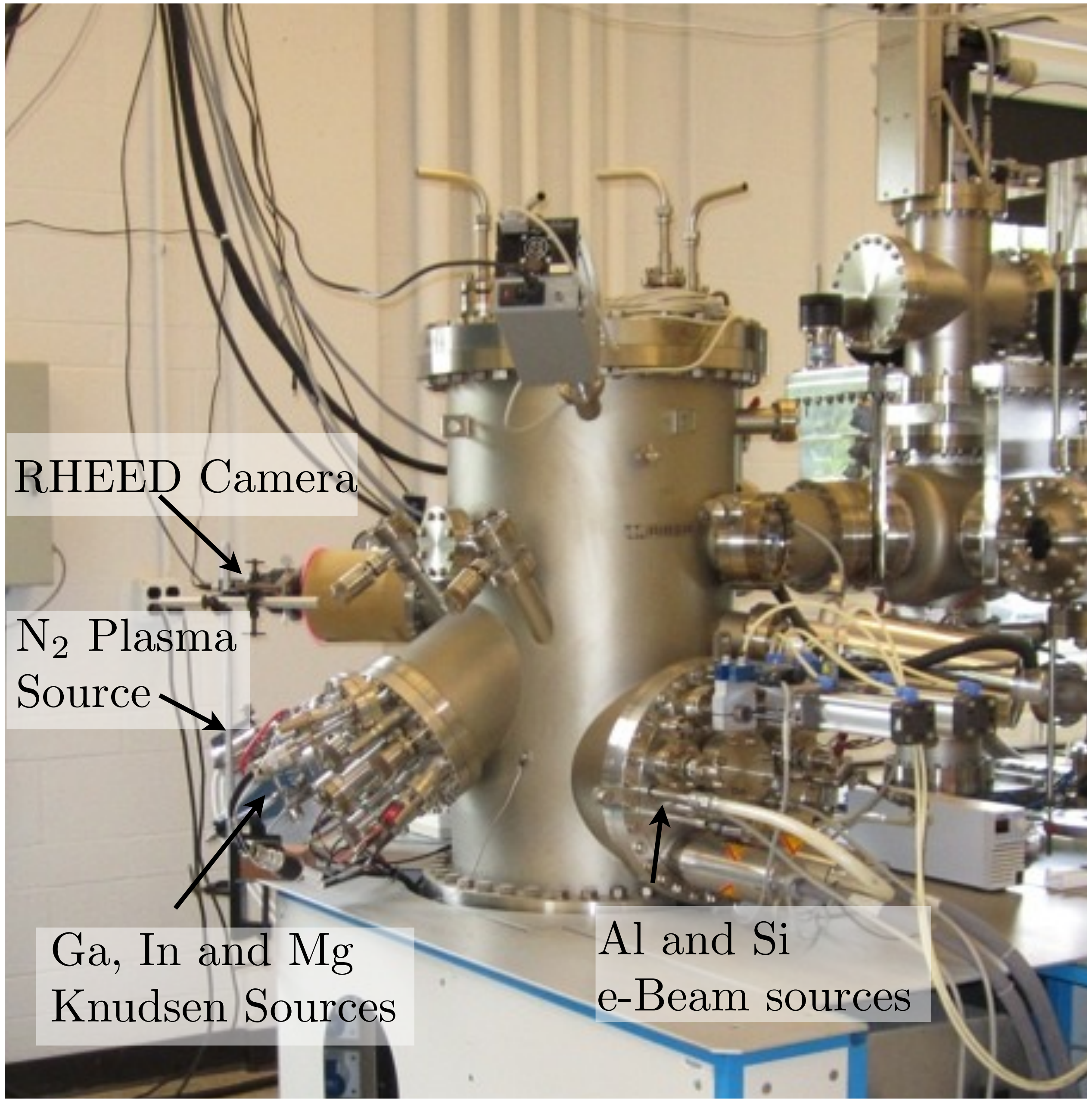
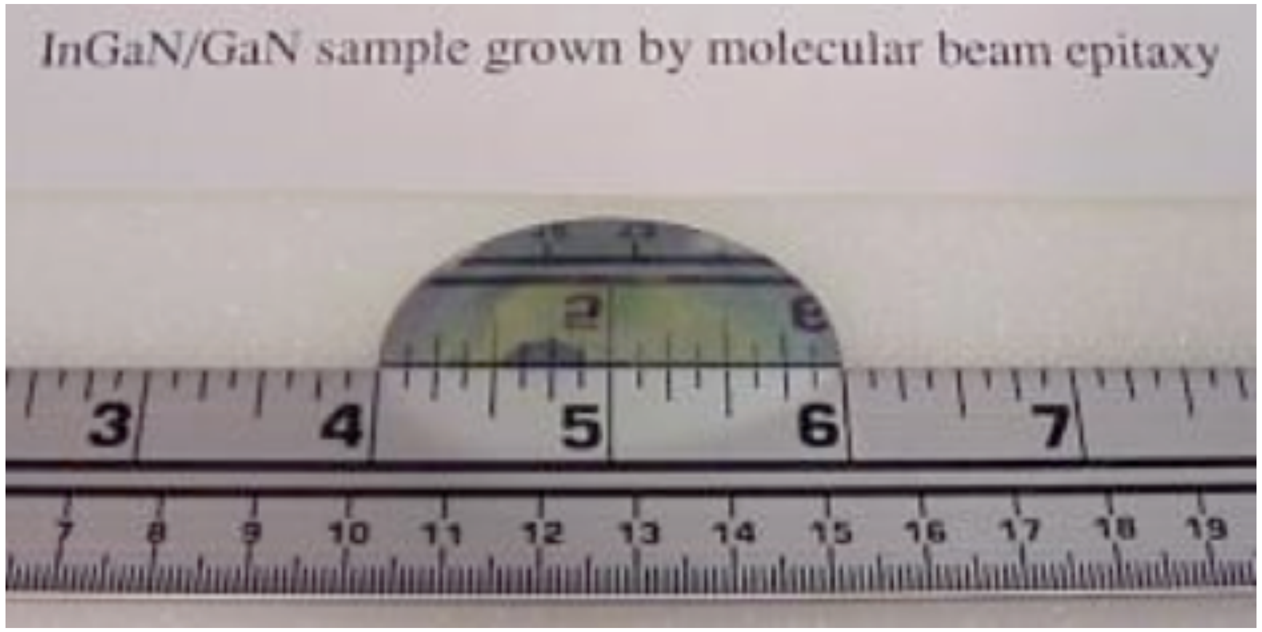
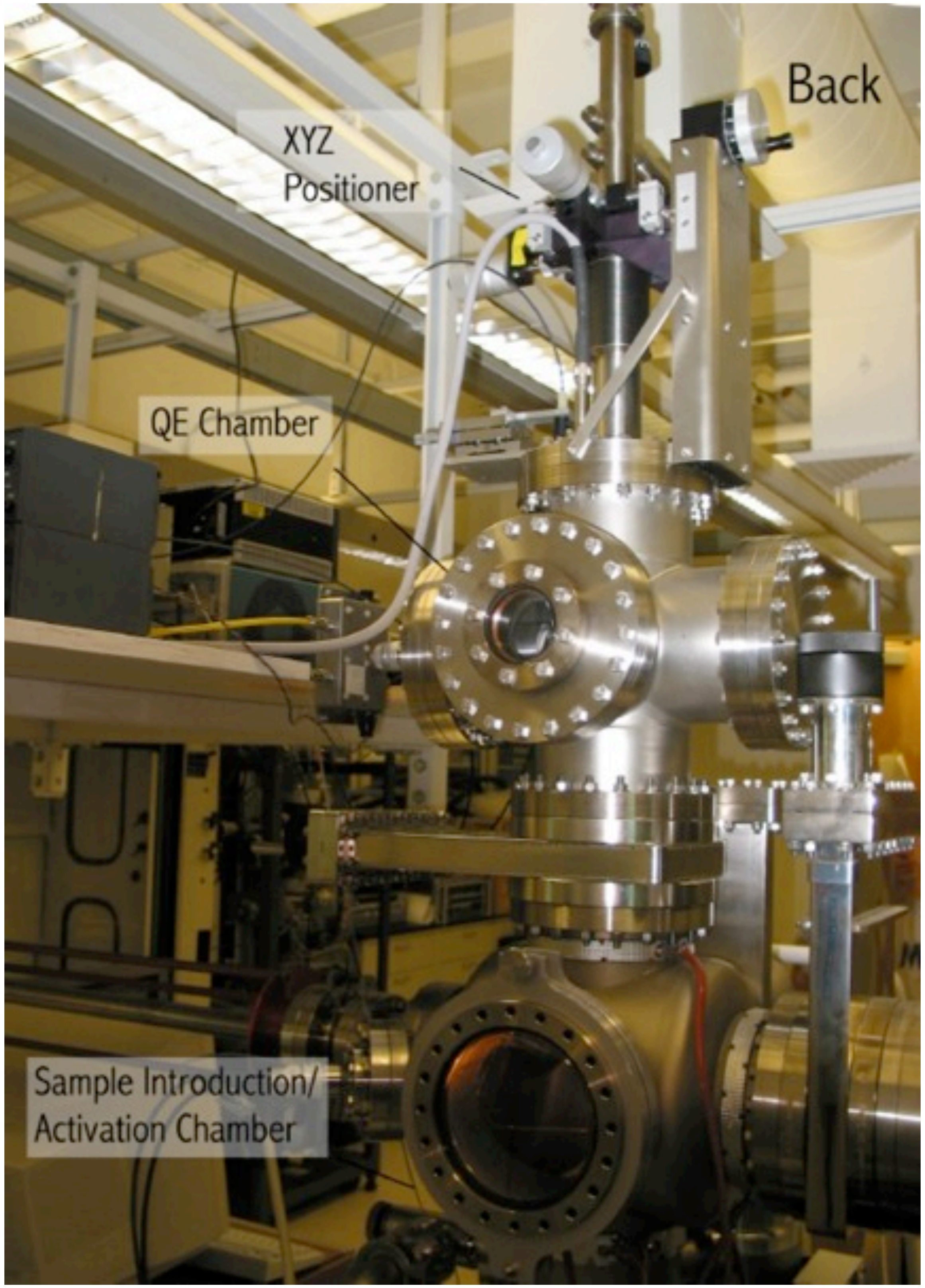




Our system currently has the capability of growing wafers up to 3 inch in diameter

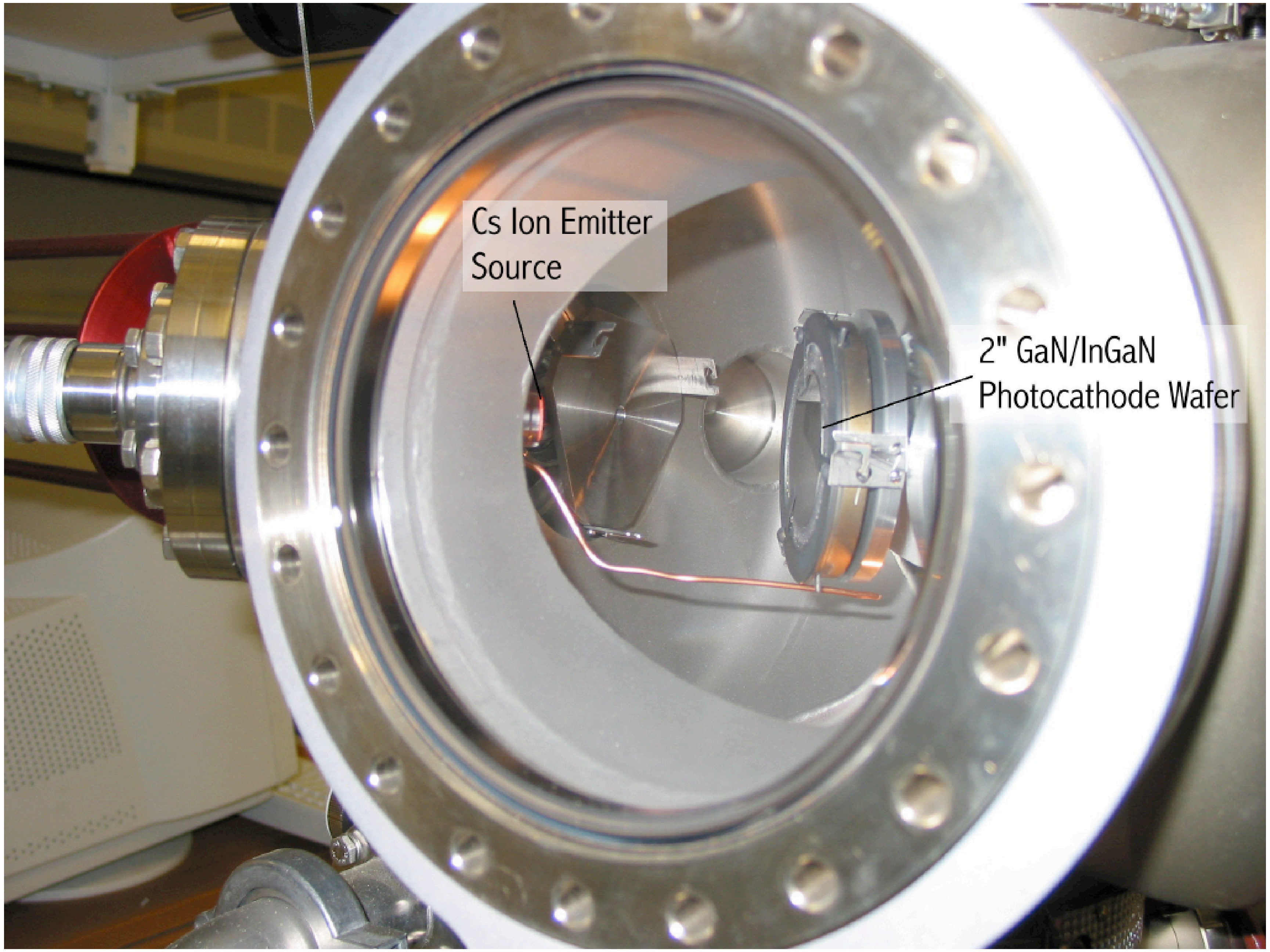
Activation and QE Measurement System



- WU system includes a number of vacuum transfer stages for in-situ Cs activation, docking with electron multipliers and readout electronics as well as in-situ QE measurements.

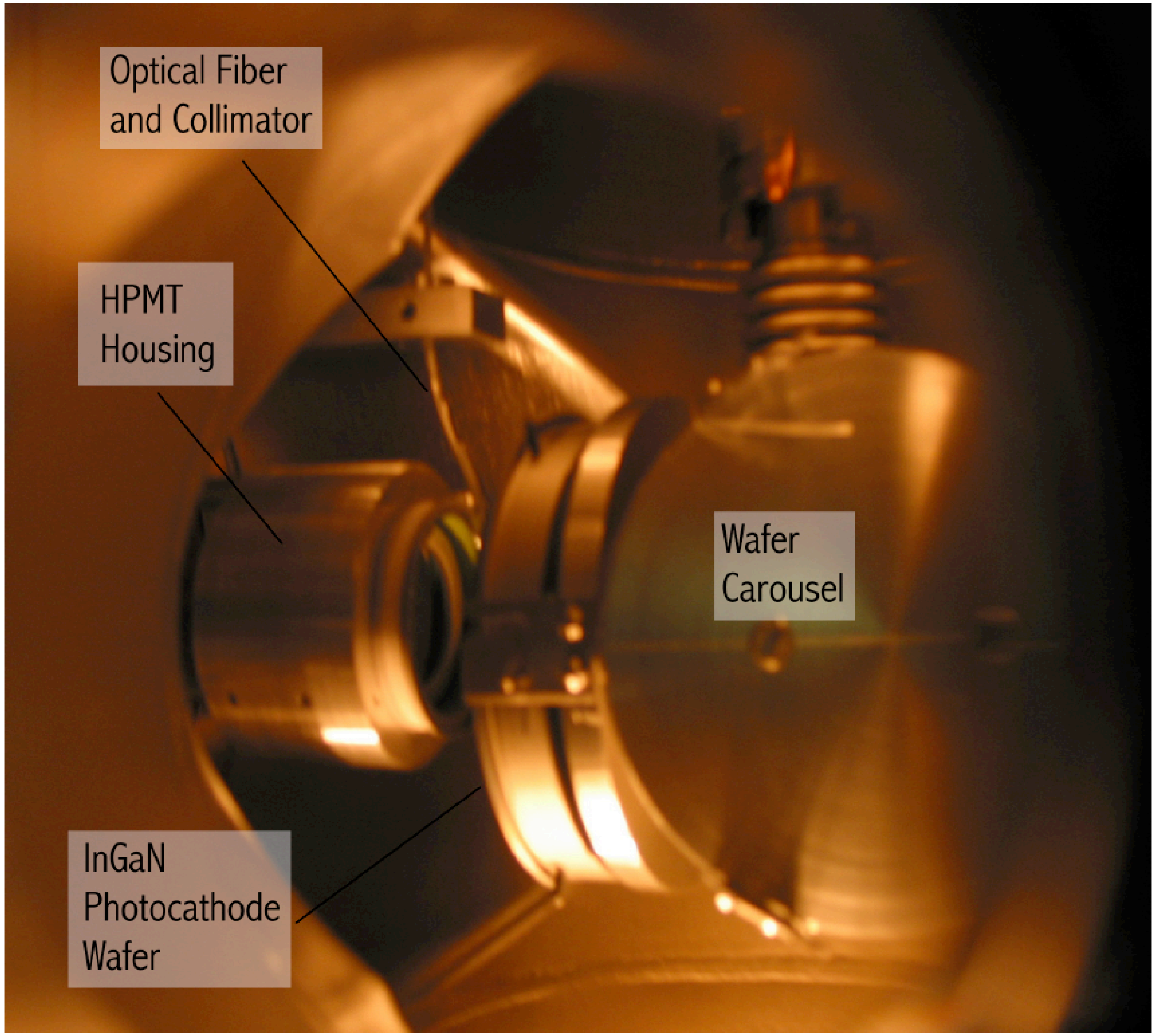
- *Unique UHV transfer capability for cathode growth, device integration and testing without removing from vacuum*

Cesium Activation



- Ion-beam source for Cs activation. Cs exposure monitored by Ion current

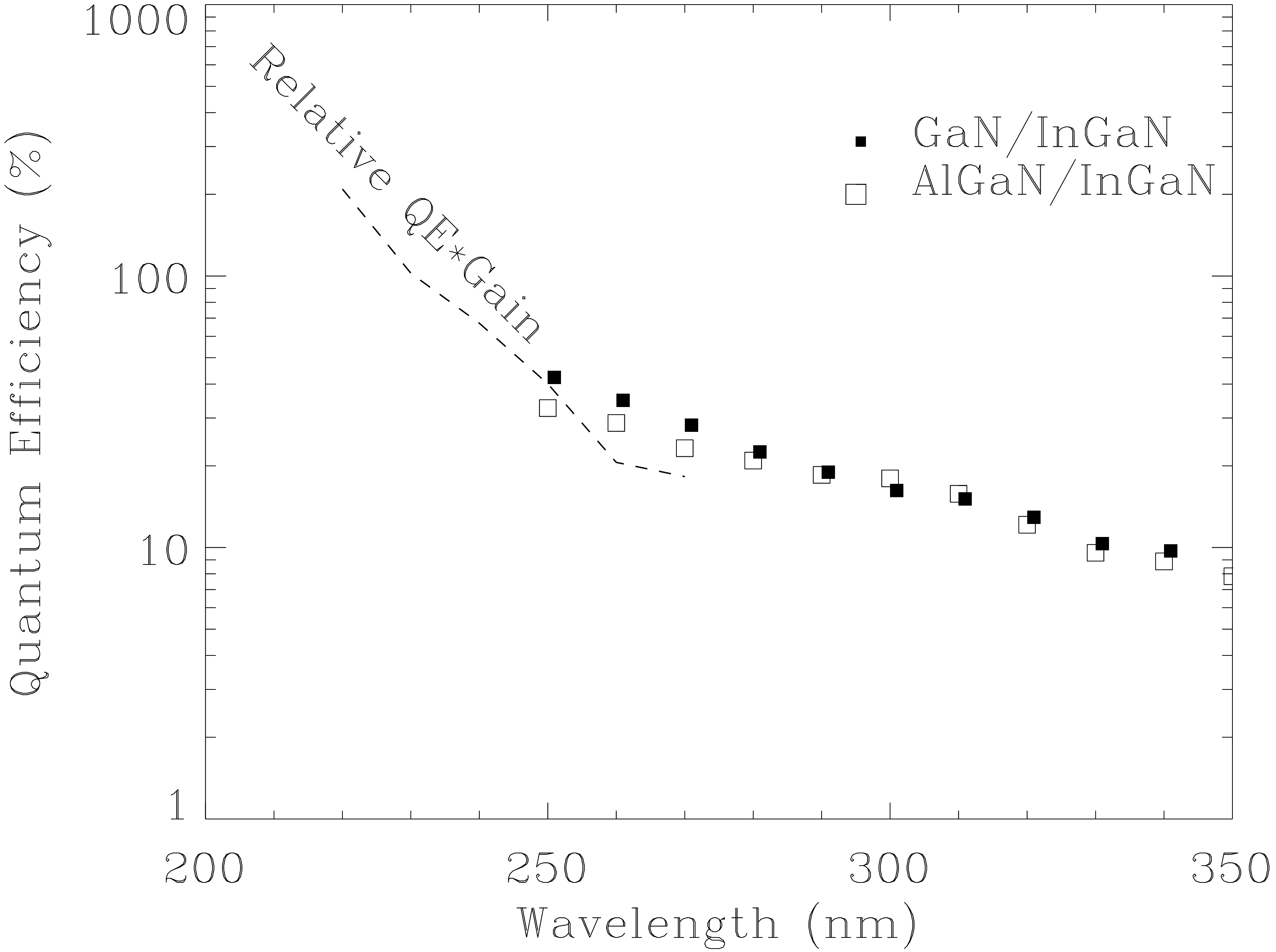
QE Measurement System



- Hybrid phototube with 7-pin photodiode array, and two independent HVs for gain and cathode bias. External low-noise preamplifier and data acquisition system connected by vacuum feedthroughs.

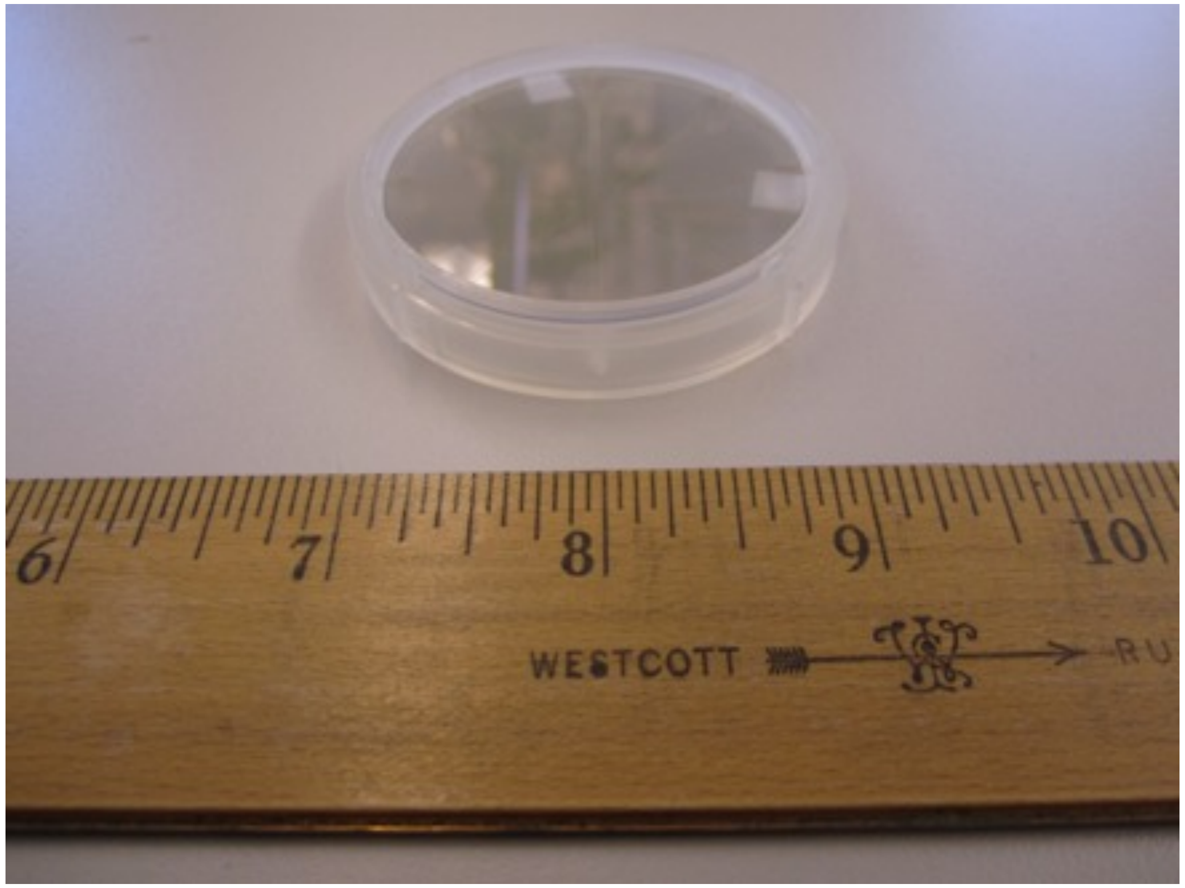
- UV-fiber coupled signal from monochromatic pulsed light source.

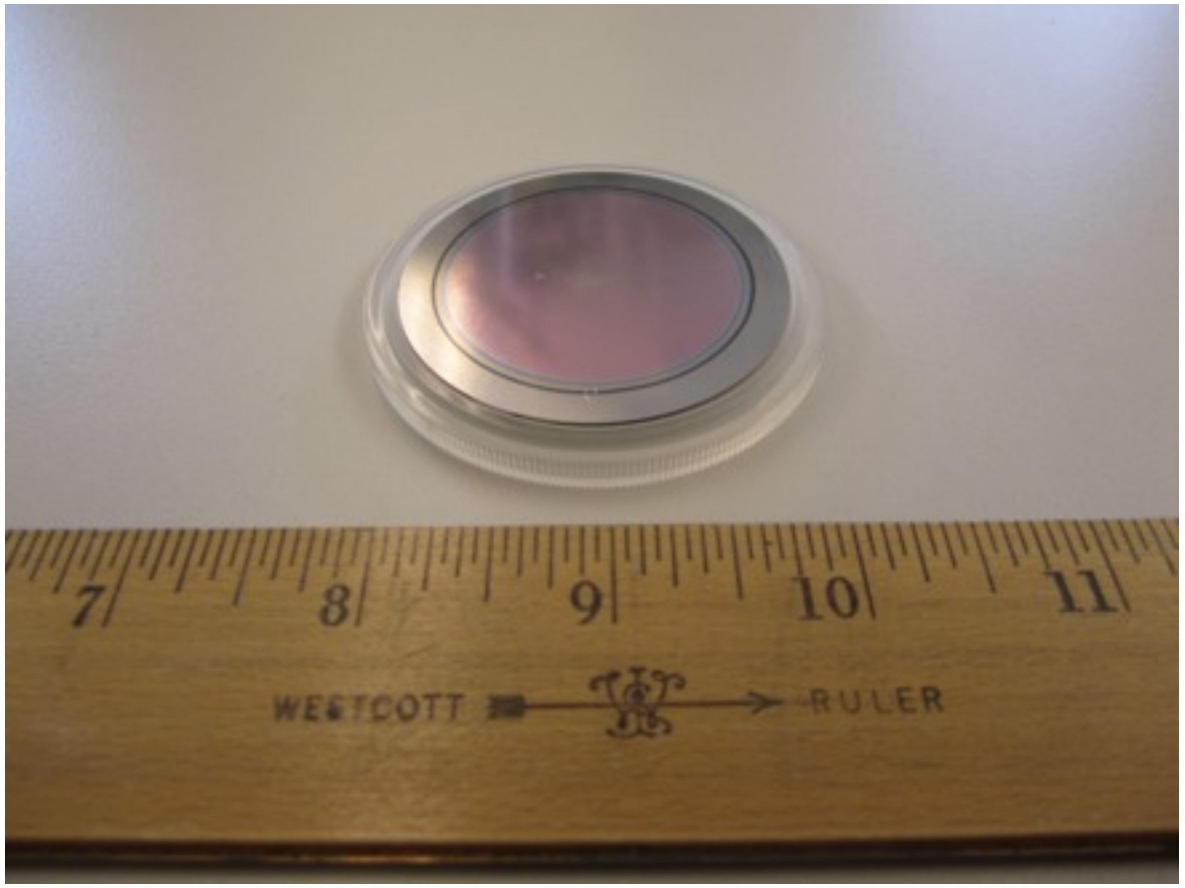
Epitaxial Photocathode QE



- Epitaxial cathode heterostructures demonstrated ~40% QE at 250 nm, rising at shorter wavelengths where our system lacked a hard UV calibration.

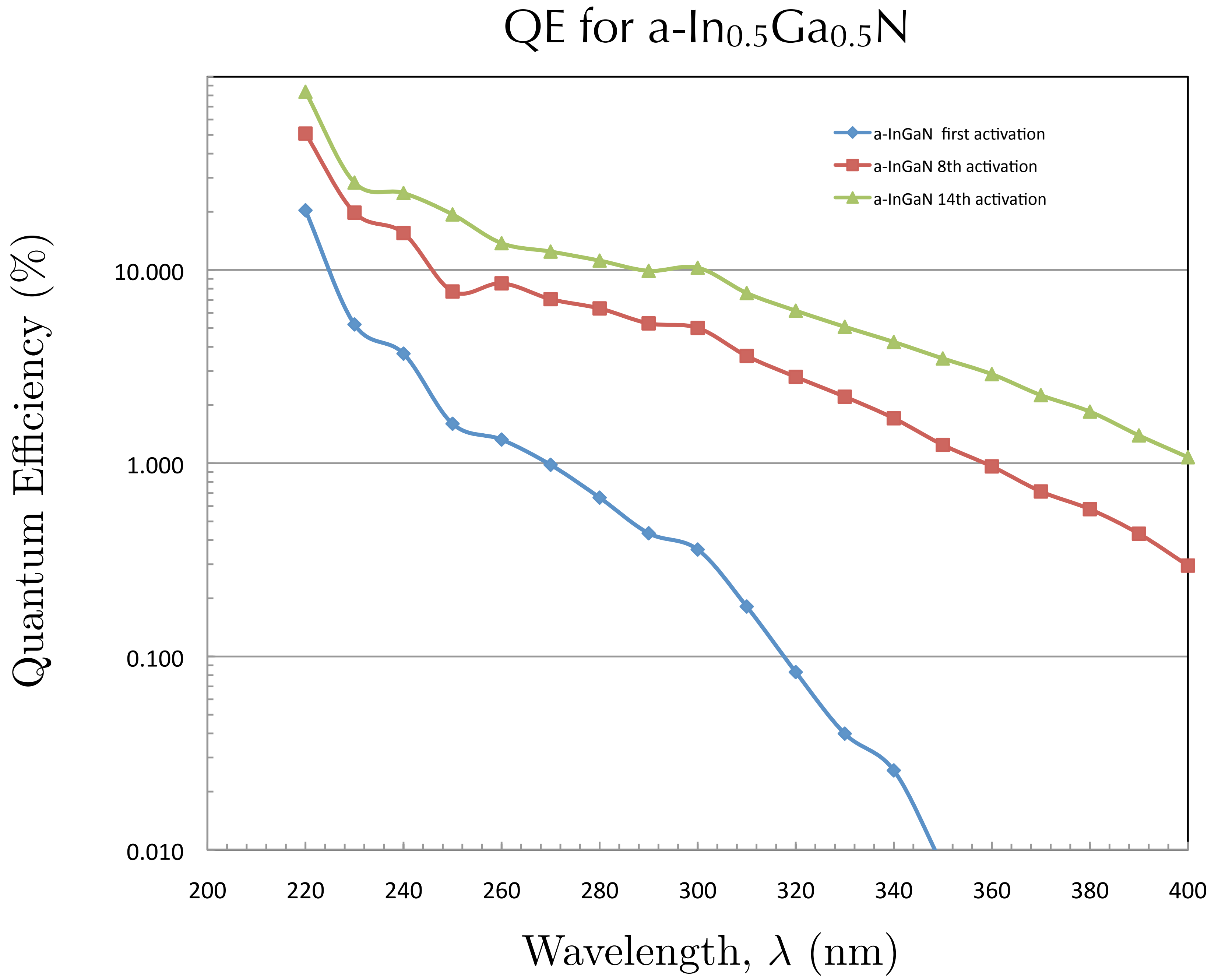
Amorphous InGaN Cathodes





- We have grown amorphous InGaN on sapphire (left) and on stainless steel (right)
- Now have the capability to grow efficient cathodes at low temperature on a variety of substrates.

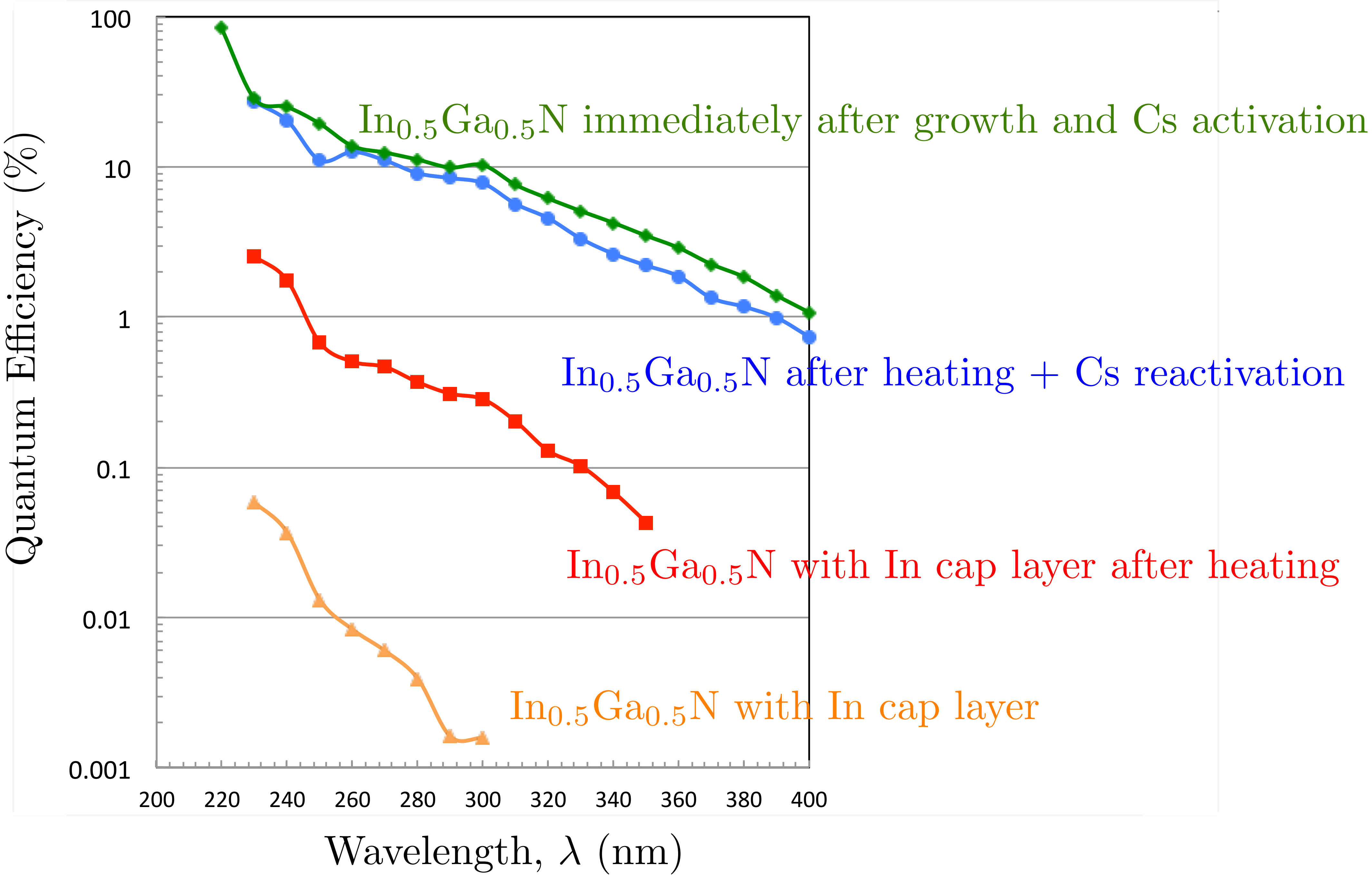
Amorphous Cathode QE



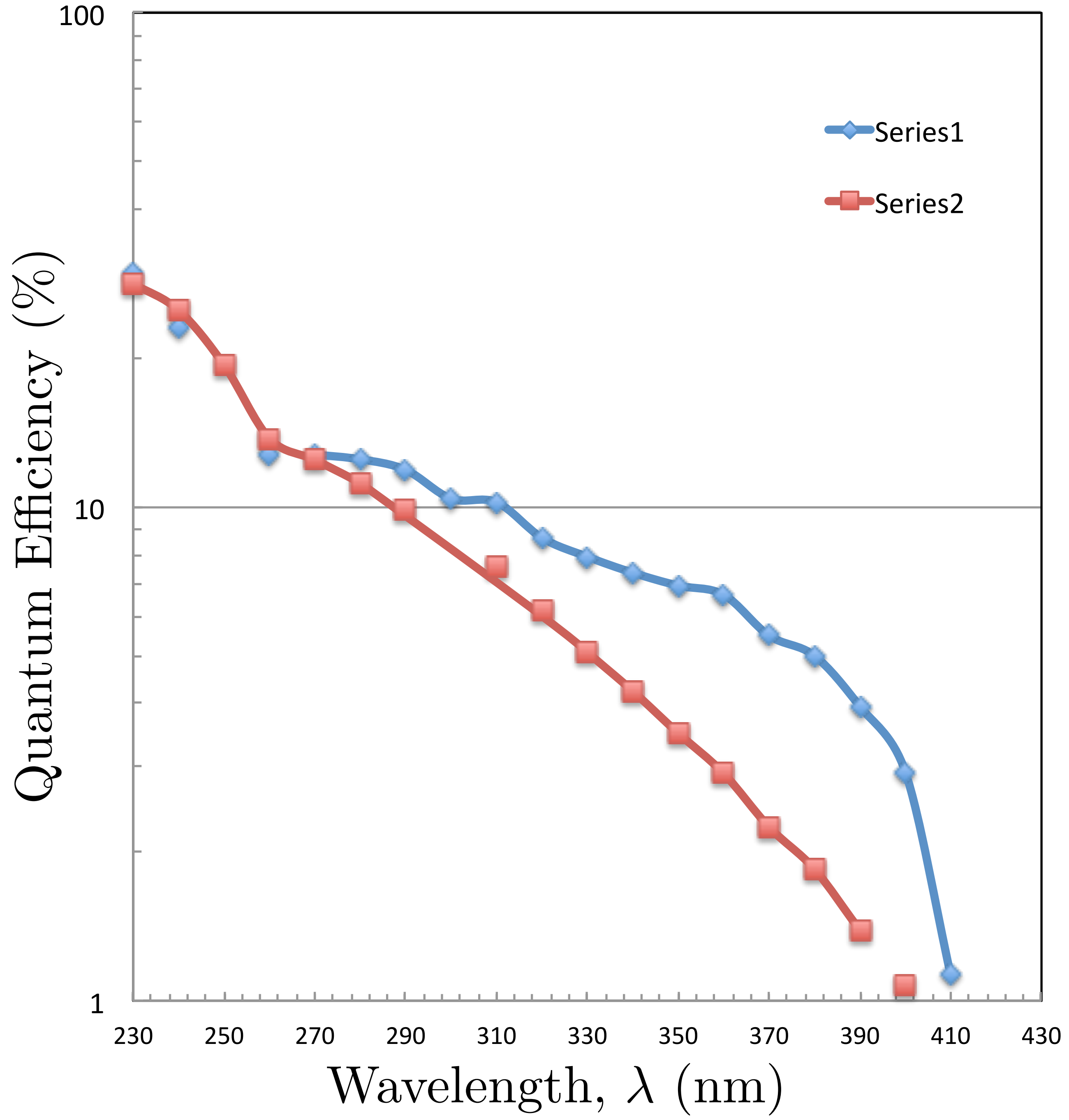
- With repeated Cesation, a-GaN cathodes reached a high QE (comparable to epitaxial cathodes)
- Final devices were robust, showing little degradation with time.

``Indium Capping'' Transfer

- Capped cathode was exposed to air (no bag or hermetic container) for several months, then capping stripped off with heat. Changes in QE through process are shown below:

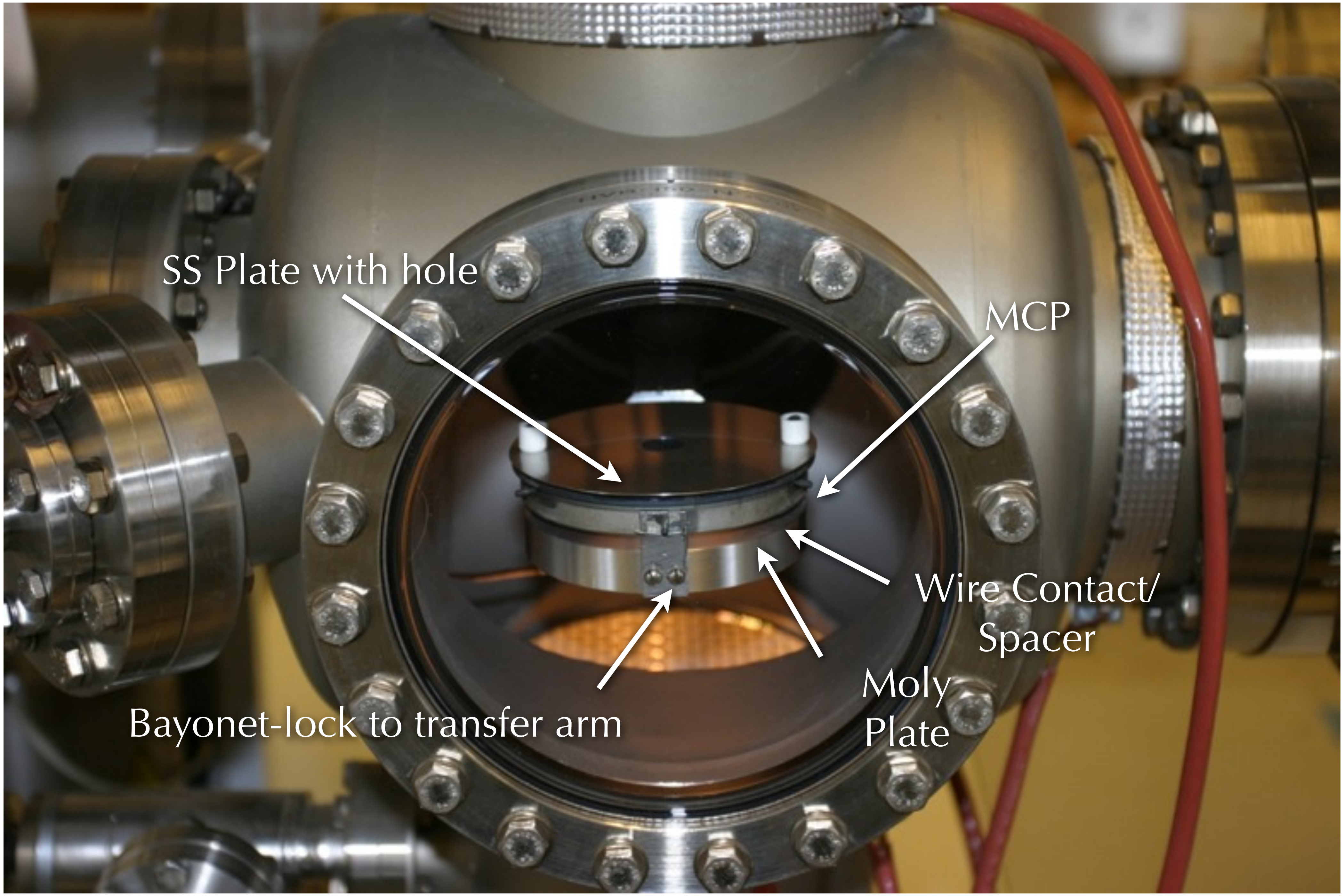


Materials Optimization for Longer Wavelengths



- Recent results from ongoing optimization shows improvements in longer wavelength response.

33mm MCP in MBE System



- Developed holder for ALD-coated MCP for a-GaN cathode deposition, Cs activation
- Modified existing HV feedthroughs to allow biasing MCP, current measurement, and pused-signal detection from anode plate

Gain and QE measurements of MCP

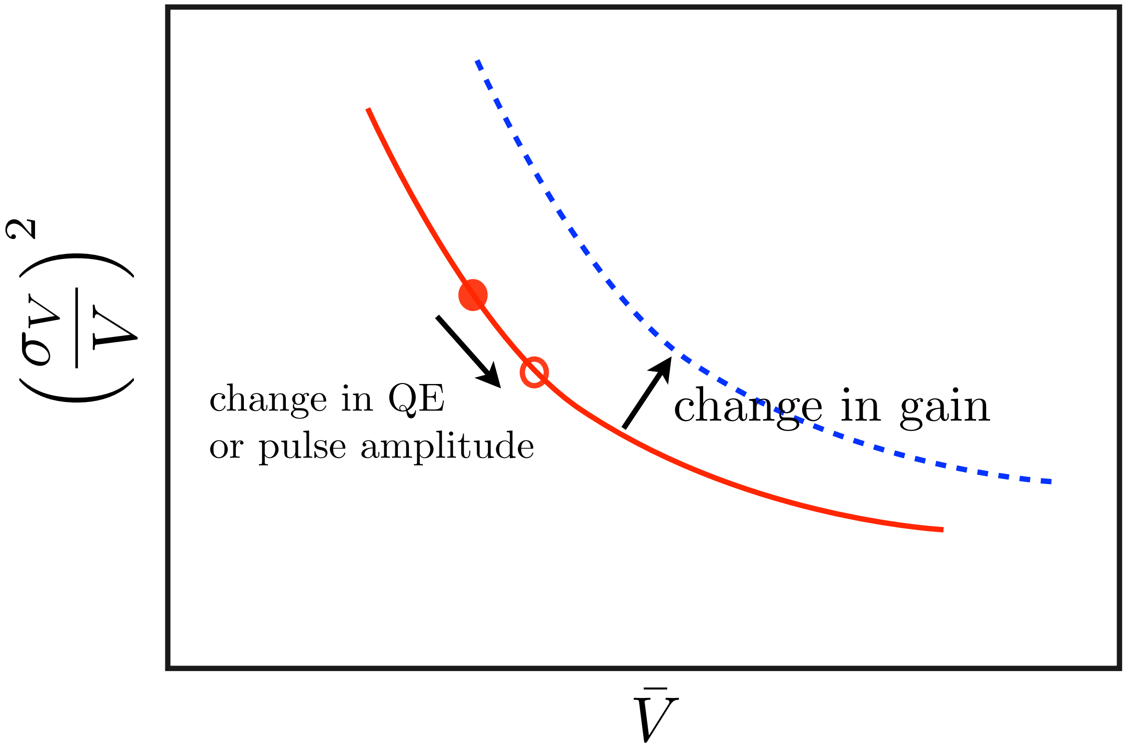
- Developed method to separate changes in gain from changes in QE

(from Senior Thesis by WU undergrad David Goldfinger)

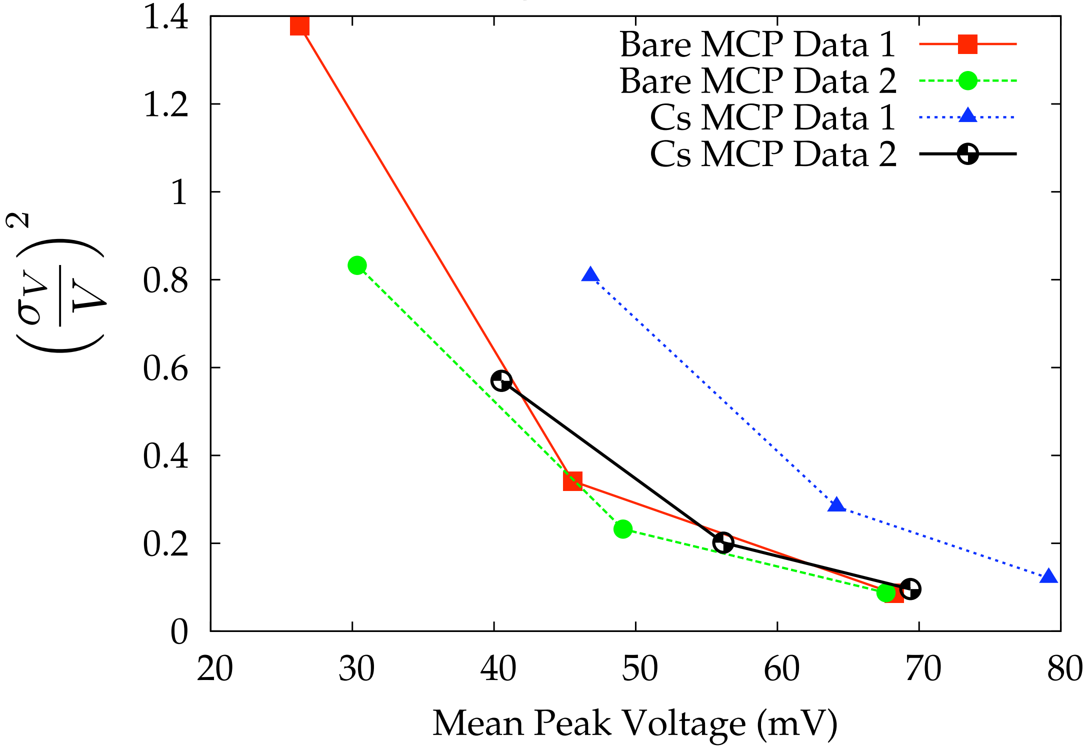
$$\frac{\sigma^2_{V_{pk}}}{V^2_{pk}} \approx \frac{1}{N_{pe}}$$

$$V_{pk} = g N_{pe} e$$

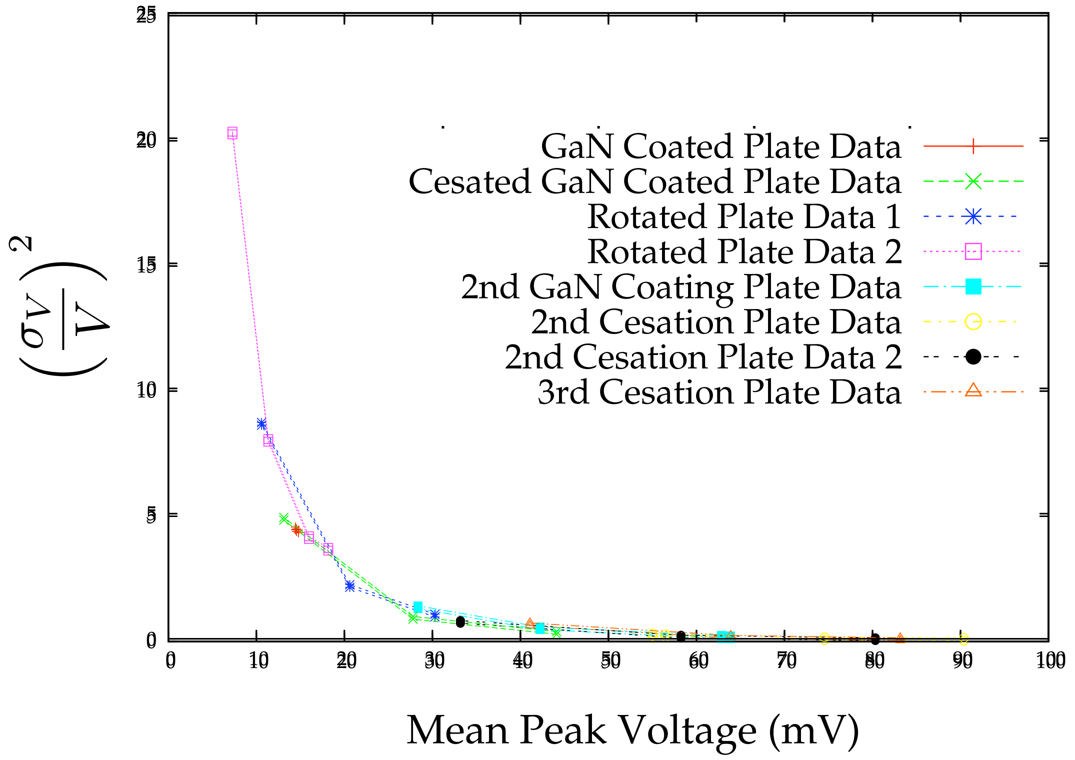
$$\left(\frac{\sigma_{V_{pk}}}{V_{pk}}\right)^2 = ge\left(\frac{1}{\bar{V}_{pk}}\right)$$



Gain change from Cesation



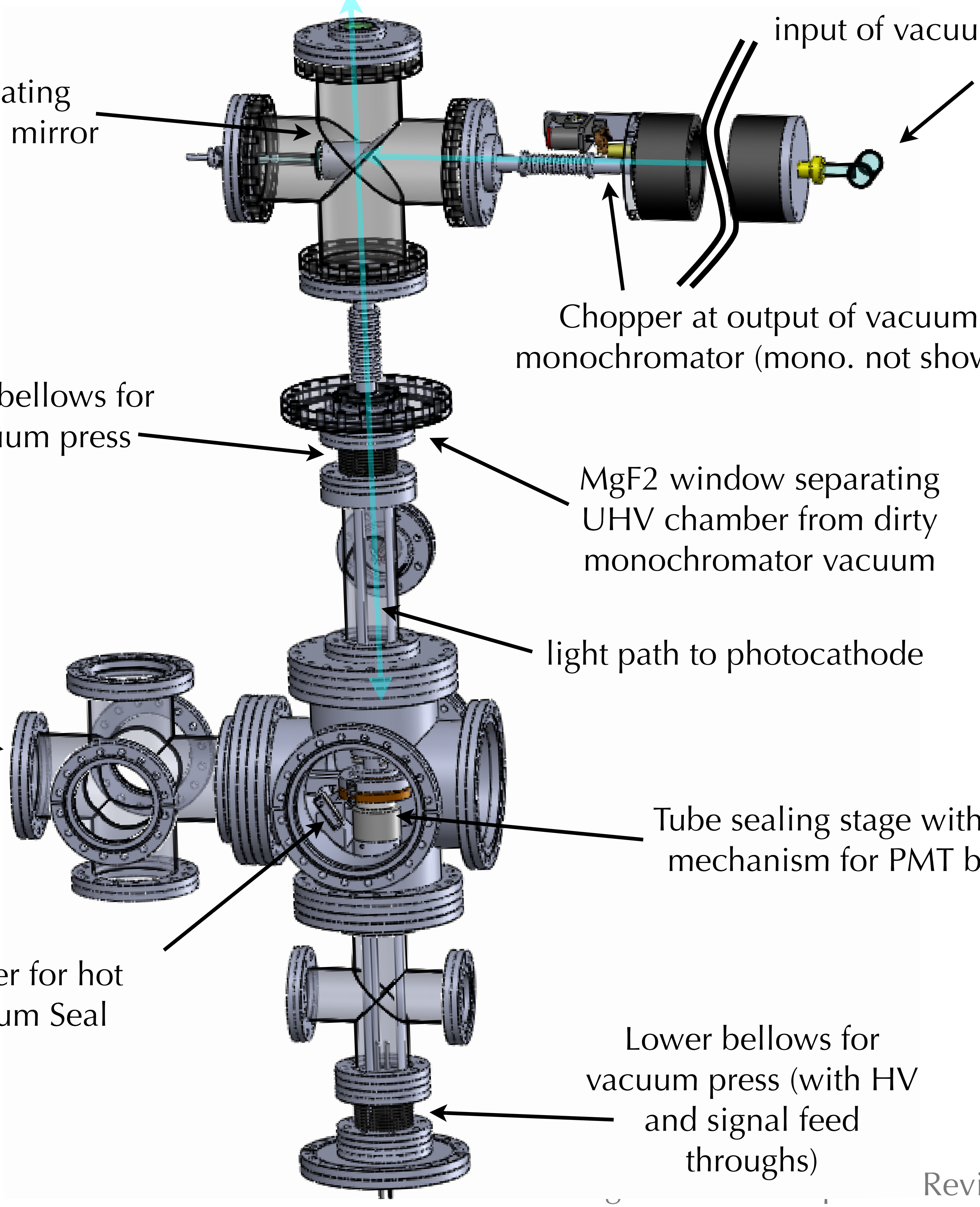
Gain change from GaN



Results of a-GaN coating of MCP

- In our UHV system, the beams for cathode growth and Cs activation are ballistic rather than vapor phase, and growth rates are slow. It is unlikely that this is directly applicable to “tubulation” (need line of sight, bias etc.)
- Initial resistance of 33mm ALD single MCP was ~200 MΩ
- Cesation of bare ALD-coated MCP caused a prompt increase in current, and reduction in inferred resistance by a factor of ~3
- After an hour the MCP resistance returned to the nominal value.
- The MCP gain measured in the first day following activation was elevated, when remeasured 4 days later the Gain had returned to the nominal (bare MCP) value.
- In our MBE system, the different source orientations and fixed angles could not provide optimum coverage of the pore openings.
- a-GaN coating showed a modest increase in QE (a factor of ~3 compared with the Cesated ALD-coated MCP) with no change in gain. Note - We did not evaluate repeated activation of a-GaN MCP, or changes in geometry in growth chamber.

Tube-Sealing & VUV Measurement System



light path to reference photodiode

Deuterium lamp at
input of vacuum monochromator

Rotating collimating
off-axis parabolic mirror

Chopper at output of vacuum
monochromator (mono. not shown)

upper bellows for
vacuum press

MgF2 window separating
UHV chamber from dirty
monochromator vacuum

Argon Ion beam
etching chamber/
metal evaporation system
(transfer arm not shown)

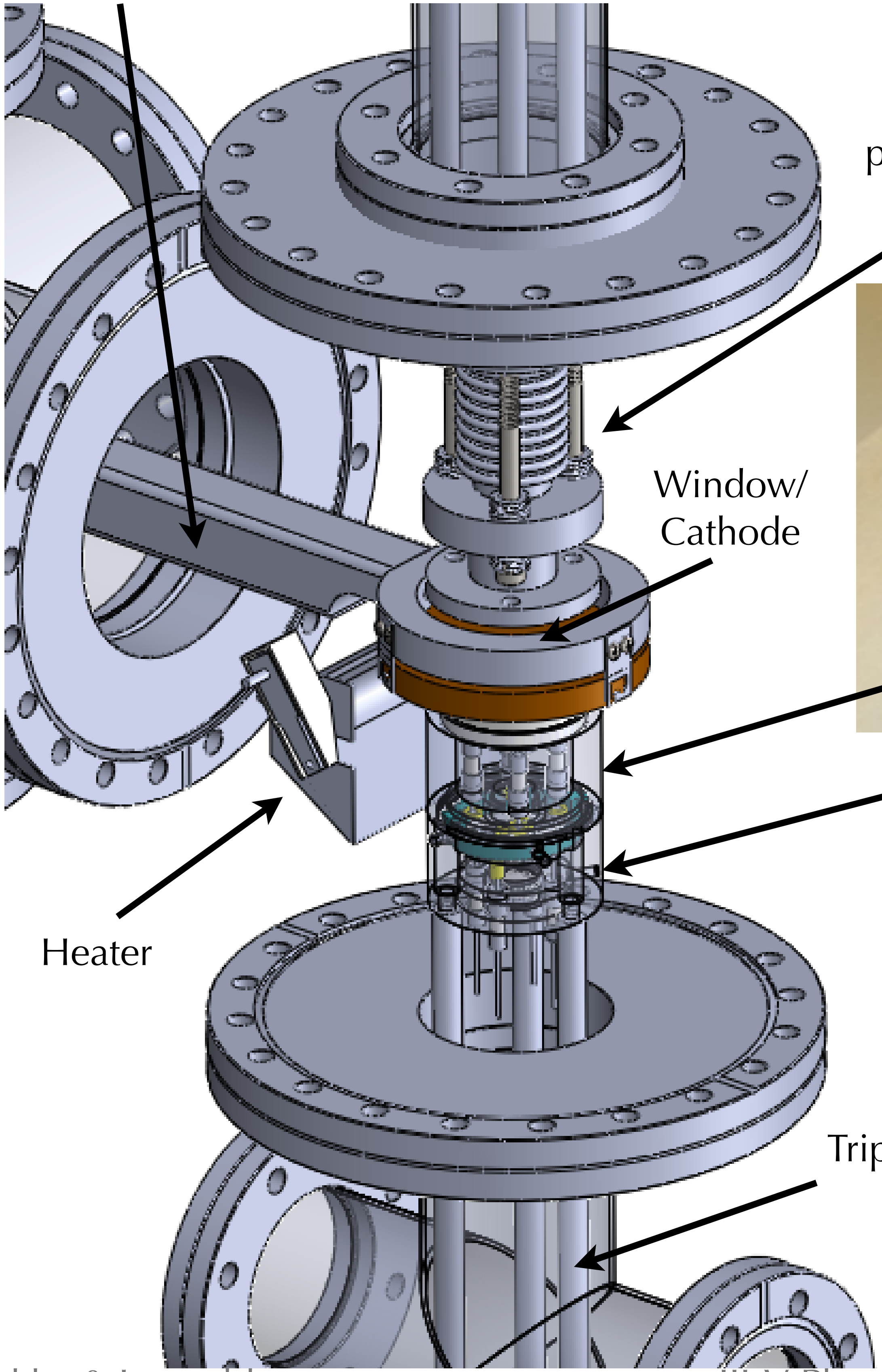
light path to photocathode

Tube sealing stage with docking
mechanism for PMT back end

Heater for hot
Indium Seal

Lower bellows for
vacuum press (with HV
and signal feed
throughs)

Tube Sealing System



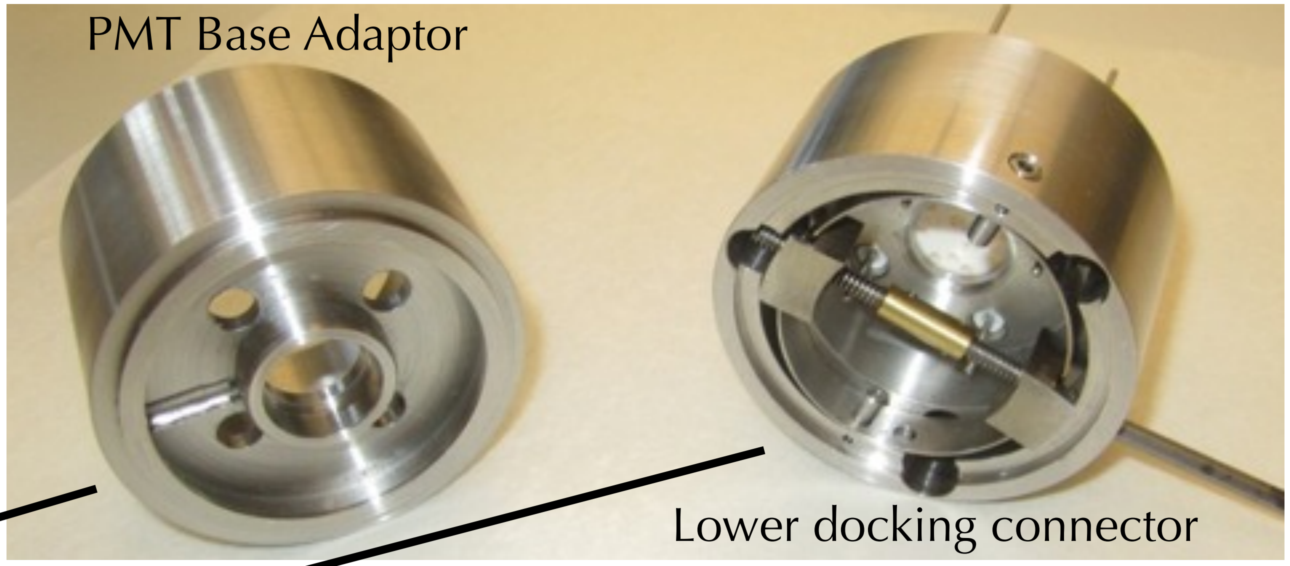
Trransfer arm

Upper docking connector with compressed bellows preload, ~1-3 deg misalignment compensator (in shop now!)

Window/
Cathode

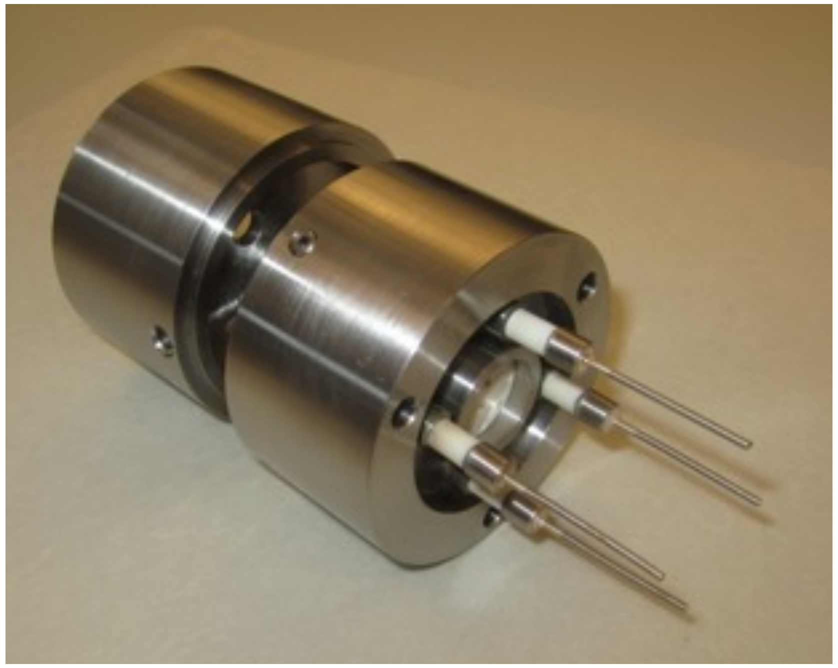
Heater

Tripod posts

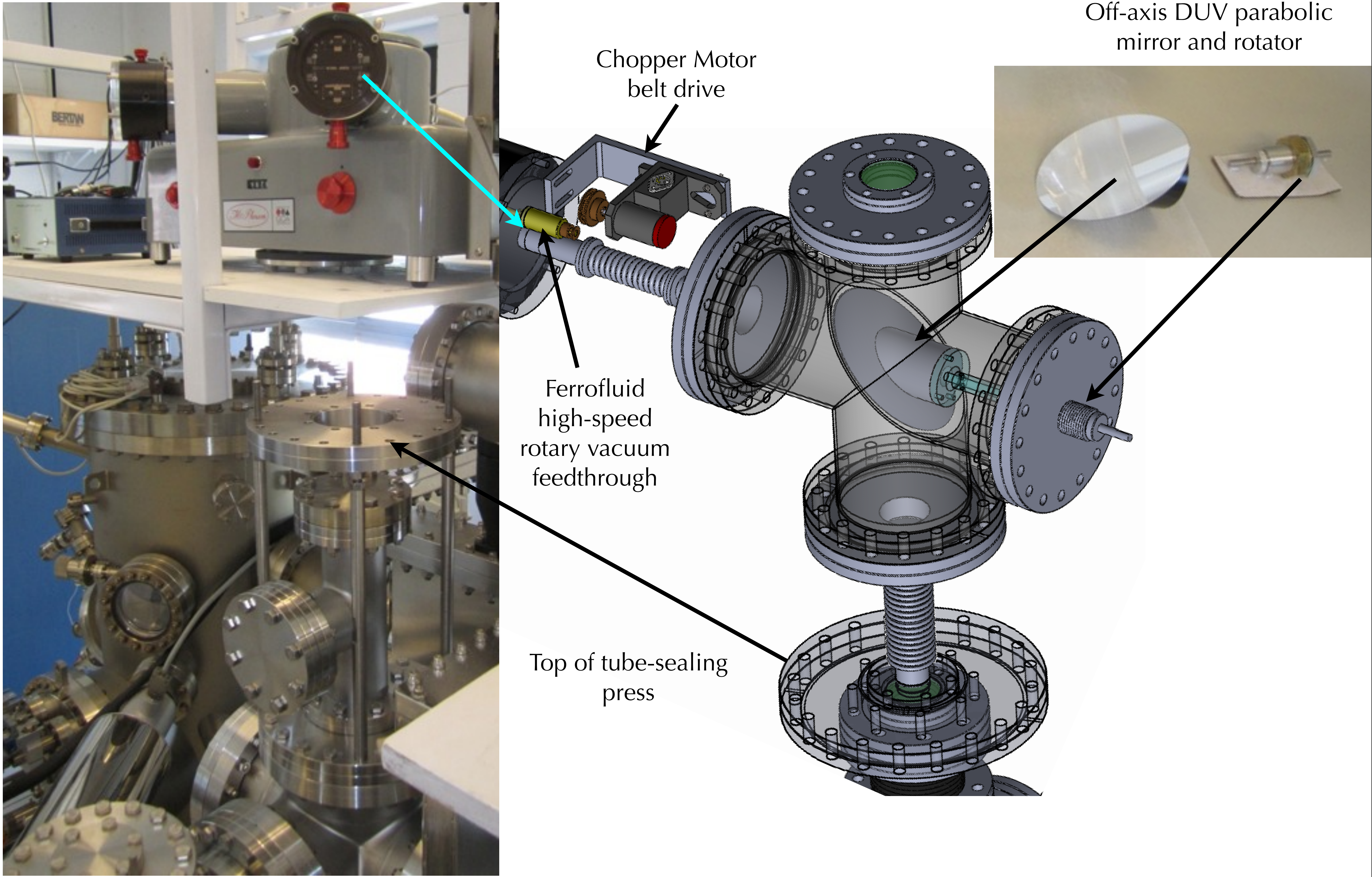


PMT Base Adaptor

Lower docking connector



Vacuum Tube Sealing Hardware



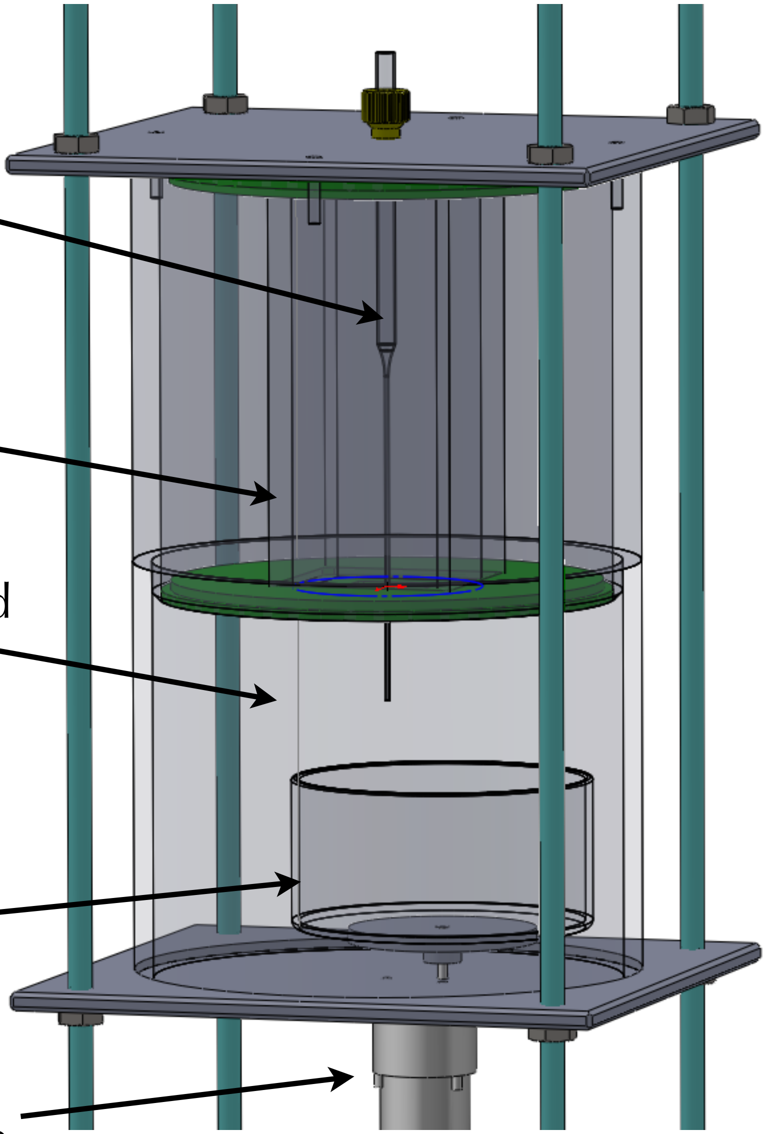
Off-axis DUV parabolic mirror and rotator

Chopper Motor belt drive

Ferrofluid high-speed rotary vacuum feedthrough

Top of tube-sealing press

Indium Preform Extrusion Oven



Pipet holding Indium (connected to nitrogen at controlled pressure)

Tube Oven with PID controller

Nitrogen-purged volume

Rotating petri dish with RO-DI water

Motor for rotating stage

PID controller reading 156 C

Speed controller (Arduino!)

- Working on our system for making hot Indium seals in our tube-sealing vacuum chamber, including new ways to reduce oxides.
- Designed and built nitrogen purged tube oven for extruding Indium O-ring into petri dish of RO-DI water. System has been tested and working, but still not optimized to produce wire preforms of consistent diameter.

Low Pressure Argon/ Argon Ion Beam

- We recently added a gas manifold, (with vacuum purge), ion-gauge and leak valve, to introduce high purity Argon gas for an Argon-ion beam system to clean substrates.
- Chamber does double-duty as Ion-cleaning, thermal evaporation system.
- Should be straightforward to use this system to evaluate reflection mode UV-cathodes in Argon gas (e.g., GEMs like readouts)

Conclusions / Future

- Making good progress on demonstrating robust, large area amorphous cathodes with extended long-wavelength response. In-house capability of growing up to 3″ cathodes at low-temperature on a variety of substrates.

- Some progress in longer wavelength (blue) response. UV-sensitive cathodes look more promising.

- Developed viable methods for cathode transfer (Indium capping, atomic Nitrogen beam exposure). Evaluating Argon-ion system which would be easier to implement in other labs.

- For the future of LAPPD, I suggest looking for areas of overlap with the Comic frontier:

    - Development of low-background PMTs with UV-response for liquid noble detectors (175 nm for Xenon, 125 nm for Argon). May need to develop new electron-multipliers since glass typically has high radioactive backgrounds.

    - Development of low-gain, high current MCPs for Atmospheric Cherenkov detectors, or for astronomical imaging (with high resolution readout).