GaN Photocathodes and EBCMOS Detectors for UV Astronomy

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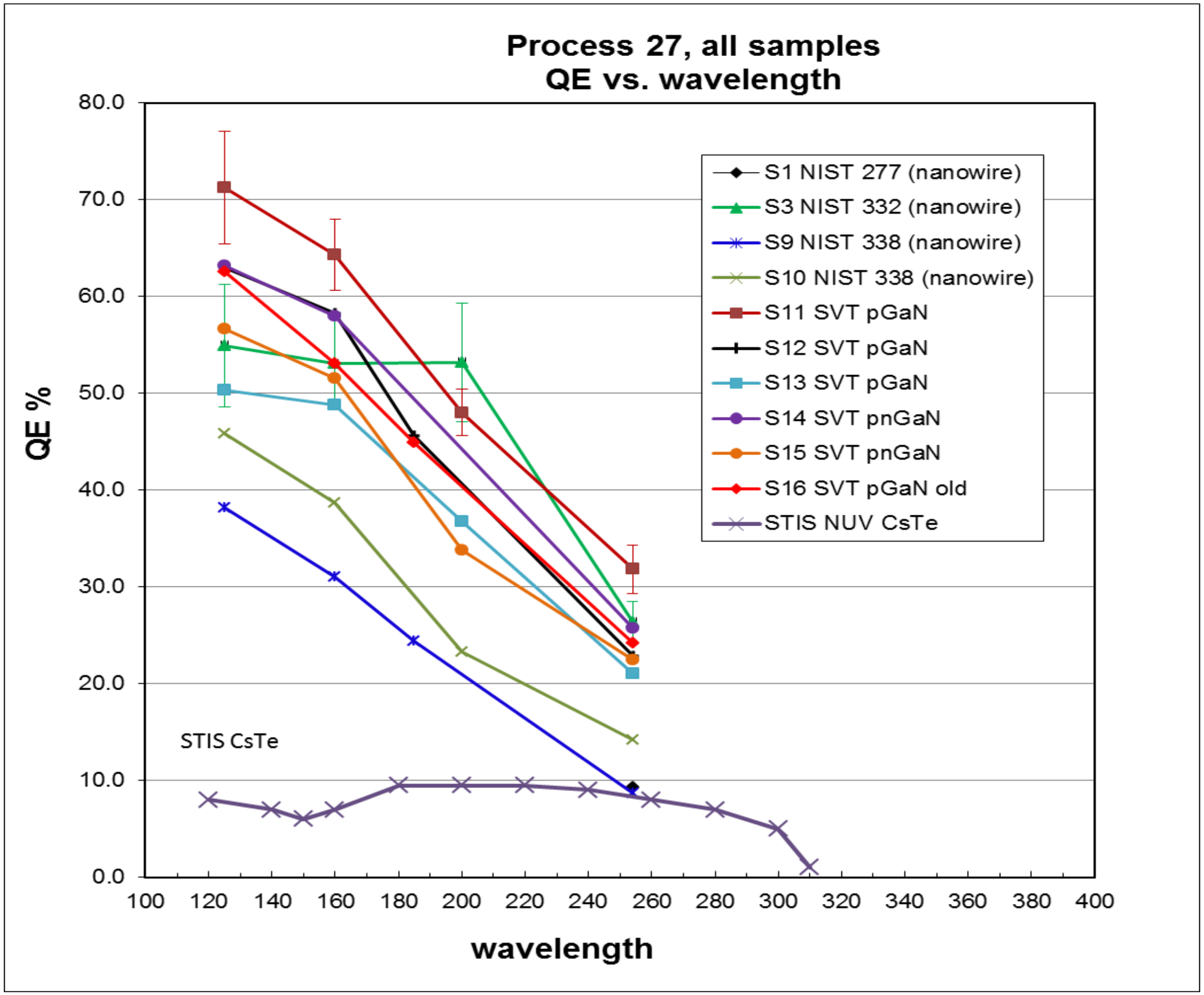
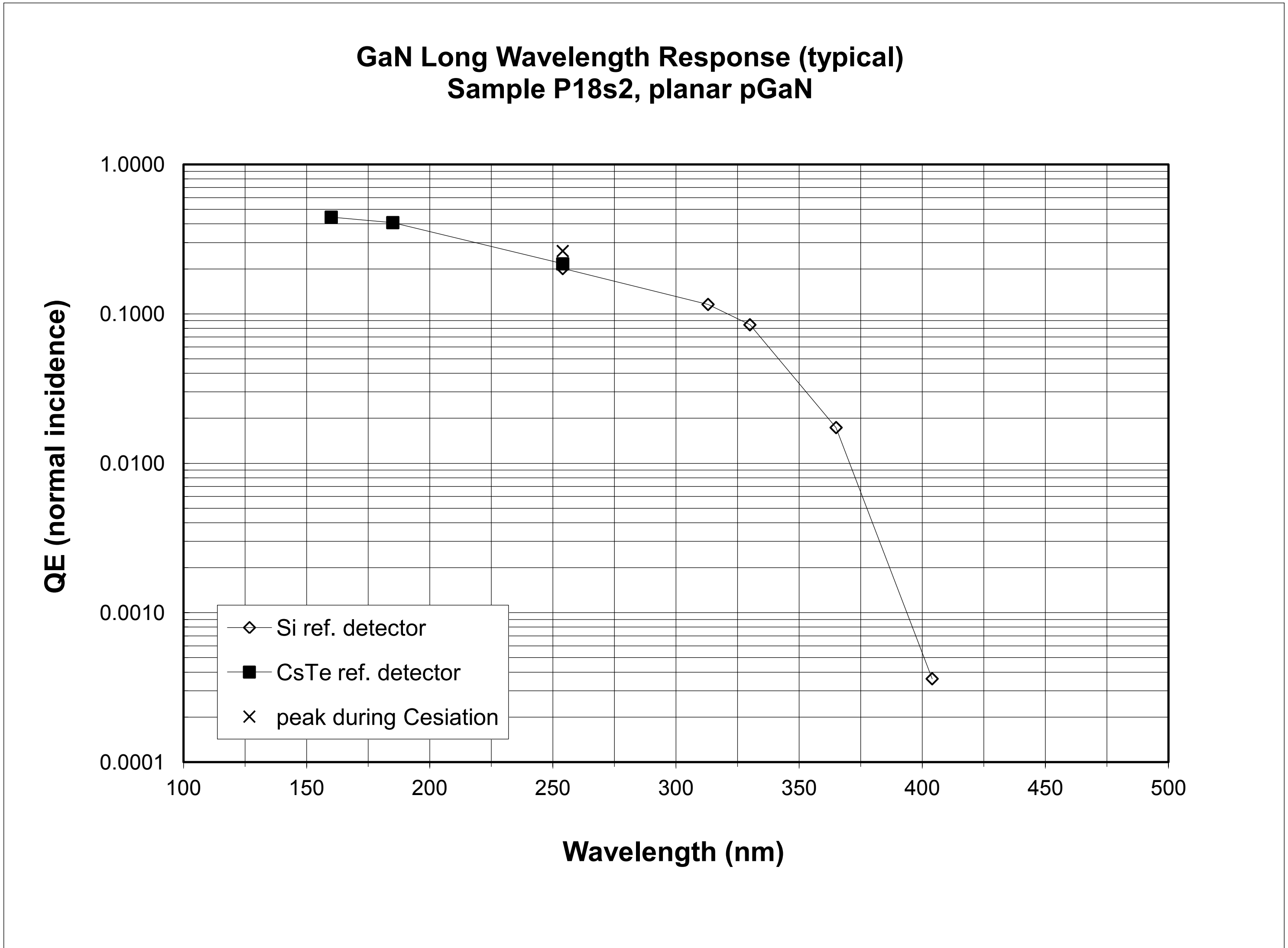
August 2011 GaN photocathode results* – process 27



*Analog mode - not corrected for photoemission coefficients

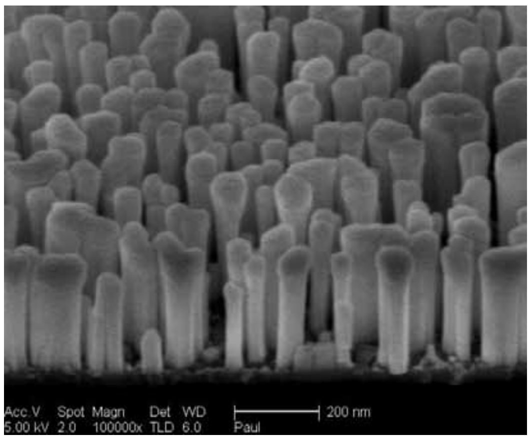
GaN QE including visible

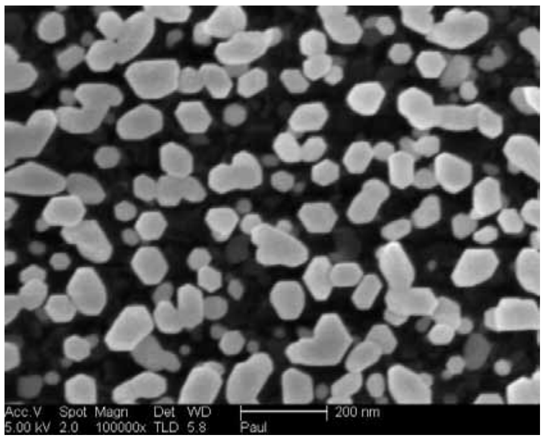


New NIST material - N277 morphology

Nanowires may lead to higher QE due to:

- Much higher quality crystal structure – higher diffusion length & QE
- Can match a variety of layers eg Silicon MCP and Ceramic MCP substrates – less dependence on substrate crystal matching.
- Surface escape barrier lowering from electric field concentration
- Higher absorption – lower reflectivity – analogous to “Black Silicon”





Growth Conditions :-
Mg cell: 360 ˚C, then 370 ˚C
Substrate: 782 ˚C ,then 637 ˚C
Time: 3h, then 1 h

N277_p09.tif, r = 20 mm
Coverage ≈ 0.48

Future GaN photocathode development

- GaN has proven to be a very efficient photocathode (> 50%) in opaque mode at wavelengths < 180 nm;
  - QEs > 70% at 121nm demonstrated by GSFC, NWU, UCB and Hamamatsu.
- There is considerable room for improvement > 180nm.

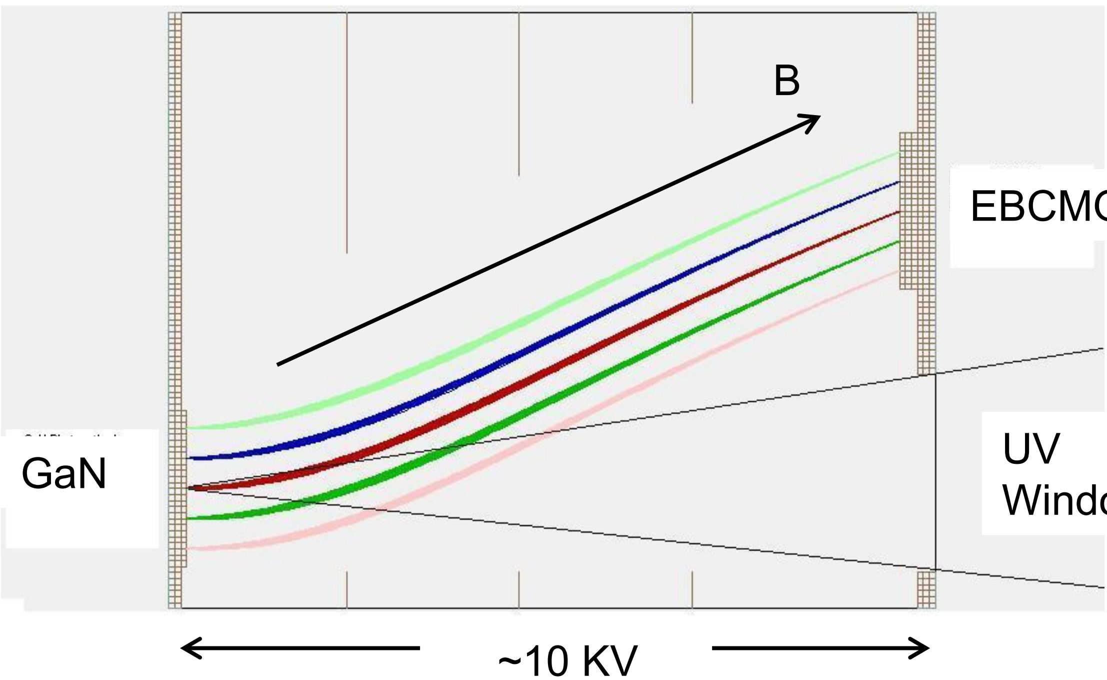
- Strategies to improve include: higher purity, low defect material leading to longer electron diffusion lengths; improved Mg p-doping profiles towards the photoemissive surface; and nano-structuring of the material leading to higher electron escape probabilities.

- Replacement of the Cs layer with tailored heterostructures including InN cap layers would allow windowless operation (higher DQE) and could enhance stability.

Using high QE opaque photocathodes in a detectors - 1

- High QE opaque photocathodes can be used most directly for photon-counting imaging with electron bombarded CCD or CMOS detector readout.
  - e.g. EBCCD flown on IMAPS (Jenkins et. al., 1988; Joseph and Jenkins, 1991)

- The oblique magnetic field allows separation of the input window from the CCD/CMOS anode. ***This is the only known method of directly using the higher-QE opaque photocathodes.***



Magnetically focused EBCMOS configuration simulated with SIMION.

1600 x 1200

11 micron pixels.

Using high QE opaque photocathodes in a detectors - 2

- A ruggedized version of the EB phosphor/CCD has been developed in a sealed tube (C. Joseph, PI), offering 25-30% peak QEs with Cs_2Te compared with ~10% for MAMA (HST) and ~9% for GALEX (NUV), both MCP detectors.
- Current magnet designs that dramatically reduce the weight and volume were first introduced by Lowrance and Joseph (1991). This newer EB package has a reduced weight by a factor of 3.
- Back-thinned CMOS detectors are preferred to CCDs because of faster framing, lower power, and improved radiation tolerance.

➢ Therefore, we plan to couple our GSFC high-QE opaque GaN photcathodes & CMOS sensors into Rutgers EB tubes.

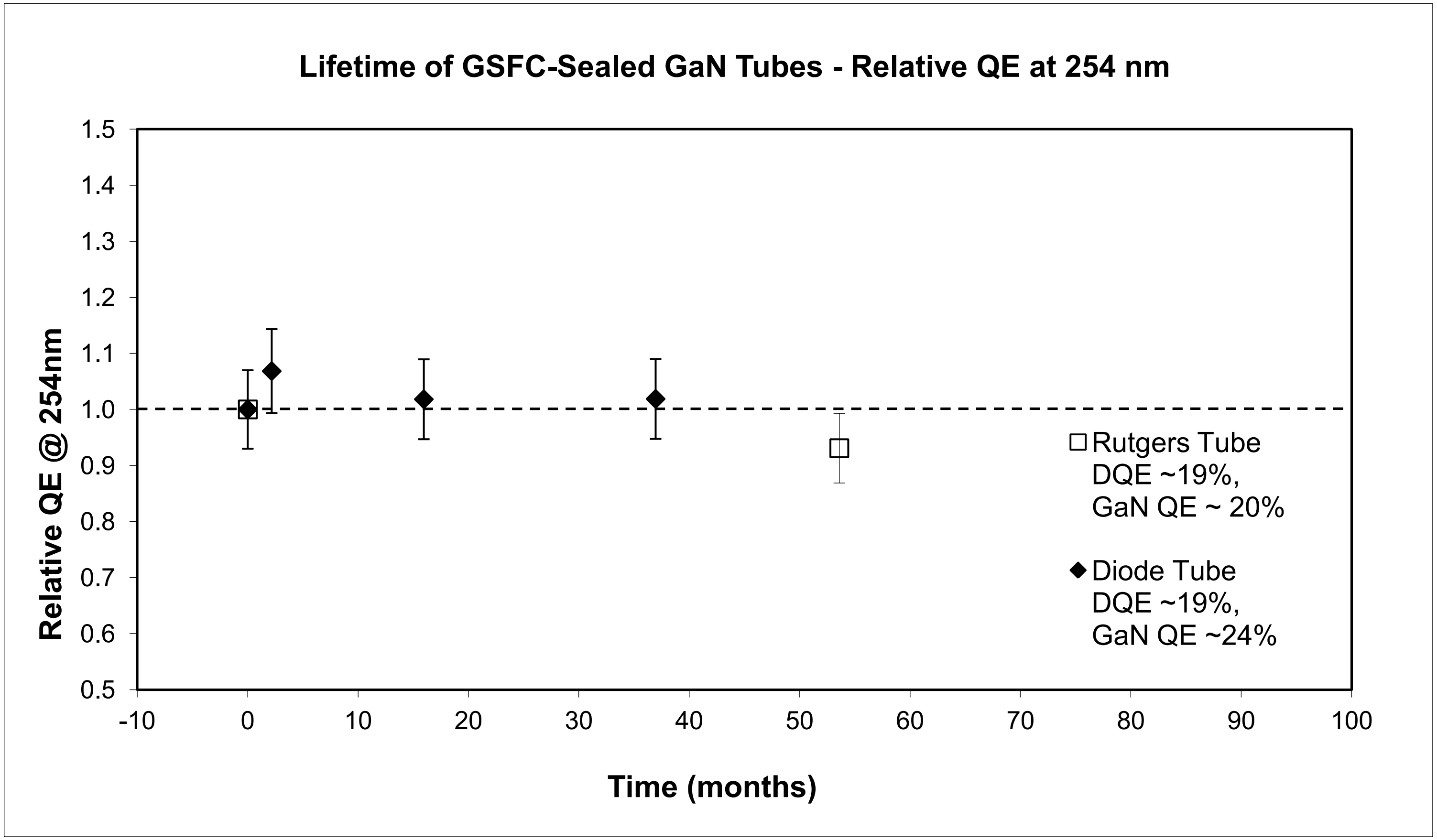
Phosphor tube – Photek/Rutgers (potentially EBCMOS)

Opaque GaN photocathode incorporated and resealed by GSFC (2007)

Using high QE opaque photocathodes in a detectors - 3

EBCMOS provides an alternate way of using a high QE opaque cesiated photocathode, avoiding problems typically associated with MCPs such as gain loss, operating cesiated MCPs, or (potentially) shorter photocathode lifetimes due to large area (MCP) sources of contamination.

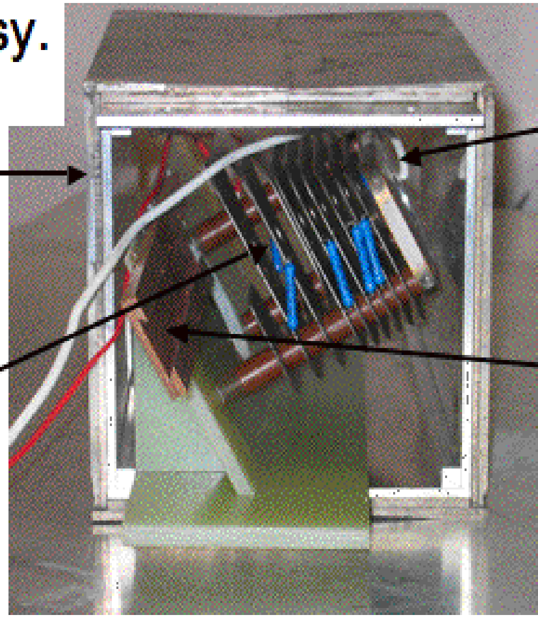
At GSFC, we have sealed cesiated GaN photocathodes into a diode tube and a Rutgers EB phosphor tube and shown their QEs to be stable over several years.



Rutgers/GSFC Bread-Board EBCMOS Detector

Demountable Tube Assy.
Side View

UV Light enters here, horizontal to the plane of the table.

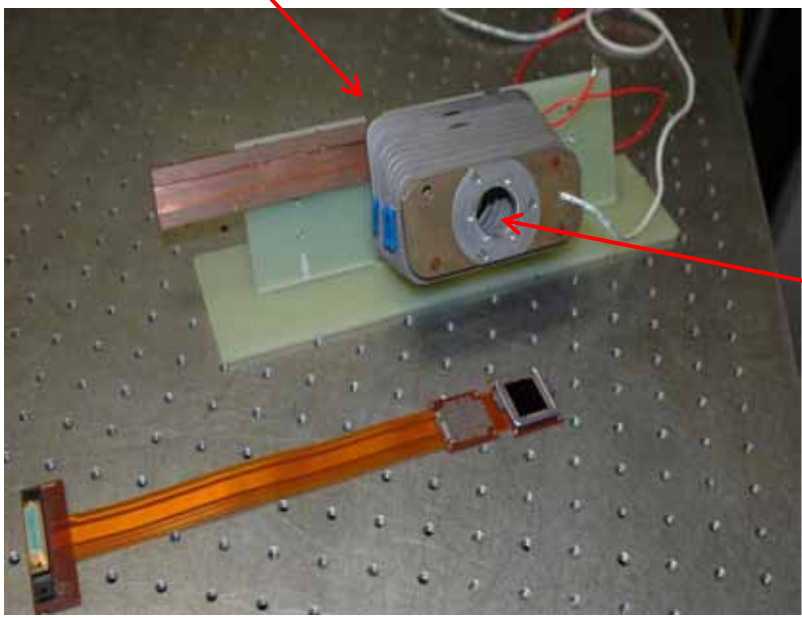


Photocathode sits on a "top-hat" piece, to be bolted back here.

Rail for CCD/CMOS chip. The chip can be mounted on a Copper slide and moved into position.

HV Electrodes with resistor chain. (Half of the resistors are on the far side.)

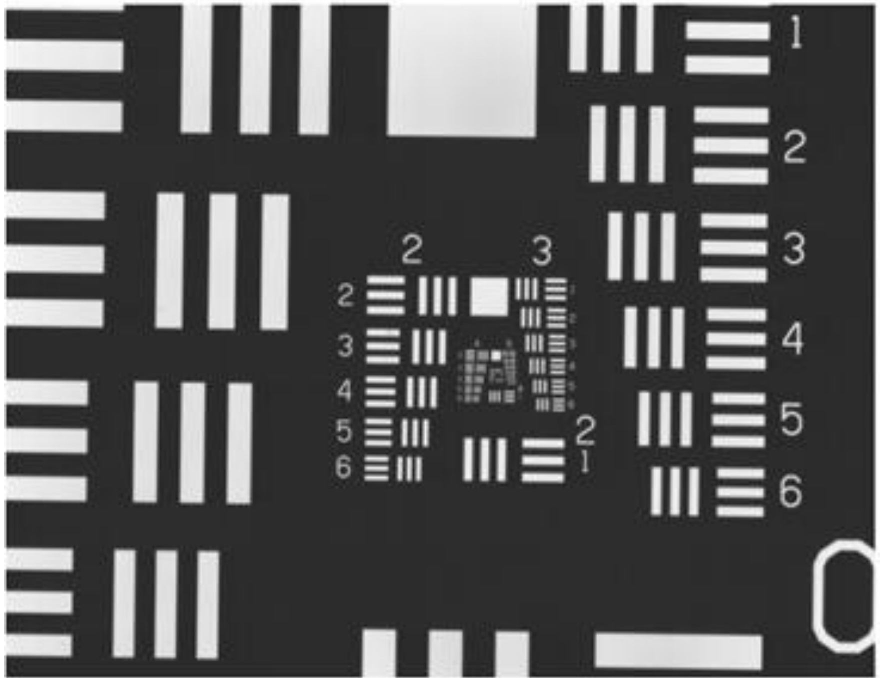
Sensor hidden behind here



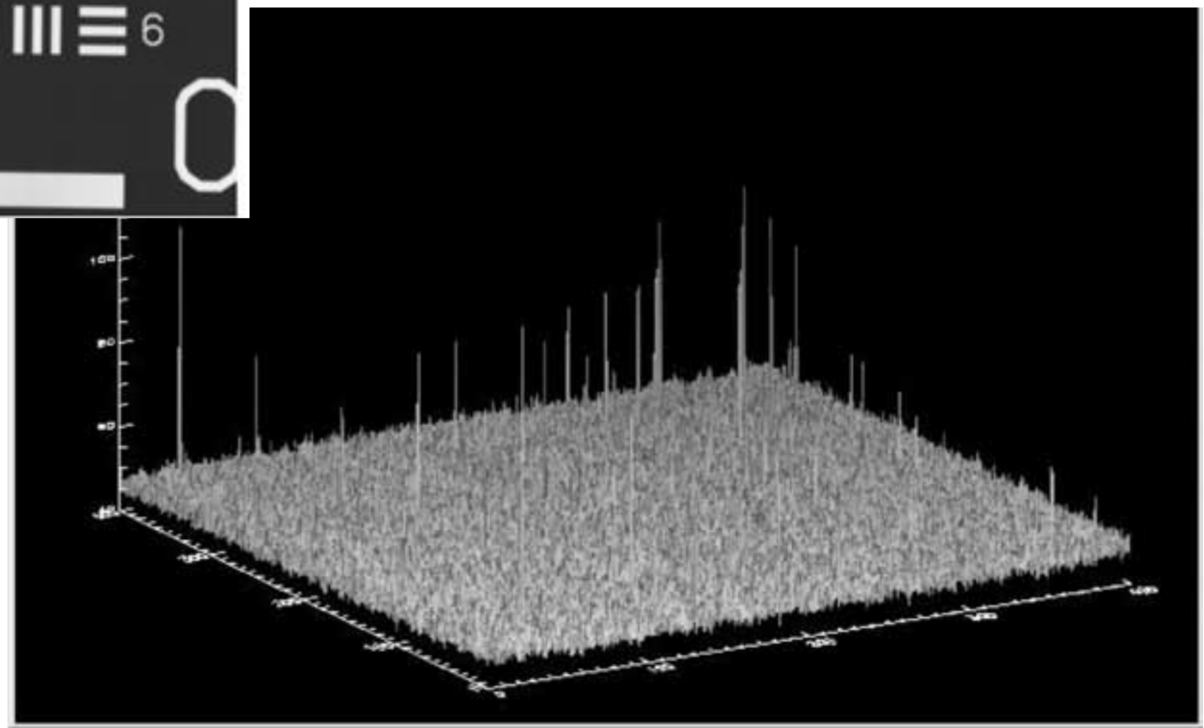
Photocathode substrate goes here

Bread-board electrodes with ISIE11 EBCMOS Sensor and Flex cable harness.

Intevac ISEE11 1640 x 1280 back thinned CMOS



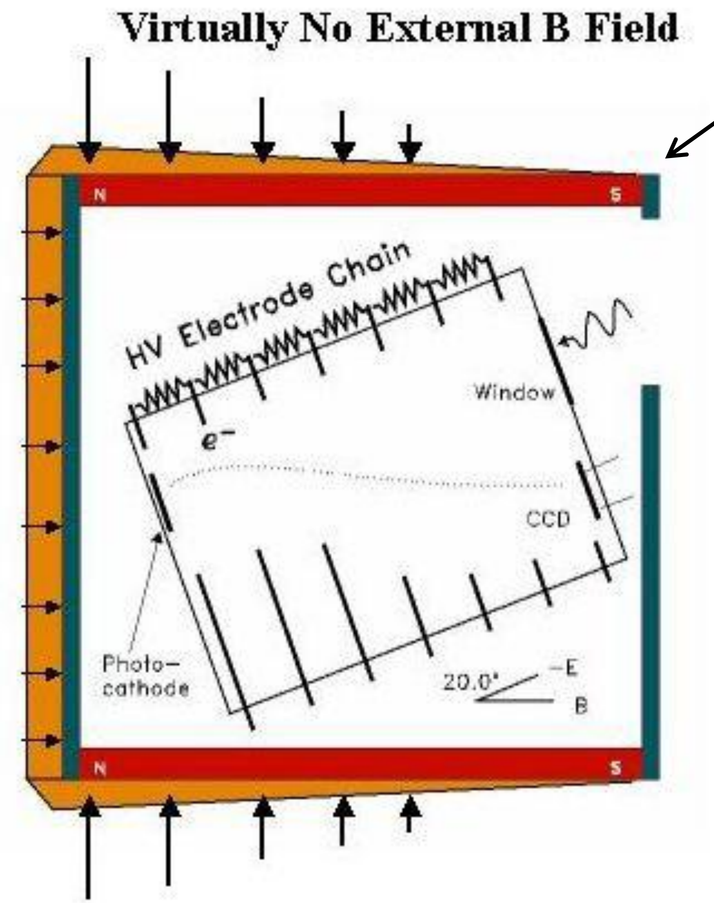
Resolution test pattern (analog)



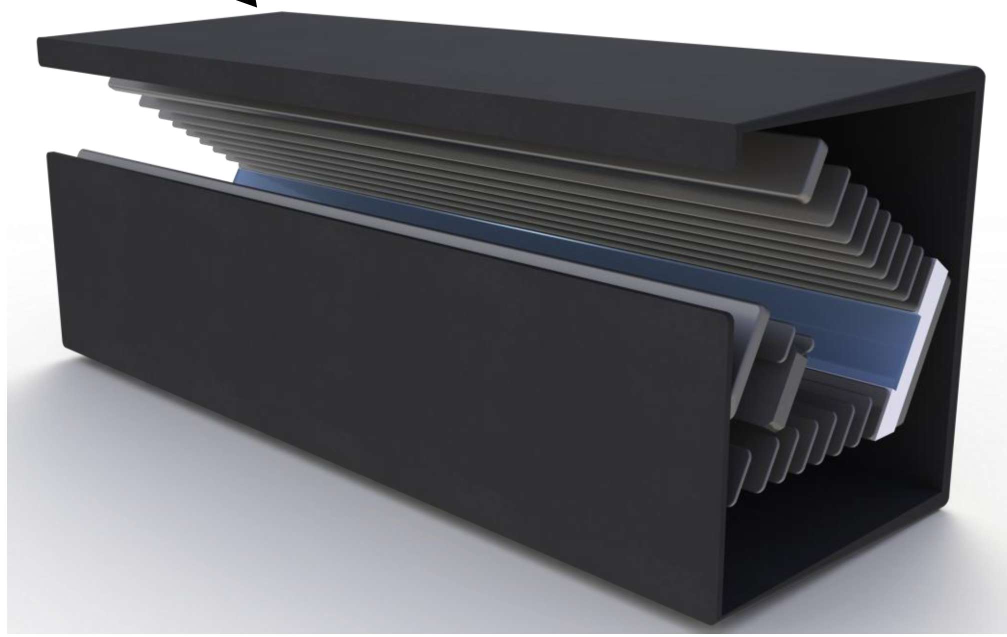
Single EB events simulated
with Xray source
(photon counting)

EBCMOS: Concept Design for Spectroscopic Application

Ref: Rutgers Open Window (KBr/CsI) EBCCD on Rowland circle
(from Lowrance, Joseph, Leupold, Potenziani, 1991)



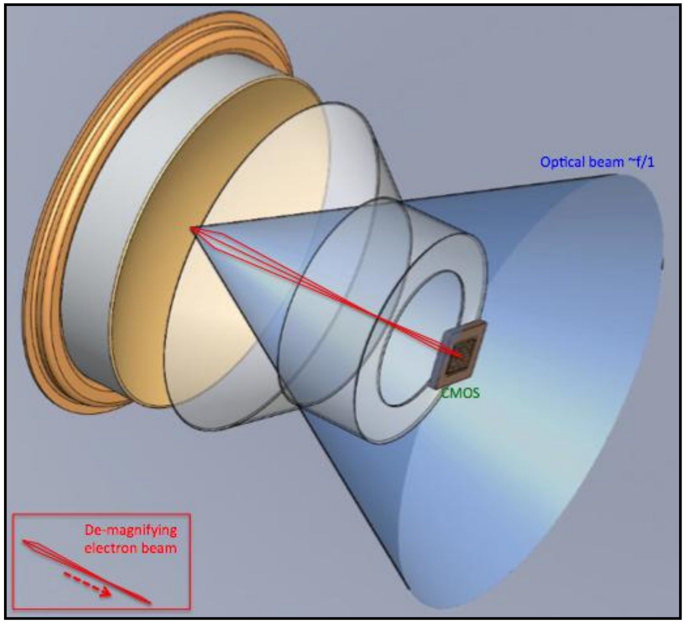
Magnet housing

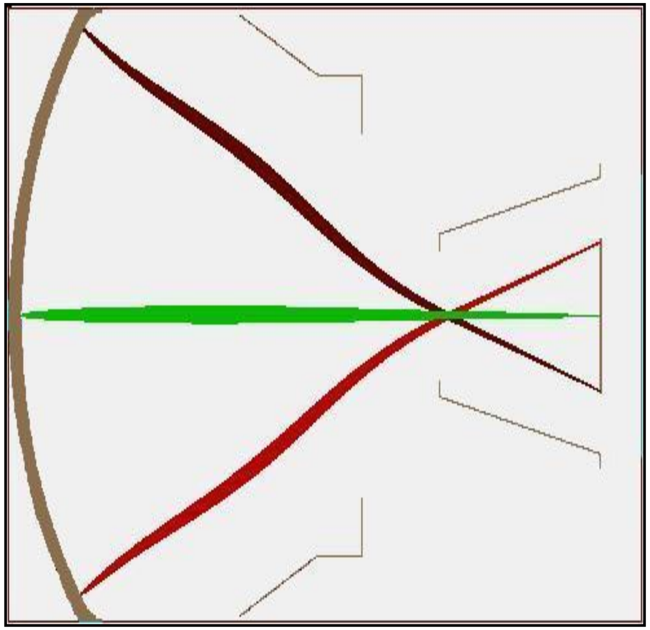


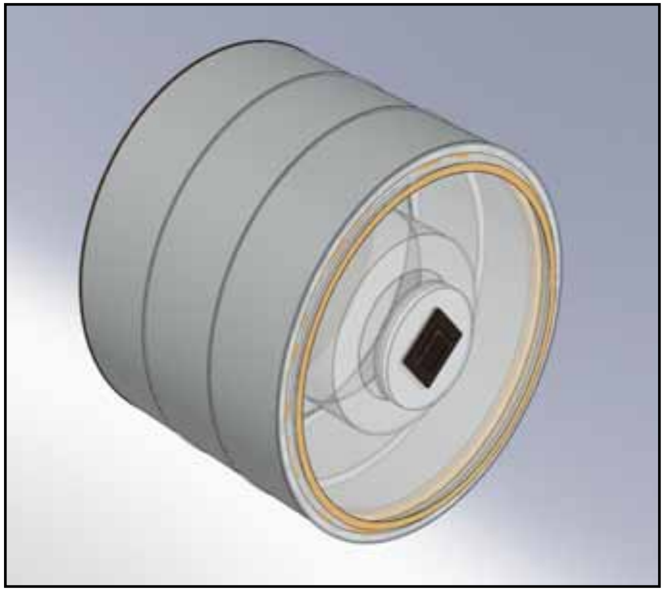
Above diagram is windowed version

Intevac 2k x 2k back-thinned EBCMOS are 2-sides buttable for a **2k x nk** detector (above model - no window example)

EBCMOS: Concept Design for f/1 Large Area Electrostatic Demagnifying Tube







Top-Left – Large area de-magnifying tube concept, with 6 inch diameter photocathode, wire mesh focusing anodes and 2k x 2k EBCMOS sensor.

Top-Right SIMION electro-optical simulation of inverter tube design – 10 kV applied voltage, transverse emission energy, 2 eV,
PSF : 60 – 75 microns (fwhm)

Bottom-left – CAD representation of high QE, high Etendue tube design, MgF_2 window, 2K x 2K sensor

Future Work

Near term (in progress)

- Demonstrate CMOS using open EB structure.
- Cesiate GaN photocathode structures that we have in hand.
  - TDI (Oxford) - planar GaN on Sapphire
  - TDI – POC – GaN on Si MCP
  - NIST nanowires
  - SVT planar, incl. gradient-doped GaN

Medium term

- Integrate 1640x1280 CMOS & GaN into sealed EB tube.
- Procure & test higher quality planar & nanowire GaN.

Longer term challenges

- Demonstrate stability across GaN bandpass
- Implement larger CMOS arrays (>10e7), mosaics
- Higher GaN QEs > 180 nm

COPAG - EBCMOS Future Prospects

Performance

	QE_{122nm}	QE_{200nm}	Int dark	# pixels	Area, cm^2
Current	0.7	0.55	very low	$2.\ 10^6$	1.6
Future, demag	0.8	0.7	very low	$1.2\ 10^7$	140

Implementation

No cooling, high voltage (~1.4 x HST/STIS MCP)
CMOS mosaicing similar to EMCCDs

TRL and other support

Current TRL ~2-3, but based on EBCCDs with TRL=9 (IMAPS rocket, AstroSPAS)
Possible non-astro NASA funding sources: Solar and Heliospheric, Planetary

Relevance to future missions

General UV imaging and Spectroscopy
Speciality: Use for UV imaging and spectroscopy without MCP damage, for circumstellar objects near bright stars, with red star rejection.

Summary

1. QEs obtained with GaN > 50% at < 180nm. Improvements needed especially at wavelengths > 180nm.
   - Work continues with collaborators (NIST) for improvements in nanowire structures and for improved GaN films from commercial suppliers.
   - Recent results for nanowire GaN from NIST is encouraging - recent sample produced a result “in the ballpark” with planar GaN.

1. EBCMOS offers an alternative to MCP-based and other UV photon counting schemes:
   - Uses photocathode in direct, opaque mode for highest QE.
   - CMOS – high frame rate, rad. hard, low power.
   - Expected longer life; GaN stability of few years demonstrated in 2 tubes.
   - Visible blind photocathodes such as GaN
   - Other designs possible, e.g., for spectroscopy and large area imaging.

2. Work in progress to incorporate GaN/EBCMOS into sealed tube:
   - Demount tube development underway to test EBCMOS operation (KBr).
   - Sealed, cesiated GaN tube demonstrated (no sensor).