Charged Particle Induced Damage and Recovery of Photocathodes Employed as Nuclear Physics Injector Sources

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Work funded by Department of Energy SBIR Grant DE-SC0002268

About Saxet

- Organization
  - Sole Proprietorship
  - Initiated in 2002

- Staff
  - Principal Scientist: Gregory Mulhollan
  - Senior Scientist: Robert Kirby (CA)
  - Research Scientist: Pingheng Zhou
  - Senior Research Associate: John Bierman
  - Senior Engineer: Duane Smith
  - Research Assistant: Tanner Horne
  - Research Intern: Steve Bierman

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- Location

– 1,982 ft^2 in the Pecan Business Park in south Austin

– Texas is the 28th state and was a republic prior to statehood

– Austin is home to the Texas state capital, the University of Texas and many high-tech companies including Dell

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- Capabilities
  - Three photocathode test systems (soon to be four!)
  - RF PECVD system for amorphous SiGe photoemitter growth
  - High vacuum (and soon XHV) chambers for STRAW gauge research
  - Sputter deposition system for metal growth
  - Auger system for surface compositional analysis
  - Clean (class 100) assembly area
  - Chemical work area
  - Optical spectroscopy bench
  - + more

John Bierman (left) and Jeff Hurst (right, now at Samsung, Austin) working on the Auger analysis system

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- Research Partners

SLAC NATIONAL ACCELERATOR LABORATORY

SSRL

PENN STATE

RTI INTERNATIONAL

- Funding Agencies/Sales

  – Government

U.S. DEPARTMENT OF ENERGY

ARMY SBIR SMALL BUSINESS INNOVATION RESEARCH

NAVY

  – Private

ITT

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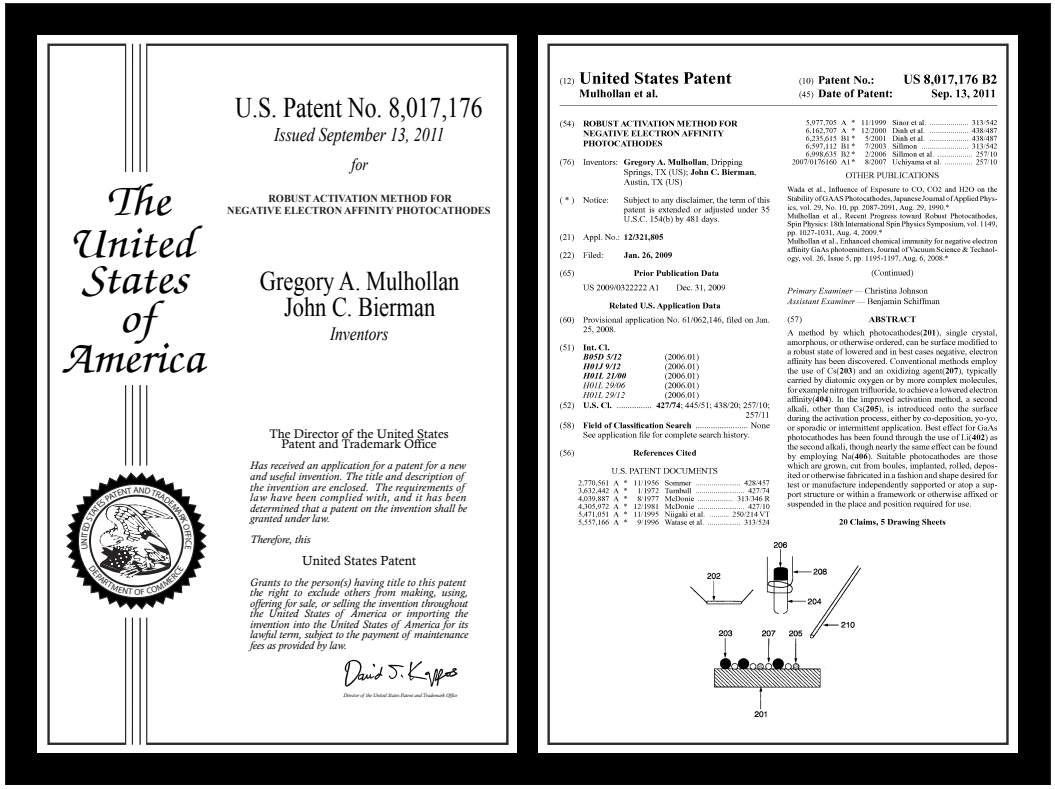
- Intellectual Property
  - – One issued patent
  - – One patent application
  - – One provisional patent application

Method for Employing Titania Nanotube Sensors as Vacuum Gauges 04/11/2011



U.S. Patent No. 8,017,176
Issued September 13, 2011
for

ROBUST ACTIVATION METHOD FOR NEGATIVE ELECTRON AFFINITY PHOTOCATHODES

The United States of America

Gregory A. Mulhollan
John C. Bierman
Inventors

The Director of the United States Patent and Trademark Office

Has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under law.

Therefore, this

United States Patent

Grants to the person(s) having title to this patent the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States of America or importing the invention into the United States of America for its lawful term, subject to the payment of maintenance fees as provided by law.

Director of the United States Patent and Trademark Office

(12) **United States Patent**
Mulhollan et al.

(10) **Patent No.: US 8,017,176 B2**
(45) **Date of Patent: Sep. 13, 2011**

(54) **ROBUST ACTIVATION METHOD FOR NEGATIVE ELECTRON AFFINITY PHOTOCATHODES**

(76) Inventors: **Gregory A. Mulhollan**, Dripping Springs, TX (US); **John C. Bierman**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 481 days.

(21) Appl. No.: **12/321,805**

(22) Filed: **Jan. 26, 2009**

(65) **Prior Publication Data**

US 2009/0322222 A1 Dec. 31, 2009

Related U.S. Application Data

(60) Provisional application No. 61/062,146, filed on Jan. 25, 2008.

(51) **Int. Cl.**
B05D 5/12 (2006.01)
H01J 9/12 (2006.01)
H01L 21/00 (2006.01)
H01L 29/06 (2006.01)
H01L 29/12 (2006.01)

(52) **U.S. Cl.** **427/74**; 445/51; 438/20; 257/10; 257/11

(58) **Field of Classification Search** ..... None
See application file for complete search history.

(56) **References Cited**

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(Continued)

Primary Examiner — Christina Johnson
Assistant Examiner — Benjamin Schiffman

(57) **ABSTRACT**

A method by which photocathodes(**201**), single crystal, amorphous, or otherwise ordered, can be surface modified to a robust state of lowered and in best cases negative, electron affinity has been discovered. Conventional methods employ the use of Cs(**203**) and an oxidizing agent(**207**), typically carried by diatomic oxygen or by more complex molecules, for example nitrogen trifluoride, to achieve a lowered electron affinity(**404**). In the improved activation method, a second alkali, other than Cs(**205**), is introduced onto the surface during the activation process, either by co-deposition, yo-yo, or sporadic or intermittent application. Best effect for GaAs photocathodes has been found through the use of Li(**402**) as the second alkali, though nearly the same effect can be found by employing Na(**406**). Suitable photocathodes are those which are grown, cut from boules, implanted, rolled, deposited or otherwise fabricated in a fashion and shape desired for test or manufacture independently supported or atop a support structure or within a framework or otherwise affixed or suspended in the place and position required for use.

20 Claims, 5 Drawing Sheets

US 20110201244A1

(19) **United States**
(12) **Patent Application Publication**
Mulhollan et al.

(10) **Pub. No.: US 2011/0201244 A1**
(43) **Pub. Date: Aug. 18, 2011**

(54) **METHOD FOR RESURRECTING NEGATIVE ELECTRON AFFINITY PHOTOCATHODES AFTER EXPOSURE TO AN OXIDIZING GAS**

(76) Inventors: **Gregory A. Mulhollan**, Austin, TX (US); **John C. Bierman**, Austin, TX (US)

(21) Appl. No.: **12/931,839**

(22) Filed: **Feb. 11, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/338,085, filed on Feb. 16, 2010.

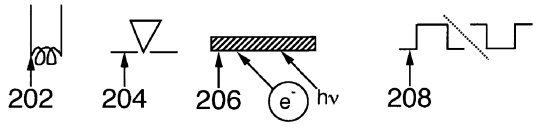
Publication Classification

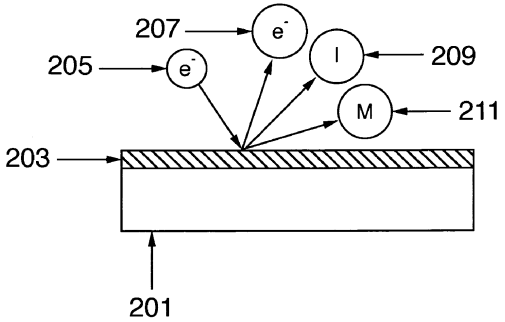
(51) **Int. Cl.**
H01J 9/50 (2006.01)

(52) **U.S. Cl.** **445/2**

(57) **ABSTRACT**

A method by which negative electron affinity photocathodes (**201**), single crystal, amorphous, or otherwise ordered, can be made to recover their quantum yield following exposure to an oxidizing gas has been discovered. Conventional recovery methods employ the use of cesium as a positive acting agent (**104**). In the improved recovery method, an electron beam (**205**), sufficiently energetic to generate a secondary electron cloud (**207**), is applied to the photocathode in need of recovery. The energetic beam, through the high secondary electron yield of the negative electron affinity surface (**203**), creates sufficient numbers of low energy electrons which act on the reduced-yield surface so as to negate the effects of absorbed oxidizing atoms thereby recovering the quantum yield to a pre-decay value.

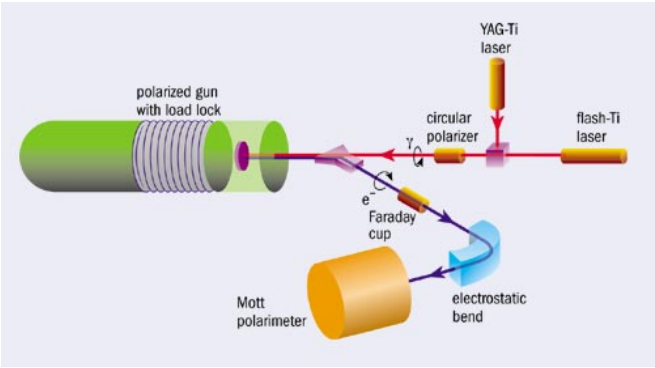




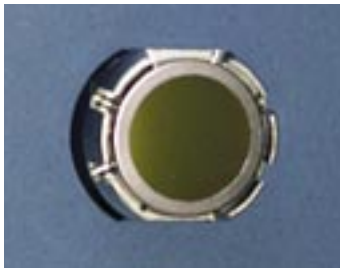
Motivation

- What do photocathodes have to do with nuclear physics?
  - Photomultiplier tubes as part of detectors
  - Particle (e^-) sources for accelerators ➔➔➔➔➔➔➔➔

- Why photocathodes as particle sources?
  - Fast time response
  - Low emittance
  - Spin-polarization



- Where are they used for nuclear physics?
  - JLab, BNL, SLAC, etc.



- What types of photocathodes are employed?
  - Metal, semiconductor and amorphous

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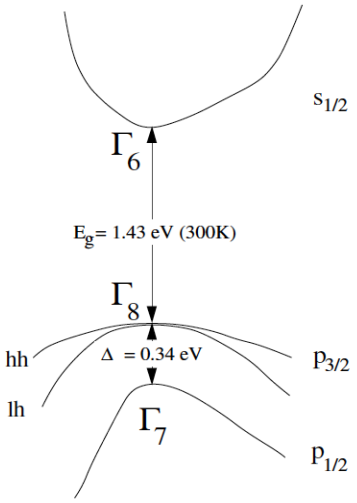
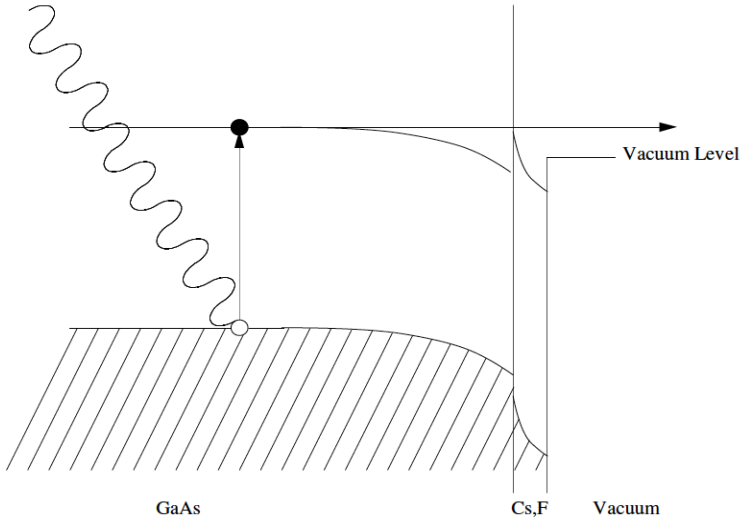
- What is a photocathode?
  - Source of free electrons
  - Electrons ejected upon photon absorption
  - Anything with sufficiently high *hv*

- Semiconductor (NEA GaAs)
  - Activation allows bandgap energy excitation to generate free electrons



GaAs band structure in vicinity of Γ point

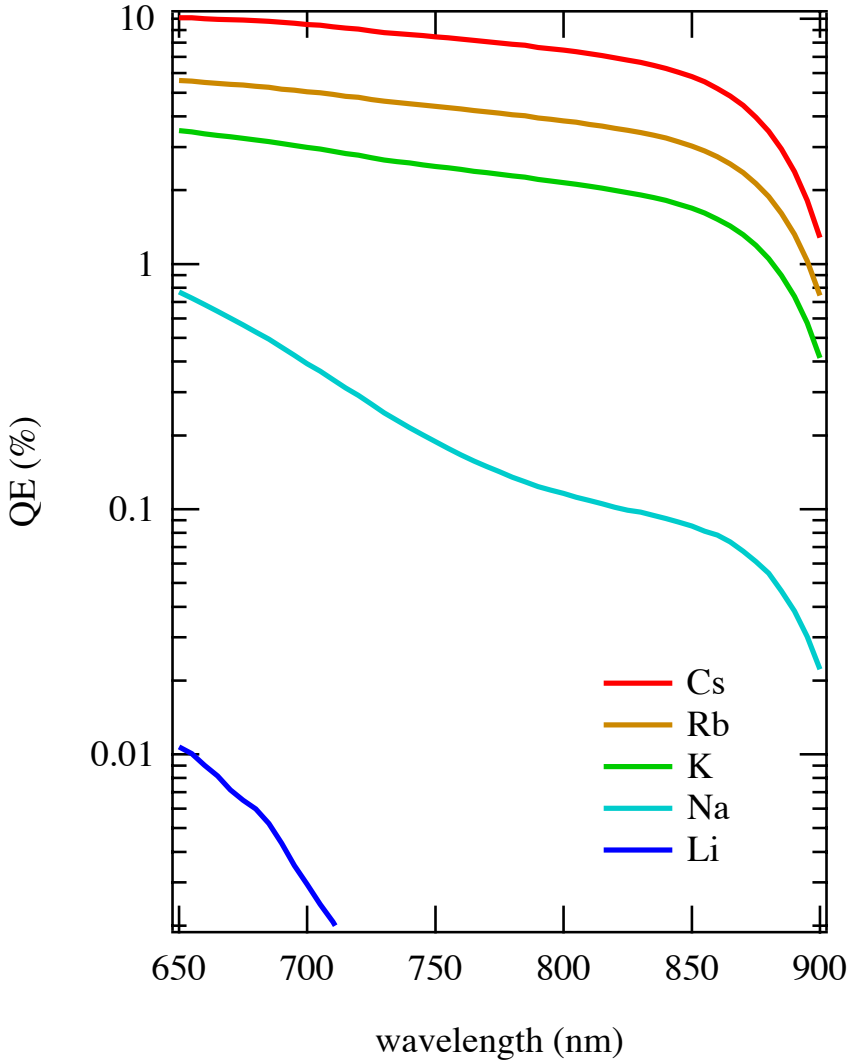


NEA Surface

– Example of photoyield (aka quantum yield, quantum efficiency (QE)) from bulk GaAs as a function of wavelength for each single species of the alkali atoms used to activate the surface

* Cesium is the best
  - ° I ~ 3.6 A
  - ° Color ~ dull red

* Lithium is the worst
  - ° I ~ 6.3 A
  - ° Color ~ white



– The photoyield always decays with time

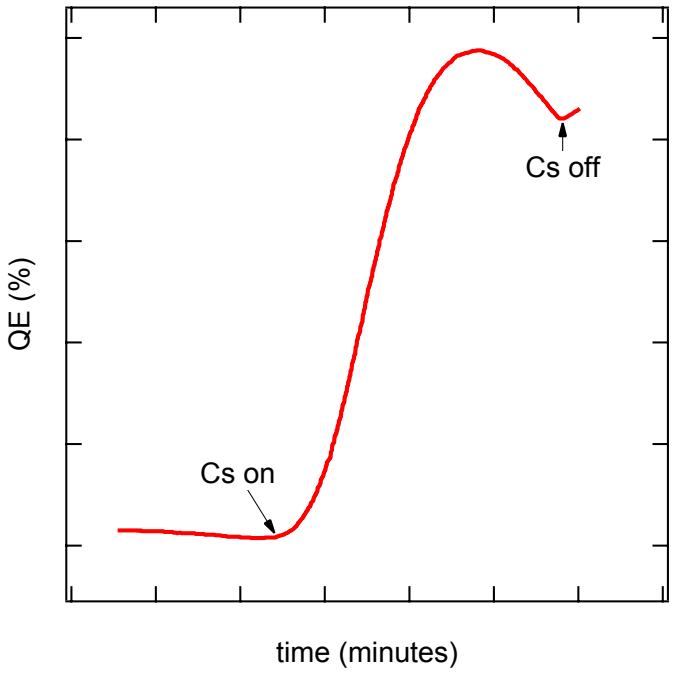
* Chemical reaction with background gas
* Kinetic damage from ion bombardment

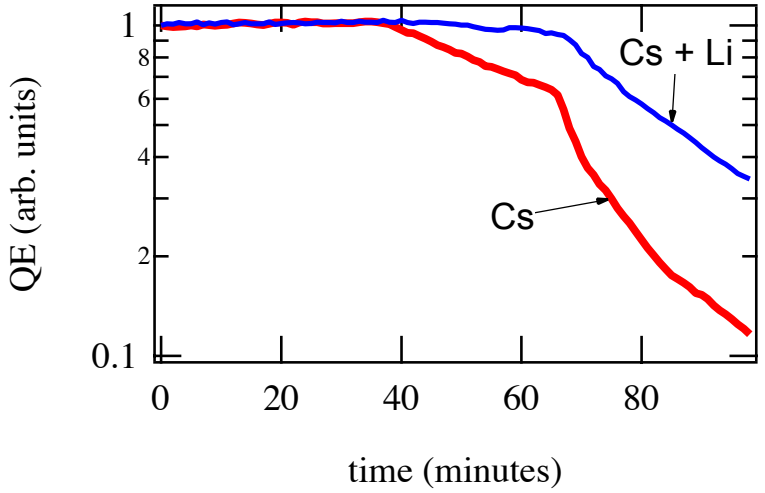
– The photoyield can be mostly recovered by the application of more alkali (Cs) if the drop is due to chemical reaction

– The photoyield can be mostly recovered by heat treatment (annealing) if the kinetic damage is not too extensive

– Better chemical resilience through bi-alkali activation

* CO_2 exposure as metric
* Cs + Li (surprise!)



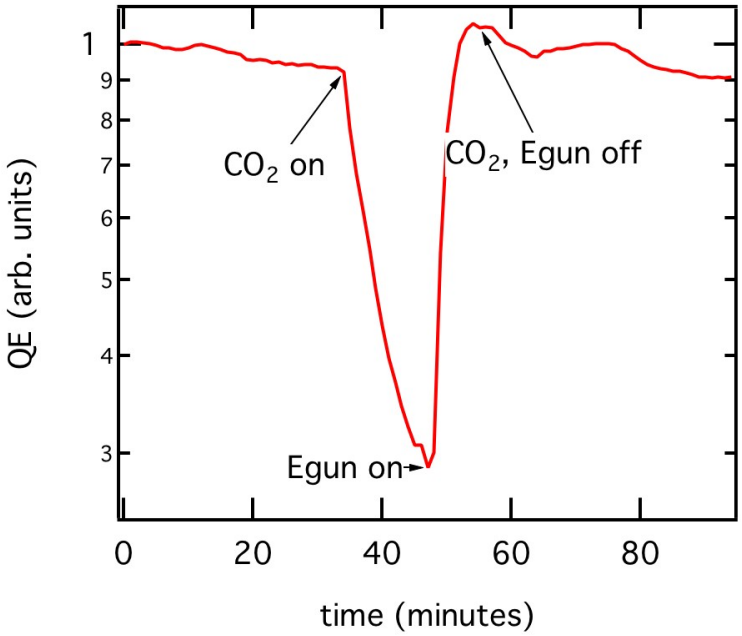


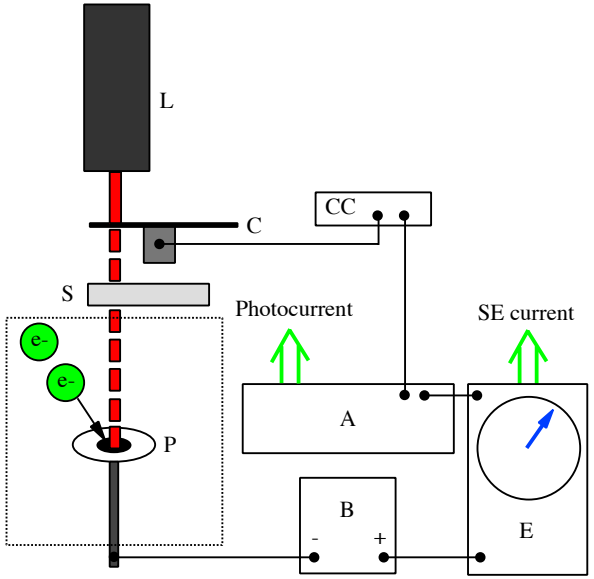
• This work (Phase I): How well does the Cs+Li help with ions? Electrons?

– The Cs+Li activated surface shows enhanced immunity to the action of H ions over that of the Cs activated surface

– New Discovery!

Low energy electrons (1-5 kV primary) can be used to recover the photoyield analogous to the application of Cs: Electron Stimulated Recovery (ESR)





Measurement configuration

Phase II

- Goals

  – Quantify ion flux, mass and energy effects on QE for Cs and Cs + Li activated NEA GaAs + subsequent CO_2 induced decay rate

  – Quantify flux and energy dependence for electron stimulated recovery

  – Determine surface chemistry modification by ESR process

  – Determine if primary or secondary electrons principal actors

  – Measure surface desorption products during ESR

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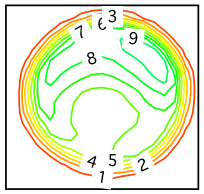
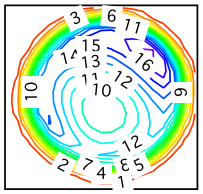
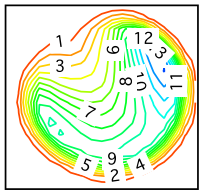
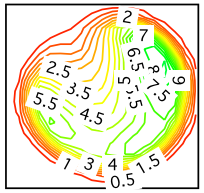
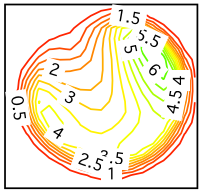
- Status
  - – Ion effects + CO_2 decay: Effects measured by mapping QE over surface
    - * Measure effect
    - * Measure ion beam profile
    - * Measure ion beam currents accurately
    - * Quantify drop in QE per ion at specific energy
    - * Quantify drop in QE for CO_2 exposure at like ion flux locations

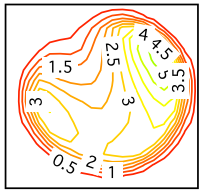

Overnight


After peak up


Ions 2.0 kV $4x10^{-8}$ Tor 1 min.


CO_2 $2x10^{-10}$ over base 5 min.


+5 min. CO_2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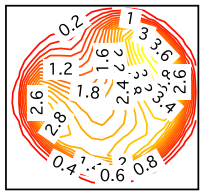
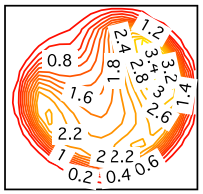
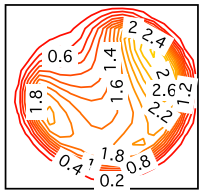
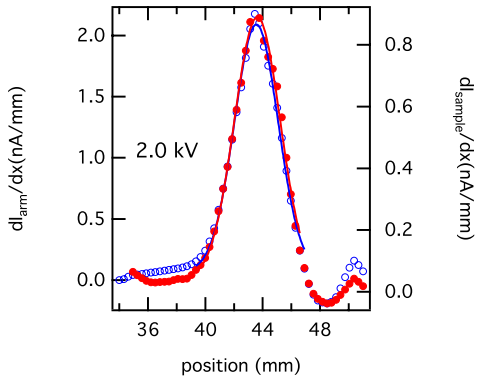

+5 min. CO_2


+5 min. CO_2


+5 min. CO_2



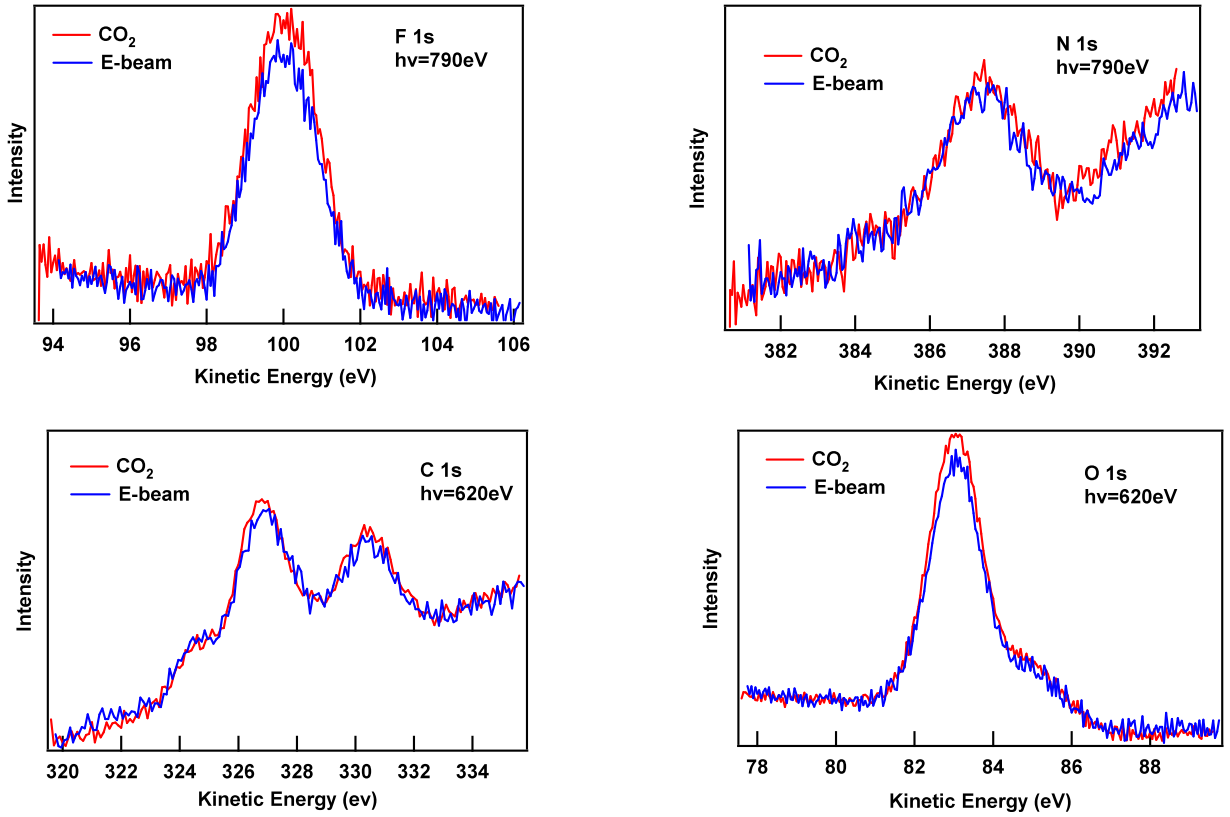
Examples (Cs activation, 633 nm):

Ion	Mass (AMU)	Ion Energy (kV)	Current (nA)	Total Ions	Photoyield drop per ion
Neon	20	2	0.59	2.22×10^{12}	2.7×10^{-10}
Neon	20	1	0.18	6.75×10^{11}	1.4×10^{-9}
Argon	40	2	3.0	1.1×10^{13}	6.0×10^{-12}
Argon	40	0.5	1.36	5.1×10^{12}	9.0×10^{-11}

– Surface chemistry modification via photoemission at SSRL

* ESR effect repeated

Cs + NF_3, normalized to Ga 3*d* intensity



Some slight reduction of O (maybe also C) is observed

– Electron energy dependence on recovery

* Little to no energy dependence for 1.5 to 5 kV primary beam energies

* Little to no dependence (but for rate) for beam currents over 2 orders of magnitude

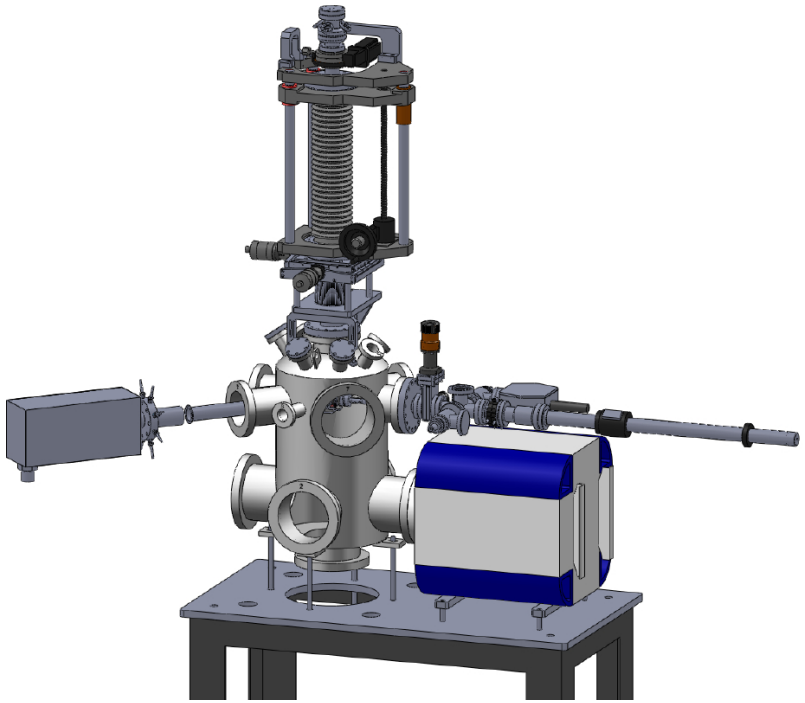
* Works on Cs and Cs + Li activated GaAs

– Primary/secondary electron causal agent determination (Y2)

* System under design

– Desorption products during the ESR process (Y2)

* System under assembly ➔➔➔➔



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- Deliverables

  – Tables of mass, energy effects on QE for H, He, Ne, Ar, Kr, Xe ions 0.5 to 2.0 kV Cs and Cs + Li activated GaAs

  – Tables of energy and flux dependence (none seen yet aside for rate change) for ESR on Cs and Cs + Li activated GaAs

  – Photoemission data on surface chemistry modification during ESR

  – Mass products of ESR process via quadrupole mass spectrometer

  – Secondary electron/primary electron determination and onset energy as for electron stimulated desorption

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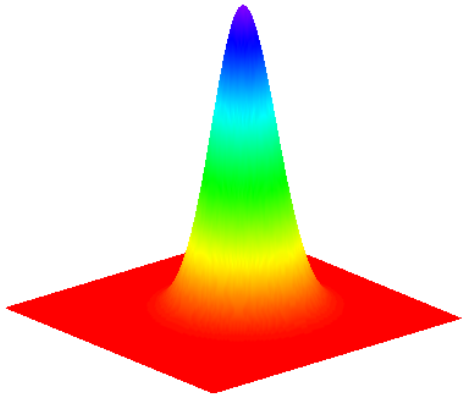
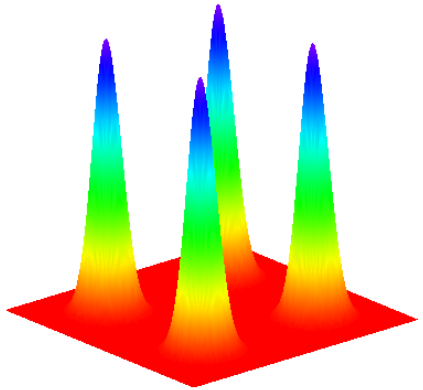
- Related Applications

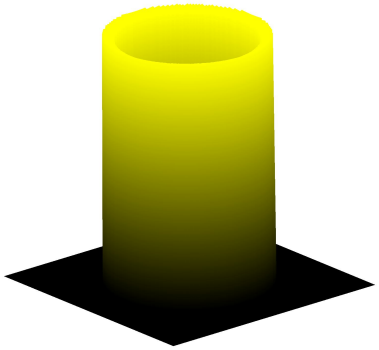
  – ESR can be used to tailor electron beam emission profile *in situ*



Off axis



Multiple beams



Hollow beam

  – More robust NEA GaAs may be used in photon driven tubes as replacement for thermionic emitter (reduced heat load from source): Medical accelerators, etc.

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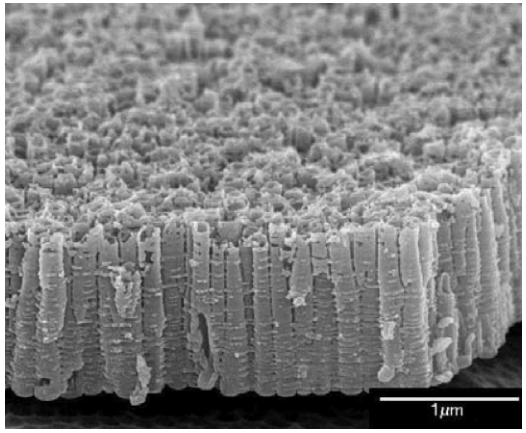
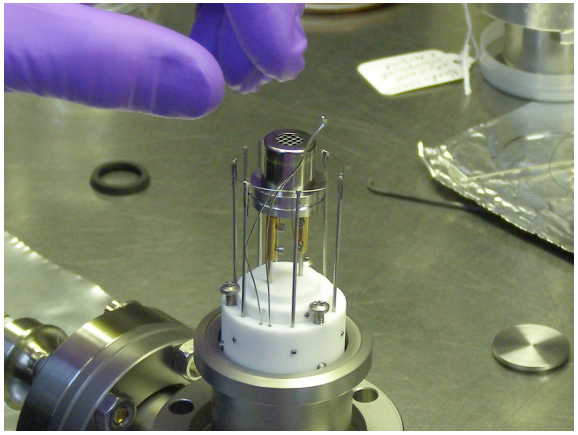
• Complementary Work

– Titania nanotubes as UHV/XHV vacuum pressure sensors





Work funded by Department of Energy SBIR Grant DE-SC0004437