SAND2008-4132C

Office of Nonproliferation Research and Development

SNM Movement Detection / Radiation Sensors and Advanced Materials Portfolio Review

An Advanced Neutron Generator for Field Based Active Interrogation Systems

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An Advanced Neutron Generator for Field Based Active Interrogation Systems

Sandia National Laboratories

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SRI International

Chris Holland, Array Fabrication
Spindt Capp, Array Fabrication

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$500k FY08 project total

Project Overview

Need

A neutron generator for active neutron interrogation, allowing field work on a broad scale for nuclear nonproliferation programs

Approach

A new ion source based upon **electrostatic field desorption** with an atomic beam, low-power consumption, and low areal power density

Benefit

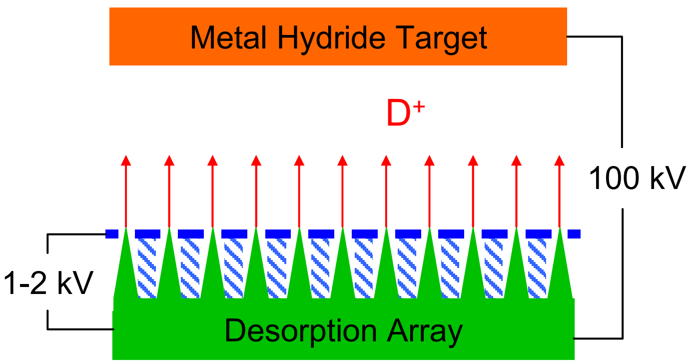
1. An easily portable neutron generator (<20 lbs.) operating with a low power overhead with a very long life (>10,000 hrs.) at a sustained yield $>10^9$ n/s.
2. A high-efficiency, high-yield neutron generator for sustained operations to serve nonproliferation and counterproliferation interrogation operations.

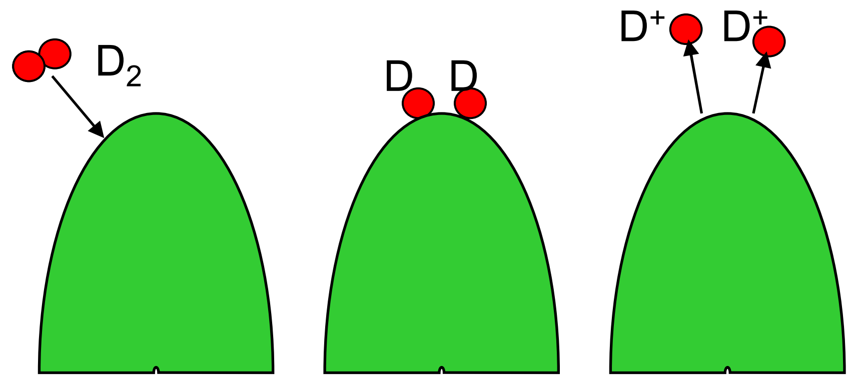
Competition

Established technology: cold cathode ion source sealed tube neutron generator (STNG) (40+ years), RF ion source STNG (50+ years), and large accelerators
Alternative approaches: wire needle arrays, carbon nanotube field ionization

Electrostatic Field Desorption (EFD)

Ion desorption is essentially a 100% energy efficient process





Electron Emission

Starts at 1 – 4 V/nm

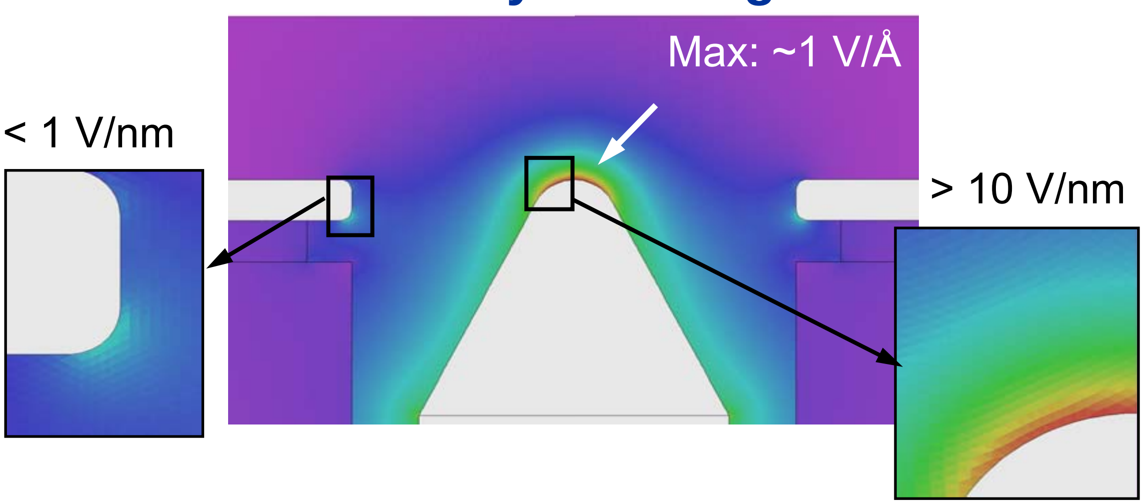
Ion Desorption

Starts at 10 – 20 V/nm

Metal Desorption

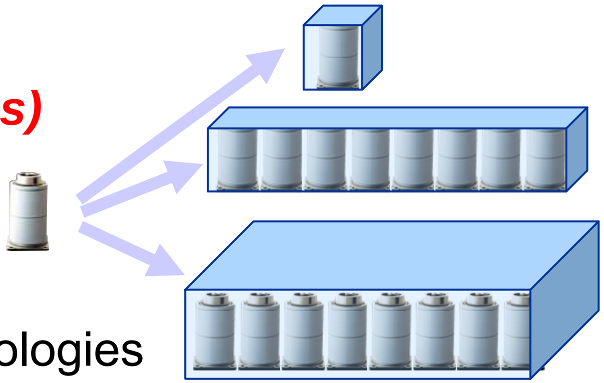
Starts at 40 – 55 V/nm

Primary Challenge



Capability Improvements

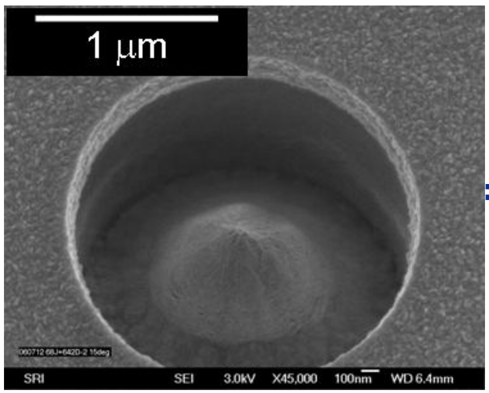
- **Neutron Generator Technology**
  - ***Higher neutron yield***
    - Atomic ions yield ~ 3–4x yield increase over molecular ion beams
    - Reasonable expectation of DT yields of 10^9 n/s/cm^2 at 100 kV
      - >4 μm tip spacing (6.25×10^6 tips/cm^2)
      - ion emission of 0.36 μC/cm^2 of substrate (0.1 μm tip radii, deuterium sticking of 10^{15} D/cm^2)
    - Scalability and low power density → ideal for very high yield systems
  - ***Reduced ion source power requirements***
    - $P = I_{average} V = 100$ mA • 1000 V = 0.1 W versus 5 to 10 W with standard NGs
    - no active cooling requirements
  - ***Short duration neutron pulses possible (< 20 ns)***
  - ***Rugged, Redundant System***



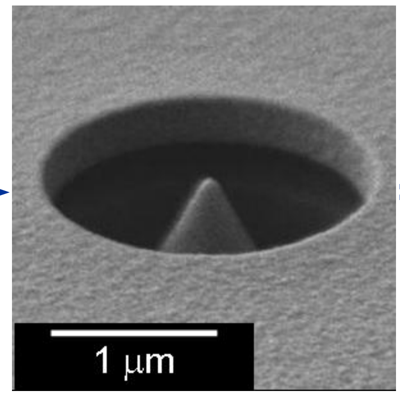
- **Foundational Technology Development**
  - The tip-on-post design may be used in other technologies
    - micro x-ray medical imaging, space craft ion thruster propulsion, microwave and THz radiation sources, and semiconductor lithography

Fabrication Progress

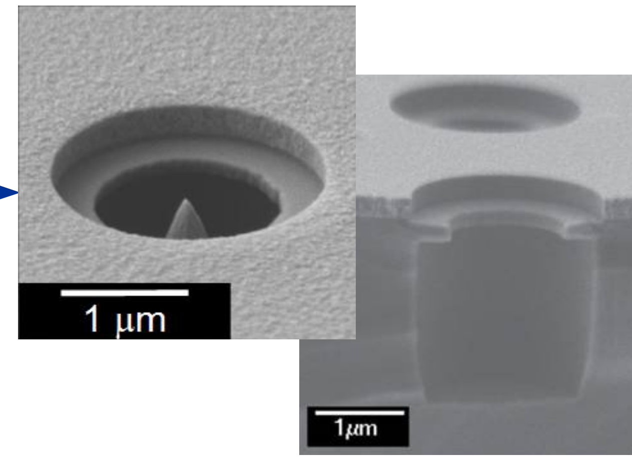
Conventional electron field emitter arrays with Mo tips.

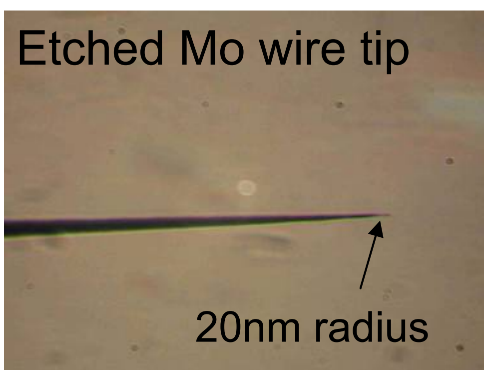


Short depth emitter with larger radii



2 µm oxide depth
Silicon nitride shield
Mo tip and gate

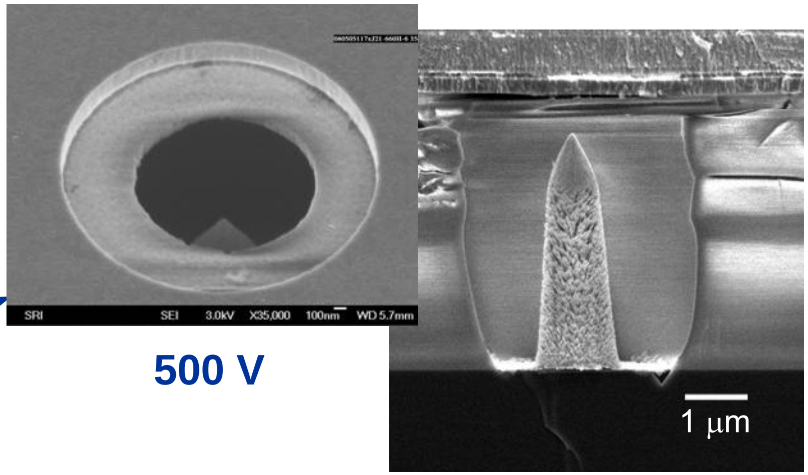




Testing of measurement techniques
Material issues
Cleaning methods

Fabrication Progress

SRI

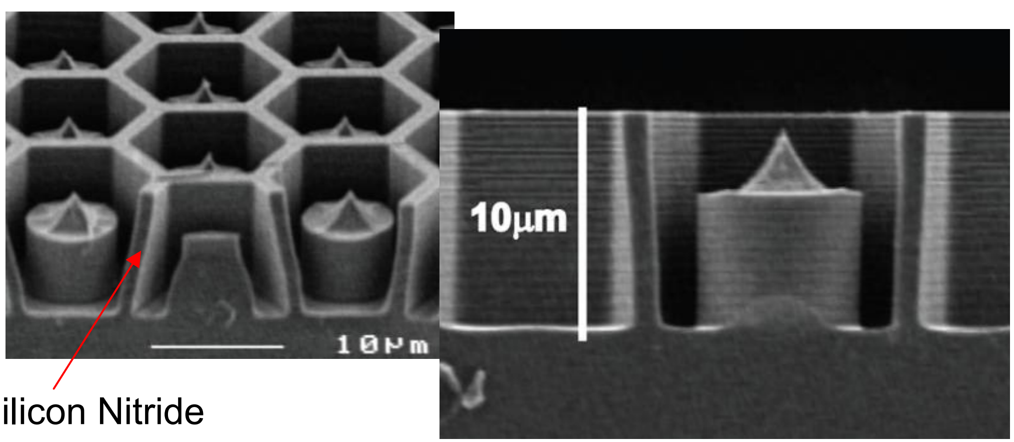


500 V

Tip-on-Post technique
4 μm oxide depth
Nitride shield
Chrome gate
Gate hole - variable diameter
Tip coplaner to or below nitride shield

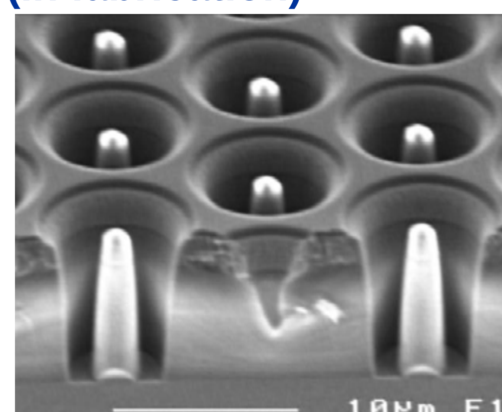
SNL

Silicon Tip-on-Post (in fabrication)



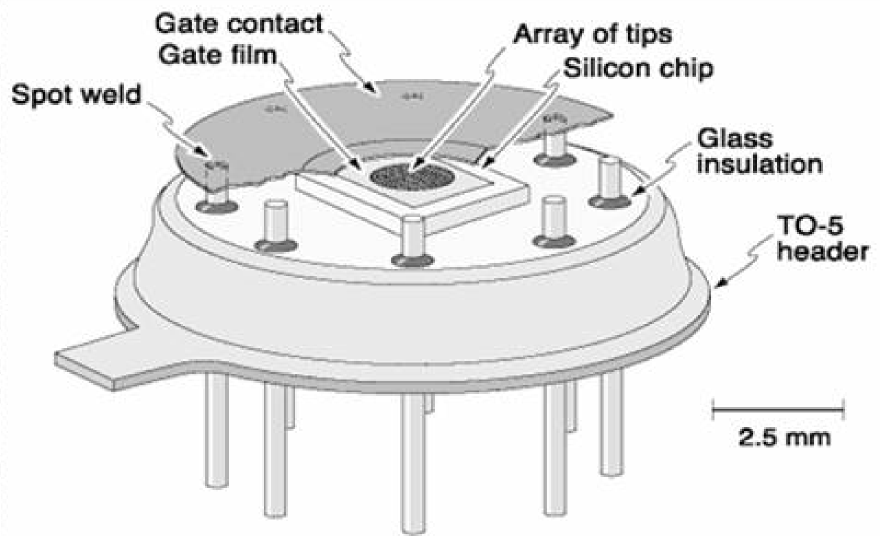
Silicon Nitride

Tungsten Tip-on-Post (in fabrication)

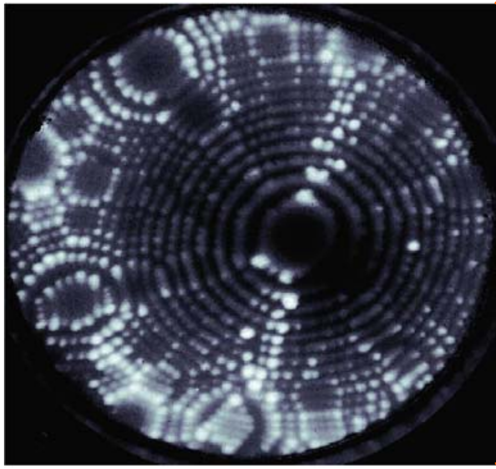


Test System – Micro Array Mount

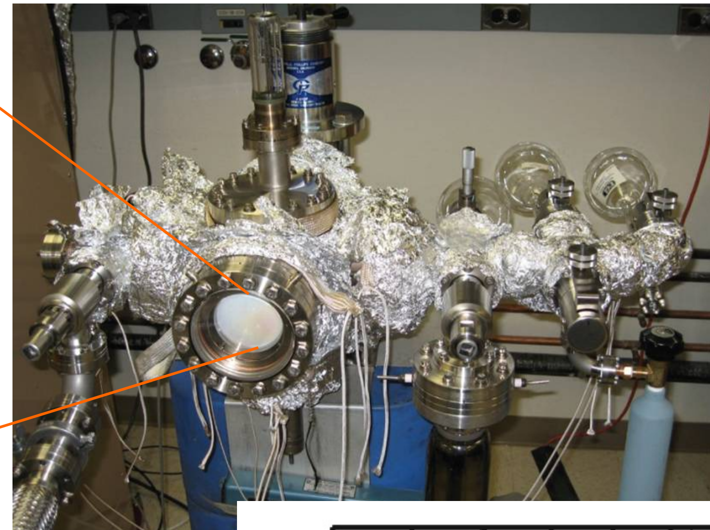
- Study ion emission from nanoemitter tip arrays:
  - **Single tip**
  - **10x10**
  - **100 x 100**
  - **1000 x 1000**
- Examine tip/array performance
  - **pulse characteristics**
  - **high voltage breakdown**
  - **dielectric strength**
  - **ion emission**
  - **ion speciation**
  - **ion contamination**
- New ceramic headers to allow for higher temperature bakes



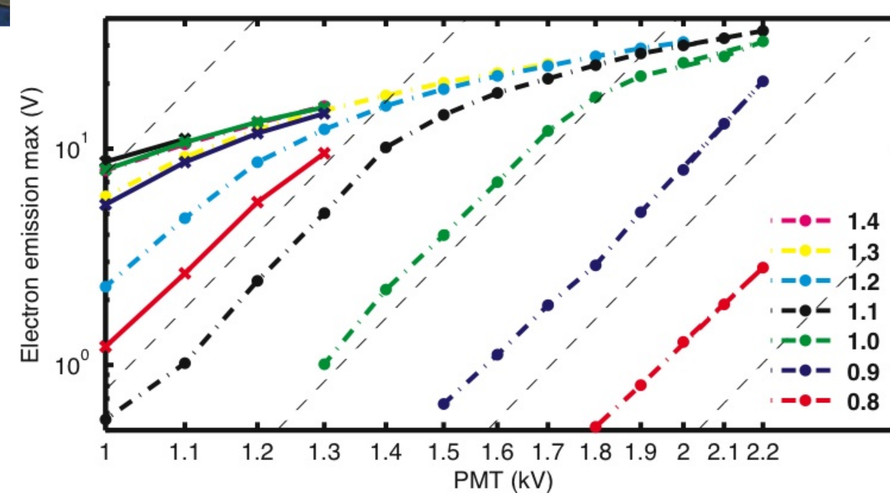
Test System – Imaging Atom Probe



Tungsten tip



Dashed
– neutral density filter
Solid
– no filter

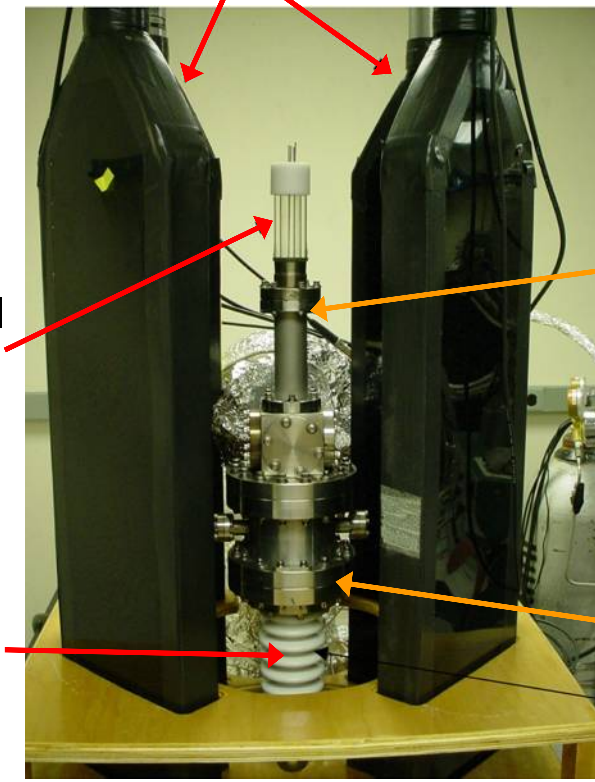


Legend shows micro-channel plate voltage

- Time-of-flight measurements (~12 cm drift distance) to analyze field desorbed species
- Ion imaging to characterize single-tip surface morphology
- Calibration of the PMT to allow for quantified ion current measurements

Test System – Neutron Detection

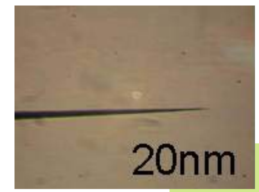
4 Plastic Scintillators

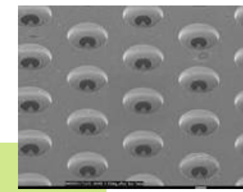


EFD source electrical feedthrough

Target high voltage feedthrough

Source = Tips / Array



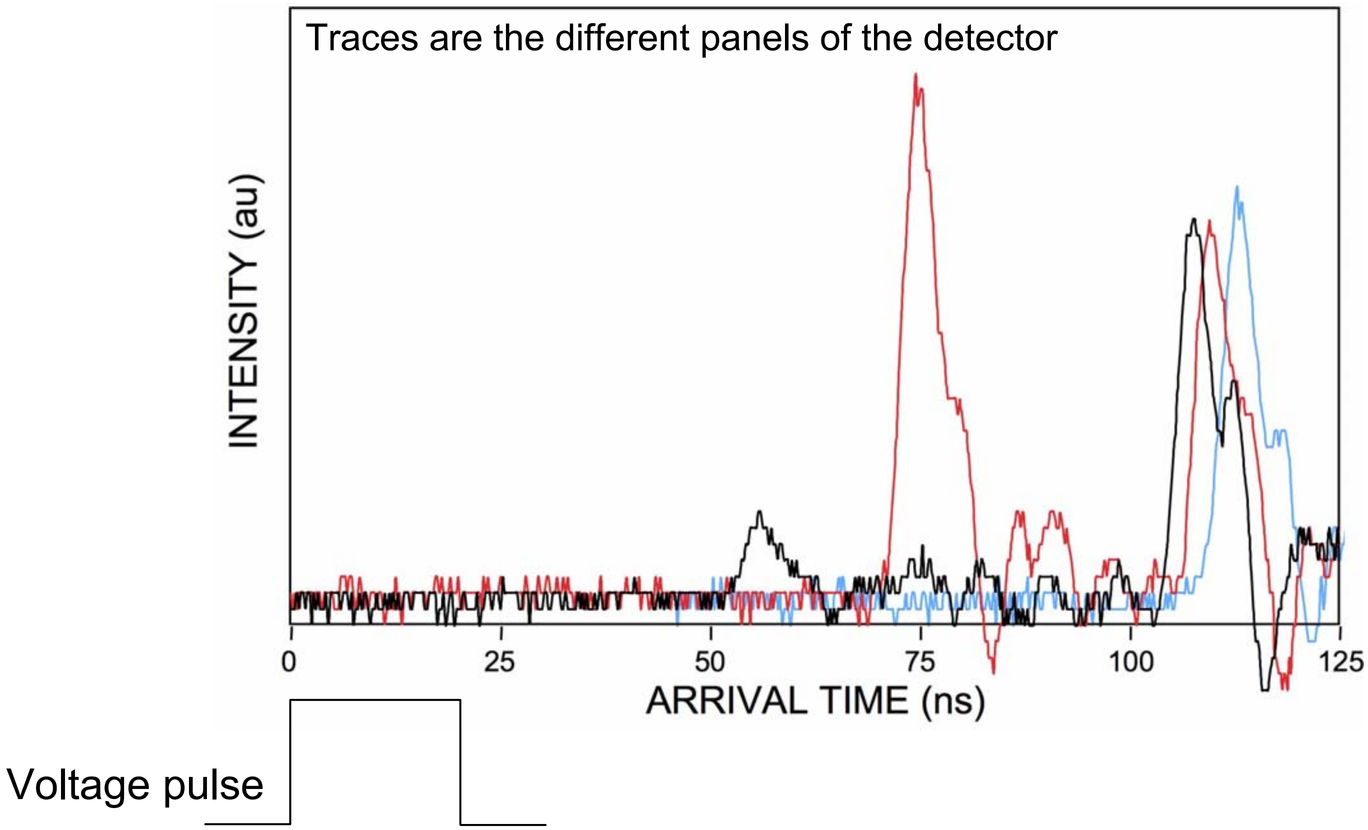


140 keV / 100 keV

Deuterated titanium target

- Tested with 10 etched tungsten wire tips
- Tested with ^{252}Cf source

Test System – Neutron Detection



- Validation of system
- Tested with 20 ns voltage pulse applied to 10 wire tips

Milestones/Deliverables

FY08 Highest Value Technical Deliverable:

Demonstrate the performance of microfabricated arrays as deuterium ion sources for neutron generators.

- ● Done
- ● Underway

FY 2008 Milestones:

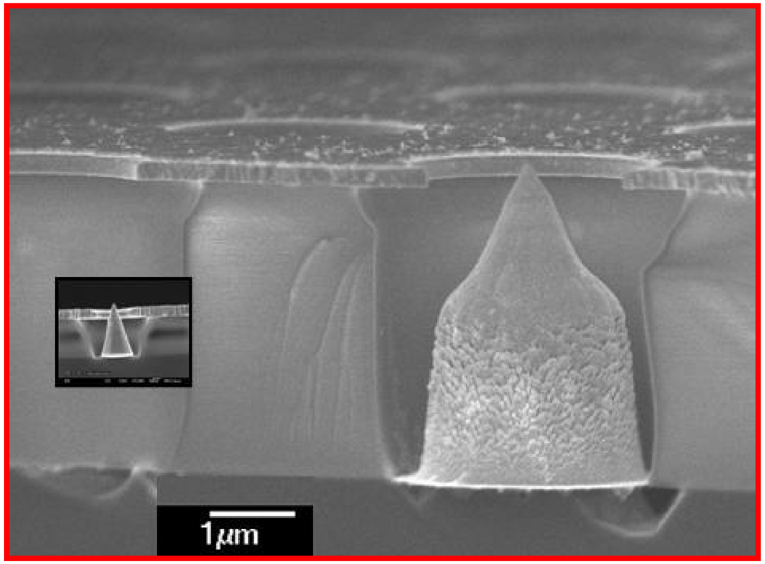
- ● First set of arrays from SRI and SNL fabricated and tested at UNM
- ● Second set of arrays from SRI and SNL fabricated and tested at UNM
- ● Characterization of ion current and neutron output from arrays
- ● Complete performance analysis of the bench-top neutron generator

FY 2008 Tasks:

- ● Task 1: Assemble prototype generator package
- ● Task 2: Characterize prototype generator operation
- Task 3: Preliminary neutron generator design for a field-able unit
  This task was zeroed out for FY08
- ● Task 4: Microfabricate field desorption sources for Year 3 studies
  This task was greatly enhanced for FY08

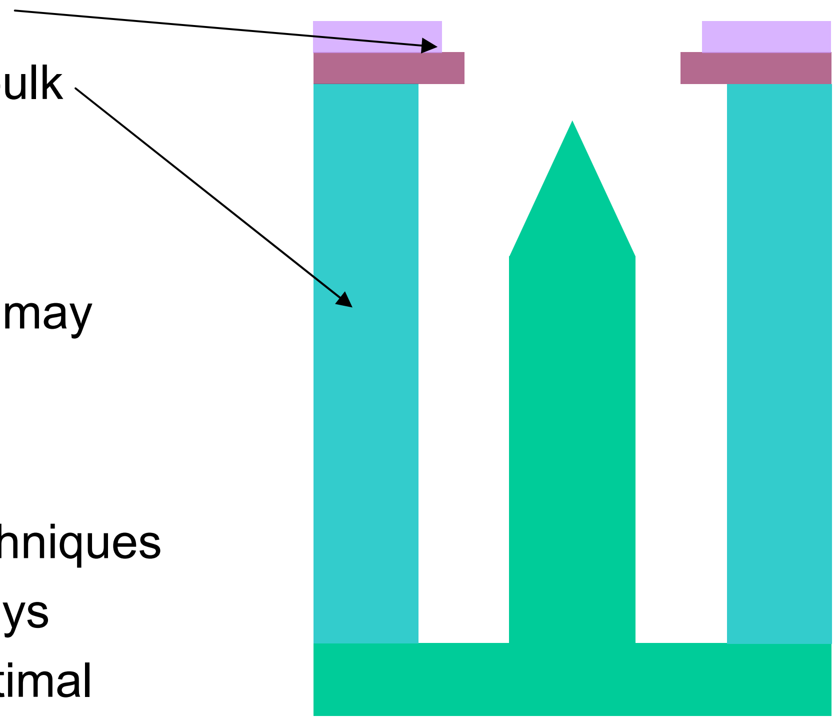
Technical Success

- **First ever manufacturing of ion emission micro arrays**
  - Successful fabrication of thick oxide (4.25μm), tip-on-post structures
  - Measurement of D^+ ions from tip-on-post structures
- **Calibration of test system for ion current measurements**
  - Very low current, non-trivial measurements
- **Design of prototype system with neutron detectors**
  - Built system with ion source, deuterium target and neutron detectors.
- **Advancements in array fabrication procedures**
  - New tip process allow for taller tips
  - Refined fabrication methods for thicker oxides
- **Results are consistent with modeling predictions**



Technical Challenges

- **High Voltage Issues**
  - Electron emission from the triple point
  - High voltage breakdown through the bulk insulator
- **Tip Array Fabrication**
  - Increase insulator thickness (new tips may provide the answer)
- **Array Cleaning**
  - Single tip studies provide cleaning techniques
  - Apply methods to microfabricated arrays
  - Ion and metal desorption would be optimal (high electric fields)



Future Work

- **Remainder of FY08**
  - Complete fabrication and testing of SNL arrays
  - Complete testing of SRI arrays
  - Measure ion current and neutrons from microfabricated array
- **NA-22 proposed work (starting FY09)**
  - Finalize fabrication techniques and demonstrate success of the EFD method
  - Pending results from above, pursue full development and testing of neutron source
- **DTRA Hydride Tip Work**
  - Current DTRA funding is to UNM for FY08
  - Have been asked to submit for follow-on funding in FY09
  - Complimentary fabrication and performance characteristic testing.

Publications and Presentations

- **Publications**
  - “Development of a Field Desorption Ion Source for Neutron Generator Applications”, D.L. Chichester, J. Brainard, P.R. Schwoebel, K.L. Hertz, C. Holland, Nucl. Inst. Meth. Phys. Res. B, **261** (2007) 835-838.
  - “Field Desorption Ion Source Development for Neutron Generators”, I. Solano, B. Reichenbach, P.R. Schwoebel, D.L. Chichester, C.E. Holland, K.L. Hertz, J.P. Brainard, Nucl. Instr. Meth. A **587** (2008) p.76-81.
- **Presentations**
  - Conference on the Application of Accelerators in Research and Industry (CAARI), Ft. Worth, TX 2006
  - American Physical Society, Northwest Section Meeting, Pocatello, ID 2007
  - 20th International Vacuum Nanoelectronics Conference, Chicago, IL 2007
  - 67th Physical Electronics Conference, Urbana, IL 2007
- **Graduate Student Support**
  - Sid Solano, M.S. Candidate, Physics, UNM
  - Birk Reichenbach, Ph.D. Candidate, Physics, UNM - *won Second Place for Best Poster at the 67th Physical Electronics Conference*