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A MICROFABRICATED FIELD DESORPTION ION SOURCE FOR NEUTRON GENERATORS

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Outline

- Motivation for neutron generators and microfabricated EFD sources
- Field Ionization and Field Desorption
- Fabrication
  - SRI
  - Sandia National Labs.
- Performance
- Summary
- Acknowledgements

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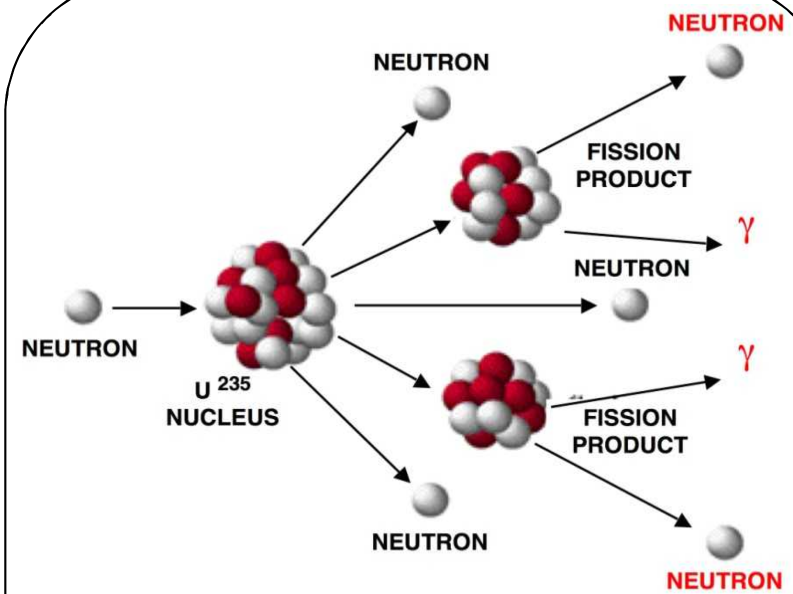
Active Neutron Interrogation systems require *improved neutron generators* for security activities.



Active Neutron Interrogation

Neutrons interact with an object and fission product decay is detected.

National Academy of Sciences Study

Fieldable neutron generators need:

- Higher neutron output
- Lower power requirements
- Longer lifetime
- Increased durability
- Lower cost
- Decreased size & weight

Fieldable detection system require yields of $\geq 10^9$ n/s.

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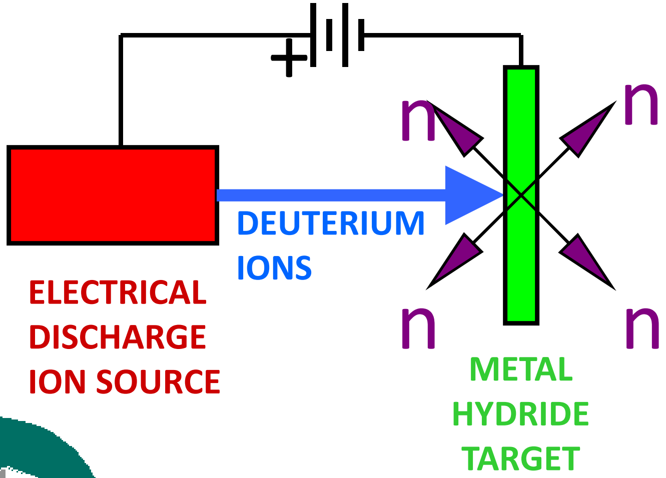
Existing compact neutron generator technology is limited by ion source performance.

ZETATRON NEUTRON TUBE
~ 10^8 n/s

Electrostatic Field Desorption is being investigated as a deuterium ion source.

Advantages:

- High *D* ion output in short pulses
- Very efficient
- Long lifetime
- Room temperature operation
- Compatible with sealed tube technology



NEUTRONS

^{2}H (d,n) ^{3}He

(2.5 MeV NEUTRONS)

OR

^{3}H (d,n) ^{4}He

(14 MeV NEUTRONS)

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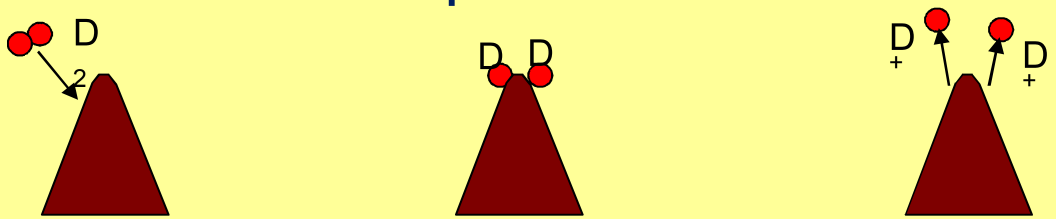
Motivation – Approach

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

Solution: A new ion source based upon electrostatic field desorption (EFD) based on microfabricated emitter tips with an atomic beam, low-power consumption, and low areal power density.

Benefit: A high-efficiency, high-yield neutron generator for sustained operations to serve nonproliferation and counter-proliferation interrogation operations.

Electrostatic Field Desorption



Deuterium gas molecules hit the metal surface.

Deuterium adsorbs onto the surface.

An applied electric field desorbs deuterons.

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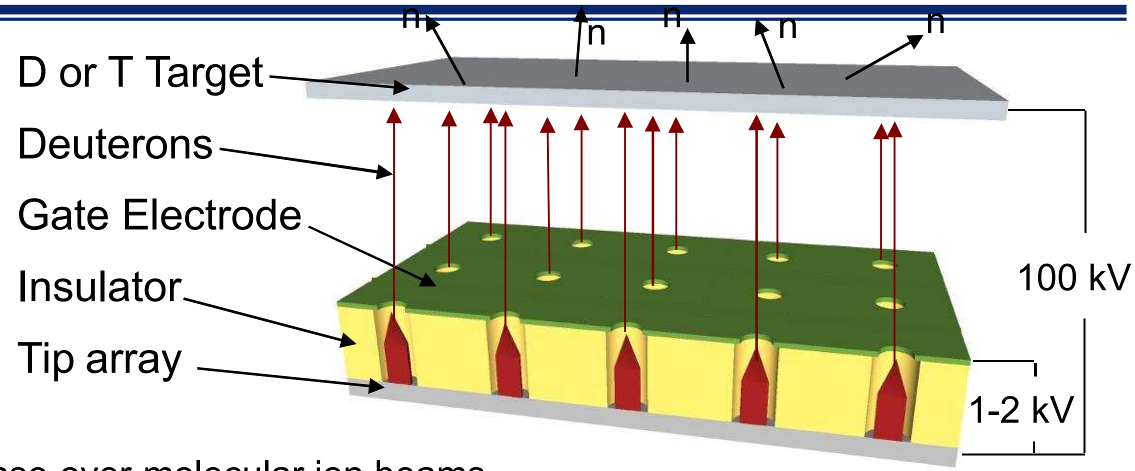
Benefits of EFD Neutron Generators



Standard MEMS manufacturing

- Low cost, mass produced devices

Higher neutron yield

- Atomic ions have ~ 3-4x yield increase over molecular ion beams
- Reasonable expectation of T(d,n) yields of 10^9 n/s/cm^2 at 100 kV

Scalability and low power density

- Large variation in yield from < 10^7 to 10^{12} neutrons/s
- Inherently distributed ion beam on target greatly increases lifetime (>10,000 hrs)

Reduced ion source power requirements

- $P = I_{average} V$ = 1 mA • 1000 V = 1 W versus 5 to 10 W with standard NGs
- No external components such as RF source or cooling system

Short duration neutron pulses

- (< 20 ns) with no dark current

Rugged, redundant system

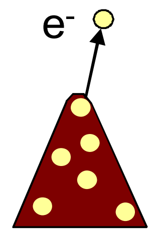
- Arrays are integrated into neutron tubes that allow tiled design and provides a flexible geometry and robustness through redundancy

Tip-to-Gate Electric Field Ratio is the Key to Success

Electron Emission

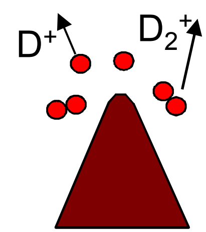
(reverse polarity)

Starts at 1 – 4 V/nm



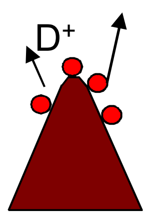
Field Ionization

Starts at 10 V/nm



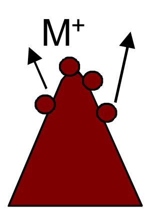
Ion Desorption

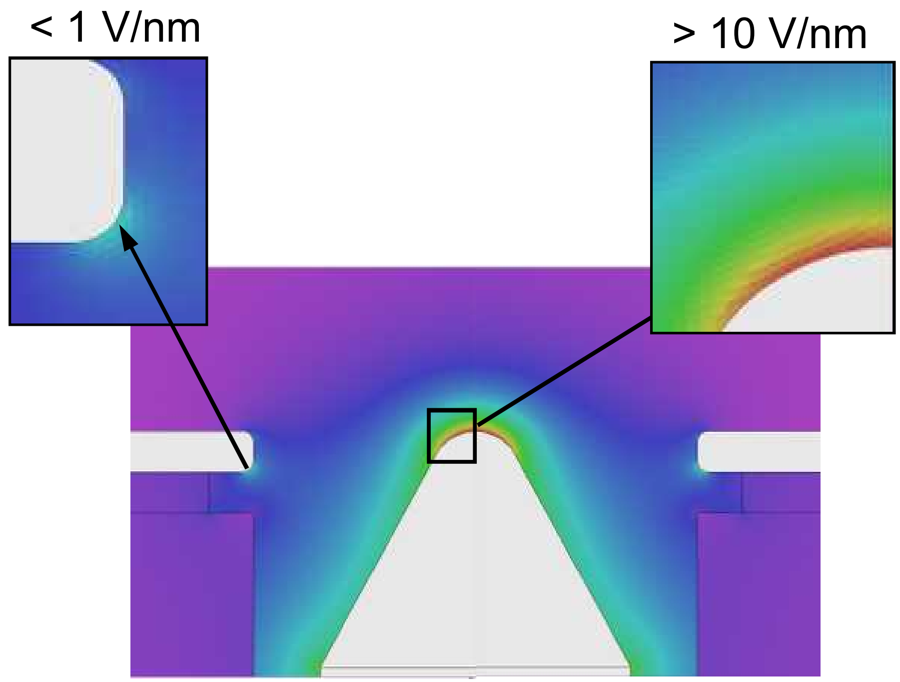
Starts at 15 – 20 V/nm



Metal Desorption

Starts at 35 – 55 V/nm





Tip-to-Gate Ratio of the Electric Field:

must be > 10, preferably 50 or more

is necessary to suppress

gate field emission onto tip

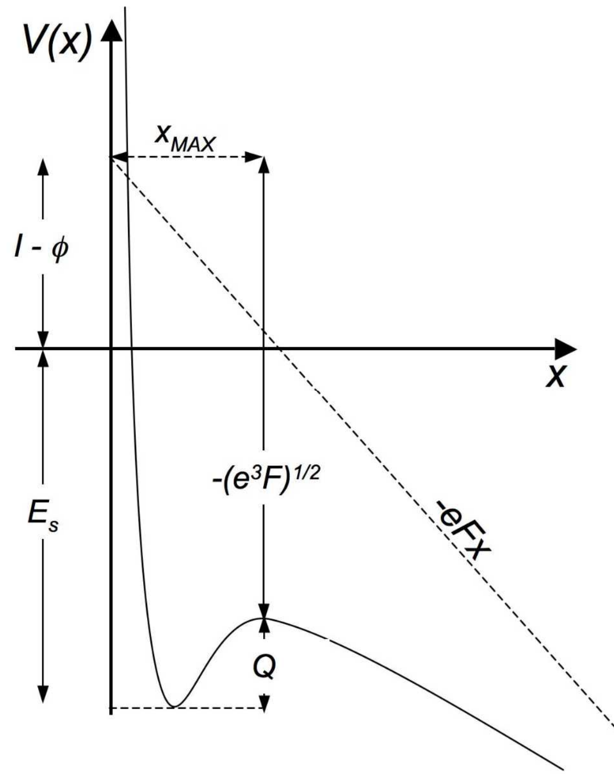
Field desorption can be modeled as a thermionic cycle

THE ENERGY TO REMOVE AN ATOM FROM A SURFACE AS A SINGLY CHARGED ION (IN ZERO FIELD) IS:

$$Q_o = E_S + I - \phi$$

E_S = SUBLIMATION ENERGY
I = ATOM IONIZATION POTENTIAL
ϕ = SURFACE WORK FUNCTION

REQUIRES ELECTRIC FIELDS OF ORDER OF A FEW V/Å



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Source Fabrication
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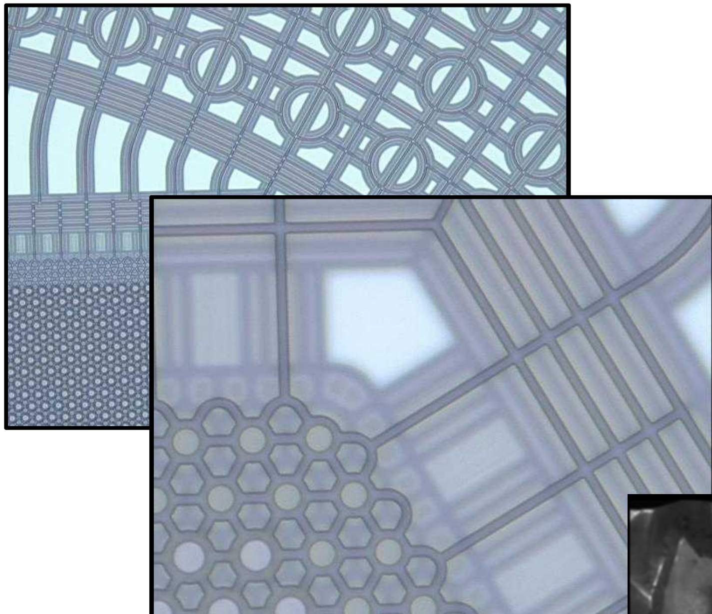
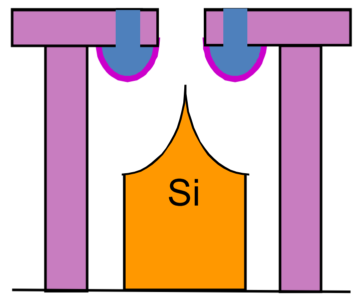
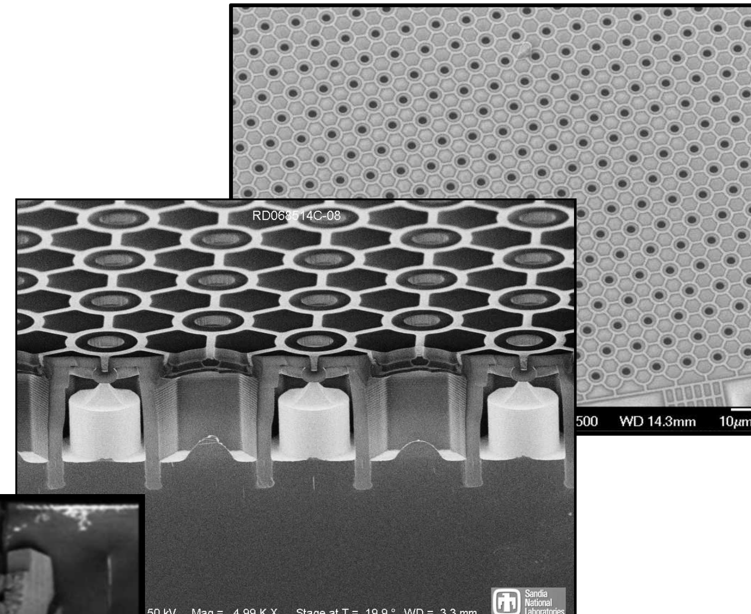
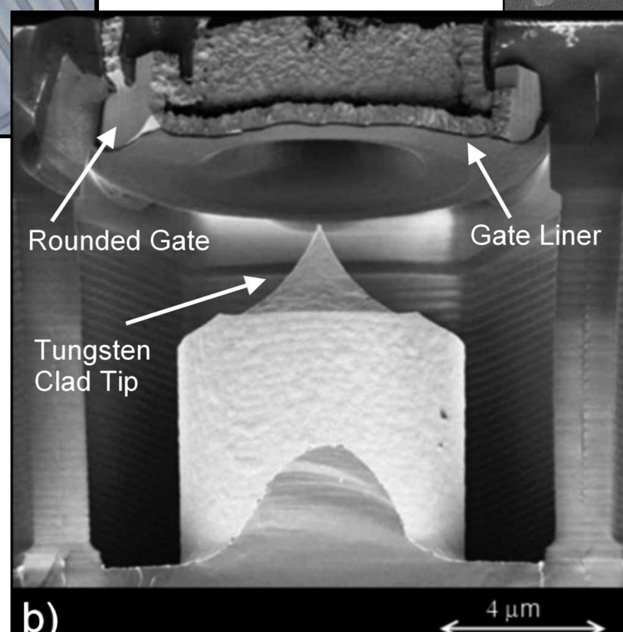
SRI International









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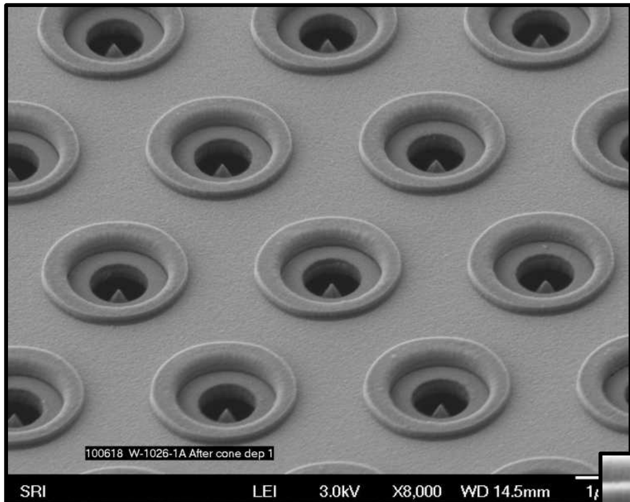
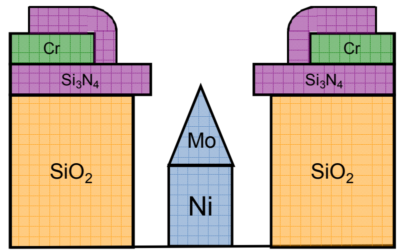
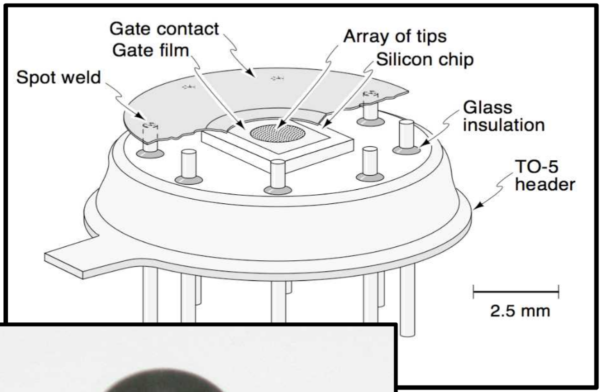
Source Fabrication
SRI

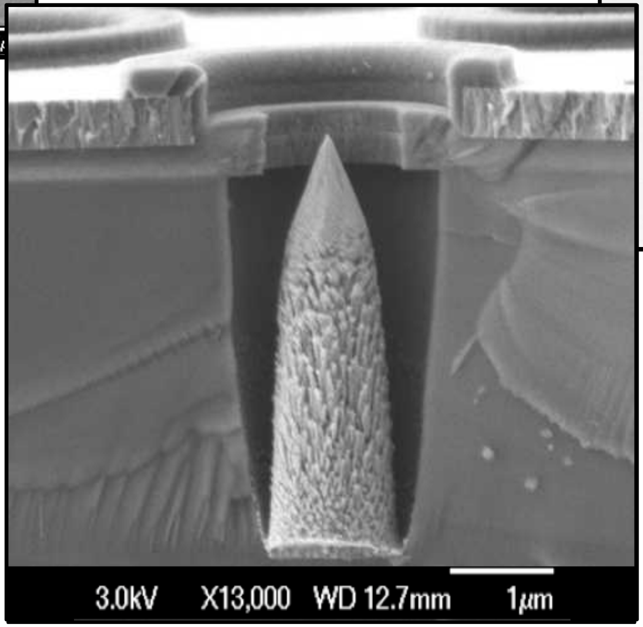
SRI International

TO-5 Package









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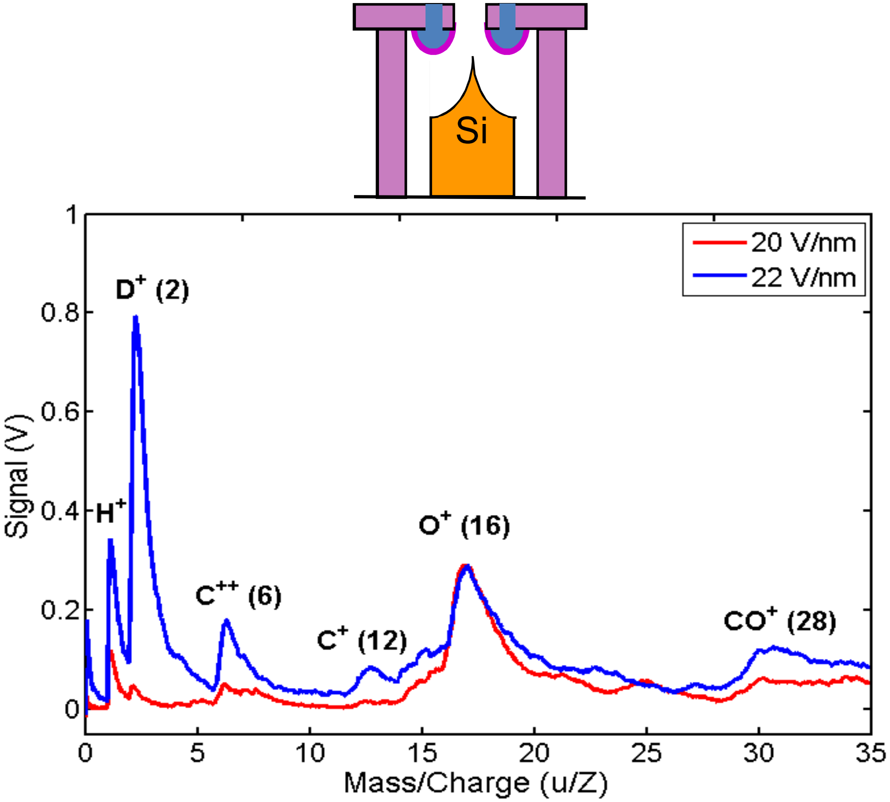
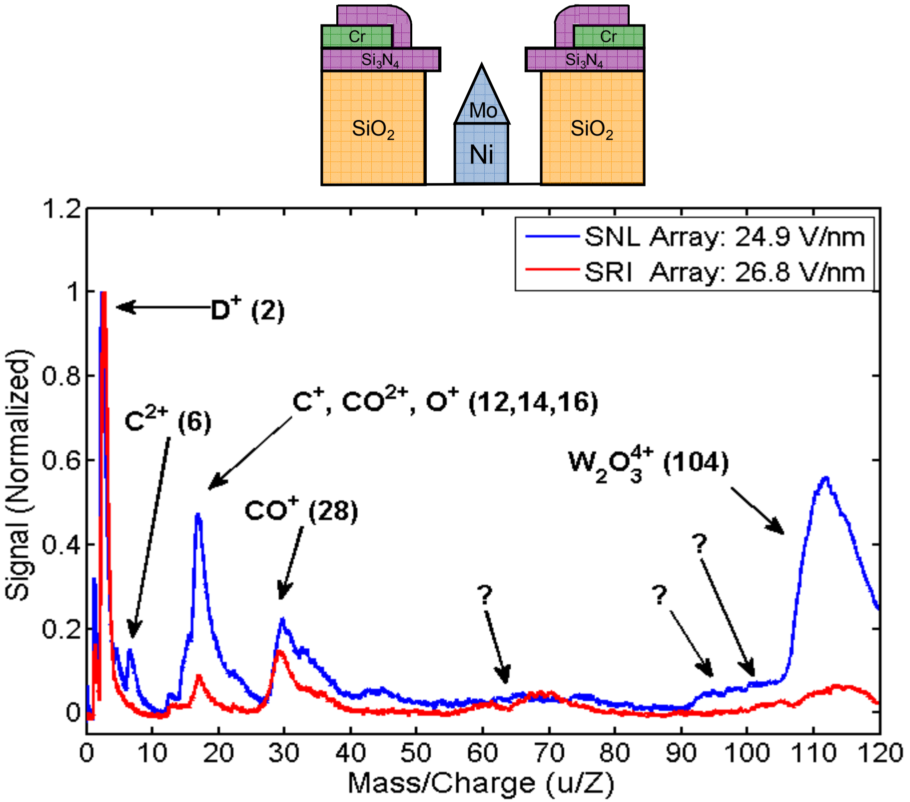
Time of Flight (TOF) Measurements of Generation Ions





- ***The onset of deuterium desorption.***
- ***Surface contaminants also desorbed from array tips.***

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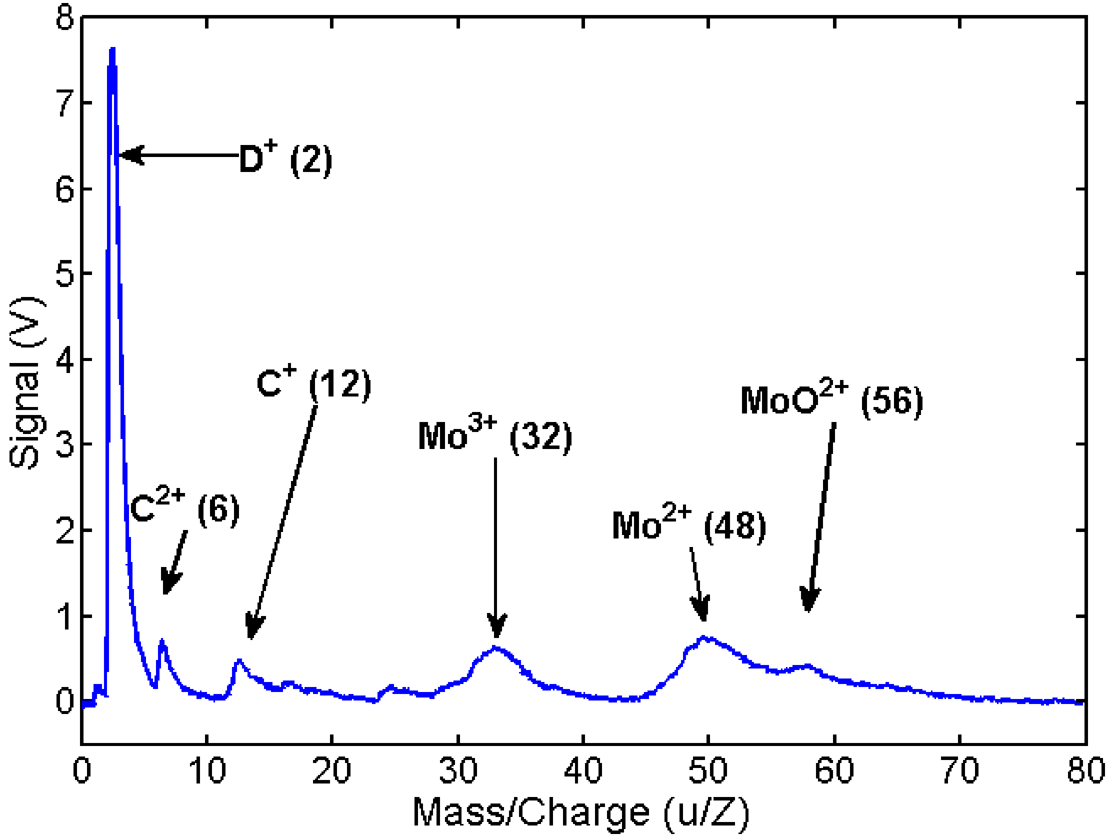
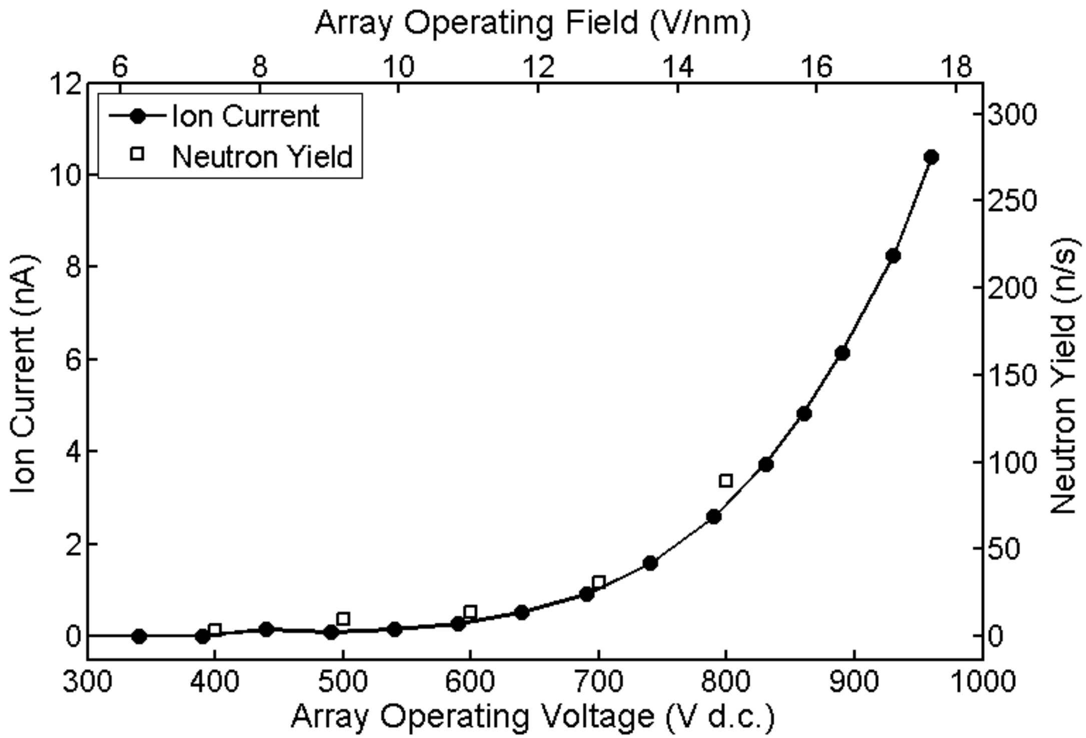
Time of Flight (TOF) Measurements of Generation Ions



- ***Surface contaminants also desorbed from array tips resulting in "cleaning"***
- ***Field evaporation of Mo tip, ~ 35 V/nm***

Neutron production from ions generated by *field ionization*



FIELD IONIZATION

- Ions produced by ionizing gas in front of the tip
- Lower fields (>10 V/nm)
- Lower yield than desorption
- Requires cryogenic cooling

~10^9 neutrons per second are predicted for a 1 cm^2 device with tip packing densities of 10^7 tips/cm^2.

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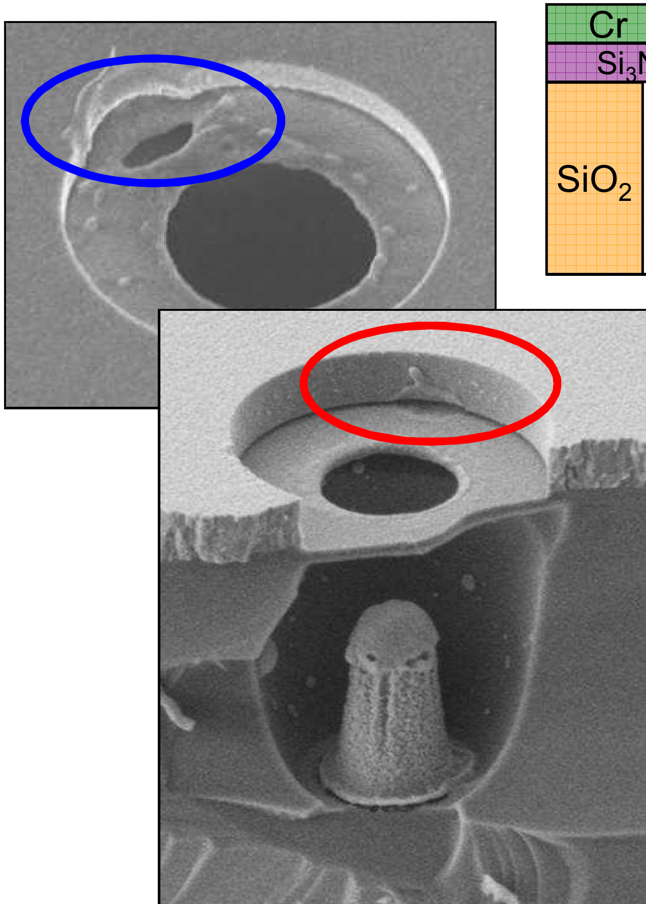
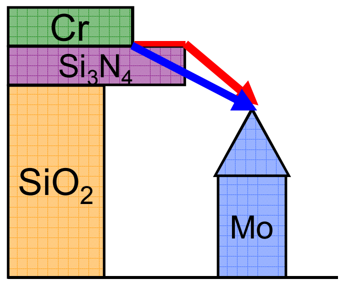
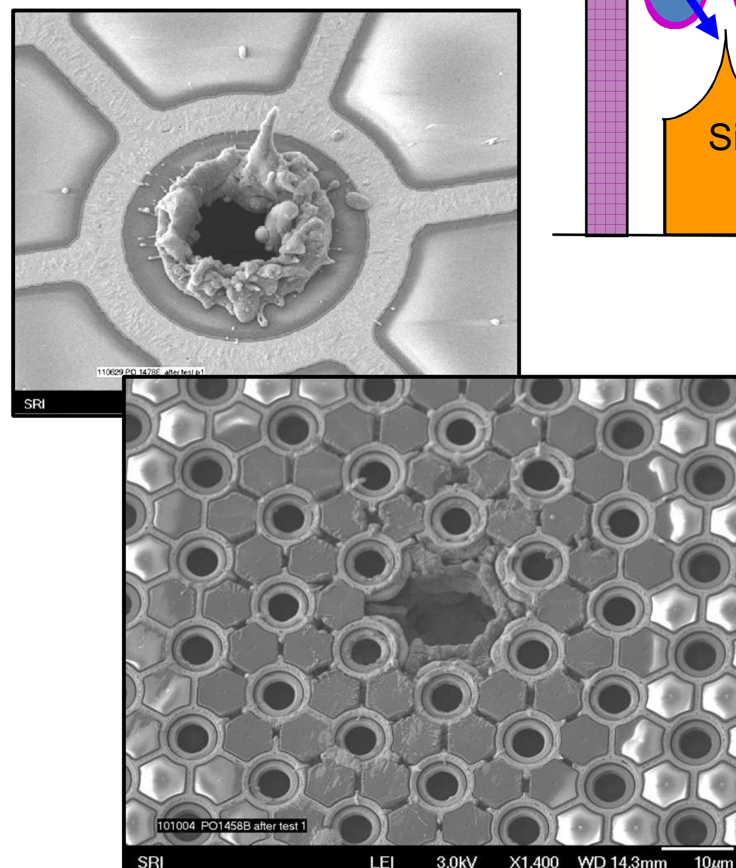
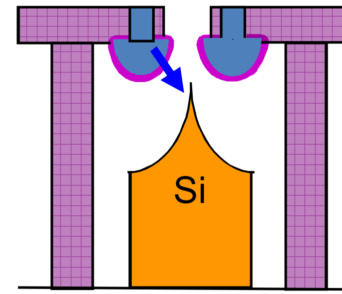
Key Failure Mechanism
Gate Field Emission

- Field Emission from gate bombards emitter tip causing melting and failure









SUMMARY

- Field ionization and Field desorption of deuterium has been demonstrated with microfabricated W clad Si (SNL) and Mo evaporated (SRI) emitter arrays
- Fields sufficiently high, >35 V/nm, to field evaporate the emitter tip have been achieved
- Neutron generation has been achieved with ions produced from 1-mm microfabricated emitter arrays
- Both gate dielectric overcoat and gate rounding are necessary to achieve field desorption and to suppress gate field emission

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ACKNOWLEDGEMENTS
Questions?

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COLLABORATORS

<u>*Experimentation*</u>
- Benjamin Johnson – *University of New Mexico*
- Paul Schwoebel – *University of New Mexico*

<u>*Fabrication*</u>
- Chris Holland, Capp Spindt – *SRI International*
- Paul Resnick – *Sandia National Laboratories*

<u>*Active Interrogation and Modeling*</u>
- Kristin Hertz – *Sandia National Laboratories*

<u>*Neutron Generator Design*</u>
- David Chichester – *Idaho National Laboratory*

BACK UP SLIDES

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Appendix

Possible Neutron Generation per Pulse per cm^2

Tip Density	1.0×10^6 tips/cm^2 of substrate
Tip radius	0.1 μm
Tip surface area	0.06 μm^2, assuming a hemispherical tip
Tip surface area/cm^2 of substrate	$0.06\ \mu m^2 * 1.0 \times 10^6$ tips/cm^2 / 10000^2
D atoms/cm^2 of tip area	1.0×10^{15} D/cm^2
D ions/cm^2 of substrate	6×10^{11} D^+/cm^2
$\mu C/cm^2$ of substrate	0.1 $\mu C/cm^2$ of substrate
Current/tip	1.0×10^{-13} C/tip

Neutrons/pulse/cm^2 of substrate	= 5×10^6 neutrons/pulse/cm^2 of substrate
	= 5×10^9 neutrons/second at 1 kHz

Pulse rate ≤ 1 kHz

Steady Increase in the Electric Field

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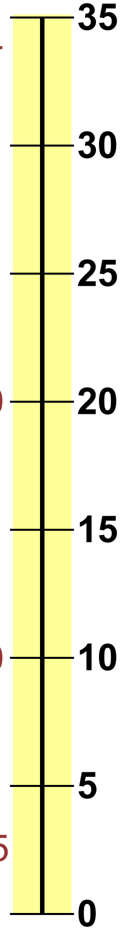
Field (V/nm)



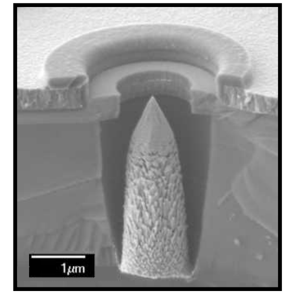
optimal desorption field (D^+ from Mo) → 34

desorption onset → 20

field ionization onset → 10

electron emission field → 2.5

30.4 (pulsed)



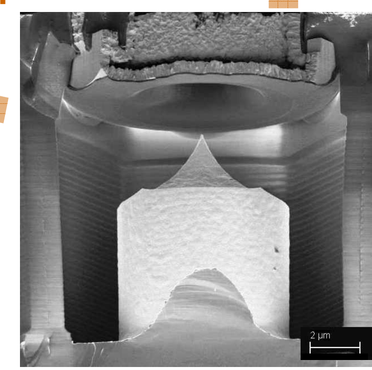
SRI with Si_3Ni_4 shield

23.5 (pulsed)

22.0 (pulsed)

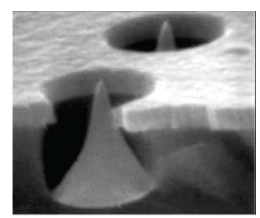
150 nm shield + solid bond-pad

15.3 (DC field)



SNL with rounded-gate + 100 nm Si_3Ni_4 shield

7 (pulsed)



electron field emitter as ion source

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