INTERNATIONAL FEMTOSCIENCE, INC.

INTERNATIONAL FEMTOSCIENCE, INC.

Jim Davidson, Dave Kerns

Small business conducting research, development and deriving applications for advanced technology in innovative *manipulation of the electron*, in all media, gas (vacuum), liquid, and solids to provide *extreme performance* electronics, sensors, power systems, energy storage and management, biological femtosystems and other highly advanced technologies

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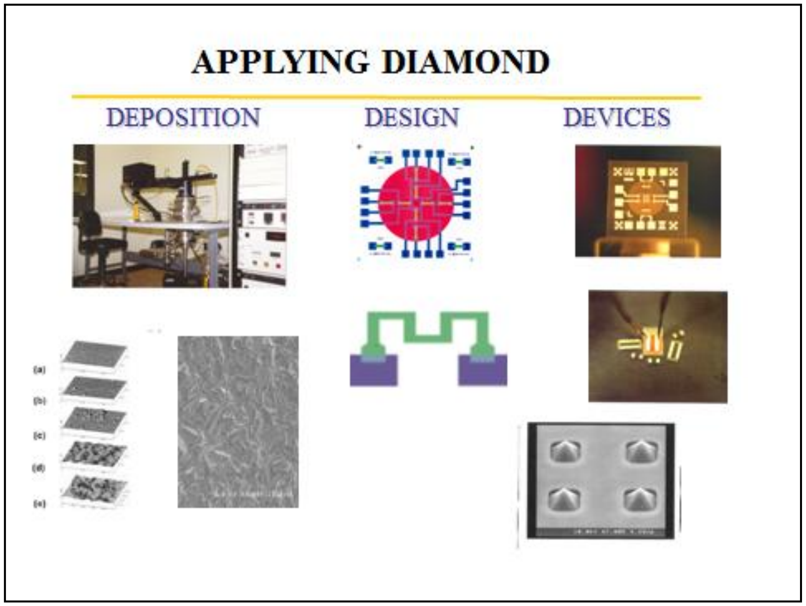
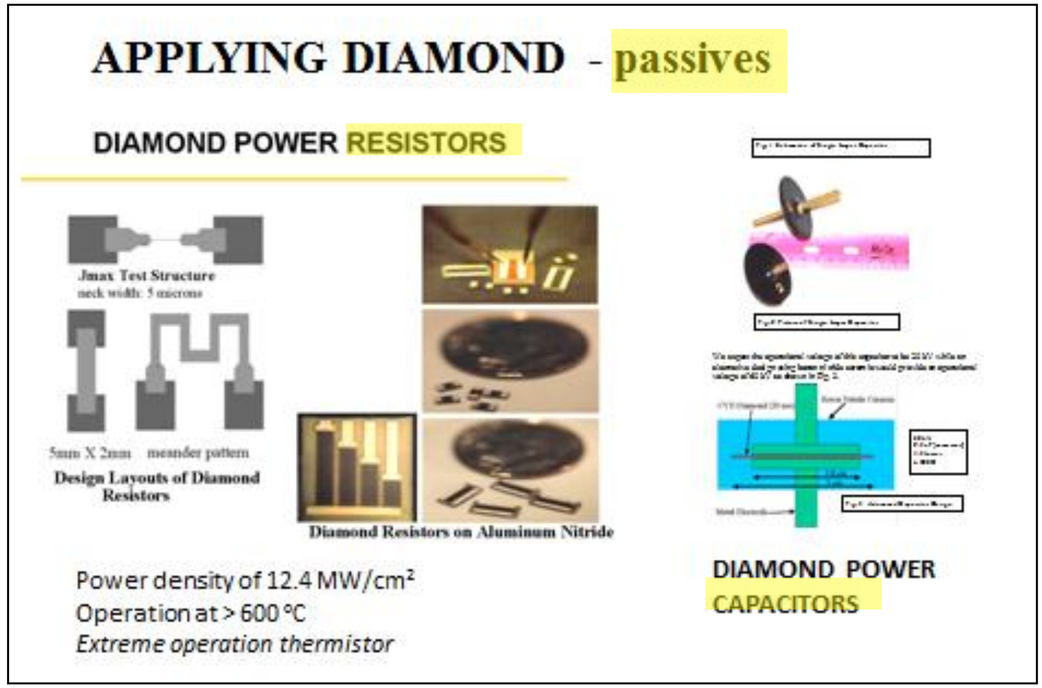
P.O. Box 50980, Nashville, TN 37205
www.femtosci.com

INTERNATIONAL FEMTOSCIENCE, INC.

Extreme Performance
electronics, sensors





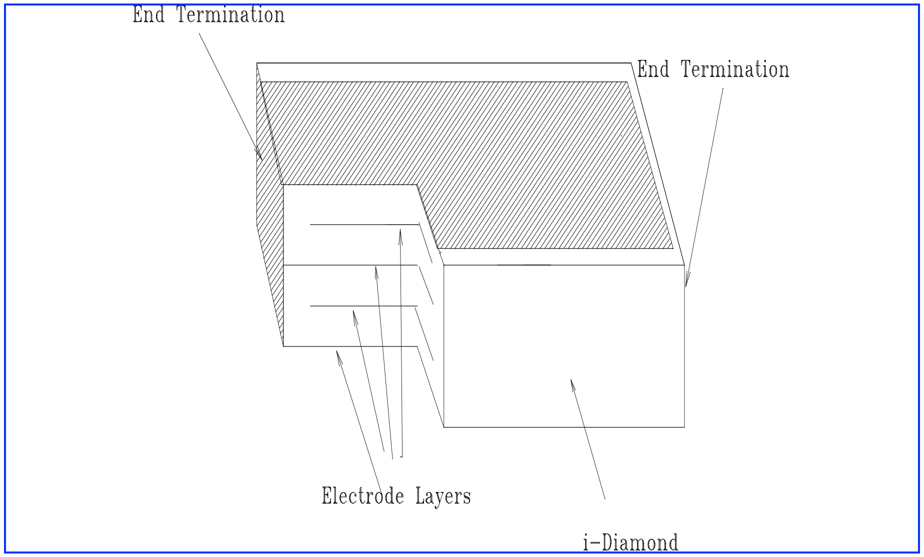
Diamond Resistors

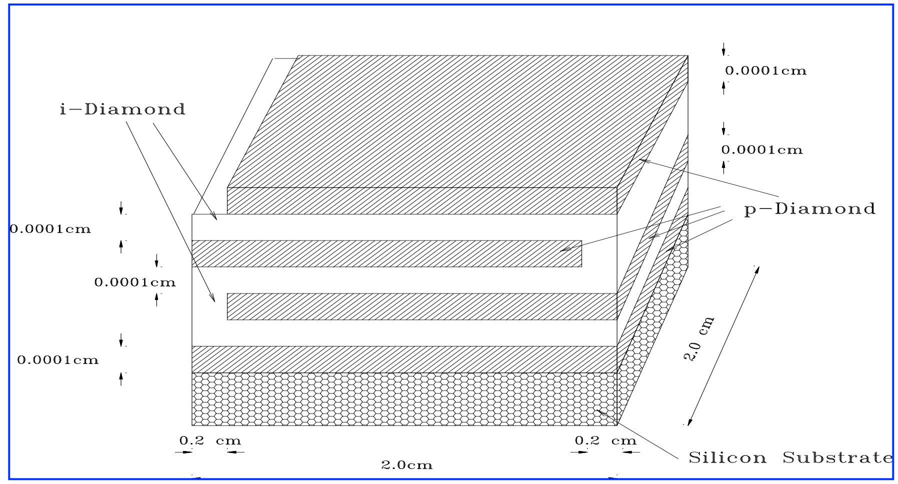
Power density of 12.4 MW/cm^2 **Operation at > 600 °C**

Extreme operation thermistor

DIAMOND POWER CAPACITORS

Designs





Comb Structured Capacitor

All Diamond

Chip Capacitor

Metal-Diamond

Volume Density of Capacitance

20 μF/cm³

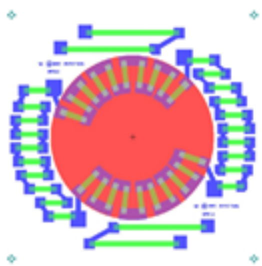
Volume Density of Capacitance

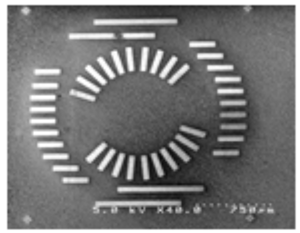
19 μF/cm³

Present Power Capacitors in Industry ~ 0.03 μF/cm³

DIAMOND MEMS *PRESSURE SENSOR*

- 30 square resistor configuration for high temperature environment

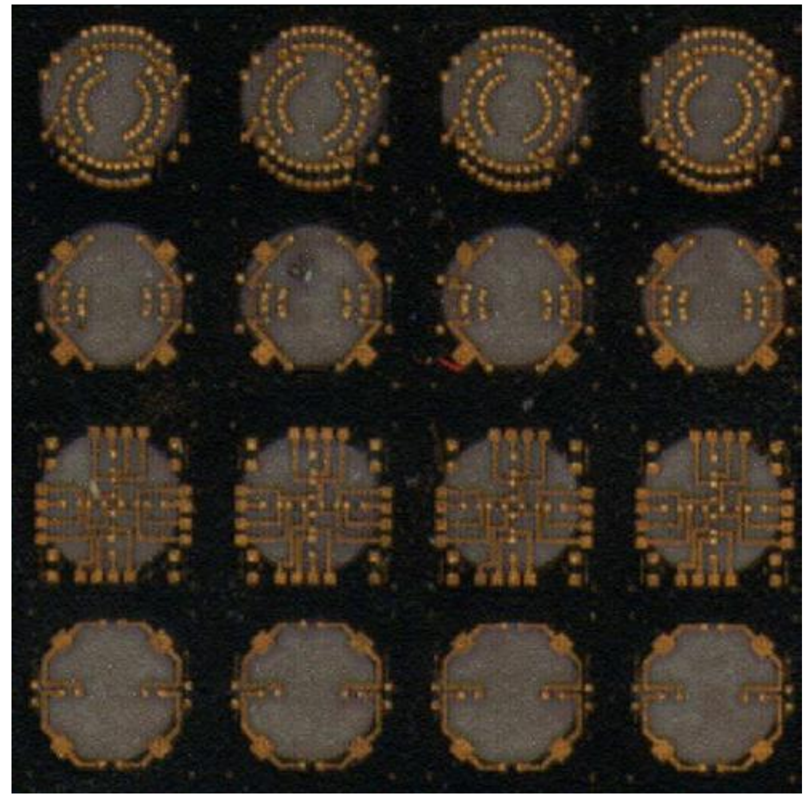




- Metal etch mask
- O_2 RIE of diamond film
- Layer uniformity

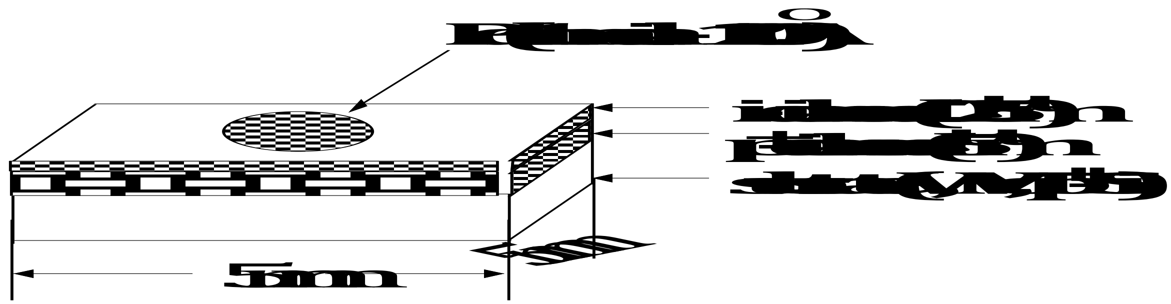
DPS OPERATED AT > 500 °C

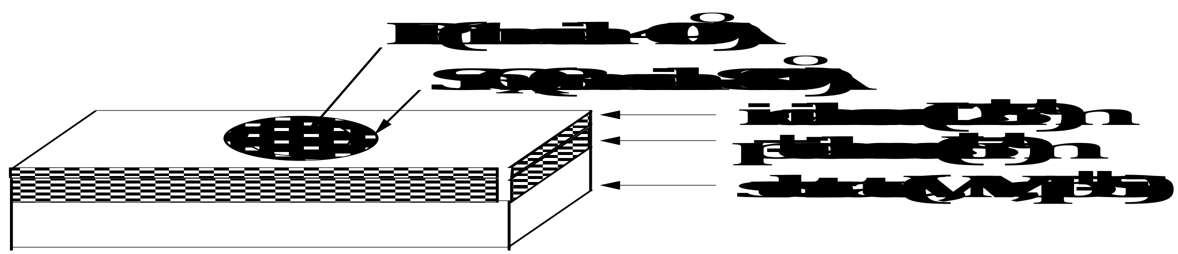
Packaging limited



4x4 array of undiced complete sensors
Each DPS is ~ 2mm in diameter

Diamond-Based MIS and CAIS Gas Sensor Structures





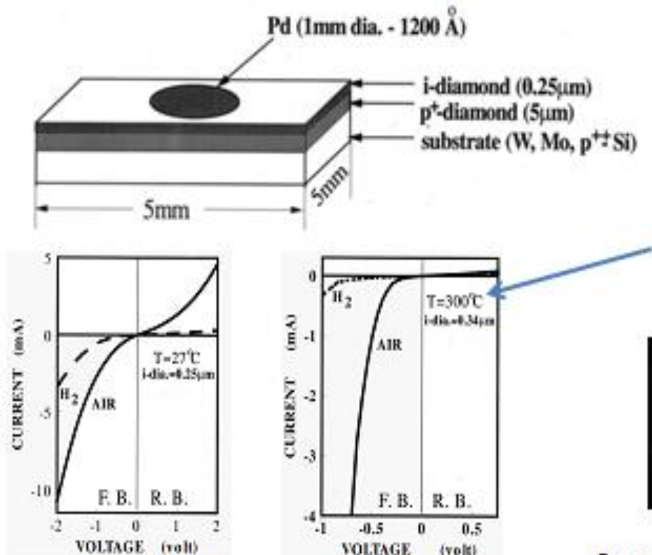
J. L. Davidson, W. P. Kang, Y. Gurbuz, K. C. Holmes, L. G. Davis, A. Wisitsora-at, D.V. Kerns, R.L. Eidson and T. Henderson, “Diamond as an Active Sensor Material”, (Invited) **Diamond and Related Materials,** Vol. 8, Nos. 8-9, pp. 1741-1747, 1999.

D. V. Kerns, W. P. Kang, J. L. Davidson, Q. Zhou, Y. Gurbuz, and S. E. Kerns, “Total-Dose Radiation-Hard Diamond-Based Hydrogen Sensor,” **IEEE Transactions on Nuclear Science**, Vol. 45, No. 6, pp. 2799-2804, 1998.

Y. Gurbuz, W. P. Kang, J. L. Davidson, and D. V. Kerns, “High Temperature Tolerant Diamond Diode for Carbon Monoxide Gas Detection, **Journal of Applied Physics**, Vol. 84, No. 12, pp. 6935-6936, 1998

Diamond Gas Sensor Structures

CVD Diamond *Hydrogen Sensor*



(a) Room Temperature (b) Elevated Temperature

Sensitivity of the MIS Gas Sensor

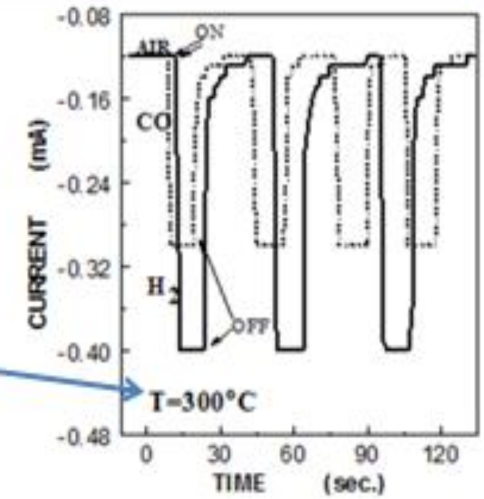
Pre-prototype Hydrogen Sensor

DIAMOND GAS SENSOR multiple species

Selectivity, *repeatability*, and *reproducibility* of the *CAIS* response
I - t Characteristics

- Fast,
- repeatable,
- reproducible,
- and selective

response to *oxygen*, *CO* and *hydrogen*



OPERATING AT 300 C

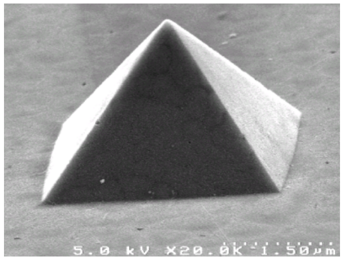
VERY RAPID RESPONSE, RECOVERY, SENSITIVITY

MULTIPLE SPECIES, LAYER SELECTION, SELECTIVITY

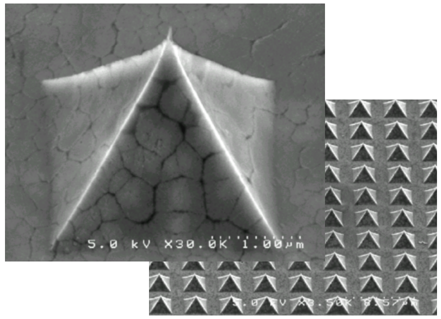
INTERNATIONAL FEMTOSCIENCE, INC.

DIAMOND VACUUM EMITTER MICROELECTRONICS

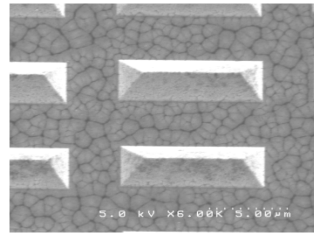
Carbon/diamond electron emission device forms



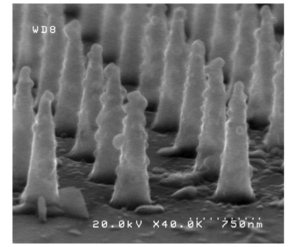
Tips



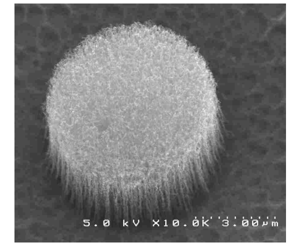
Array



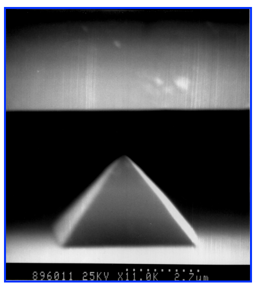
Edges



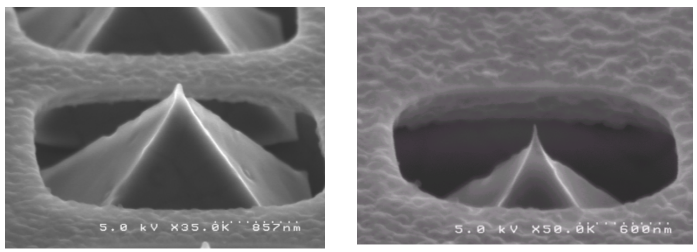
Nano-Scale Cones



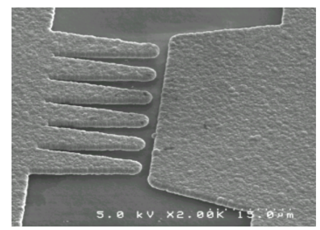
CNTs



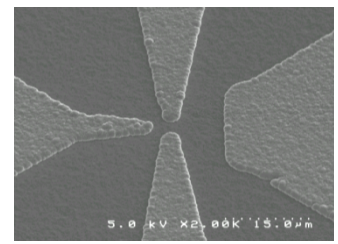
Capped diode



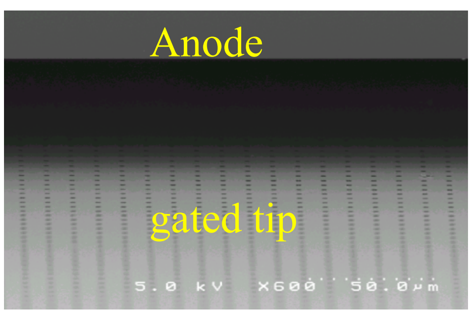
Gated diode/ triode



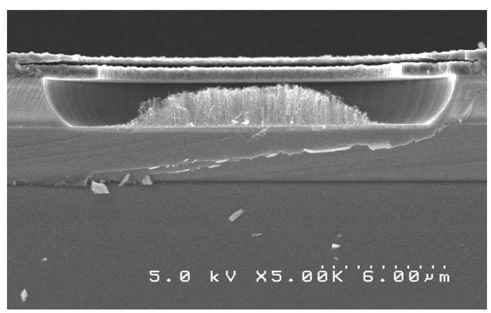
Lateral diode



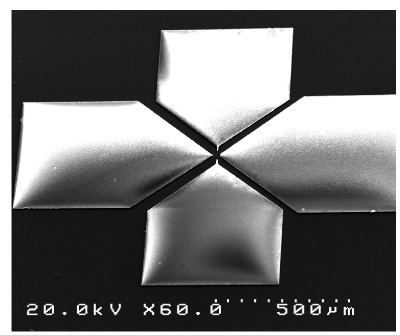
Lateral triode



Triode



CNTs diode/Triode

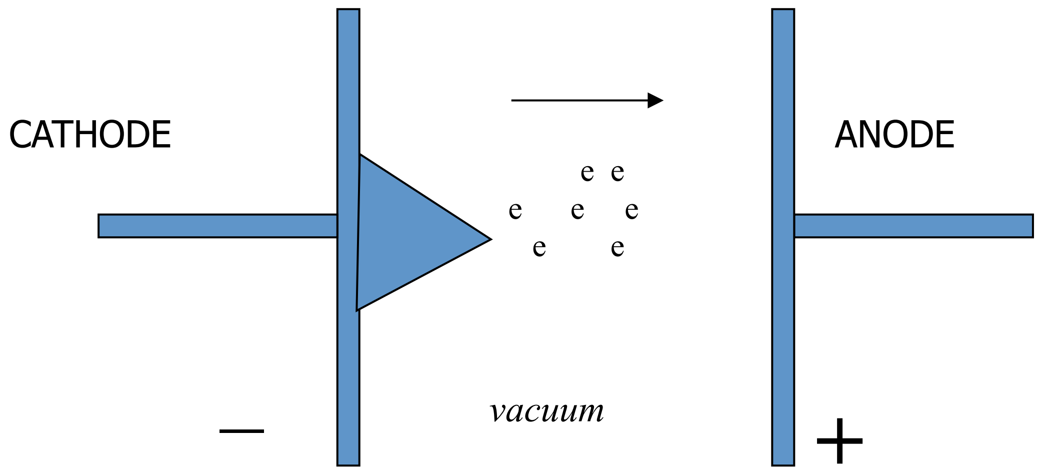


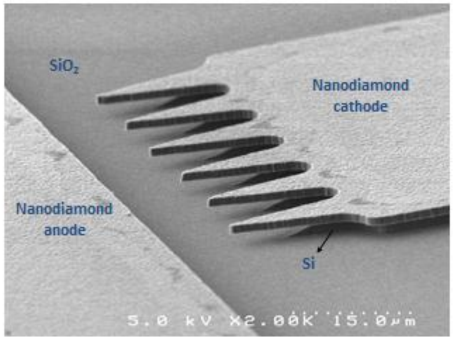
Lateral triode

Simplified Electron Emission Process

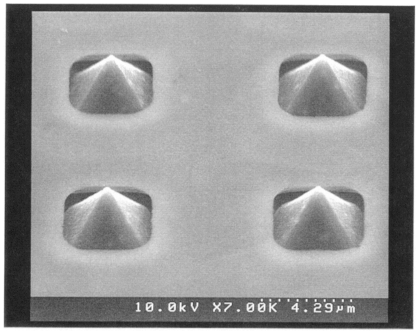
Fowler-Nordheim cold cathode tunneling

Micro-Tip Emitter





lateral



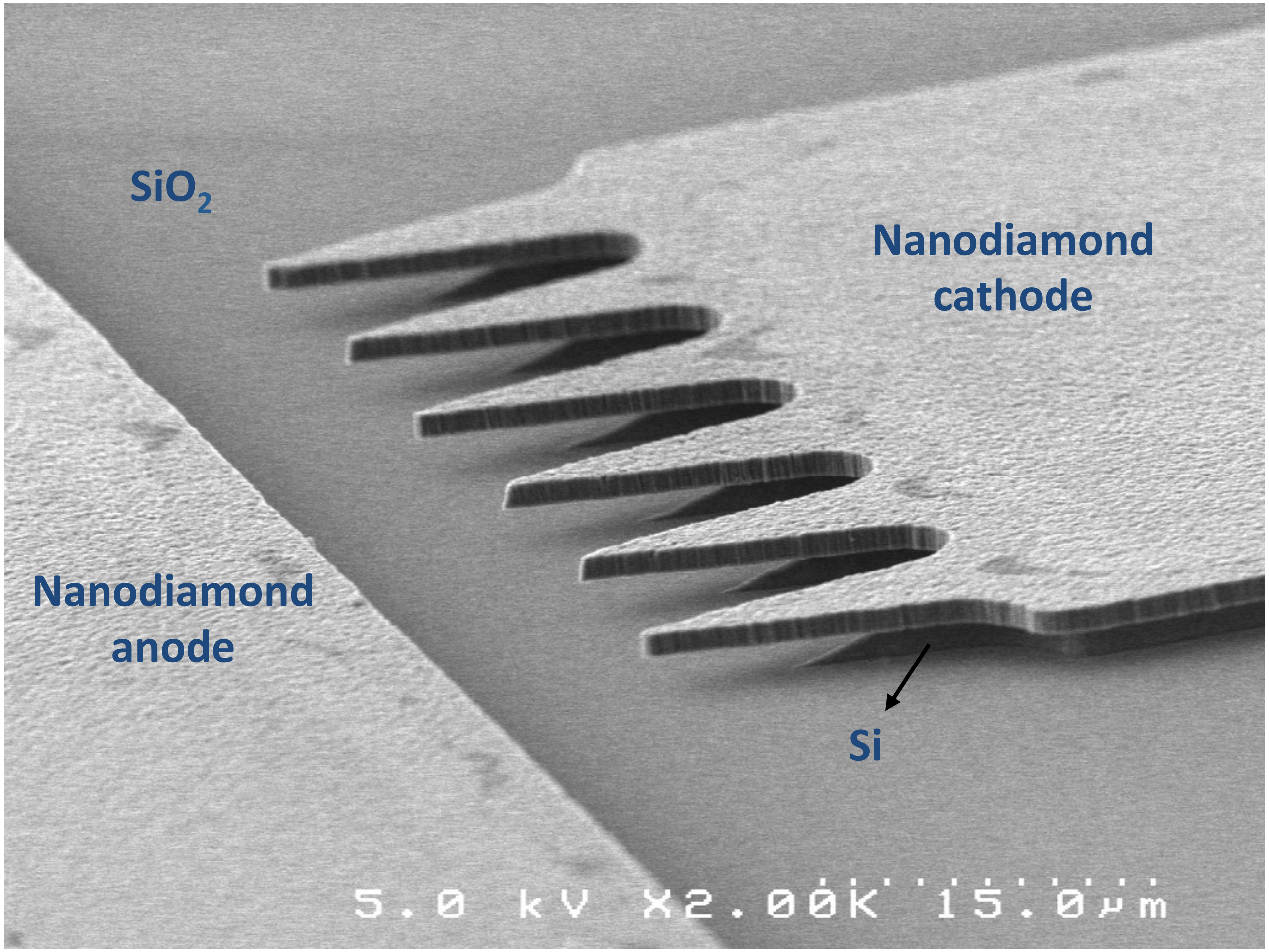
vertical

Diamond is the best electron emitter material.

{ lightning rod ‘in reverse’, a nano-vacuum tube }

Replace **solid state** **Extreme operational limits**

Nanodiamond lateral device

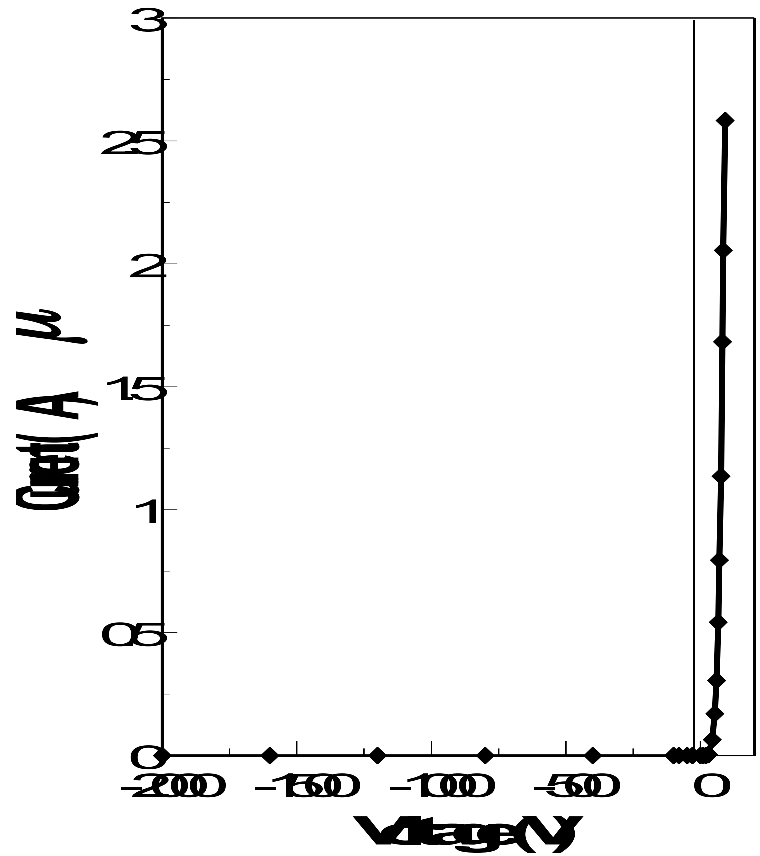


High magnification SEM image
of the lateral device structure

Diamond Emitter Diode

- **Low turn-on voltage**
- **High emission current**
- ***Extremely low reverse leakage current (less than 1pA, noise level)***
- ***High breakdown voltage of more than 2000 V***

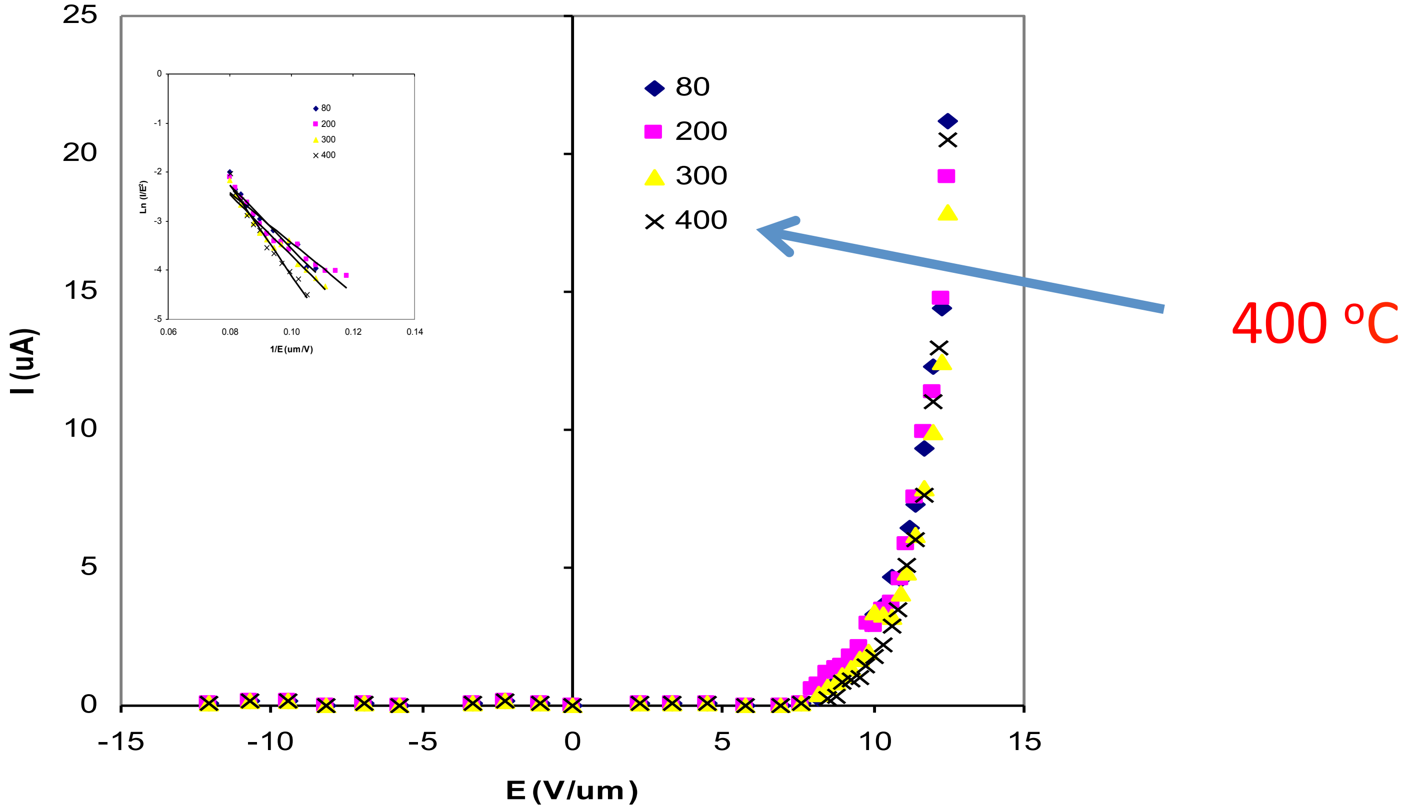
and DEVICES THAT ARE TEMPERATURE AND RADIATION *IMMMUNE*



I-V plot of diamond emitter diode

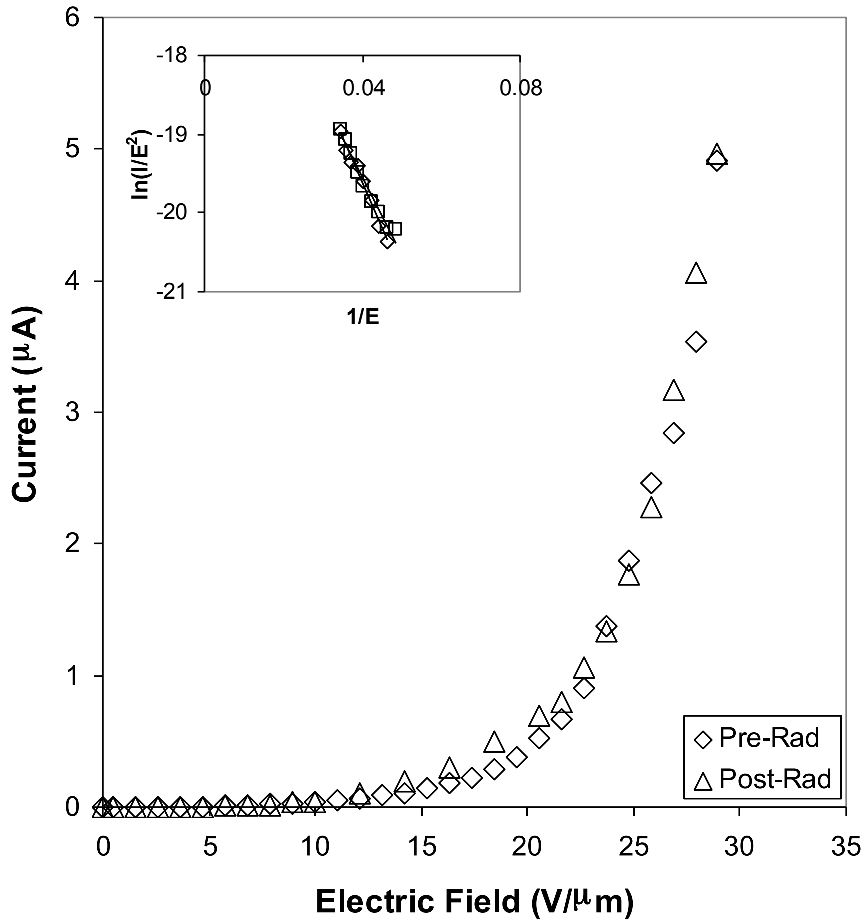
(Invited) J. L. Davidson, W. P. Kang, K. Subramanian and Y. M. Wong, "Forms and behaviour of vacuum emission electronic devices comprising diamond or other carbon cold cathode emitters", **Proceedings of the Royal Society (Excellent in Science)**, May 21-22, London, UK.

Diamond Emitter Diode
High Temperature Characteristics



- Emission current is *unaffected* by temperature changes
- Turn-on voltage is unaffected by temperature changes
- Negligible reverse leakage current

Nanodiamond lateral device *Radiation Hardness*



Neutron radiation test:

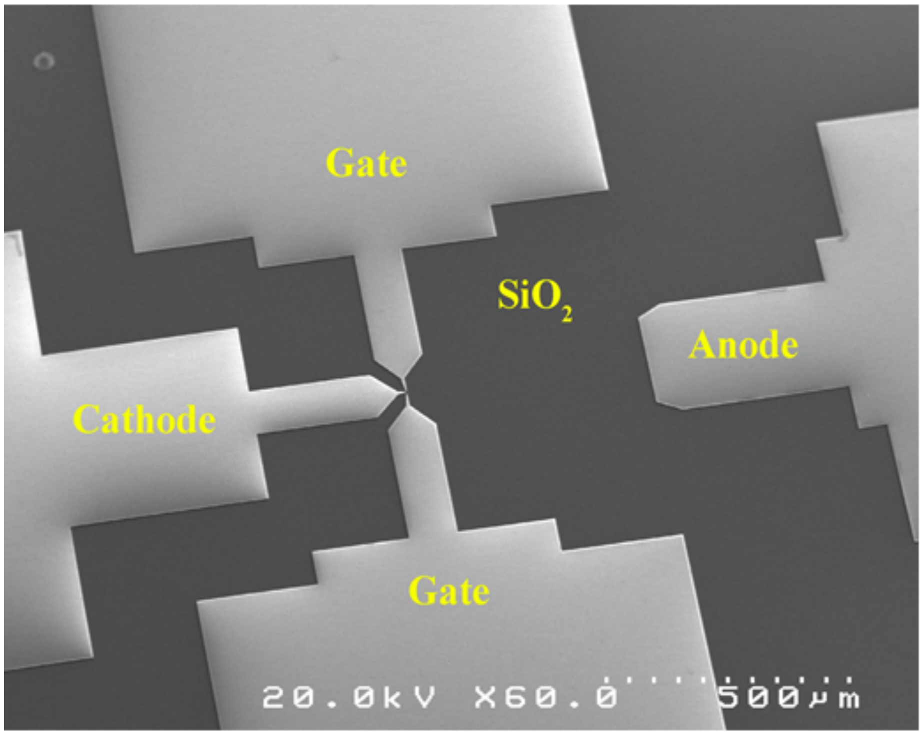
- **$4.4(10^{13})$ neutrons/cm^2**
  high fluence irradiation
- **No discernable difference** in **physical size or appearance** (dilation/expansion/change in anode-cathode spacing) of diamond devices (SEM)
- No change in **resistivity** of nanodiamond film
- No significant difference in the **I-V emission** behavior before and after neutron exposure

Diamond Vacuum Microelectronics technology *capable of operating efficiently at both low & high temperatures* ***(350 °C)****, with an inherent "hardness" to high radiation exposure, for*

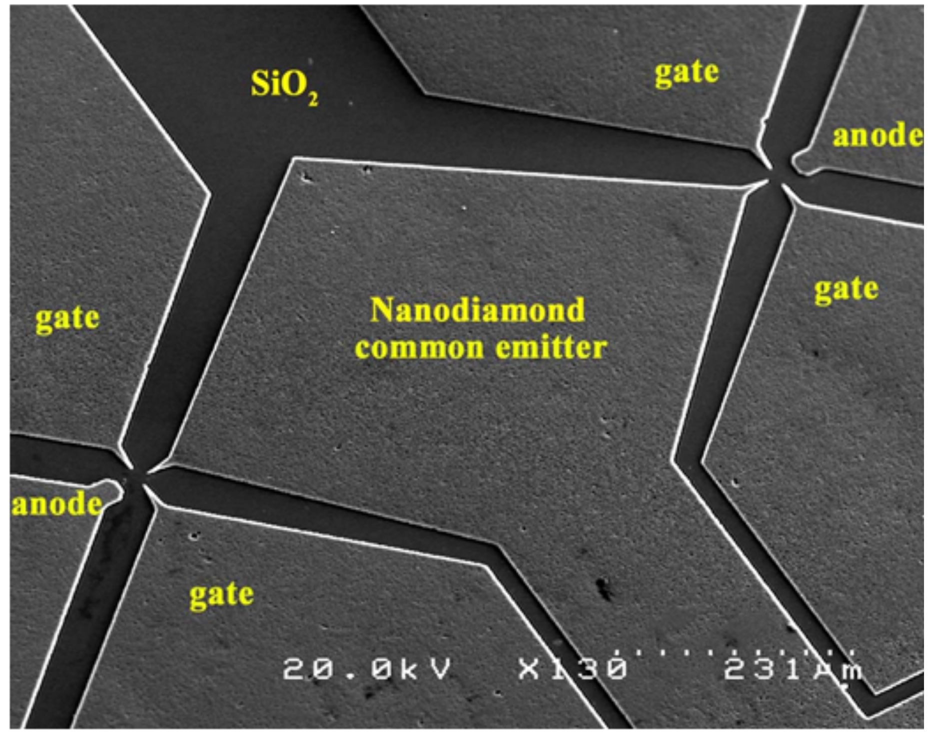
Extreme Environment Electronics

3 TERMINAL DEVICE *DVFET*

(a)



(b)

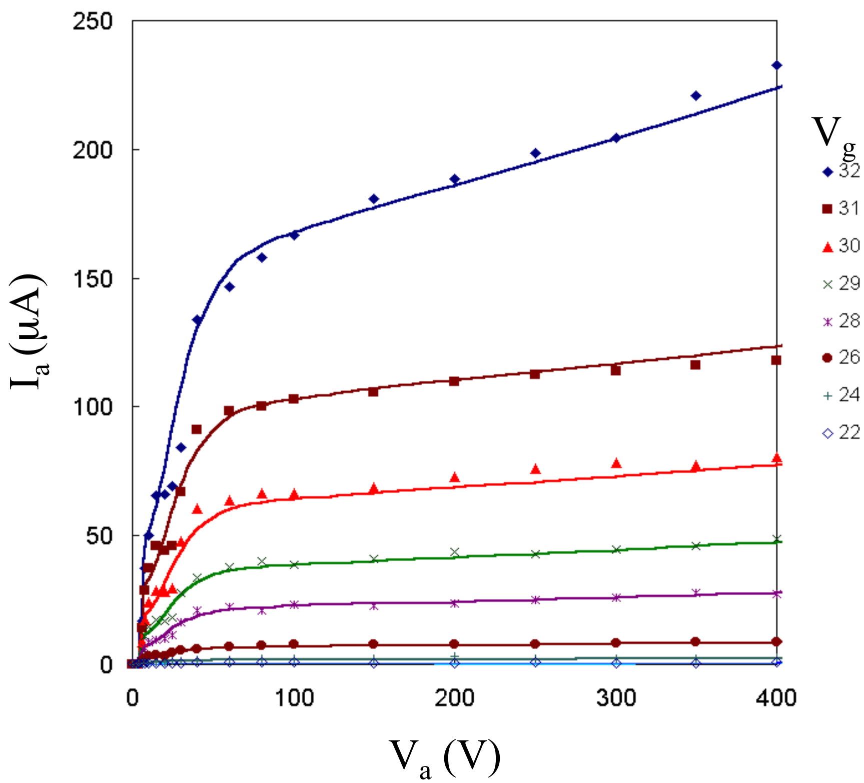


SEM micrographs:
(a) Nanodiamond lateral triode, 2 µm gate-cathode spacing & 0.5 mm anode-cathode spacing;
(b) SEM micrograph of a nanodiamond lateral double triode with a common emitter.

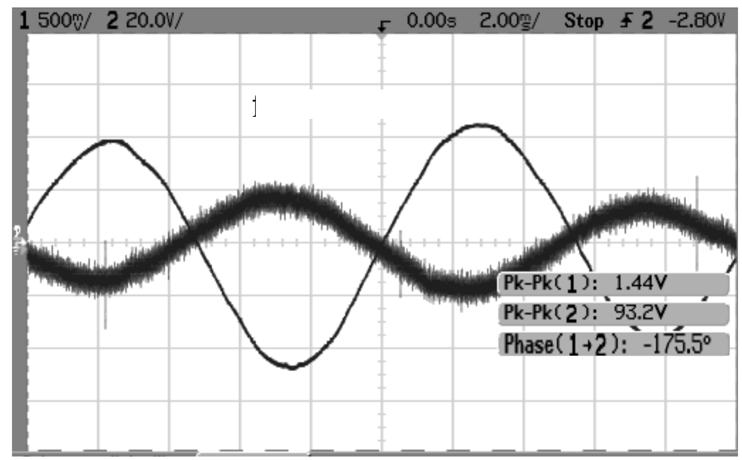
Diamond VFET

-Low turn-on voltage of 22 V
-High emission current 200 μA
-Low anode saturation voltage (40V) for large anode-cathode spacing (1mm)
-High dc voltage gain of 800

-High ac voltage gain of 70
-Capable of producing large AC output voltage (>100 V peak to peak)



DC characteristic



AC characteristic

CONCLUDING

THE TECHNOLOGIES DISCUSSED:

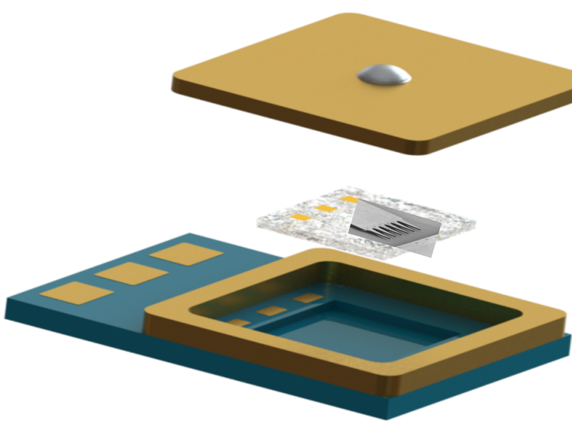
R, C, SENSORS, DIODES, TRANSISTORS, and more,

PERFORM AT SUCH EXTREMES (T, RAD, etc.)

THEY *OUTPACE* CONVENTIONAL PACKAGE/ASSEMBLY TECHNOLOGY

There is an essential need for packaging/assembly technology for extreme environments

APEI, Inc. is a state-of-the-art high performance electronics company with capabilities from inception through manufacturing of fully qualified systems.



IFSI and APEI, Inc. are collaborating to arrive at components, sensors and devices that *operate* at unprecedented extreme ambient conditions

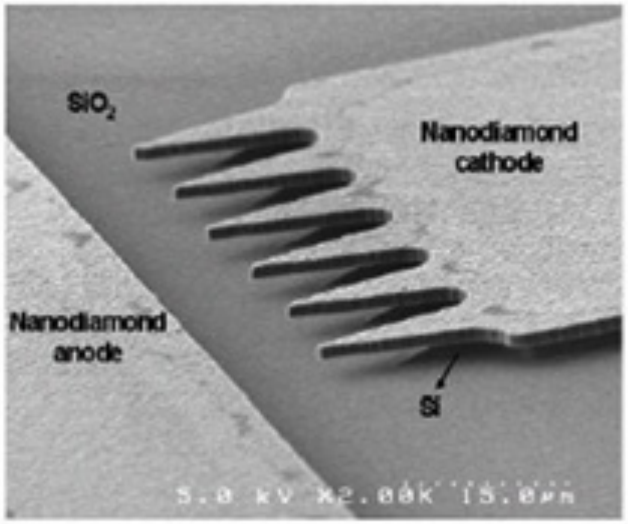
INTERNATIONAL FEMTOSCIENCE, INC.

Prototype, depicting an exploded view of a diamond vacuum device packaged inside the integrated high temperature vacuum package

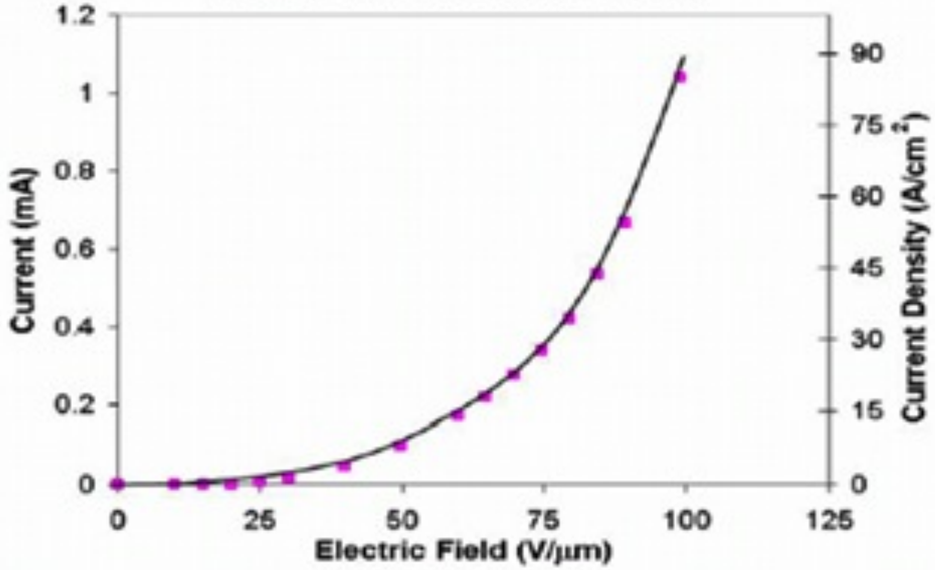
FINISH

Diamond Emitter Diode   forward characteristics

6 Finger Lateral Device



Measured Emission



- Lateral Planar Device
- 6 Finger Device

- 184 uA/Tip at 495 volts
- 91 mW/Tip
- 85A/sq cm * 495V= 42 kW

(* refers to active surface area of device)

Emission current scaling in lateral devices