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MINIATURIZATION TECHNOLOGIES FOR DEPLOYABLE SYSTEMS

MEMS, MICROSENSORS, AND NANOTECHNOLOGY

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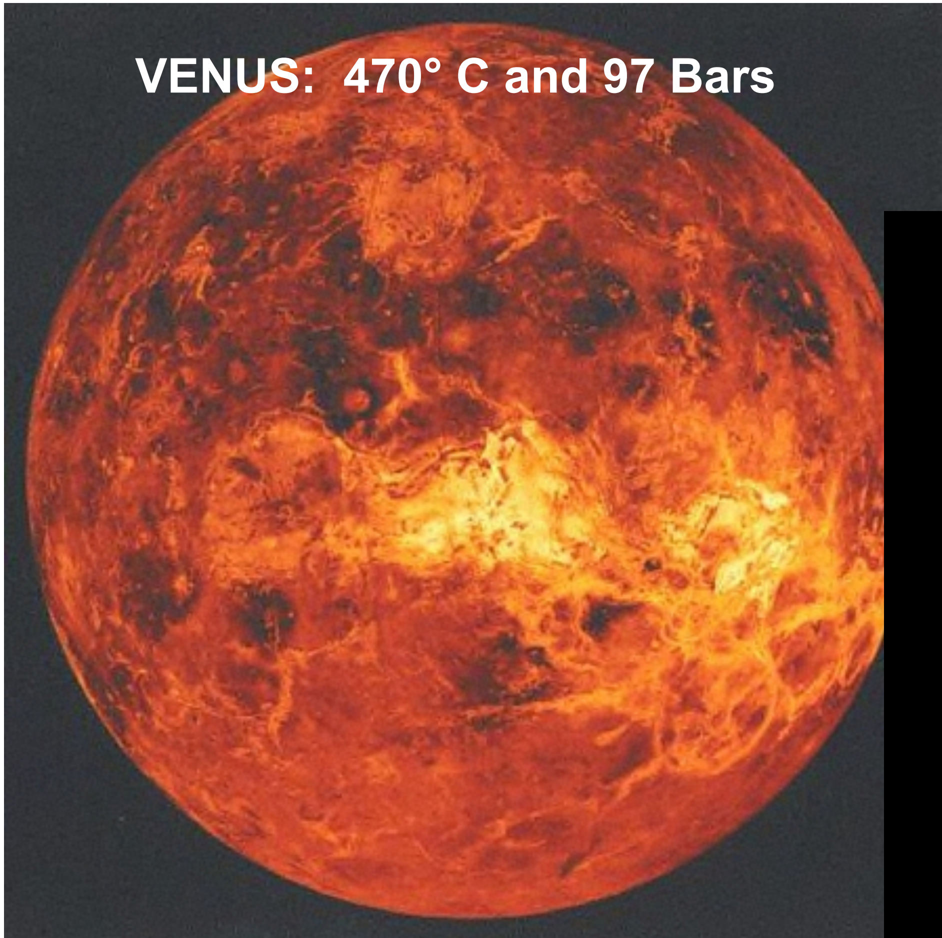
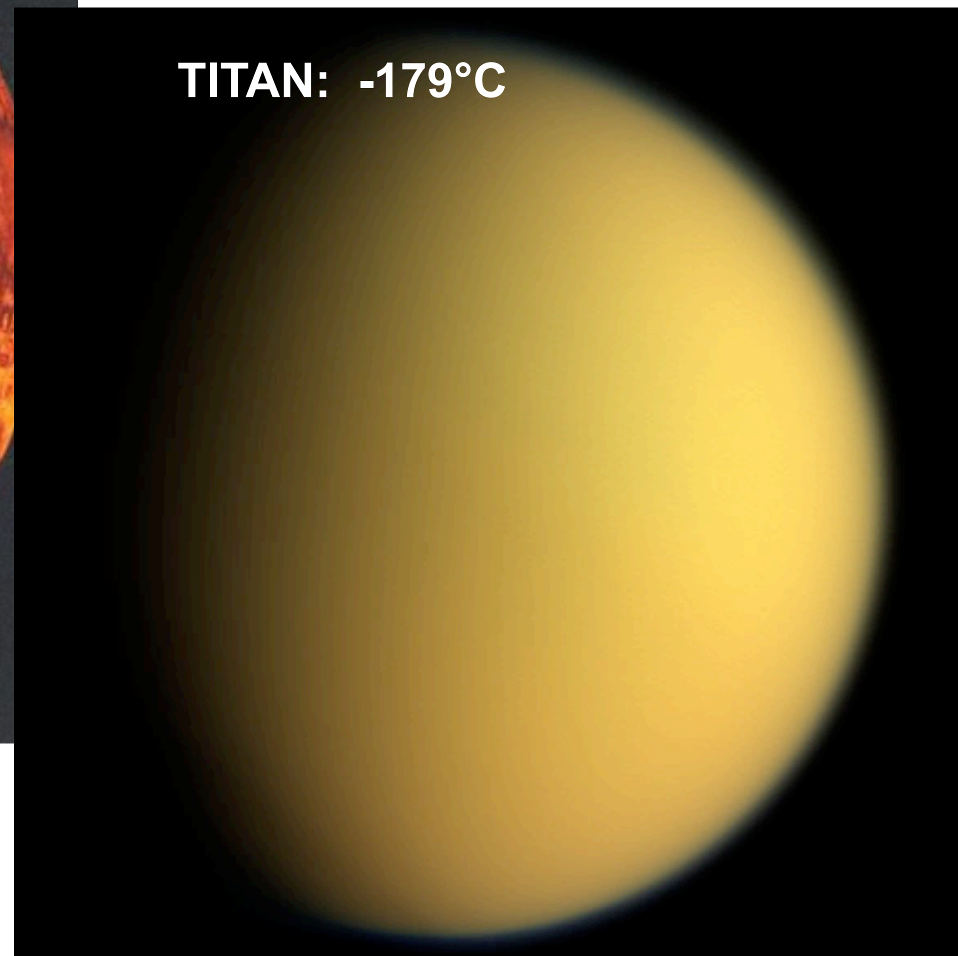
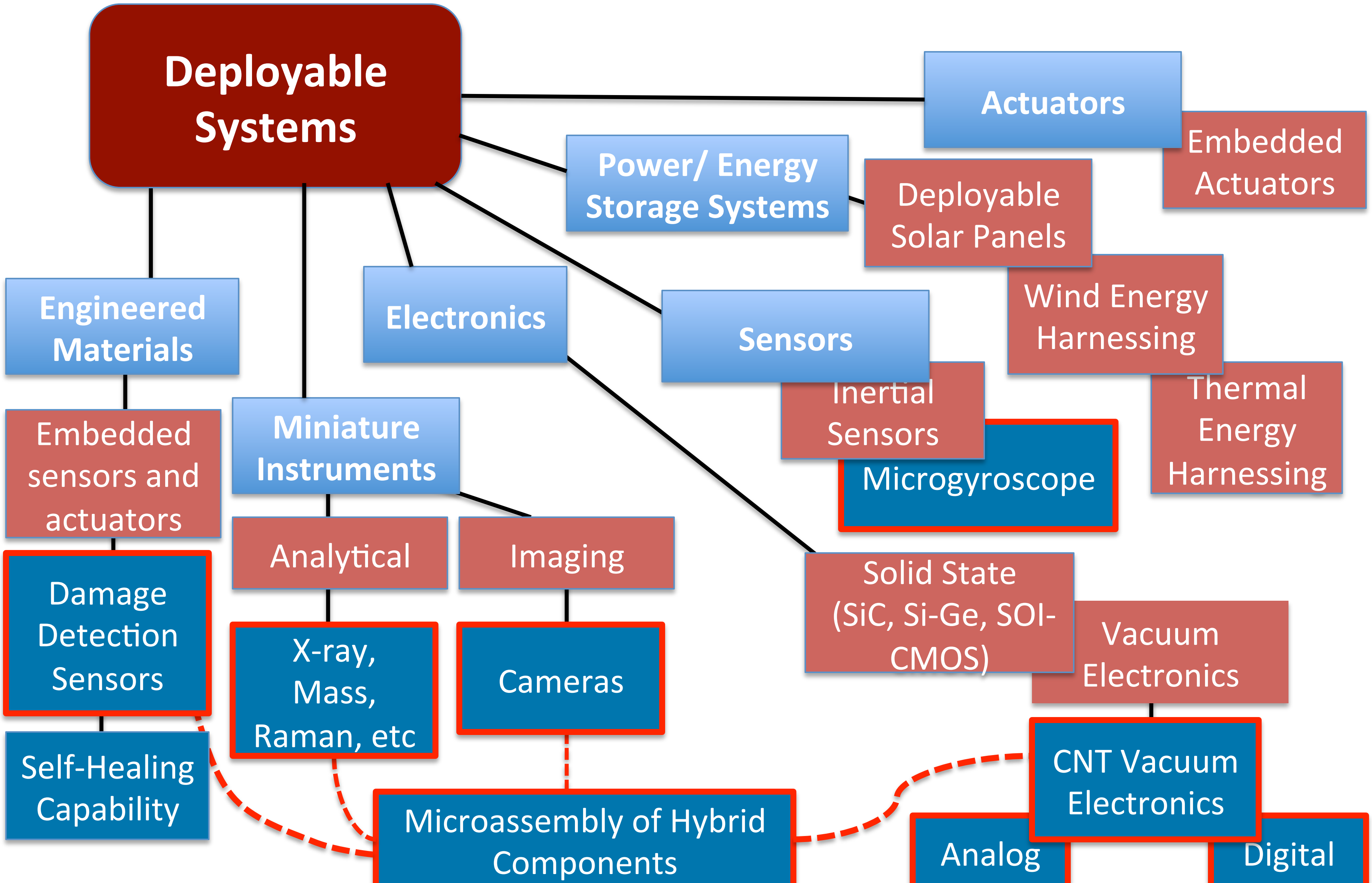
Document Clearance CL#11-1602 and CL#13-4110

Extreme Environments





Introduction



Extreme Environment Miniature Systems

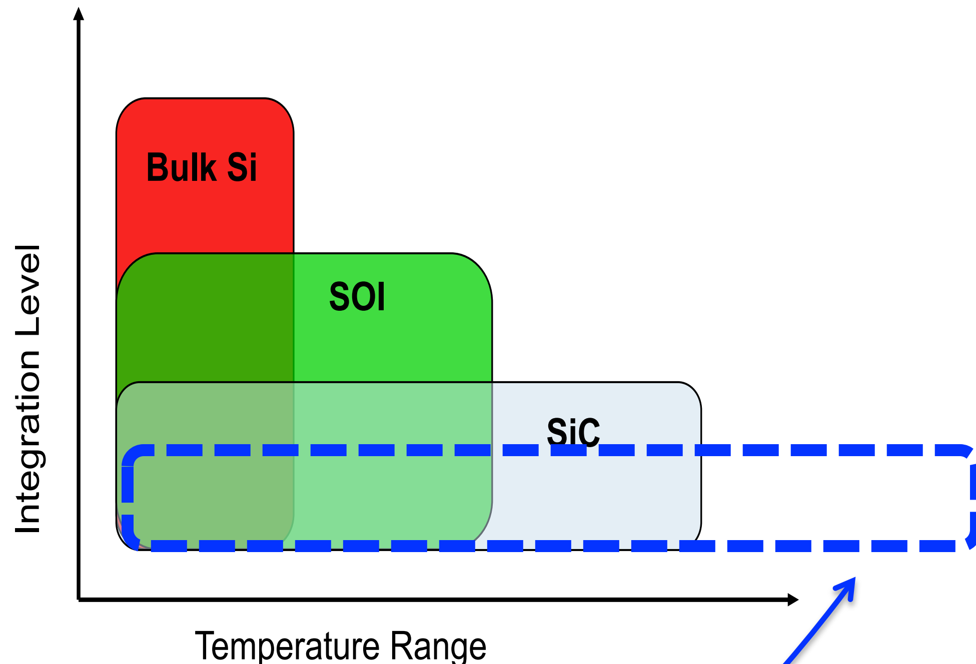
- Survive high/low temperature, high pressure, high radiation, corrosive environments
- Self Sufficient:
  - *Energy harnessing from surroundings*
- Multifunctional
- Long lifetime
- Vibration tolerant
- Reliable
  - *maintenance free*

Miniaturization Technologies

- Device/system design
- Material selection for extreme environments
- Components identification
- Pattern development
- Lithography and/or Patterned synthesis
- Micromachining
  - *Bulk: remove material from bulk to create patterned shapes*
  - *Surface: add material on a supporting structure to create patterned shapes*
- Post processing
  - *Device release*
  - *Interconnects*
  - *Electroplating/Molding*
- System development using assembly
  - *Monolithic*
  - *Modular*
  - *Hybrid*

Extreme Environment Devices

Material or Device	Theoretical Max [ºC]
Bulk Silicon	225+
SOI	300+
Gallium Arsenide-based	400+
GaN-based	600
Silicon Carbide	600
Diamond	800
Vacuum Electronics	1000



Based on data presented at the NASA JPL Extreme Environment Workshop held in May 2003

E. Kolawa, M. Mojarradi, A. Stoica, L. Del Castillo et al

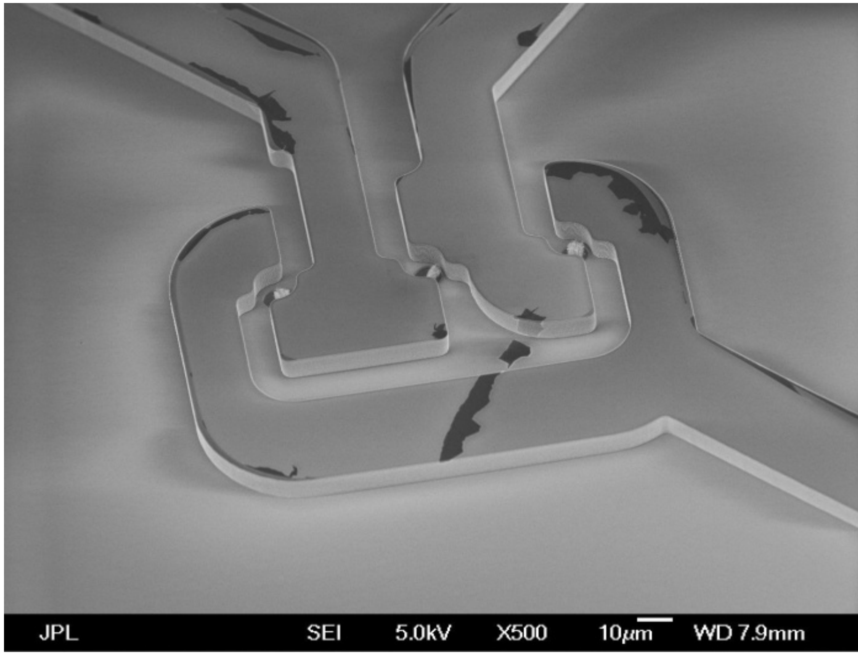
Vacuum Electronics

4 kilobits of memory “stick?”

…the circuit size was a “big” problem!

Google Images

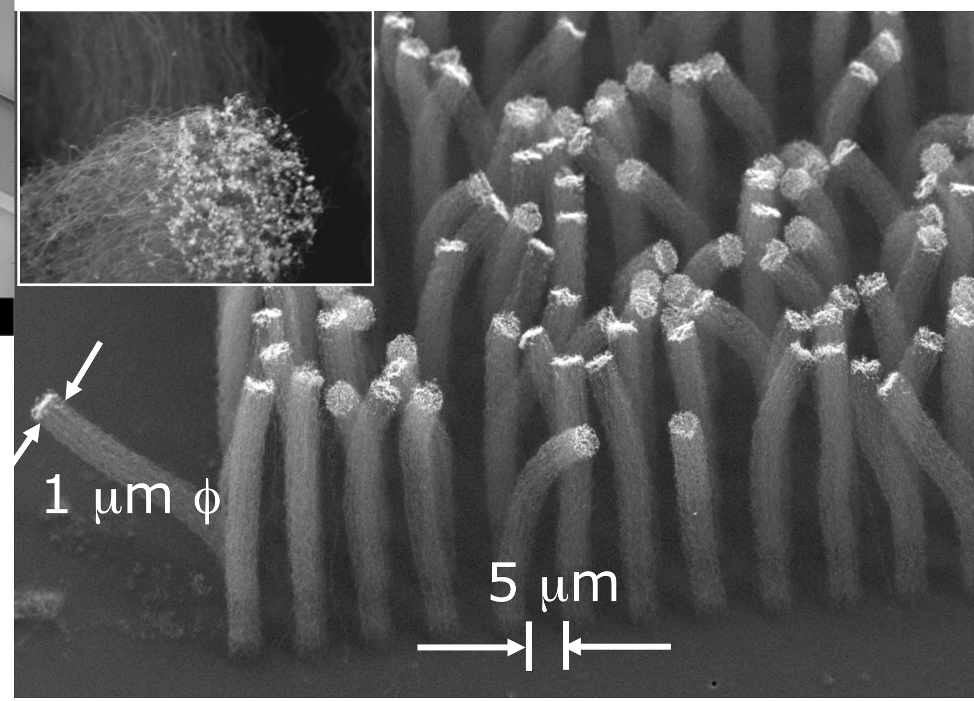
Carbon Nanotube Vacuum Electronics



Silicon Micromachining

+

Carbon Nanotubes



SMALLER devices!

Large scale integration is possible: the entire circuit is vacuum packaged

COLD and **LOW POWER** operation

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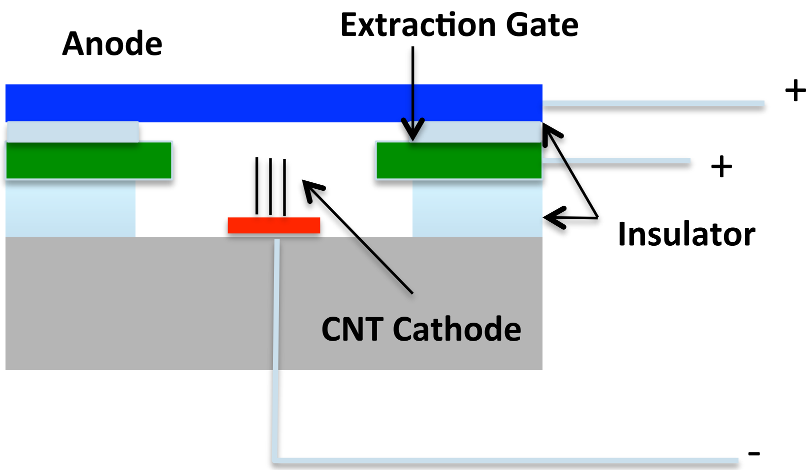
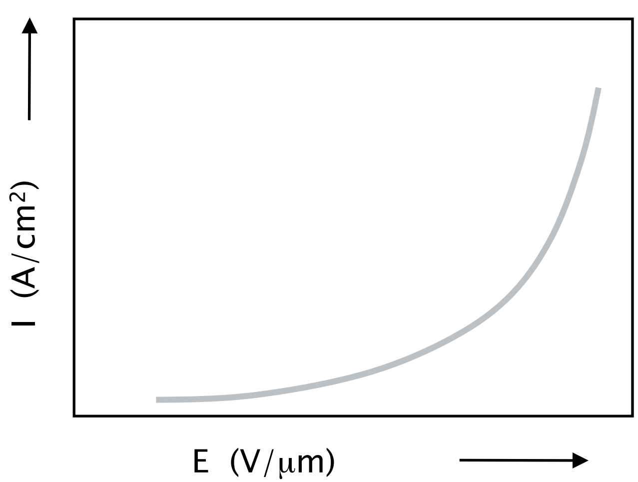
Carbon Nanotube Vacuum Electronics



I–V Curve



$$I = 1.54\times10^{-6}\,\frac{\gamma^2 A_{(e)}}{\phi}\cdot\left(\frac{V}{d}\right)^2\cdot e^{\left[-6.8\times10^{7}\cdot\frac{\phi^{3/2}\cdot d}{\gamma V}\right]}$$

I : Emission current (A)

V: Biasing voltage (V) ;

d : gap

a, b: constants

ϕ: Work function

γ: Field enhancement factor

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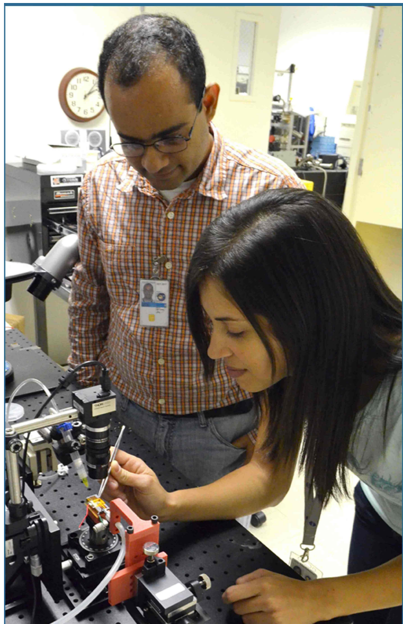
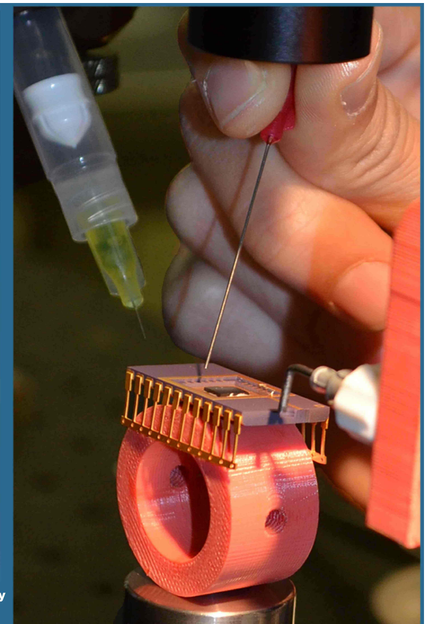
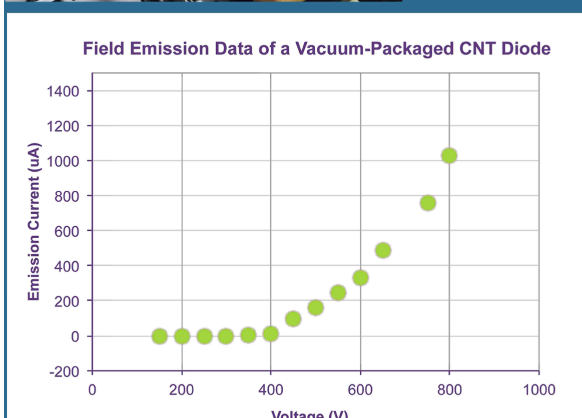
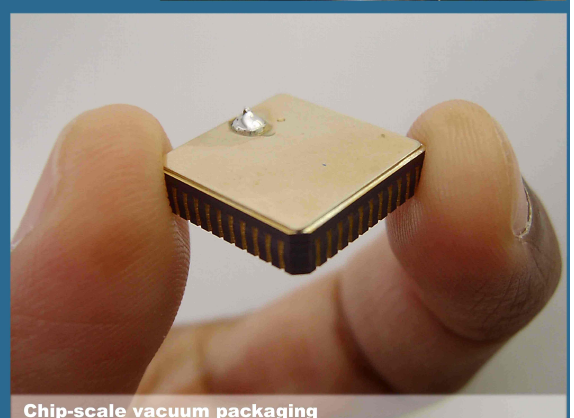
Carbon Nanotube Vacuum Electronics









- Use different material parts to make an electrode stack.
- Implement hybrid microassembly process to align and stack different electrode layers: cathode, spacers, extraction grid, modulating grid, anode, etc.
- Chip-scale vacuum packaging to produce discrete or circuit-level vacuum electronic components.

Carbon Nanotube Vacuum Electronics

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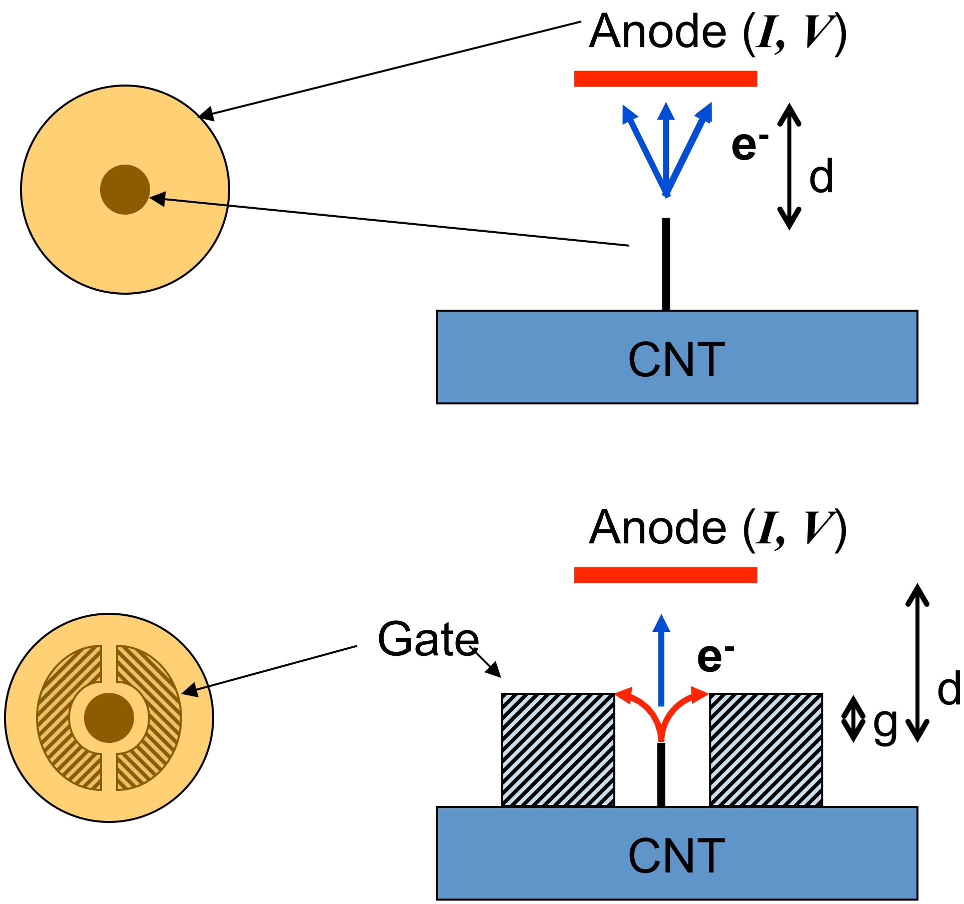

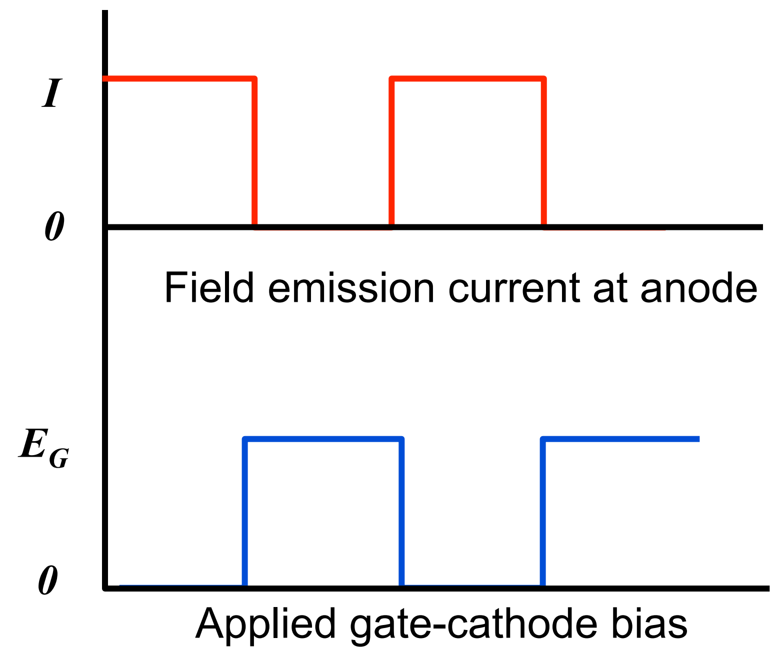

$d > g$

$V_G = V$

$E_G > E > E_{th}$

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CNT “Digital” Vacuum Electronics

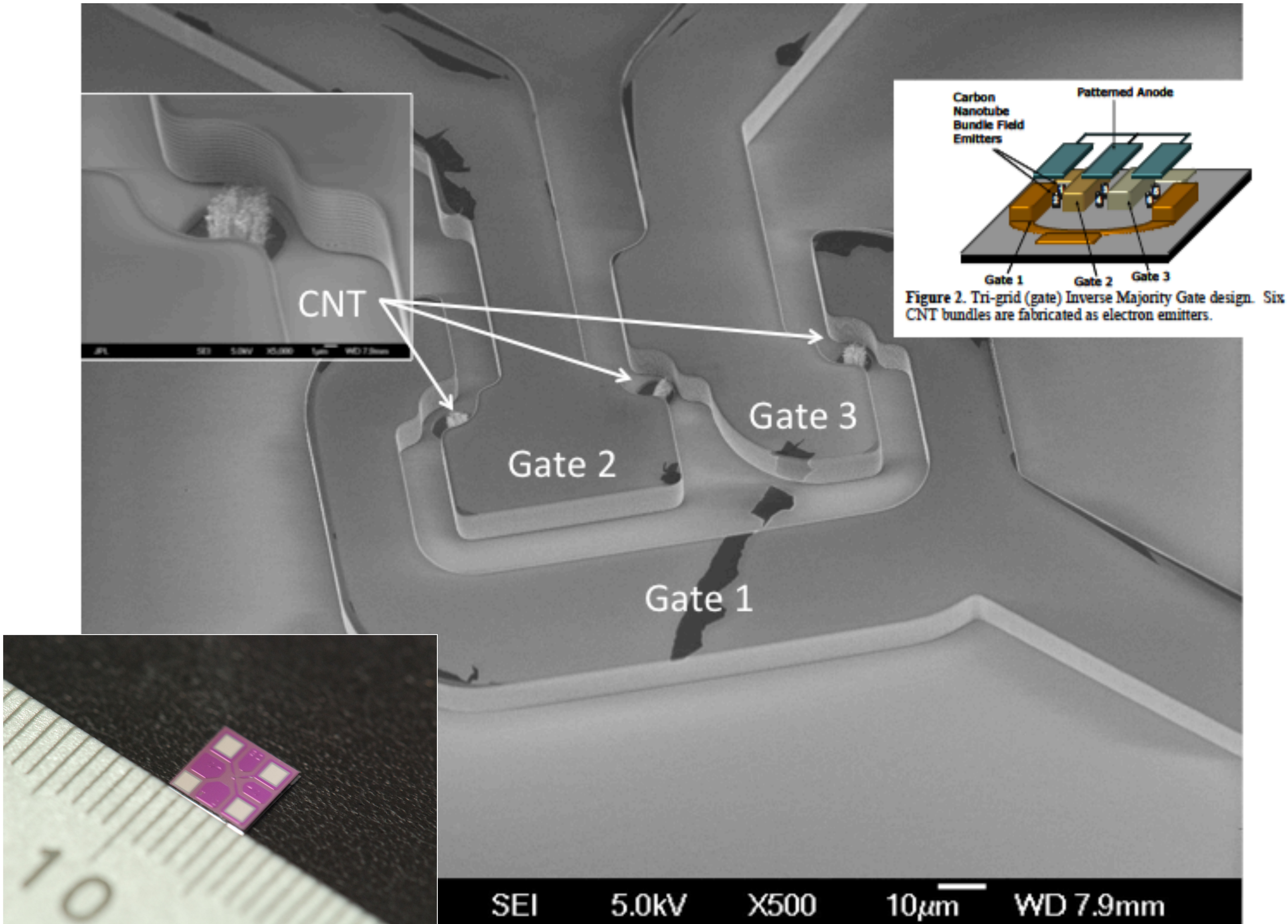
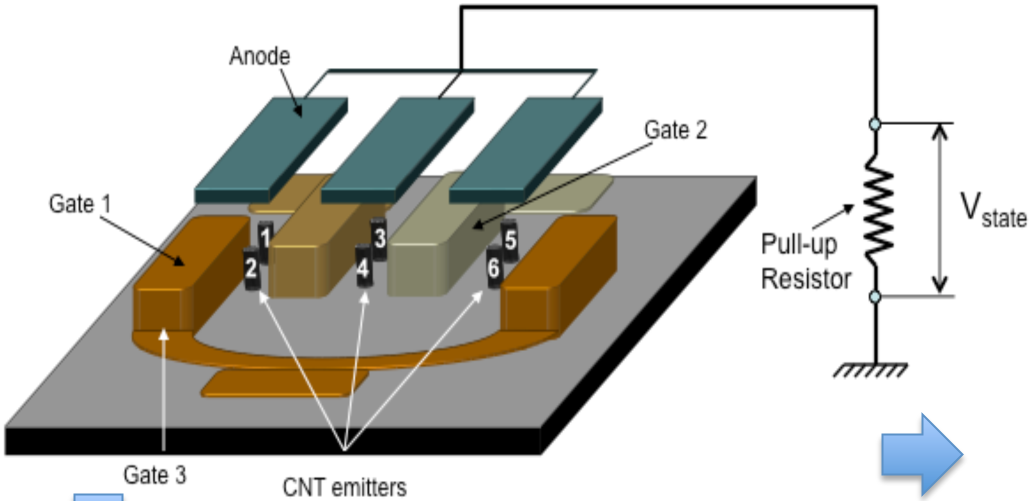


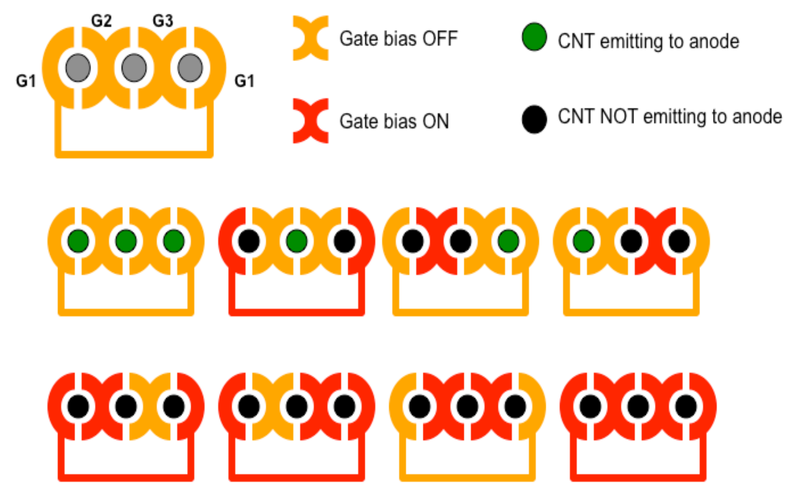
Figure 2. Tri-grid (gate) Inverse Majority Gate design. Six CNT bundles are fabricated as electron emitters.

CNT "Digital" Vacuum Electronics

Inverse Majority Gate Device Schematic



Operational Schematic



Truth Table

Number of Logic States	Gate 1	Gate 2	Gate 3	Output
1	0	0	0	1
2	0	0	1	1
3	0	1	0	1
4	0	1	1	0
5	1	0	0	1
6	1	0	1	0
7	1	1	0	0
8	1	1	1	0

Combination of NAND and NOR gates

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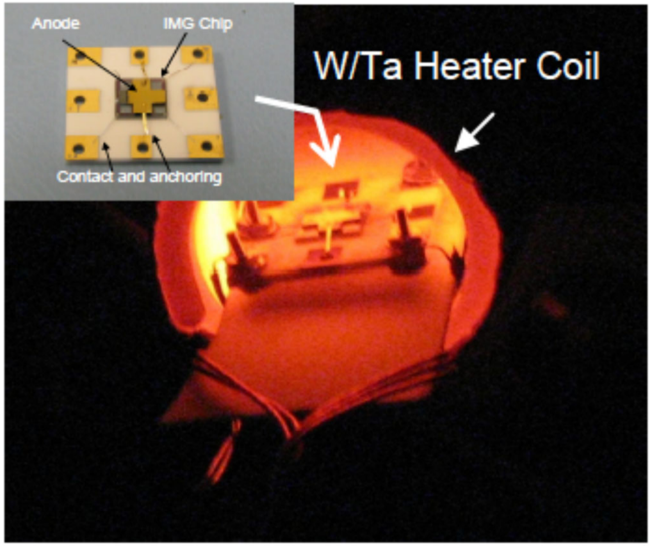
CNT “Digital” Vacuum Electronics



Truth table of IMG

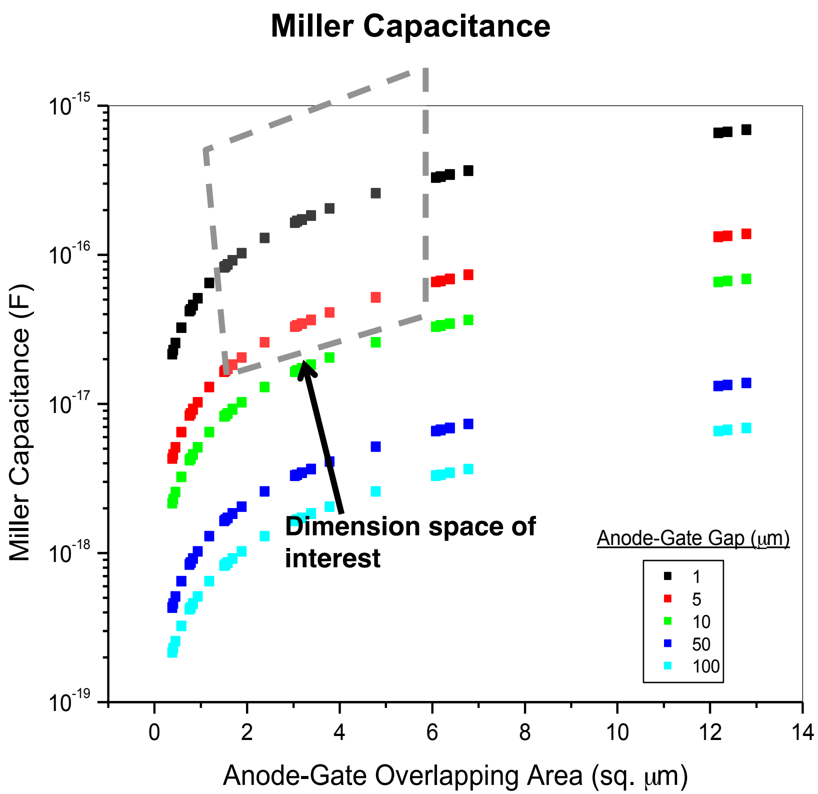
Gate 1	Gate 2	Gate 3	Output
0	0	0	1
1	0	0	1
0	1	0	1
1	1	0	0
0	0	1	1
1	0	1	0
0	1	1	0
1	1	1	0

Experimental Results

Va (V)	Vg1 (V)	Vg2 (V)	Vg3 (V)	Ia (nA)	Output State
50	0	0	0	3.2	1
50	10	0	0	2.8	1
50	0	10	0	3.6	1
50	10	10	0	0.7	0
50	0	0	10	2.5	1
50	10	0	10	0.35	0
50	0	10	10	0.27	0
50	10	10	10	0	0

CNT "Digital" Vacuum Electronics

For a Full Adder	Solid State (0.18 μm process)	Solid State (0.09 μm process)	IMG-based (0.5 μm process)
Footprint (μm)	13.86 x 5.4	8.12 x 2.52	18 x 4



- Traditional vacuum tubes operate at 1300° to 1500° C, so are natural choices for high-temperature electronics.
- Device can be designed for smaller footprint
- Switching frequency- 10-100 GHz possible; *limited only by the K-A electron transit time*
- Low level current (tens of nA) operation ensures long operational lifetime (10,000 hours tested for CNT flat panel displays).
- CNT emission more stable at 700° C (<1% variation tested).

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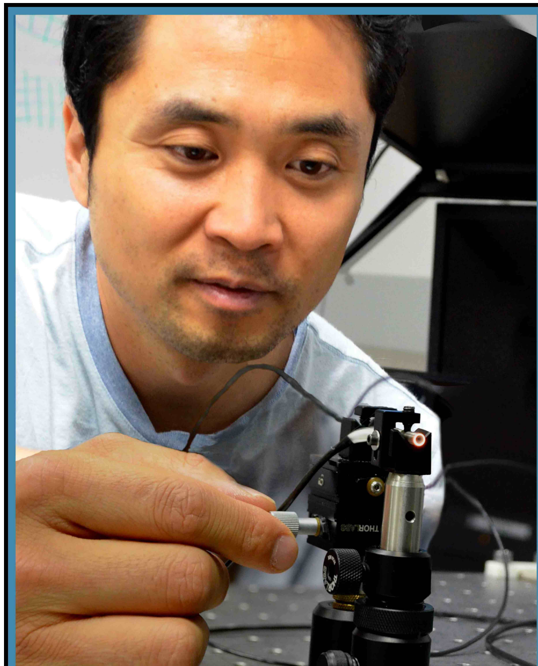
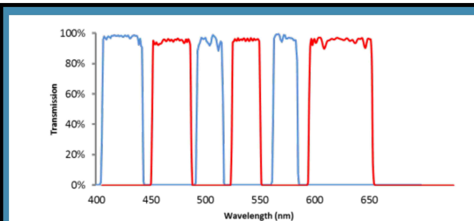
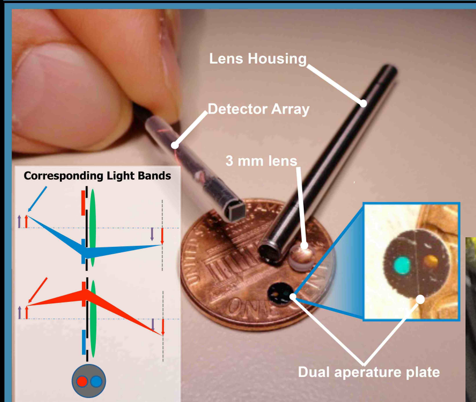
Miniature Stereo Camera



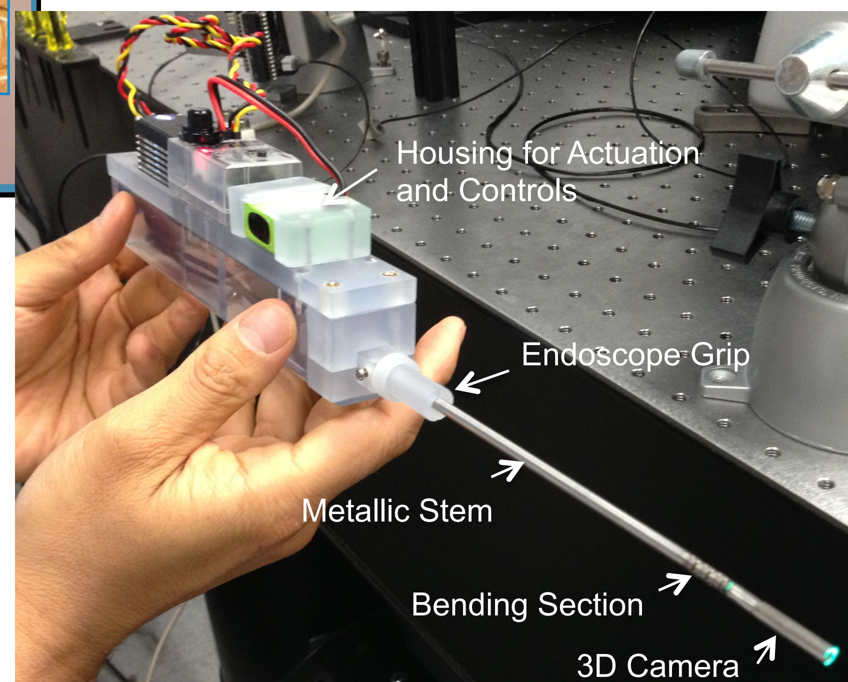


Actual transmissions of the Semrock Co.'s CMBFs



The smallest stereo camera, with lens diameter < 3mm. This was done by placing complementary multiband pass filters in a single-lens, dual aperture system.

3D-MARVEL: A unique endoscopic tool capable of sweeping the stereo camera in the horizontal plane over an angle of ±60° making it possible to get a panoramic view of the operative field.



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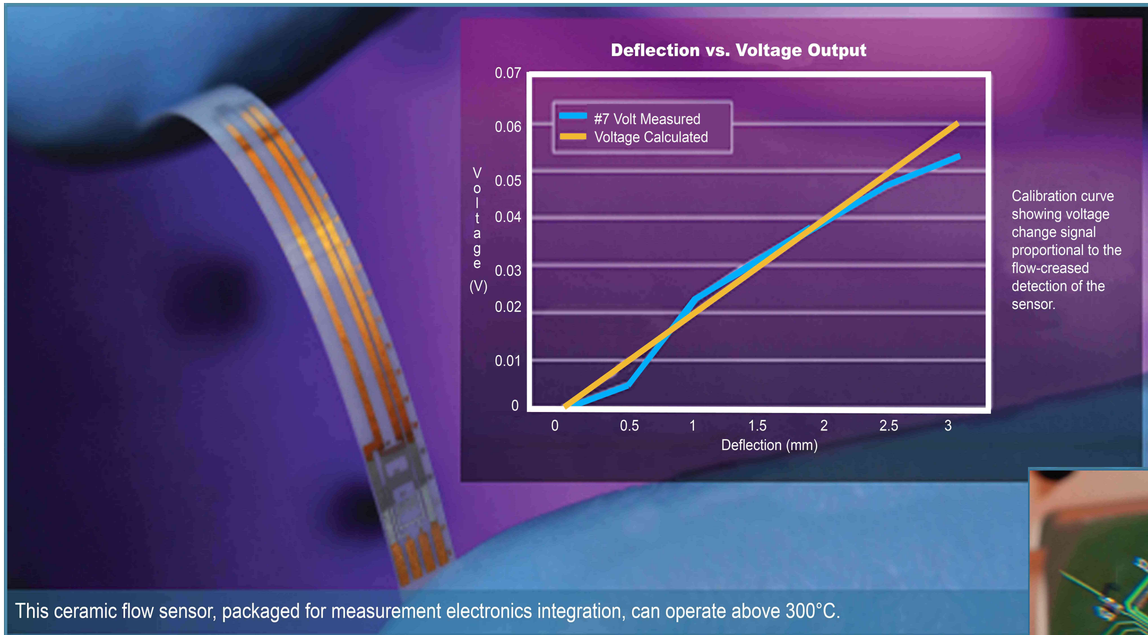
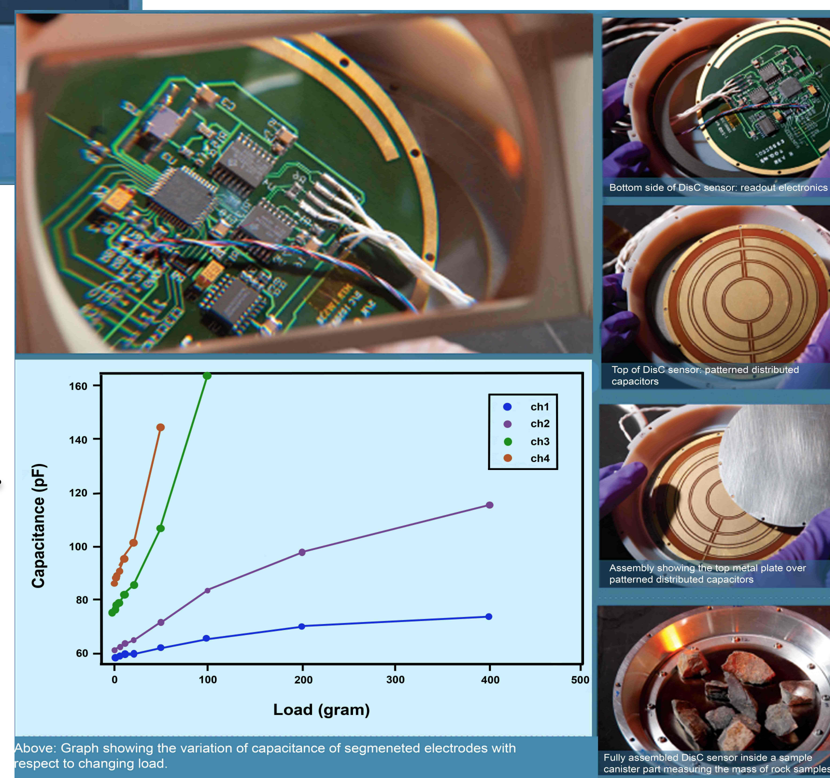
Harsh Environment Sensors



This ceramic flow sensor, packaged for measurement electronics integration, can operate above 300°C.

Strain-gauge based high temperature flow sensor demonstrated on flexible ceramic substrates for oil and gas industrial applications

- New material and design scheme implemented to meet sample sensor requirements for planetary sample return missions.
- Capacitive sensor that measure weight of the sample on a planetary surface was demonstrated as an integral part of the sample collection canister.



Bottom side of DisC sensor: readout electronics

Top of DisC sensor: patterned distributed capacitors

Assembly showing the top metal plate over patterned distributed capacitors

Fully assembled DisC sensor inside a sample canister part measuring the mass of rock samples

Above: Graph showing the variation of capacitance of segmeneted electrodes with respect to changing load.

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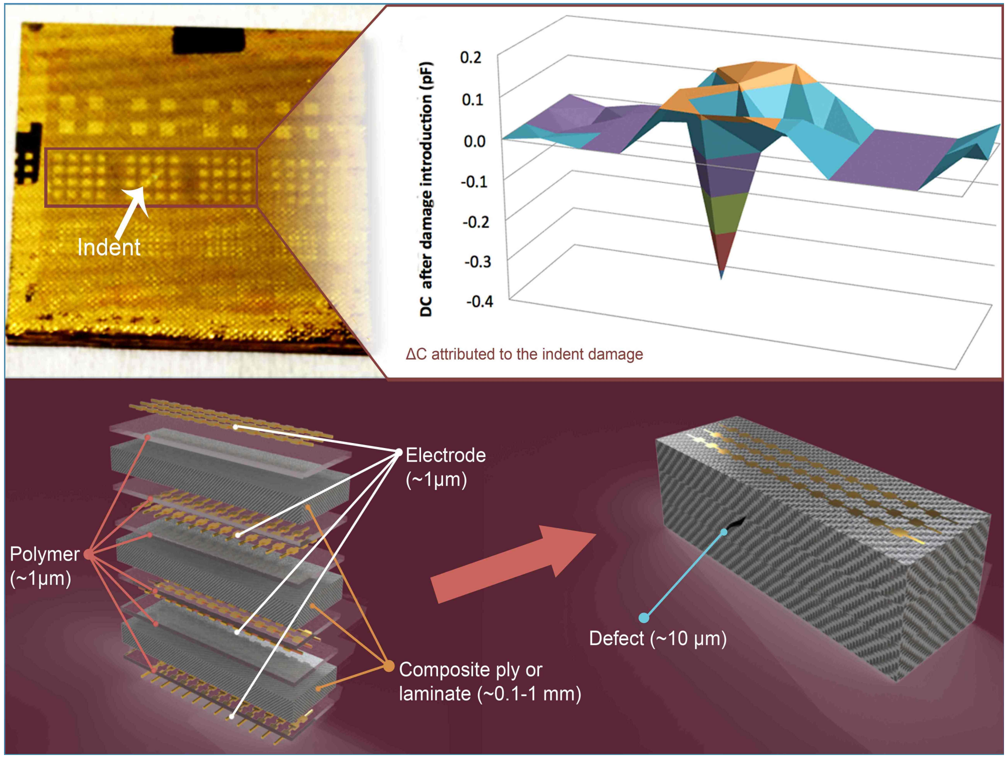
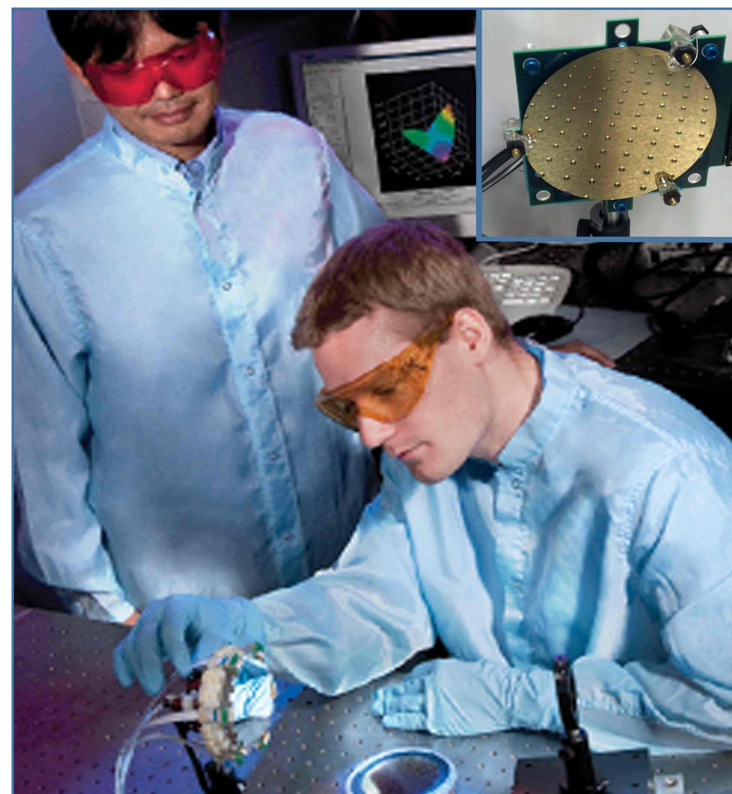
Material Integrated Sensors and Actuators



Using an array of embedded capacitance sensors, carbon fiber and carbon nanotube composites are being made capable of detecting and pin-pointing structural damages for repair/healing.



In collaboration with Caltech, light-weight, deformable-membrane mirror technology for in-space reconfigurable large-area telescopes systems is under development. These silicon membrane mirrors use integrated piezo actuators to provide active control of the reflecting surface.

ACKNOWLEDGMENTS

The research presented here were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

I thank the sponsoring agencies that supported projects reported in this presentation:

NASA (OCT and CIF), JPL R&TD, DARPA, Commercial Entities (Oil an Gas, Skull Base Institute)

Work done by NAMS group members: Drs. Karl Yee, R. Toda, L. Del Castillo, V.Scott, R. Murthy, and S.Y. Bae

Collaborators: M. Mojarradi, S. Pellegrino, F. Hadaegh

Thank You!