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Ultra High-Density Single-Walled Carbon Nanotube Transistors and Diode Rectifiers



13 SEPTEMBER 2010

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

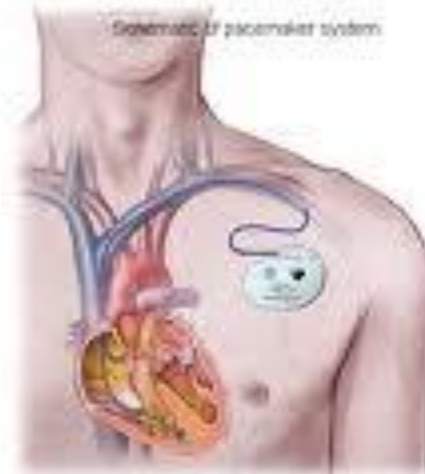
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Switches and AC-DC Power Converters: Technological Applications



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Funding:

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ARL Director's Research Initiative

- Background
 - Technologies: Switches (Transistors, Diodes), Power (AC-DC) Converters
 - Material: Carbon Nanotubes (Single-walled)
- ARL Developed Technologies
 - Massively parallel arrays of transistors
 - Approach and device performance
 - Arrays of Diode Rectifiers → AC-DC conversion
 - Approach and Device performance
- Summary

LETTERS TO NATURE

Helical microtubules of graphitic carbon

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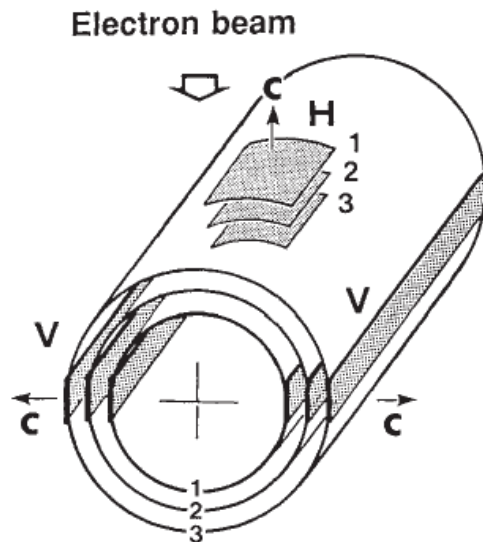


FIG. 2 Clinographic view of a possible structural model for a graphitic tubule. Each cylinder represents a coaxial closed layer of carbon hexagons. The meaning of the labels V and H is explained in the text.

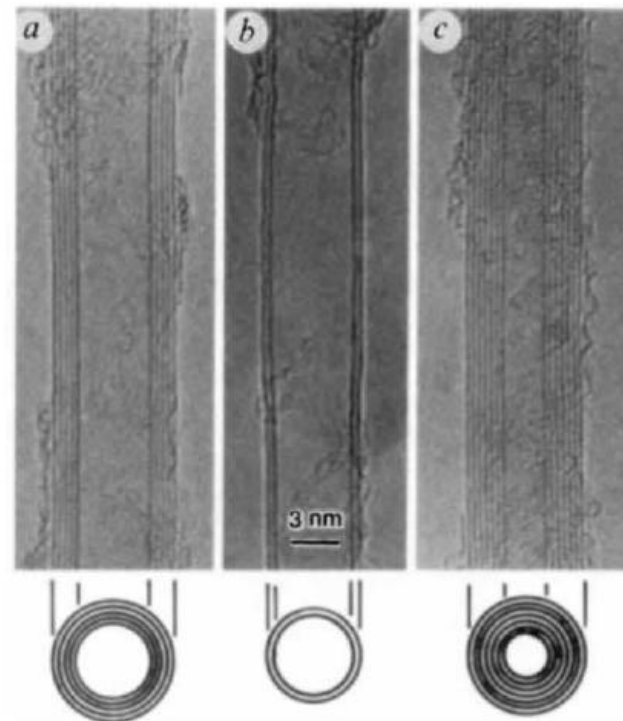
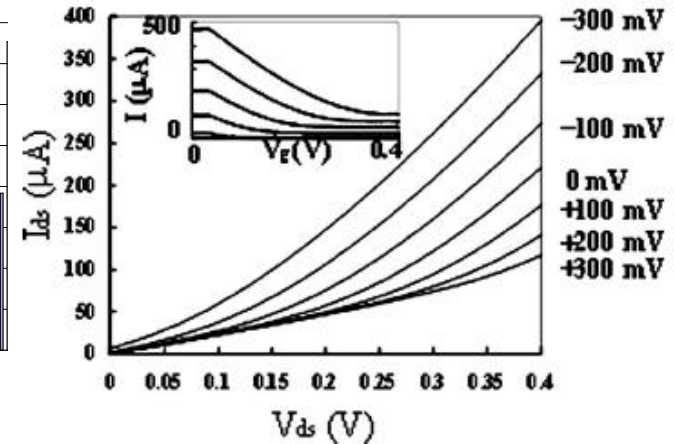
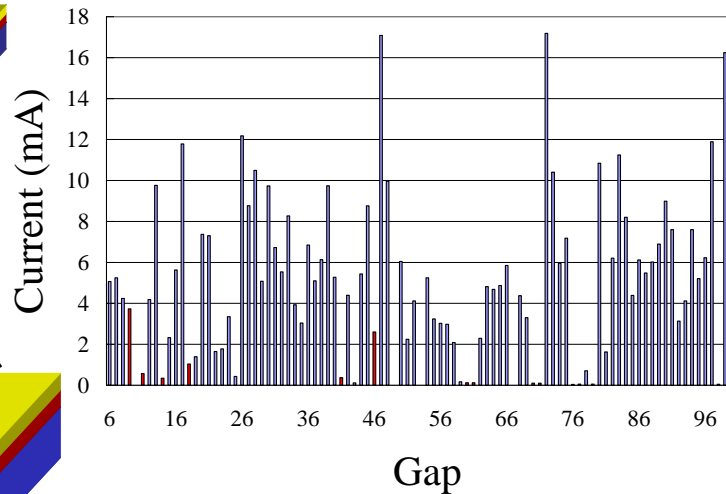
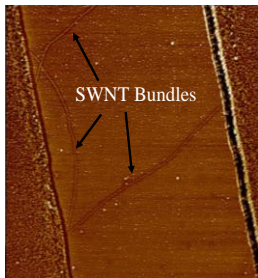
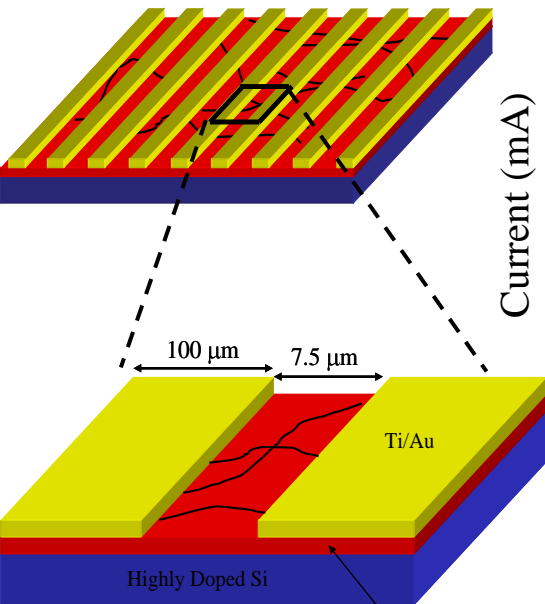


FIG. 1 Electron micrographs of microtubules of graphitic carbon. Parallel dark lines correspond to the (002) lattice images of graphite. A cross-section of each tubule is illustrated. *a*, Tube consisting of five graphitic sheets, diameter 6.7 nm. *b*, Two-sheet tube, diameter 5.5 nm. *c*, Seven-sheet tube, diameter 6.5 nm, which has the smallest hollow diameter (2.2 nm).

S. Iijima, *Nature* 354, 56-58 (1991)

S. Lastella, et al, *J. Appl. Phys.* **99**, 024302 (2006)

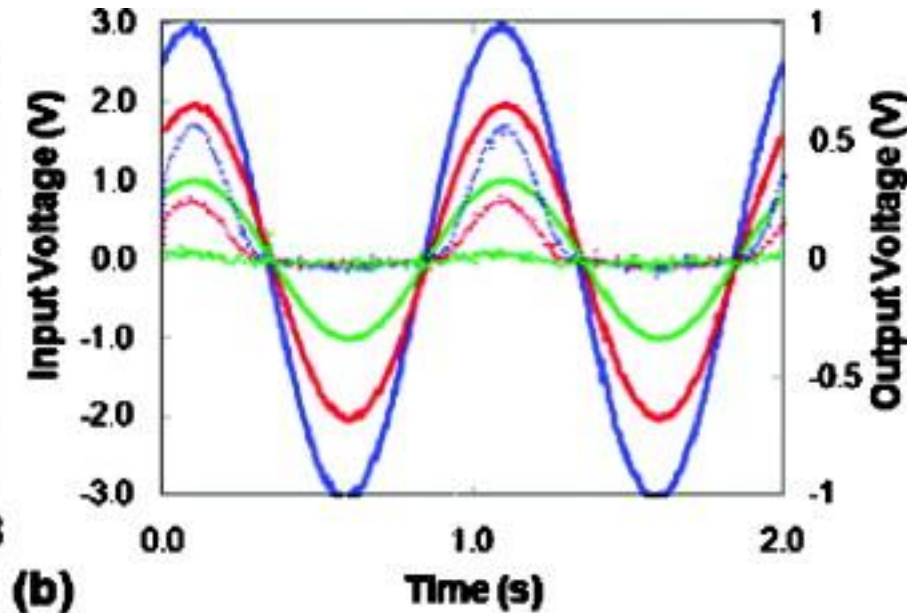
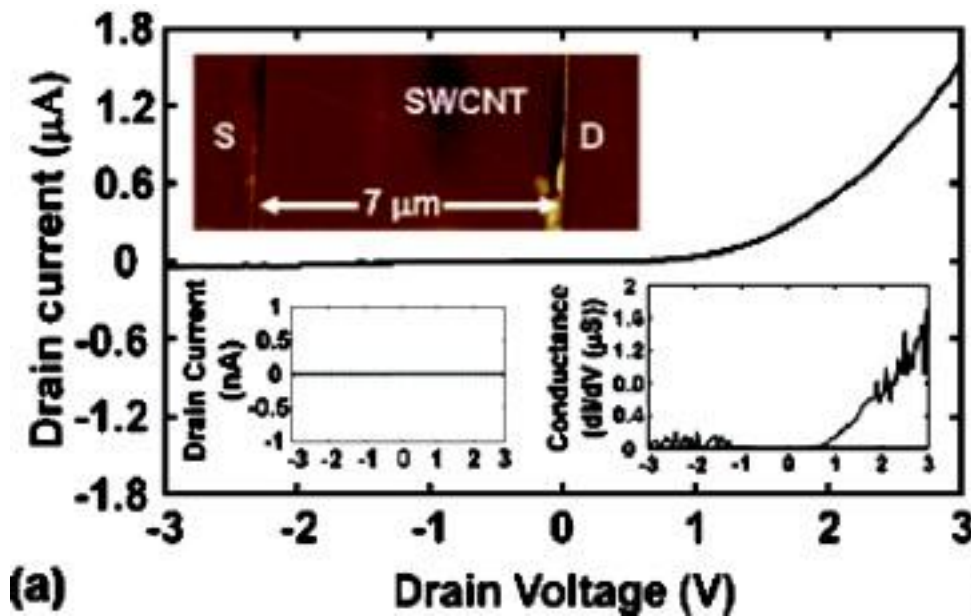
Technologies: Massively parallel switches, chemical-biological sensors



- Scaled-up device fabrication (more than 160 devices)
- Three step fabrication
- Over 375 SWNT channels in single device
- High current = 17.2 mA (max)
- 96% functional yield

G. Mallick and S. P. Karna, "A FIELD EFFECT TRANSISTOR ARRAY USING SINGLE WALL NANO-CARBON TUBES" Patent filed - ARL 06-55; Serial Number 11/790,052, Filing Date: 04/23-2007

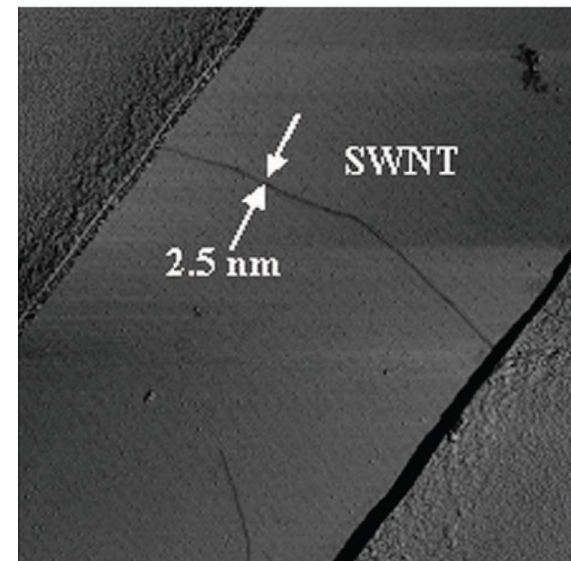
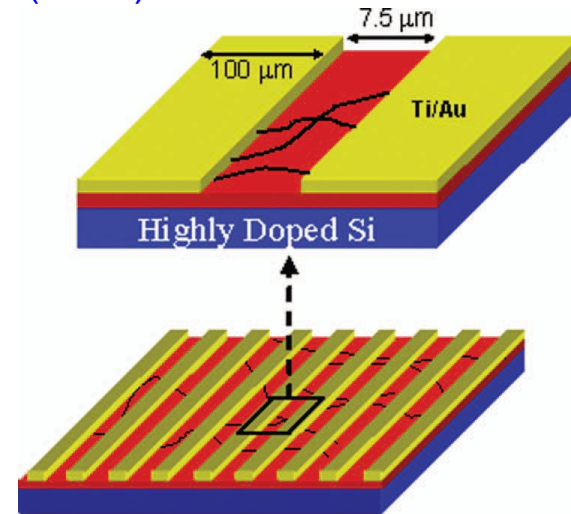
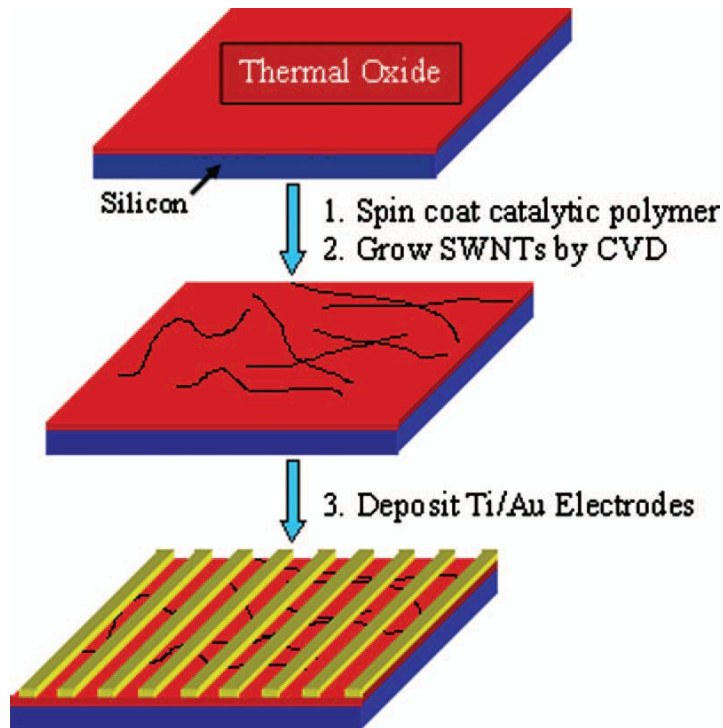
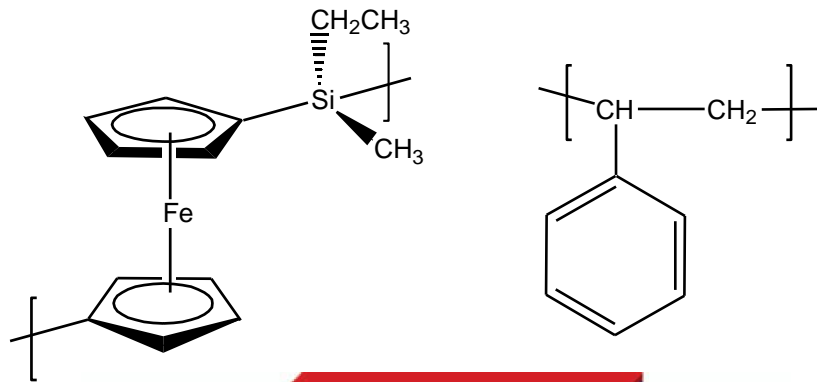
G. Mallick et al, *Appl. Phys. Lett.* **96**, 233109 (2010)



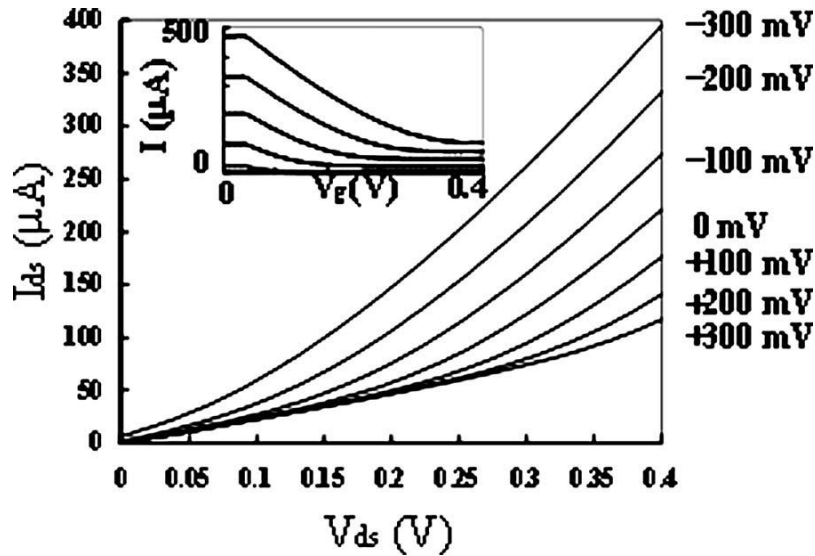
The lower right inset is the conductance (dI/dV) plot. The lower left inset is the I-V trace of a blank $7 \mu\text{m}$ gap device.

ac-to-dc half-wave conversion of 1 Hz ac inputs/dc output at 1 V (green solid/dashed), 2 V (red solid/dashed), and 3 V (blue solid/dashed), respectively.

S. Lastella, et al., *J. Appl. Phys.* **99**, 024302 (2006)

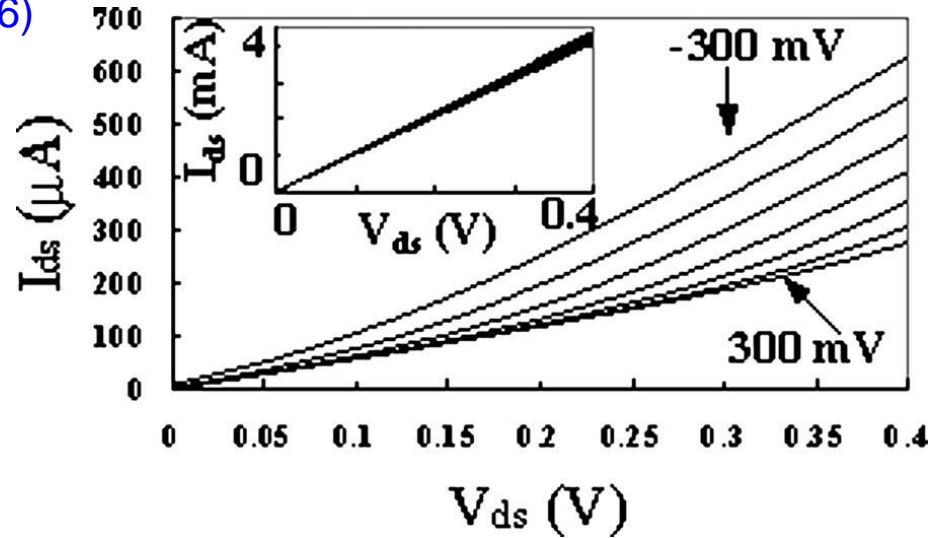


S. Lastella, et al., *J. Appl. Phys.* **99**, 024302 (2006)

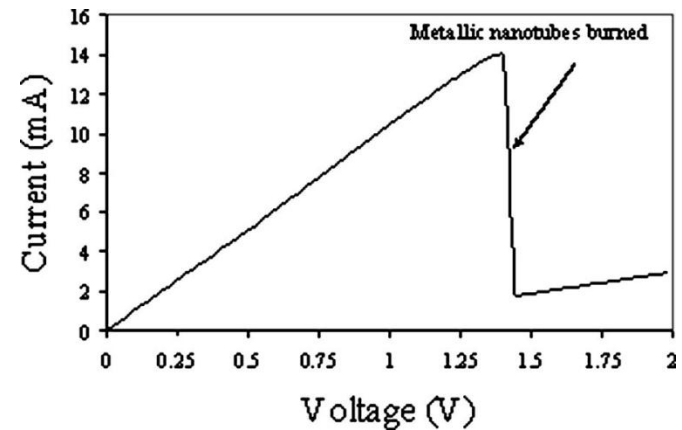


Semiconducting Channel

Electric-field-induced
breakdown of metallic tubes

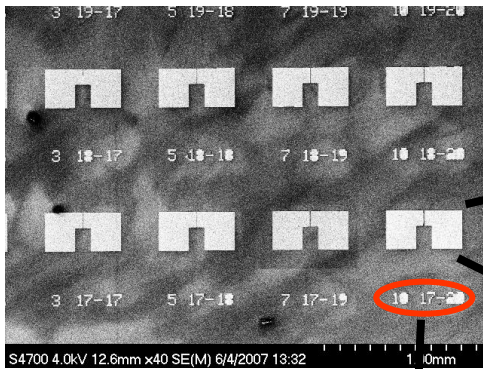


Predominantly metallic Channel: Pre (inset) and post-electric field treatment

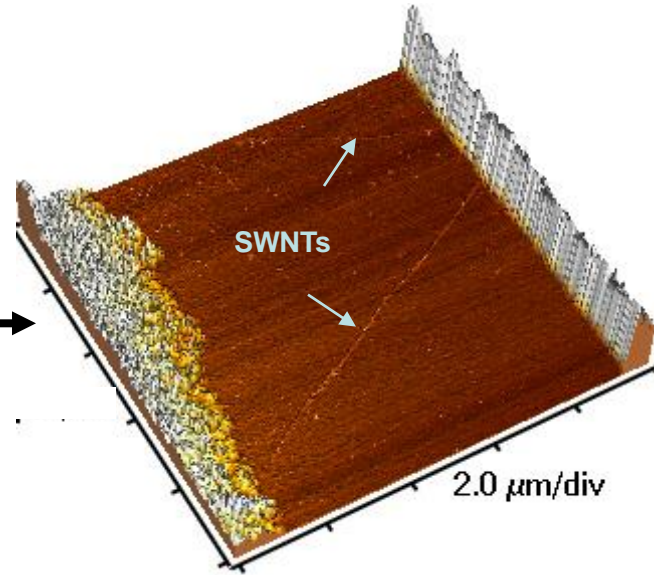
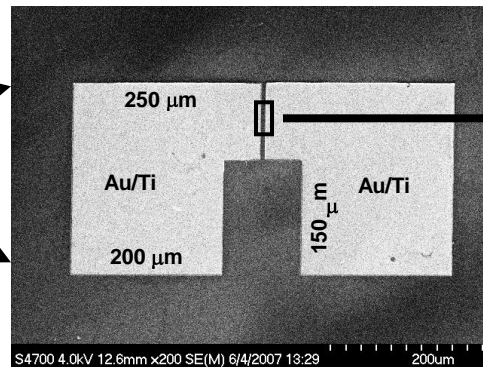


G. Mallick, et al, *J. Nanosci. Nanotech.* **10**, 6062 (2009).

SEM images of FET device patterns



Matrix:
 Gap = 10 μm
 Row = 17
 Column = 20



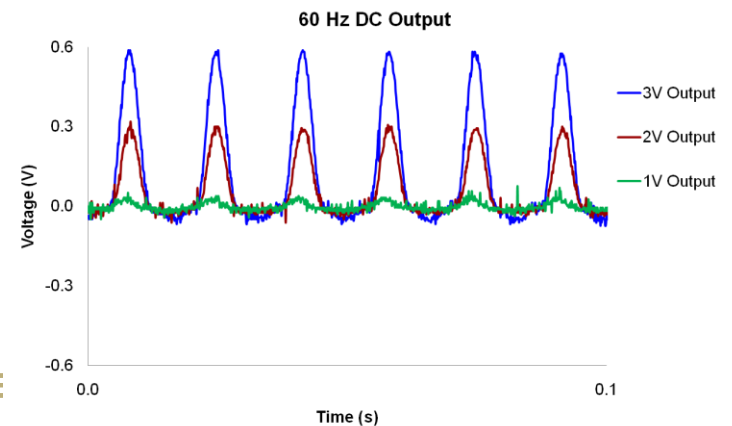
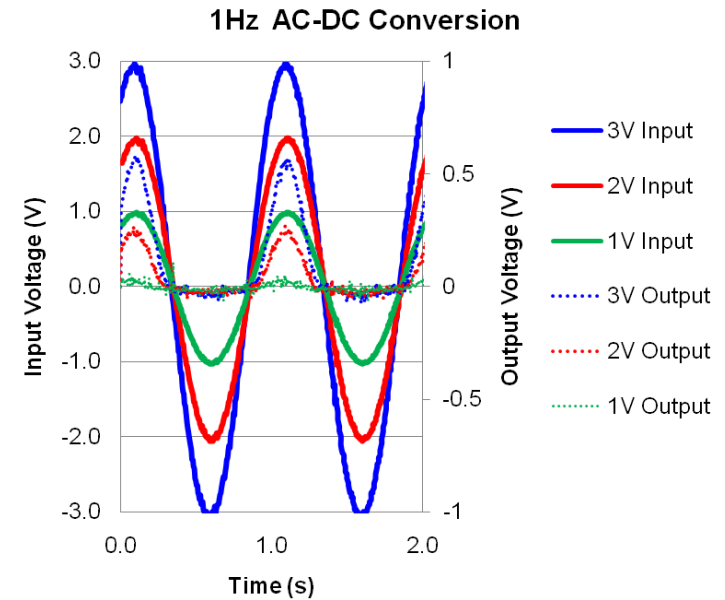
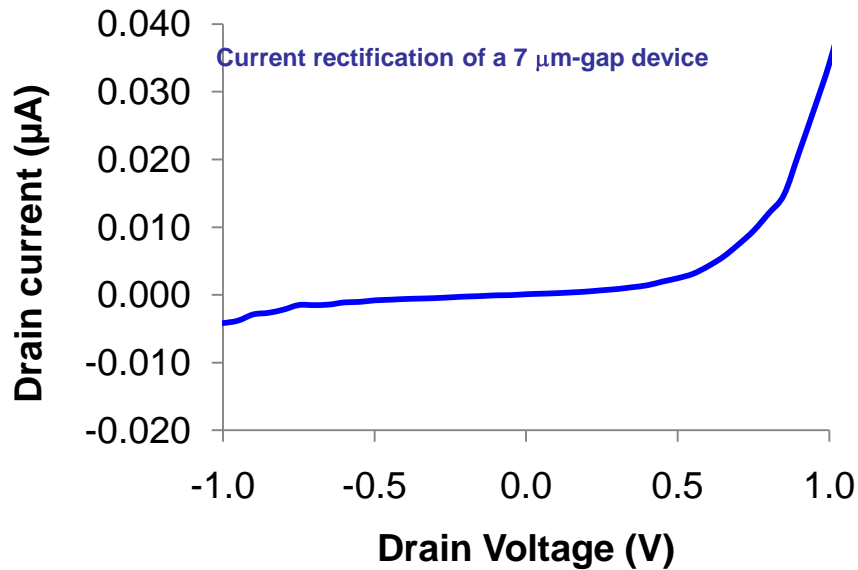
AFM image of 10 μm gap device with SWNT connecting the two electrode pads

Each device is uniquely labeled, hence traceable

35% of the total devices were active, out of which 70% showed rectification, and rest showed metallic (Ohmic) behavior.

G. Mallick et al, *Appl. Phys. Lett.* **96**, 233109 (2010)

First ever experiment to demonstrate AC-to-DC power conversion with a CNT diode



- High density Planar SWNT FETs
- High-density Planar SWNT Diode rectifiers
- Simple, three-step process
- Highly compatible with Si-technology
- Easy for technology insertion, new designs.
- Low-cost, low-dimension, ultra light-weight, low-power consumption
- Potential Technologies:
 - Switches: all kinds, logic devices, space electronics
 - Power converters: AC-DC conversion, remote power converters, biomedical devices.