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Hysteresis Reduction and Breakdown of Carbon Nanotube Field-Effect Transistors (CNTFETs)

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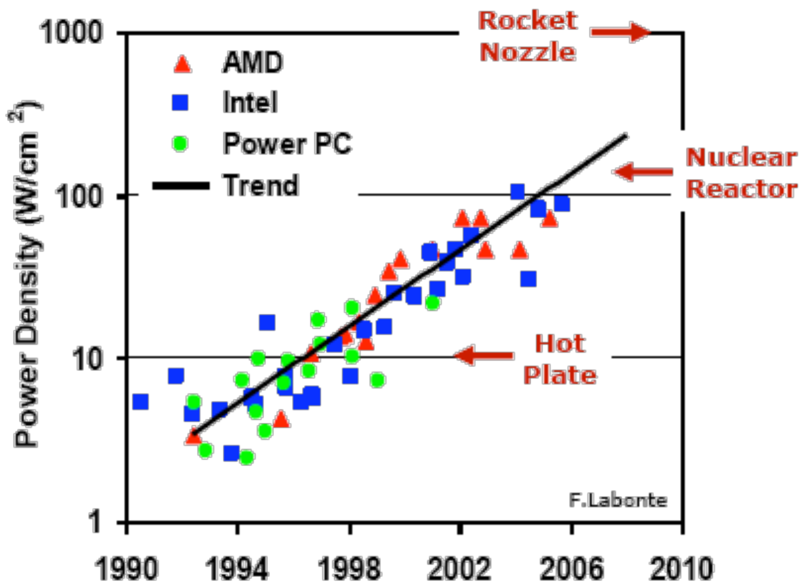
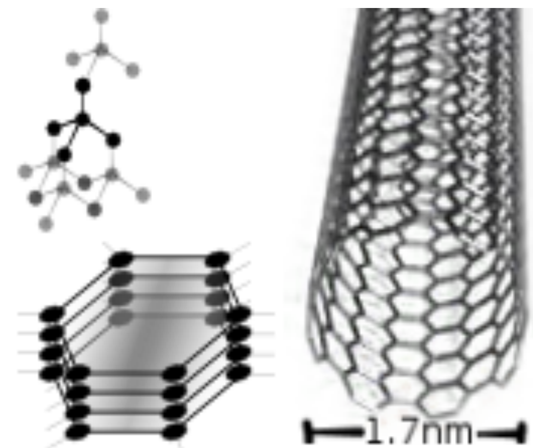
Outline

- Motivation
  - Nanoelectronics: scale down transistor size and reduce power consumption
  - Carbon Nanotubes and Carbon Nanotube Field Effect Transistors (CNTFETs)
- Electrical Characterization of CNTFETs
  - Pulsed I-V characterization
  - Joule heating breakdown



Carbon Nanotubes

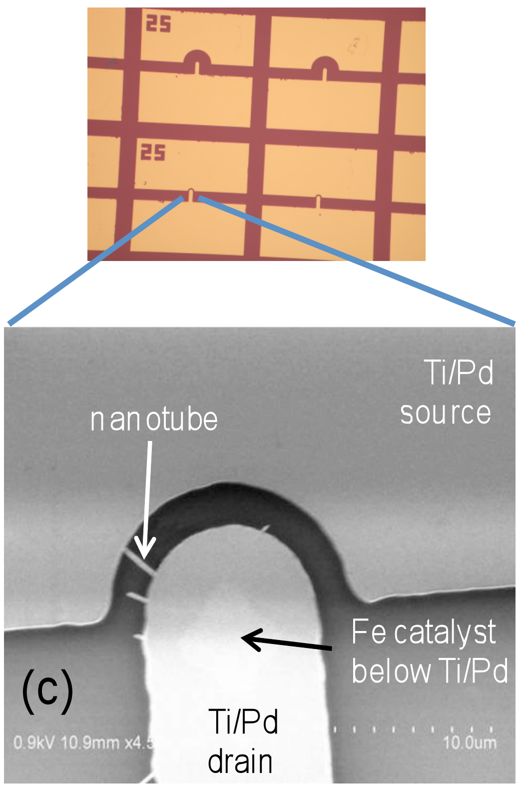
- Carbon nanotubes (CNTs) are 1D tubes of hexagonally arranged carbon atoms
- CNTs feature extraordinary electrical conductivity (~10 times Cu/Ag) and thermal conductivity (similar to $C_{diamond}$)
- Less heat dissipation → closely packed transistors → satisfy Moore's law



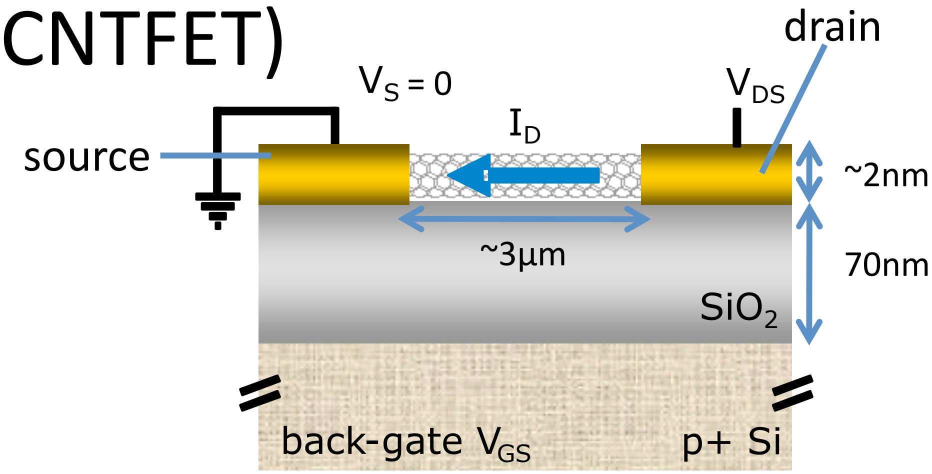
Diamond (top left), graphite (bottom left), & SWNT (right) structural comparison

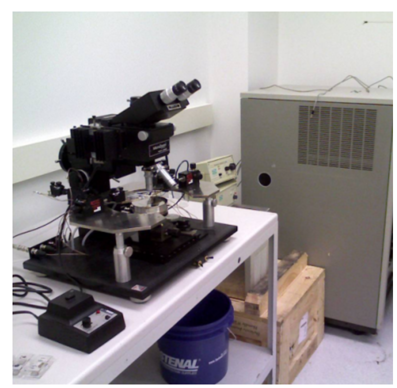
Carbon Nanotubes in FETs

- Field-effect transistor (FET) created with carbon nanotubes (CNTFET)



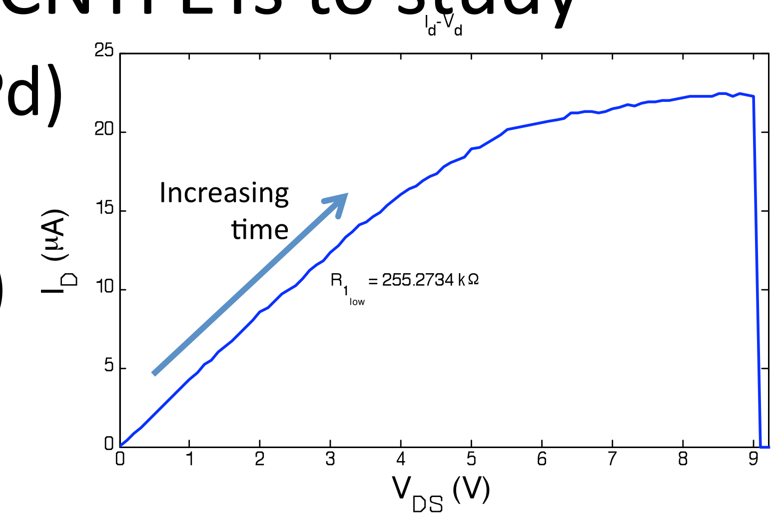
Courtesy of Albert Liao





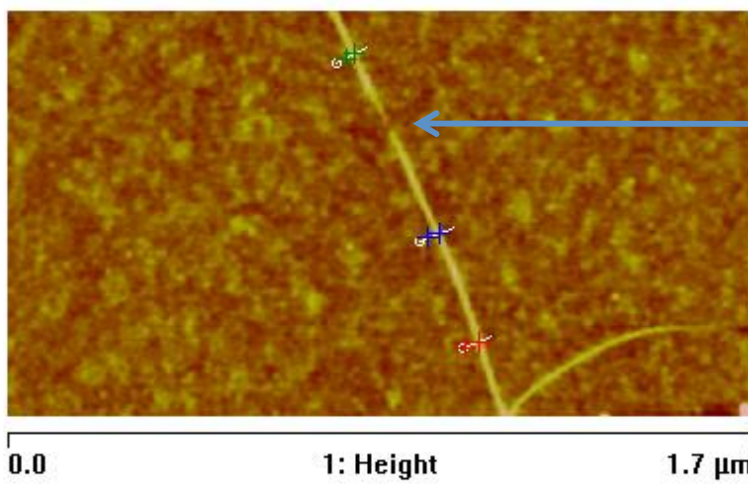
Electrical Characterization

- Transfer characteristic: sweep gate voltage (V_g) from -15 V to 15 V to -15 V, at constant drain voltage (V_d) and measure drain current (I_d)
- I-V characteristic: increase V_d at constant V_g, measure I_d (until breakdown)
- Finding singly connected CNTFETs to study
  - Contact resistance (CNT+Pd)
  - Saturation current
  - Amplification (I_{on}/I_{off} ratio)



CNTFET Breakdown Study

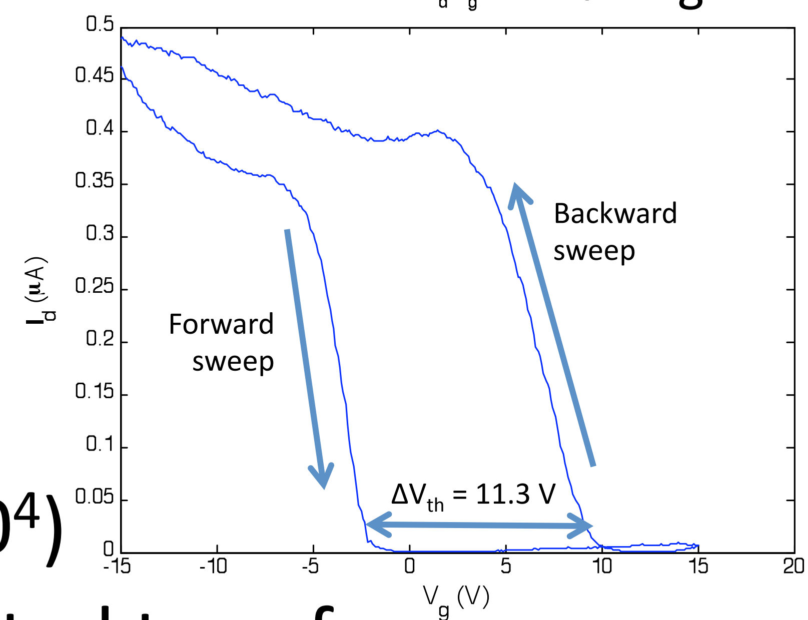
- Power dissipated in CNT and into substrate and contacts need to be optimized
- Compare breakdown drain voltage of CNTFET with diameter, length, and contact resistance
- Determine length, diameter, and breakdown location with atomic force microscopy (AFM)



Breakdown location

Hysteresis

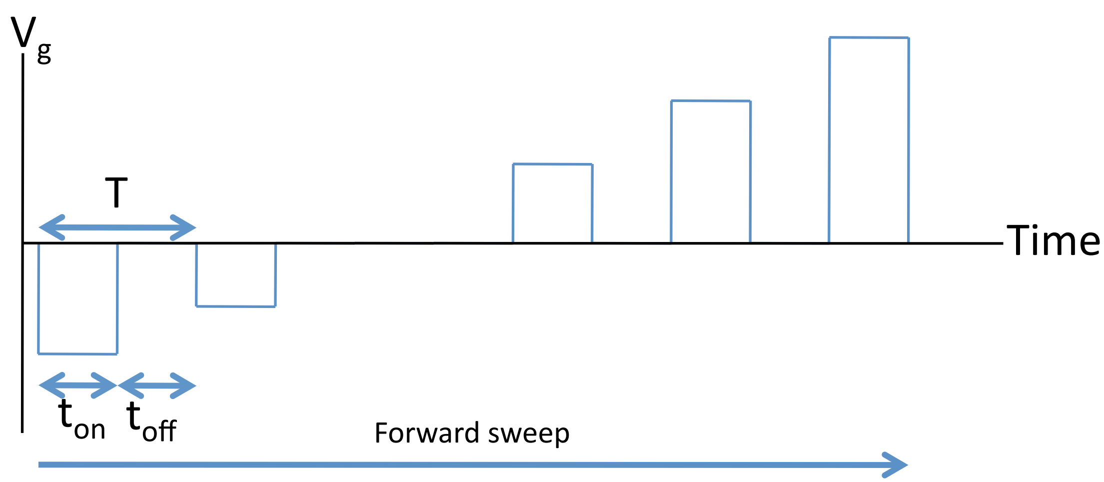
- Charge trapping leads to hysteresis gap in I_d-V_g
  - Traps on water on CNT surface and oxide
  - Traps inside the SiO_2
  - Traps on SiO_2/Si interface
- Unclear threshold voltage and mobility (vary[1,2] by 10^4)
- Solution: determine a central transfer characteristic (I_d-V_g) where $\Delta V_{th} \rightarrow 0$



[1] T. Dürkop, S. A. Getty, E. Cobas, et al., Nano Letters 4, 35 (2004).
[2] X. Zhou, J. Park, S. Huang, et al., Physical Review Letters 95, 4 (2005).

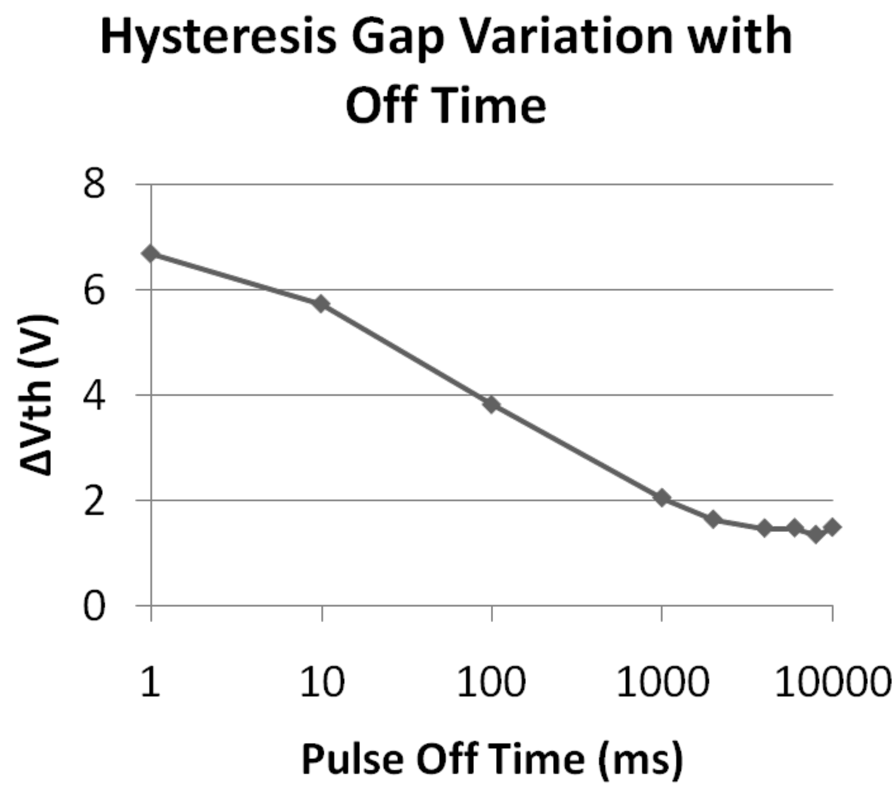
Reducing Hysteresis

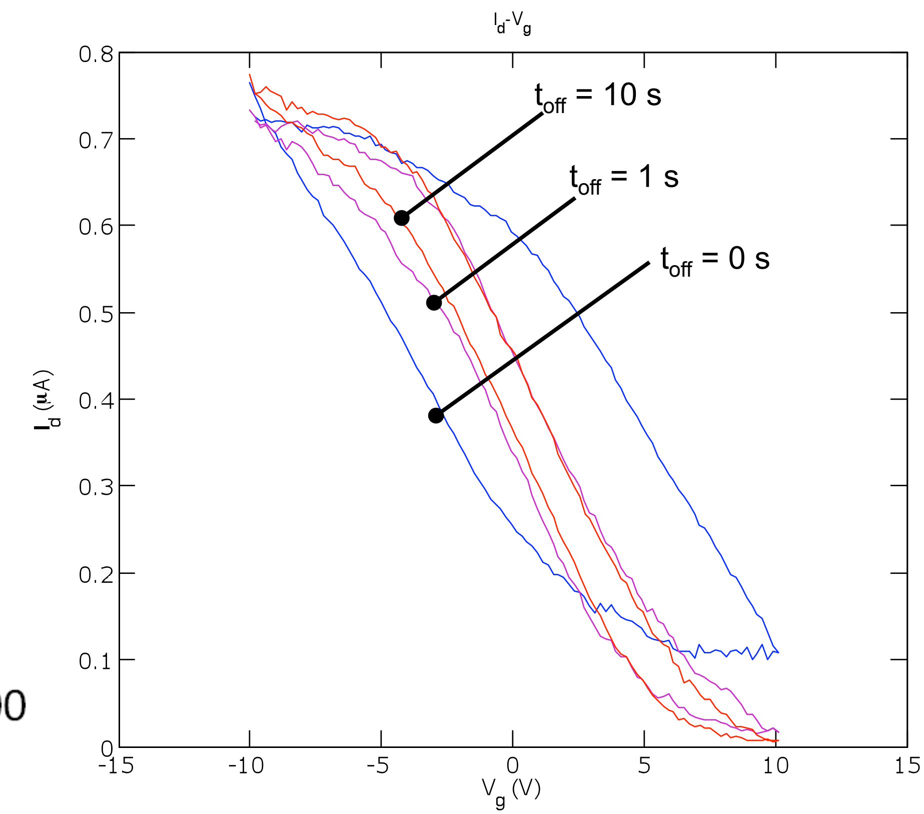
- Pulse V_g while maintaining 50 mV drain bias
- Pulse width and duty cycle
  - Changing on time has little effect
  - Off time varied from 1 ms to 10 s
- Also varying temperature and environment



In Air at 453 K

- Pulse off-time varied only; on-time variation had no effect





Hysteresis Study Summary

- Factors reducing hysteresis gap ΔV_{th} in I_d-V_g measurement
  - Pulsed V_g
  - Smaller sweep window
  - In vacuum
  - Higher temperature
- No observed differences in I_d-V_g with
  - Dry N_2 flow over devices in air
  - Variations in pulse on time

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Micro and Nanotechnology Laboratory
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PopLab at Illinois
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