SINGLE WALL CARBON NANOTUBES FOR PRINTED ELECTRONICS

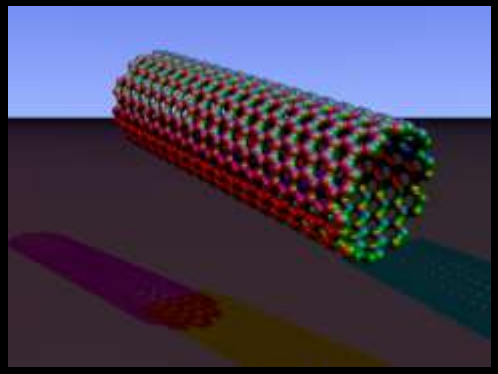
Philip Wallis, SouthWest NanoTechnologies

CONTENTS

- What are Carbon Nanotubes?
- Properties of Carbon Nanotubes
- Advantages of Printed Electronics
- Overcoming Barriers to Adoption
- Current Status for TCF and TFTs

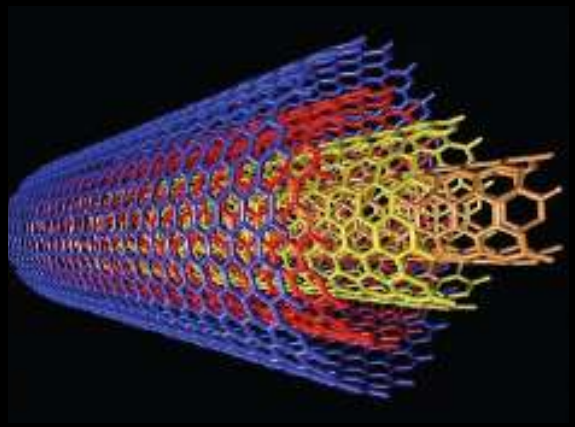
MAJOR CATEGORIES OF CARBON NANOTUBES

Single Wall Carbon Nanotubes
d ~ 1 nm



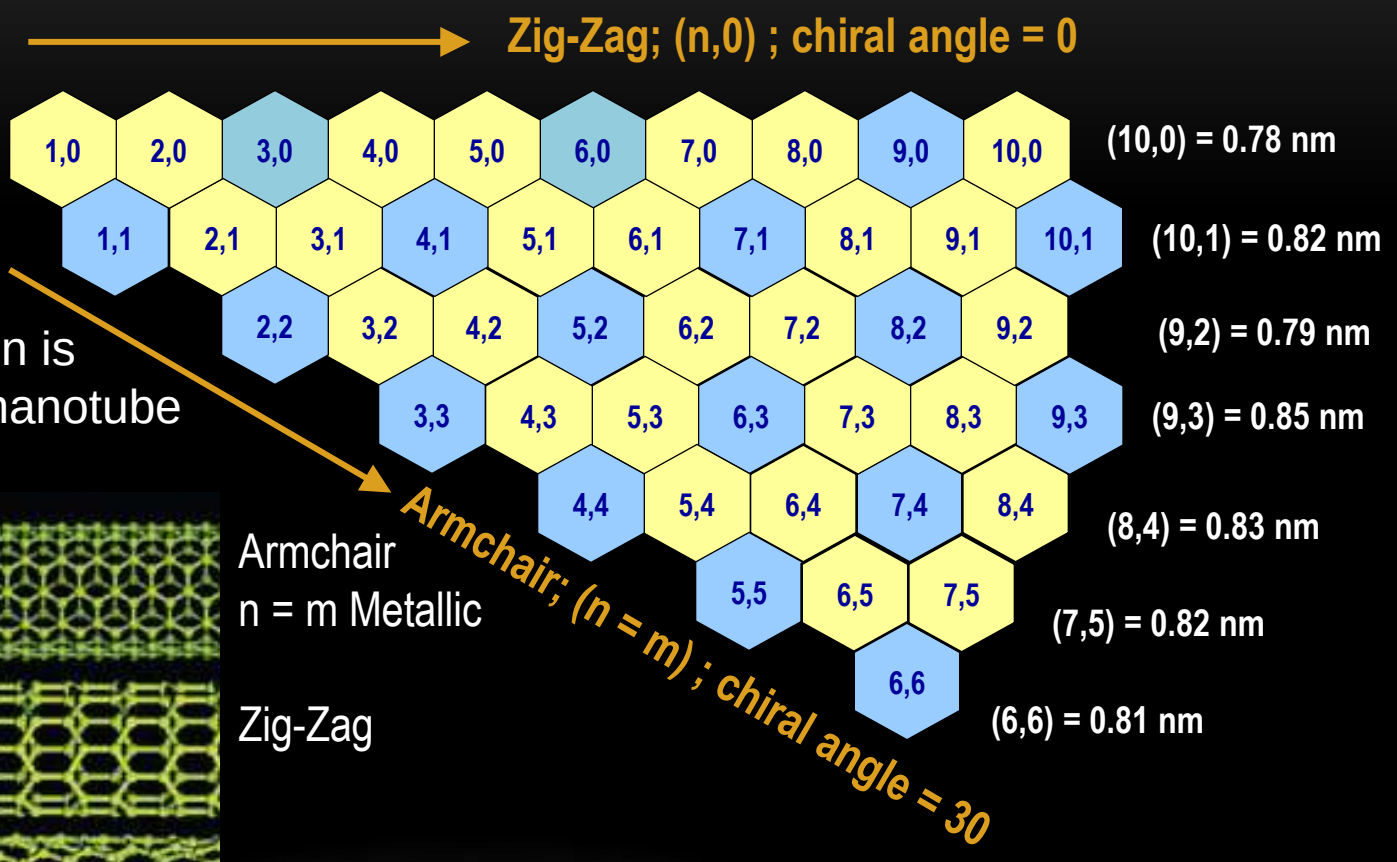
Thin Films for Electronics

Multiwall Carbon nanotubes
5 < d < 200 nm

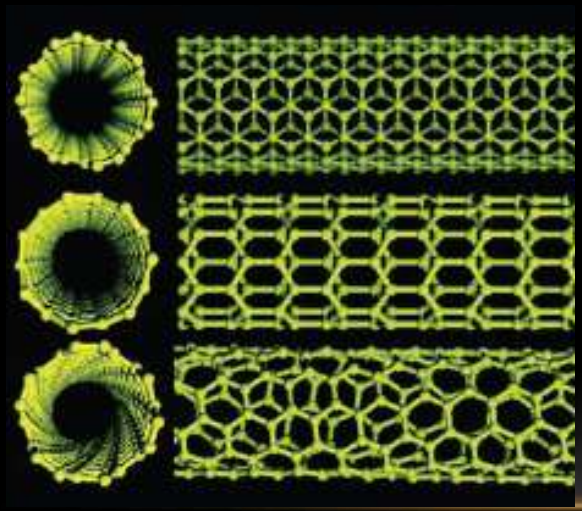


Additives for plastics and resins.

SWCNT CHIRALITY AND DIAMETER



Distance from origin is proportional to nanotube diameter



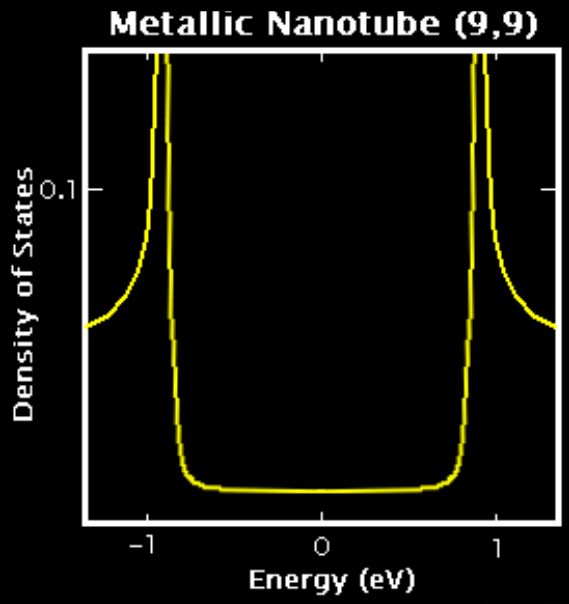
Armchair
n = m Metallic

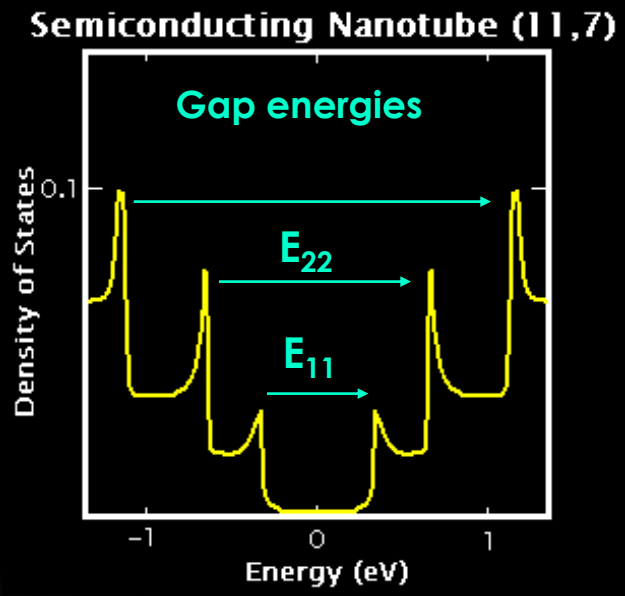
Zig-Zag

Chiral

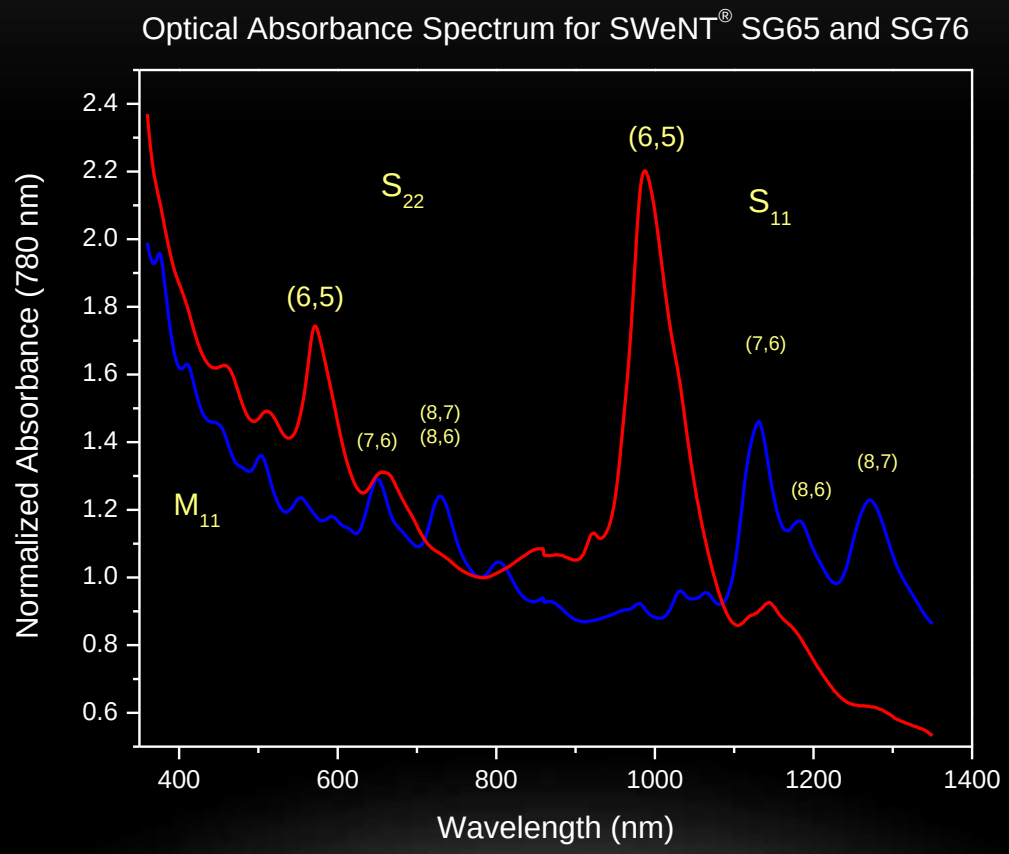
SWCNT DENSITY OF STATES

Metallic tubes have non-zero electron density at the Fermi level.
Semiconducting tubes have zero density and exhibit a band gap.





OPTICAL ABSORBANCE SPECTRA



WHY CARBON NANOTUBES

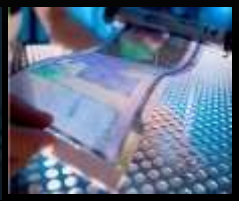
- “Discovered” by Iljima in 1991 >20 Years Ago
- 50X Stronger than Steel
- More Conductive than Copper
- ½ Density of Al
- Metallic or Semiconducting
- Optically Transparent

POTENTIAL APPLICATIONS

Lighting

Touch

Displays



TFTs

Sensors

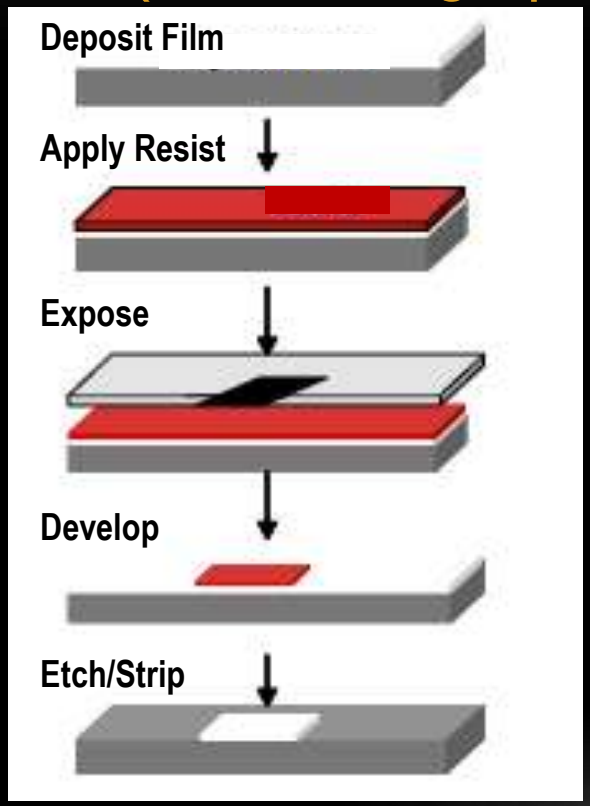
Solar

High Performance Computing

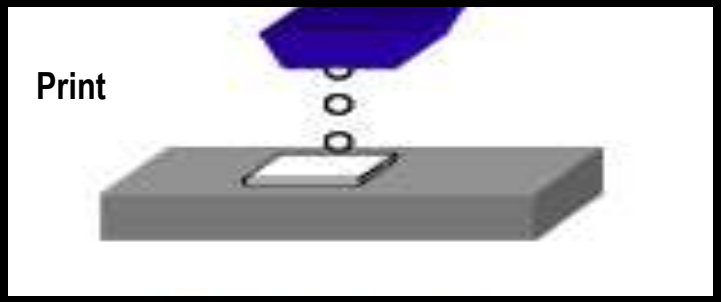
Carbon
Electronics

WHY PRINT ELECTRONICS?

Subtractive Process (Photolithography)



Additive Process (Printing)



- *Less steps*
- *Less waste*
- *Lower cost*
- *Short cycle time*

OVERCOMING THE BARRIERS TO ADOPTION

- Quality and Consistency
- Availability
- Cost
- Purity
  - Other Carbon Forms
  - Residual catalyst
  - Chiral Mixture
- Handling
- Processing / Printing

MANUFACTURING PLATFORM

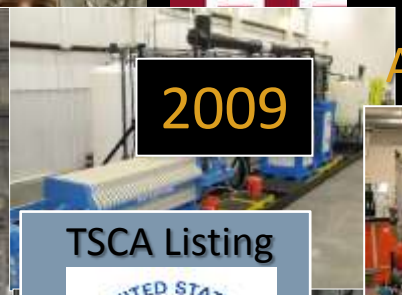
2008

Large Scale Production

2001

F

2009



TSCA Listing

Apps Dev Ctr

CHASM TECHNOLOGIES

Canton, MA

Norman, OK

SWeNT

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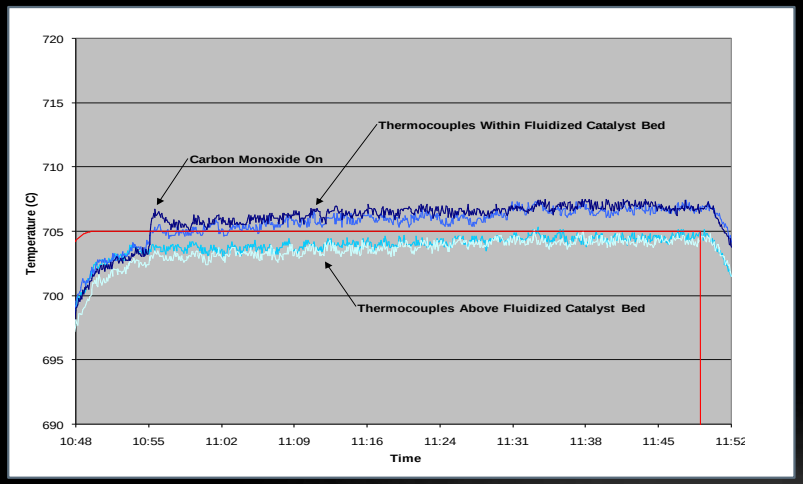
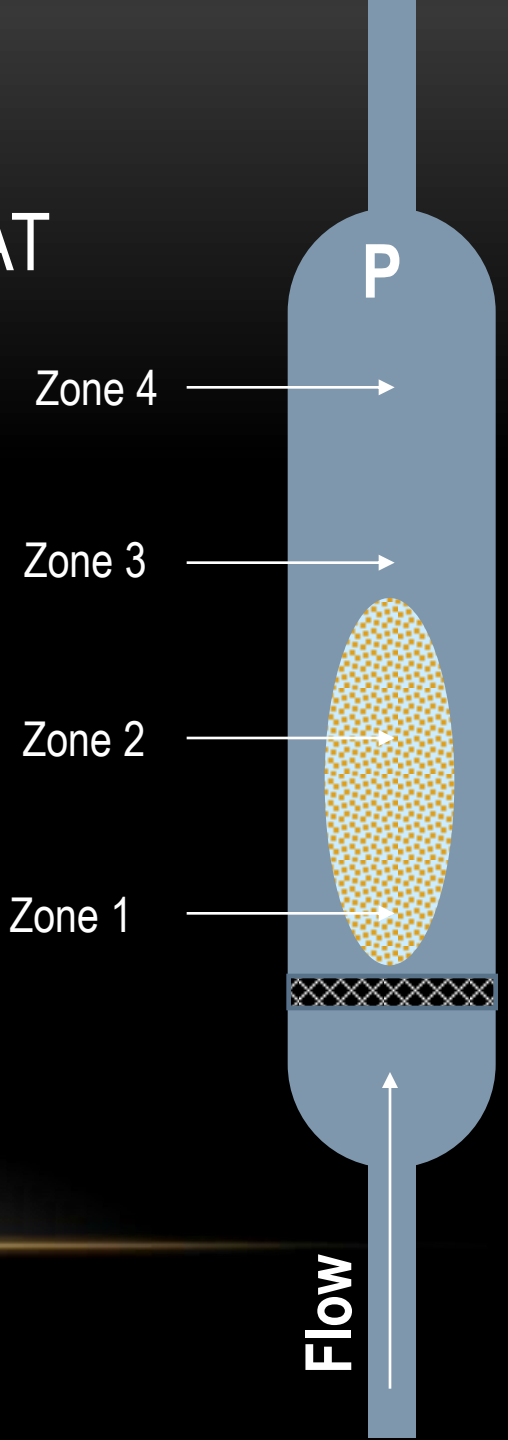
TECHNOLOGY PLATFORM - CoMoCAT

- CO disproportionation (2 CO → C + CO_2)
- Supported transition metal catalysts
- Fluidized bed for uniformity
- Moderate temperatures (700 – 900°C) with precise control (±1° C)
- Moderate pressures = 1 – 10 atm





CUSTOMIZATION OF SWCNT

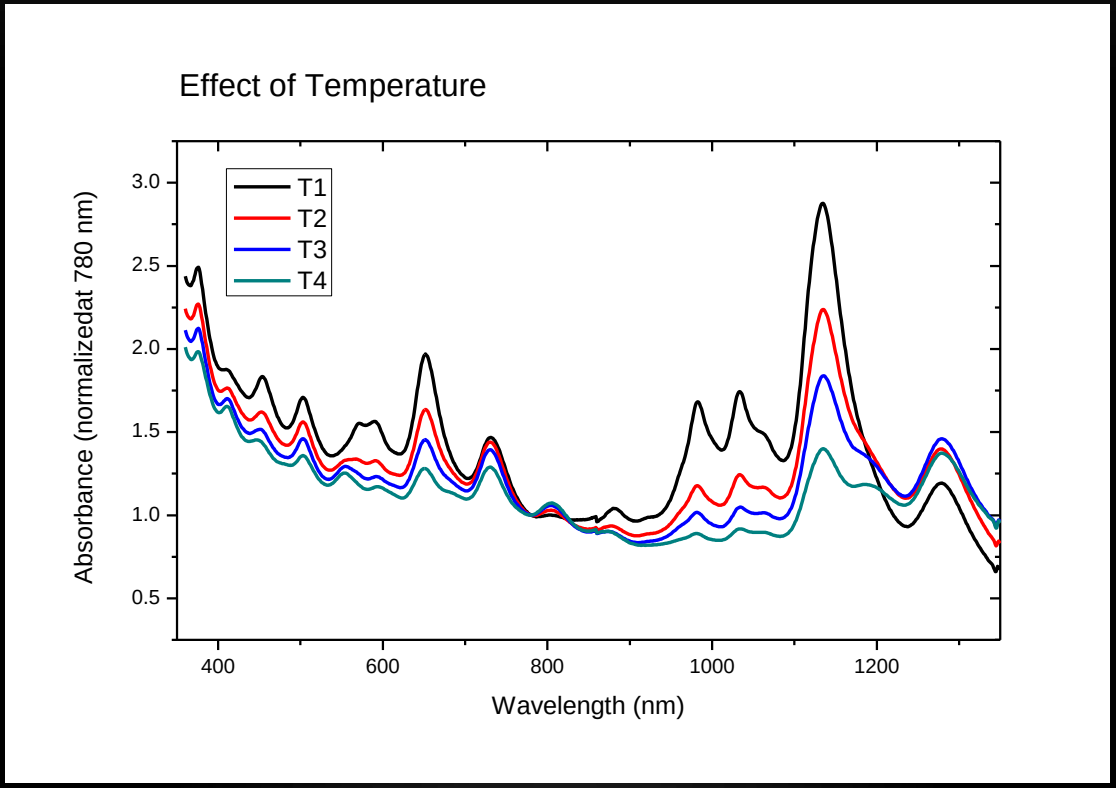
Variables

- Temperature
- Pressure
- Catalyst Composition
- Gas composition

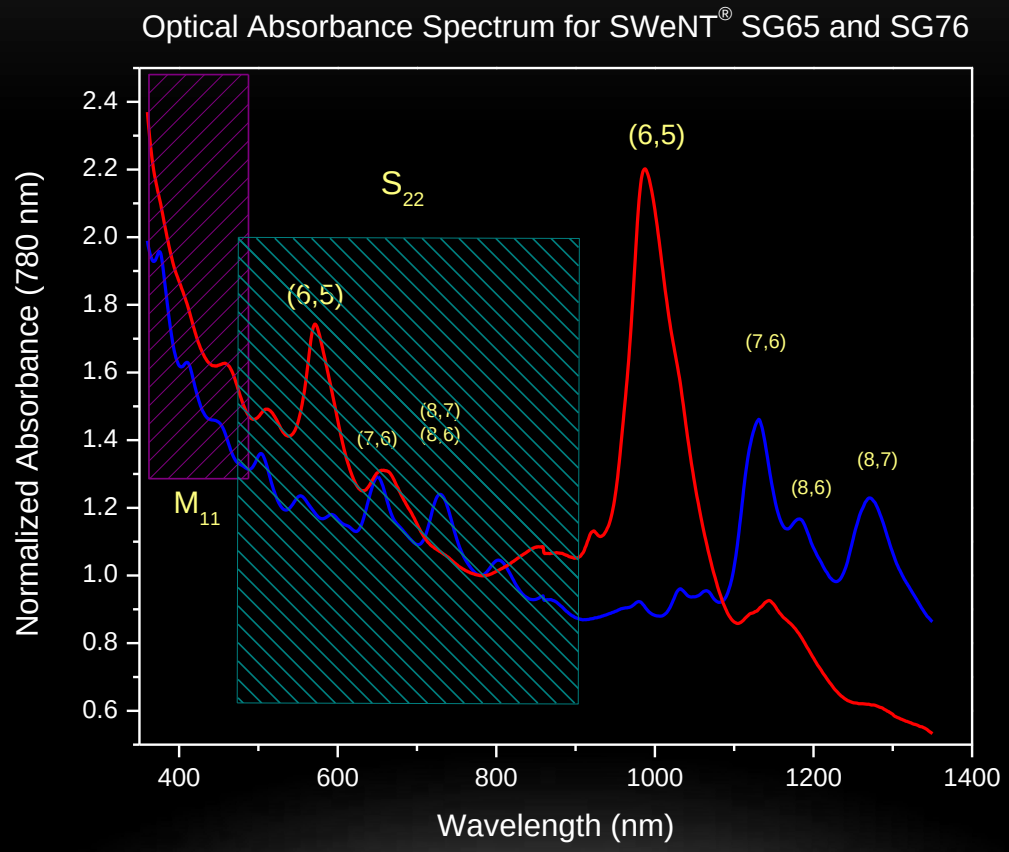
Effects

- Diameter Control and Distribution
- Tube Length
- Bundle Size
- Purity

EFFECT OF TEMPERATURE



QUALITY MEASUREMENTS
OPTICAL ABSORBANCE SPECTRA



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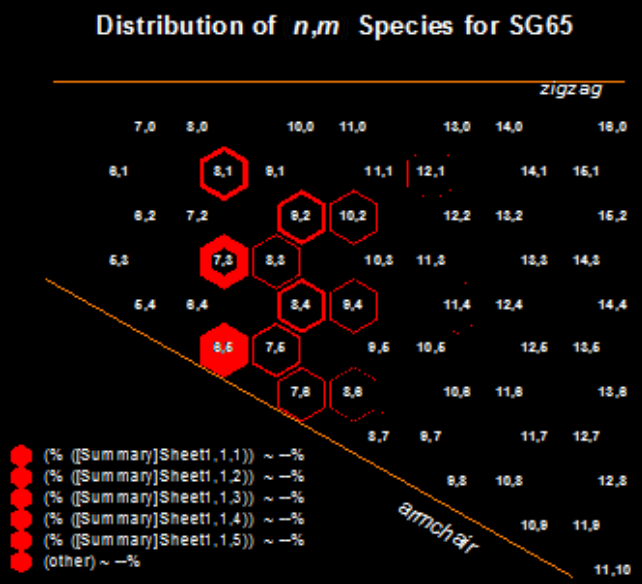

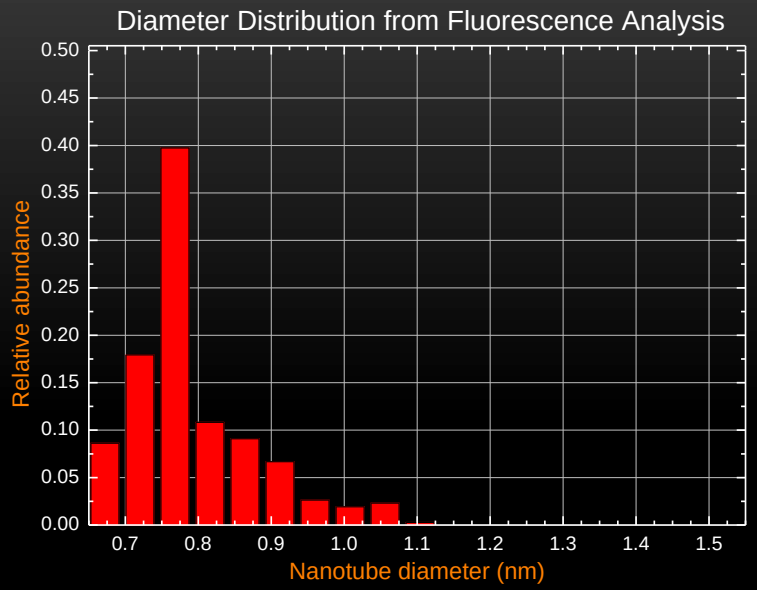

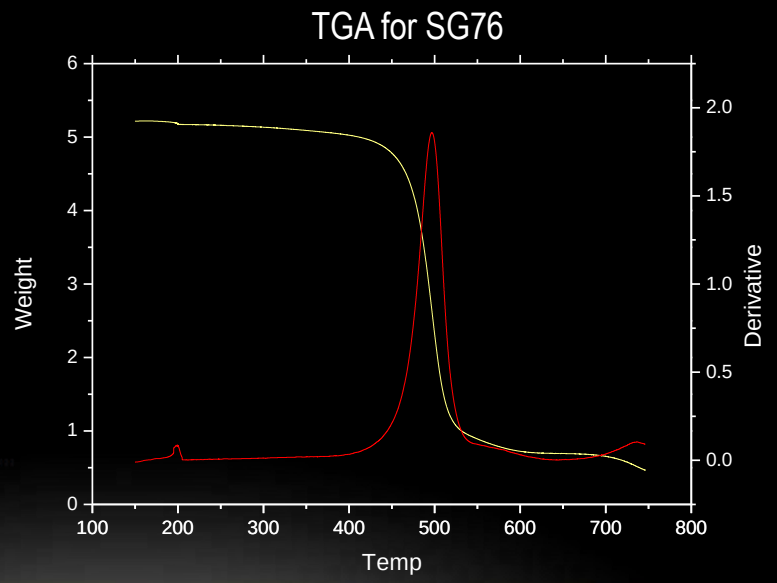

OVERCOMING THE BARRIERS TO ADOPTION

- Quality and Consistency
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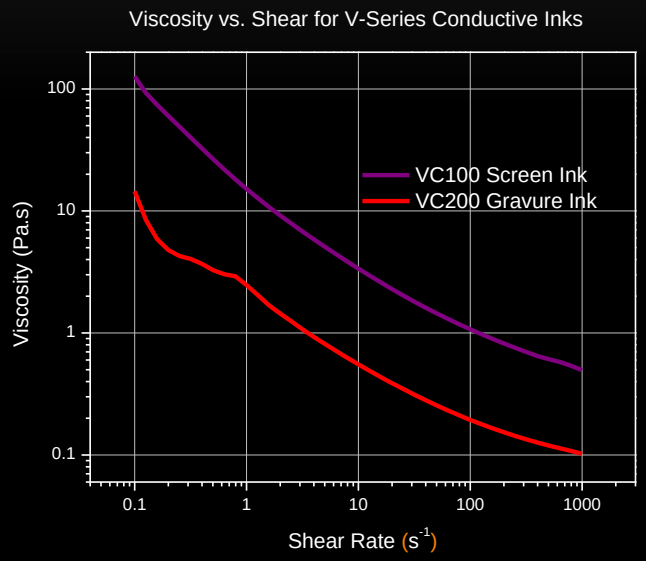
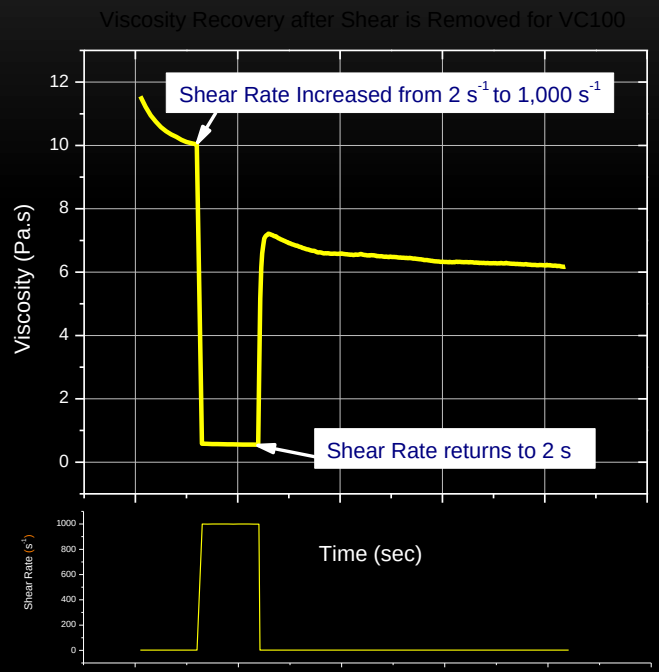
RHEOLOGY OF V-SERIES SCREEN AND GRAVURE INKS

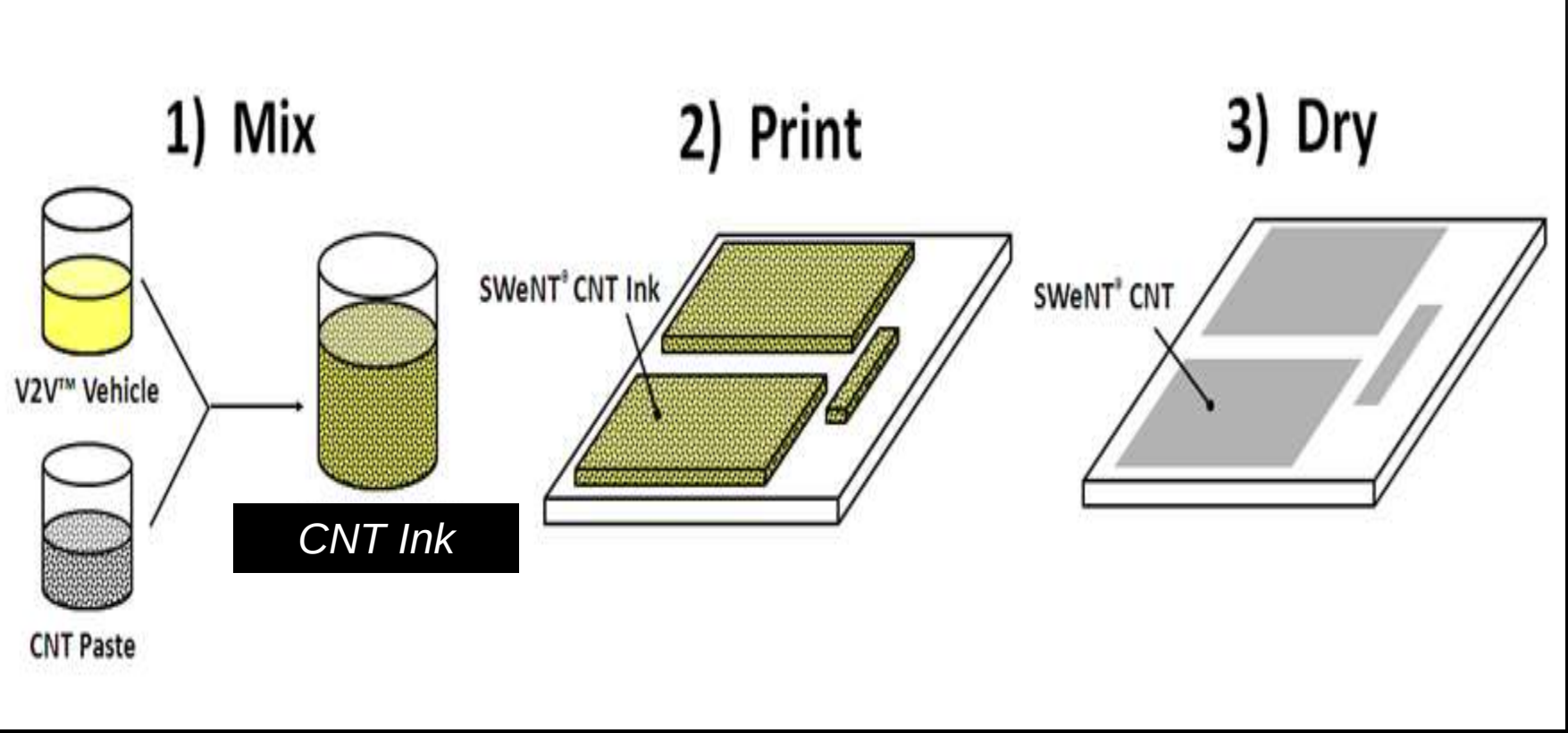




Recovery to 80% of original viscosity ~7 seconds after reduction of shear rate

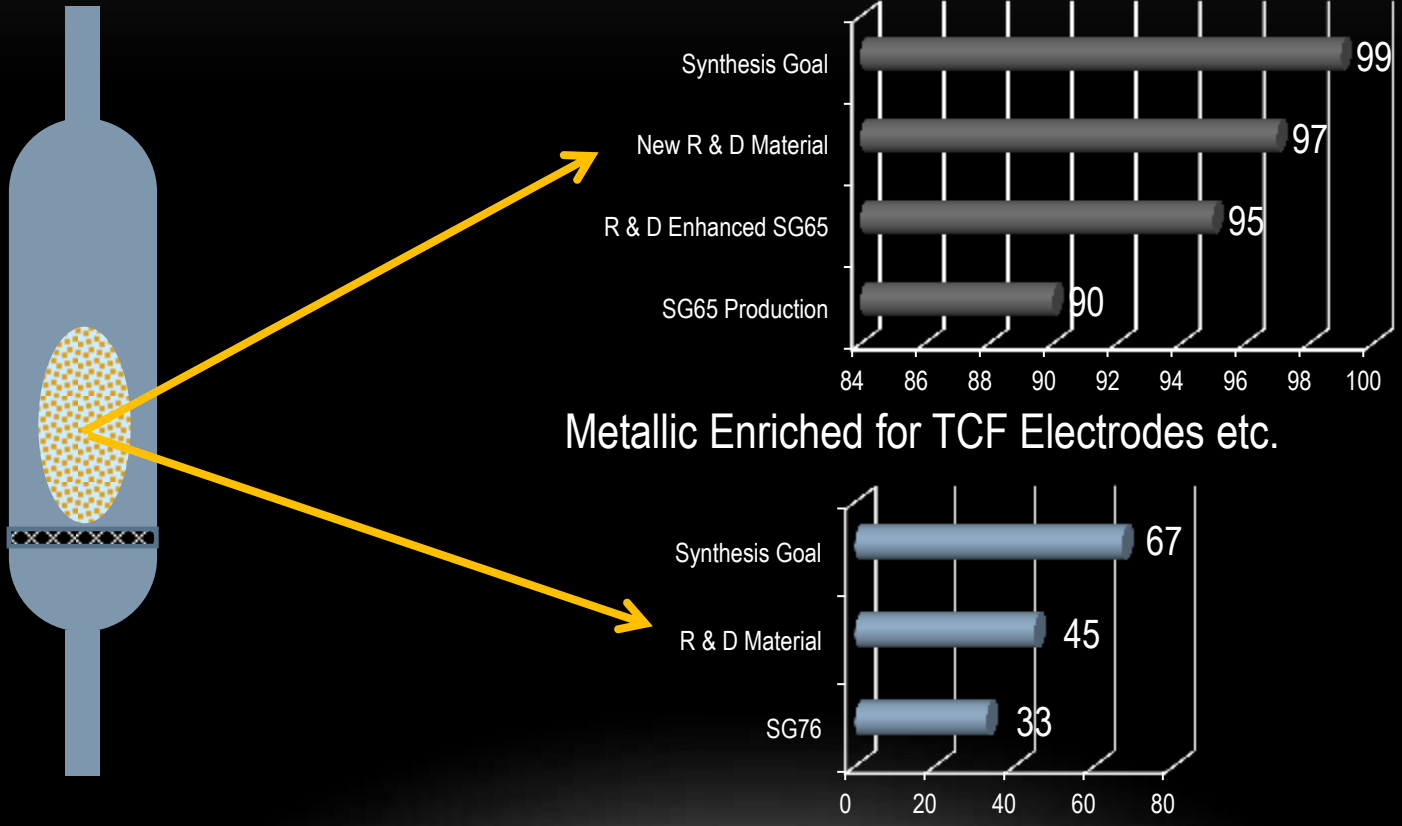
Courtesy Dr. Erika Rebrosova, Western Michigan University

V2V™ INK TECHNOLOGY*

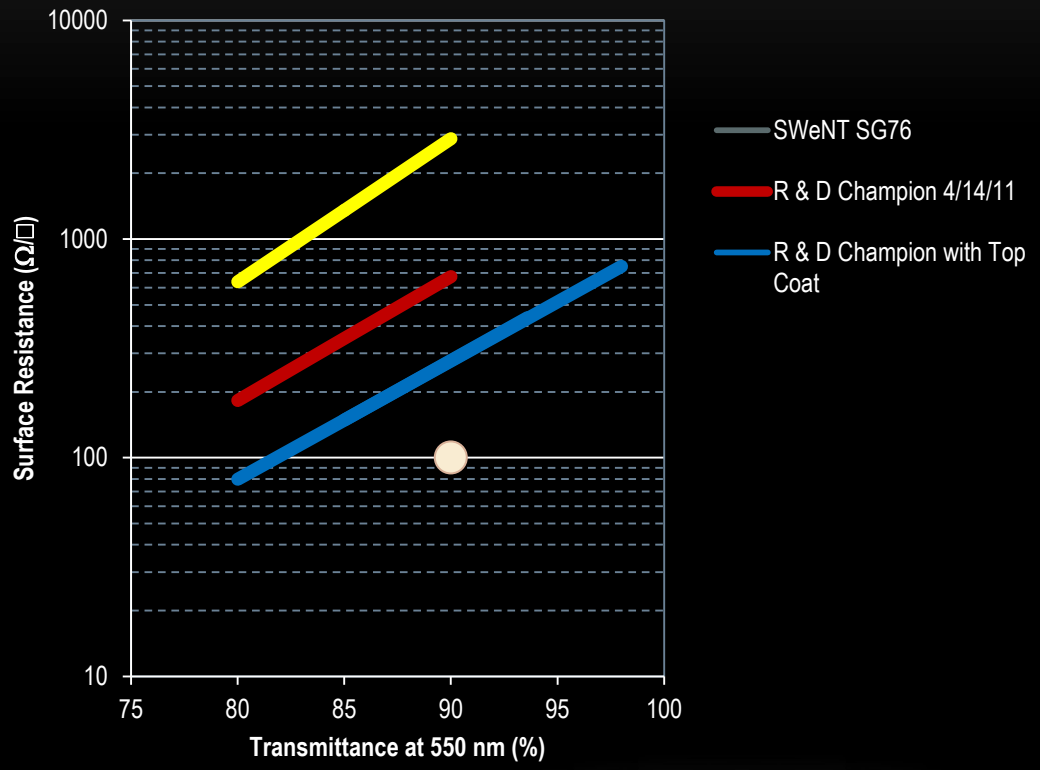


CNTs can be printed using Standard Industrial Printing Equipment

SWCNT TAILORED FOR APPLICATIONS

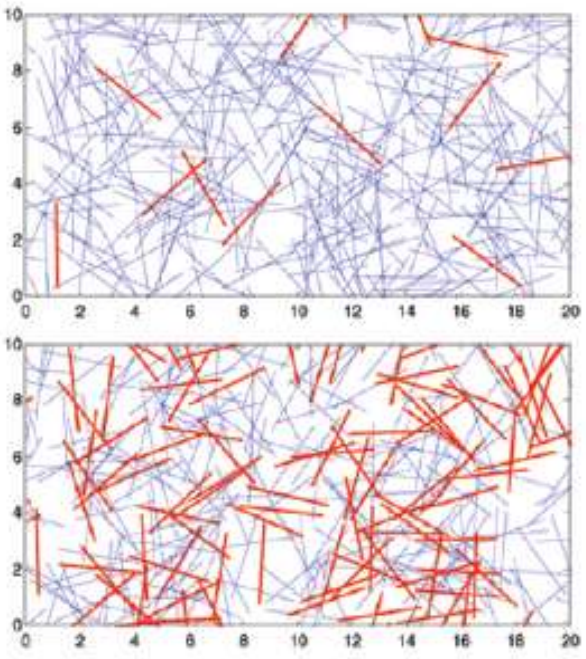


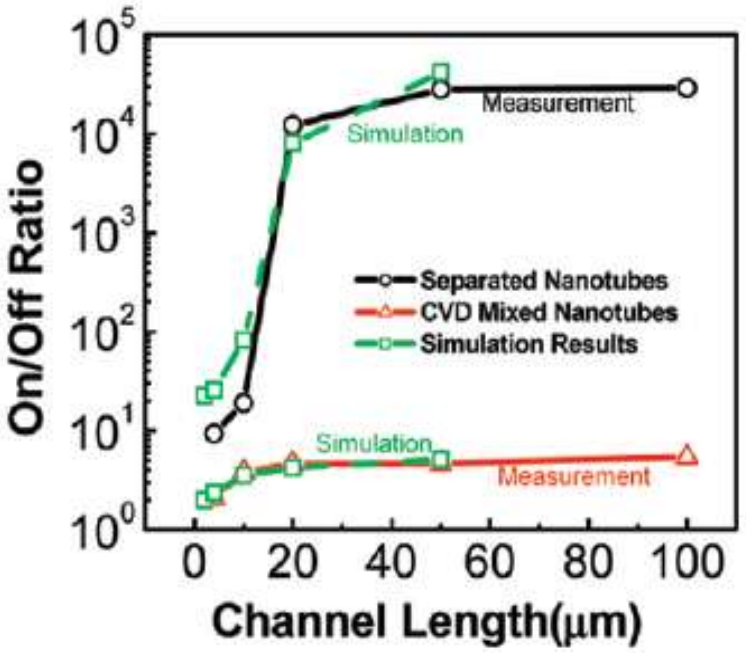
METALLIC ENRICHED FOR TCF



CNT TFTs

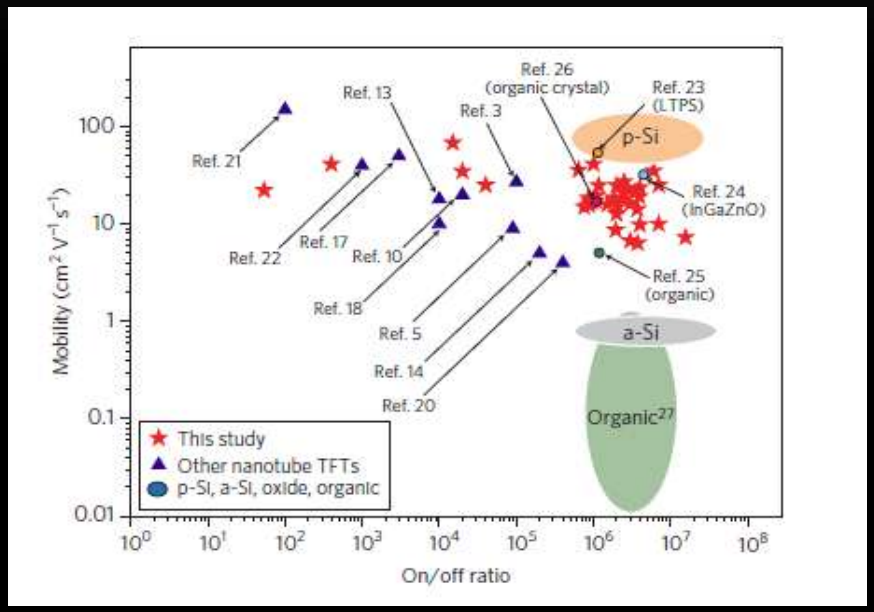
ref. Zhou et al, Nano Lett. 9, 4285 (2009)

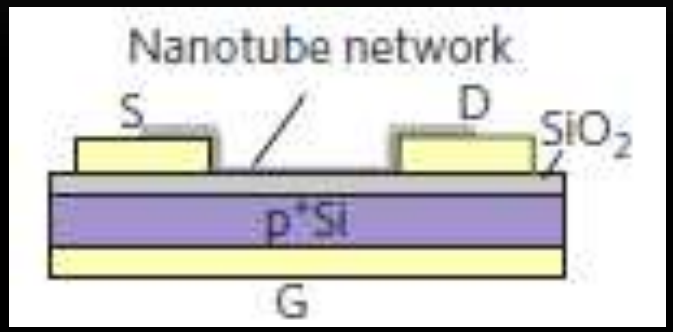




Red = Metallic CNT
Gray = SC CNT

FLEXIBLE, HIGH PERFORMANCE CARBON NANOTUBE INTEGRATED CIRCUITS



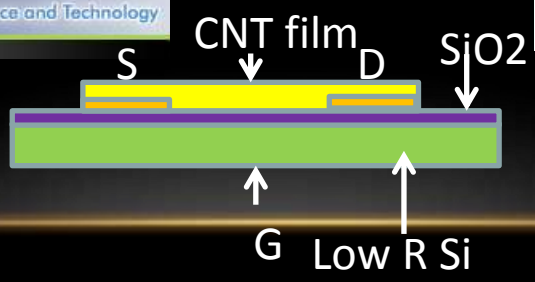


CNT TFTs can have 100X higher Mobility than a-Si and Organic semiconductors!

Ref. Sun, D.M. et. al. *Nature Nanotechnology Letts* **6**, 156–161 (2011).

SEMICONDUCTING ENRICHED SWCNT INKS FOR PRINTING THIN FILM TRANSISTORS

Raw material	Max ON/OFF	Max Mobility cm2/V.s	Channel L µm	Channel W µm
Goal	$>10^6$	> 10 $cm^2/V/s$	20 – 40 µm	40 – 80 µm
Current Commercial SWCNT	10^5	> 10 $cm^2/V/s$	35	50 - 150



Cross-Sectional View of BSI Test TFT

THANK YOU

QUESTIONS?