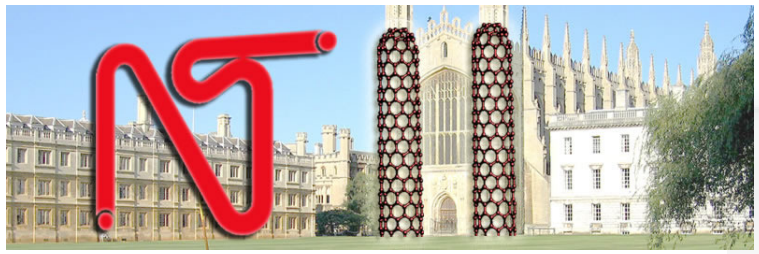
NanoIntegris

Monodisperse SWNT – Applications and Device Performance

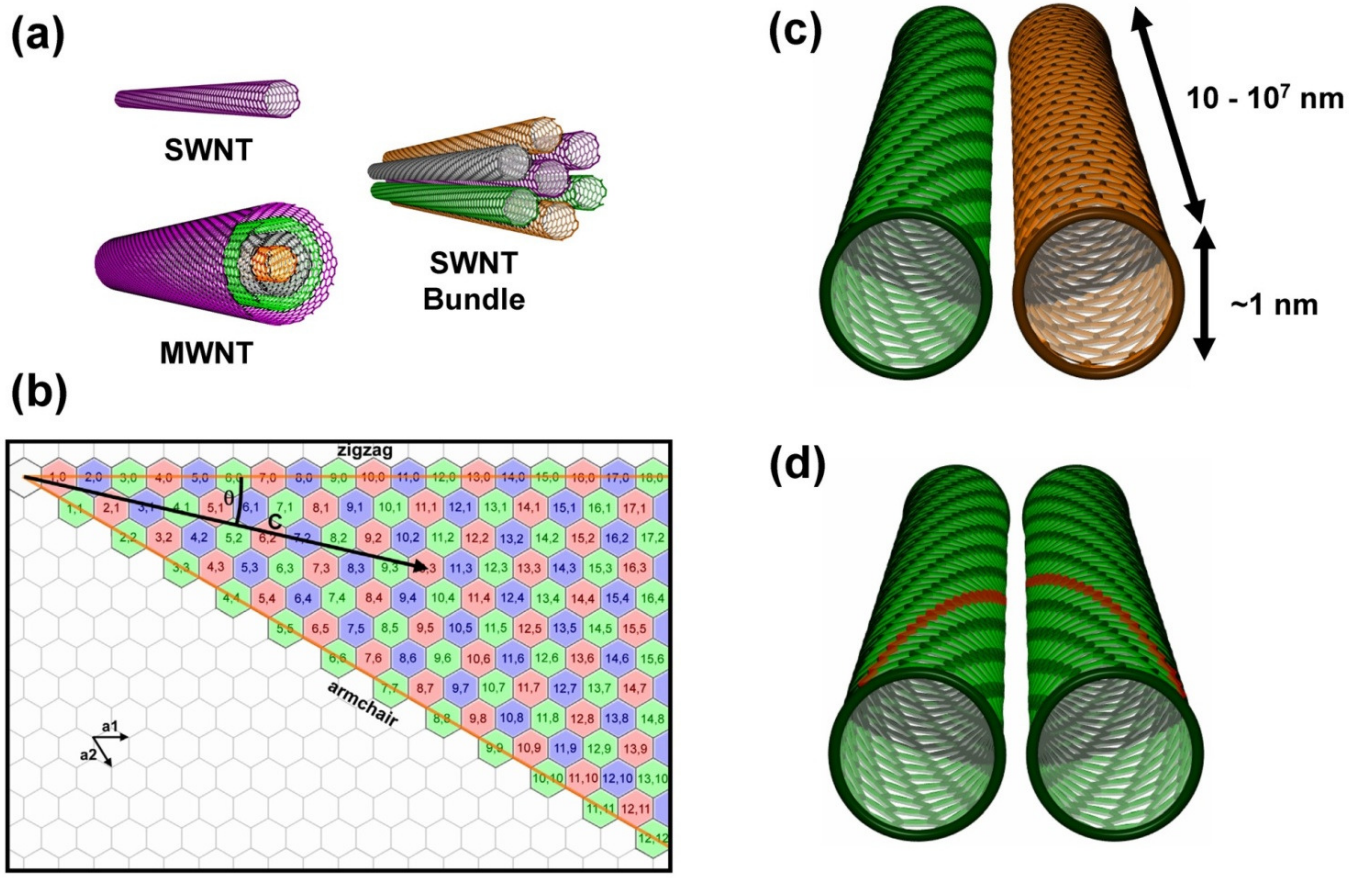
Dr. Nathan Yoder

Chief Technology Officer,
NanoIntegris



July 14, 2011

Carbon Nanotube Polydispersity

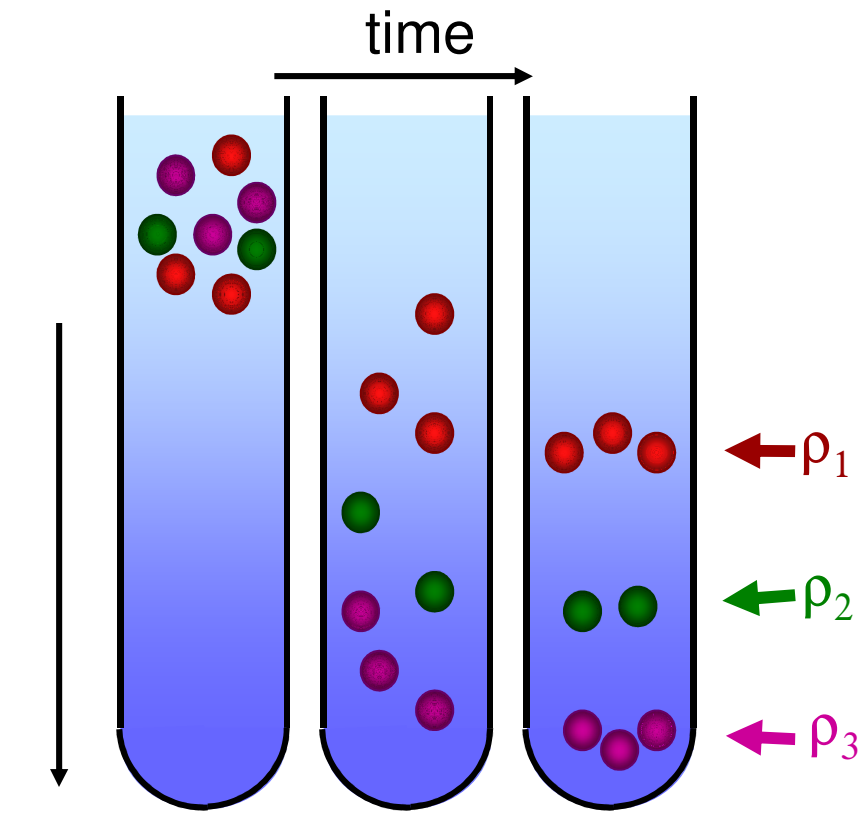


- Current growth methods yield mixtures of CNTs
- Post-growth separation methods are required

Review Article: M. C. Hersam, *Nature Nanotechnology*, **3**, 387 (2008).

Separation in Density Gradients

Nano Letters, **5**, 713 (2005); Nature Nanotechnology **1**, 60 (2006)



$a = \omega^2 r$

- **Mixed CNT sample is centrifuged**
- **Nanotubes travel through gradient**
- **Distinct bands form at equilibrium**

ARTICLES

Sorting carbon nanotubes by electronic structure using density differentiation

MICHAEL S. ARNOLD, ALEXANDER A. GREEN, JAMES F. HULVAT, SAMUEL I. STUPP AND MARK C. HERSAM*

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History

Date	Milestone
Q1 2007	NanoIntegris founded
Q1 2008	Increased Production Capacity by 100x
Q3 2008	First commercial sale
Q1 2009	Increased Production Capacity by additional 100x
Q3 2009	Commercial sales effort initiated
Q1 2011	> 400 Customers & 40 publications to date

Facilities

- 2,000 sq ft laboratory in Illinois Technology Park in Skokie, IL (30 minutes from Chicago and O'hare)

Materials

SuperPureTubes™
99% Purified Carbon Nanotubes

IsoNanotubes-S™
Semiconducting Carbon Nanotubes

IsoNanotubes-M™
Metallic Carbon Nanotubes

Applications

- Transistors
- Chemical & Biological Sensors
- Photodetectors & Photovoltaics
- Optoelectronic Devices

For more information visit:
http://www.nanointegris.com/en/publications

Display Applications for s-SWNT

- Motivation
  - Display Market > $100B
  - Backplane Materials ~ $2B
  - a-Si incapable of meeting industry needs
  - Push for solution to replace vacuum steps
  - Drive for durable & flexible displays

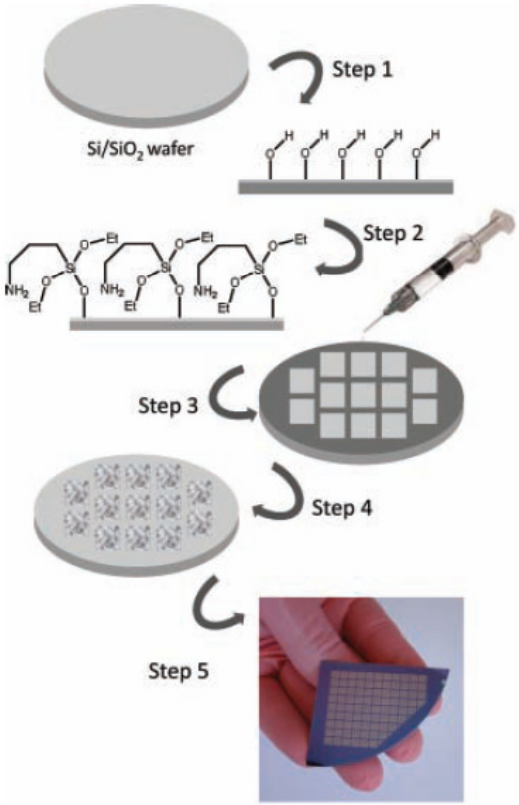
- Solution: CNT-TFTs for display backplanes
  - High mobility (5-50 cm^2/V-s)
  - Solution processable
  - Mechanically flexible

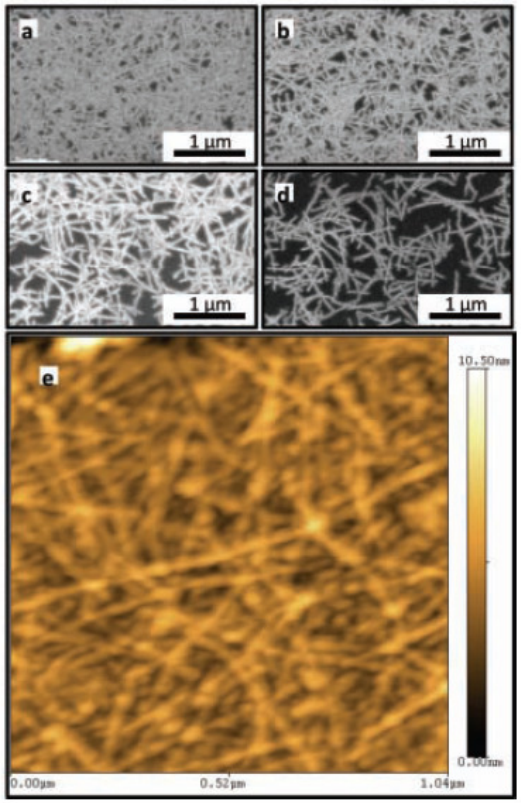
Technical Requirements

- μ = >5 cm^2 / V-s
- $I_{ON} / I_{OFF} = 10^6\text{-}10^8$
- Bias-stress stability

Transistors Using IsoNanotubes-S™

Burke et al, *Advanced Materials*, **23**, 94 (2011).



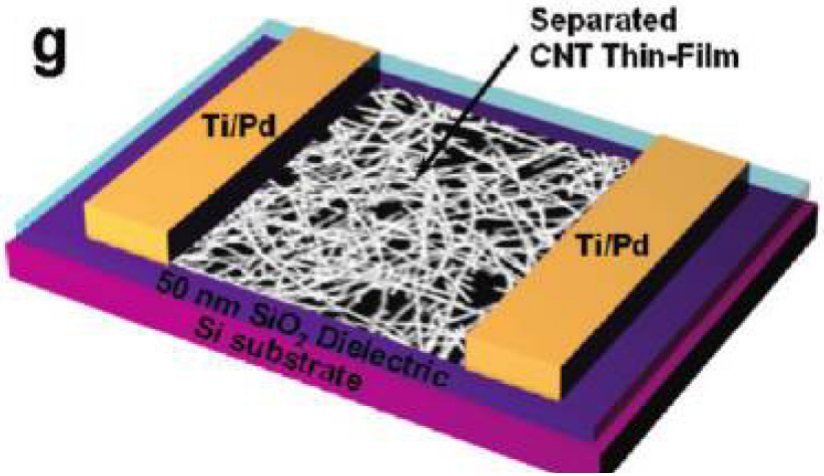


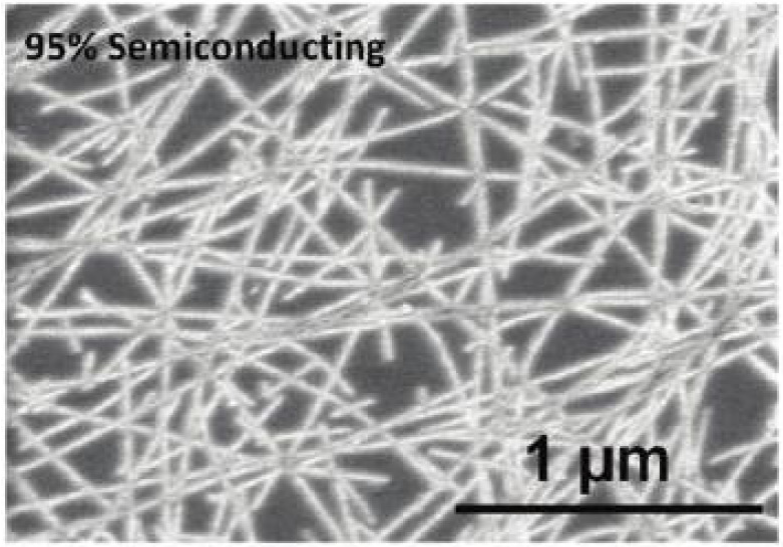
Transistor Performance

- **Mobility = 10 cm^2/V-s**
- **$I_{ON}/I_{OFF} = 10^5$**

Transistors Using IsoNanotubes-S™

Chongwu Zhou Group, *ACS Nano*, **4**, 7123 (2010)



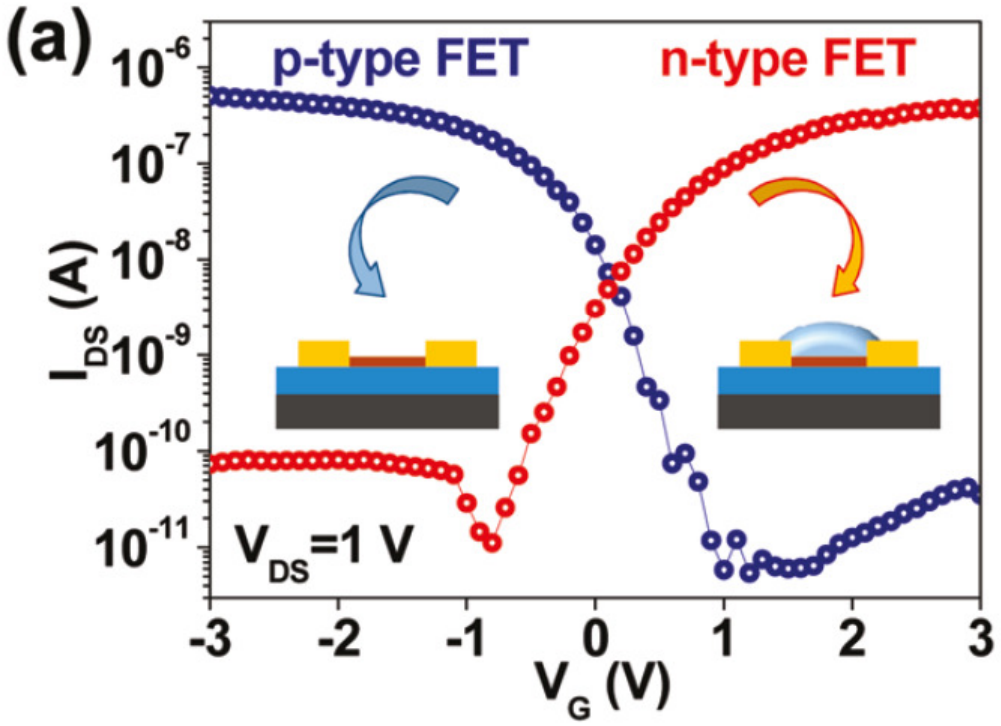


Transistor Performance

- **Mobility = 20-67 cm^2/V-s**
- **$I_{ON}/I_{OFF} = 10^4 – 10^5$**

CMOS Devices with Viologen Doping

Young Hee Lee Group, *ACS Nano* (2011) → POSTER P19



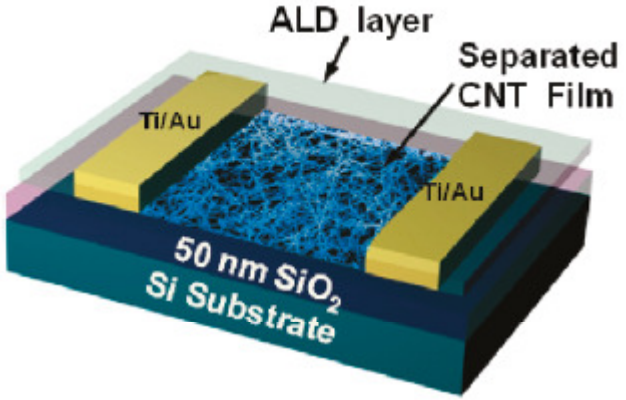
Transistor Performance

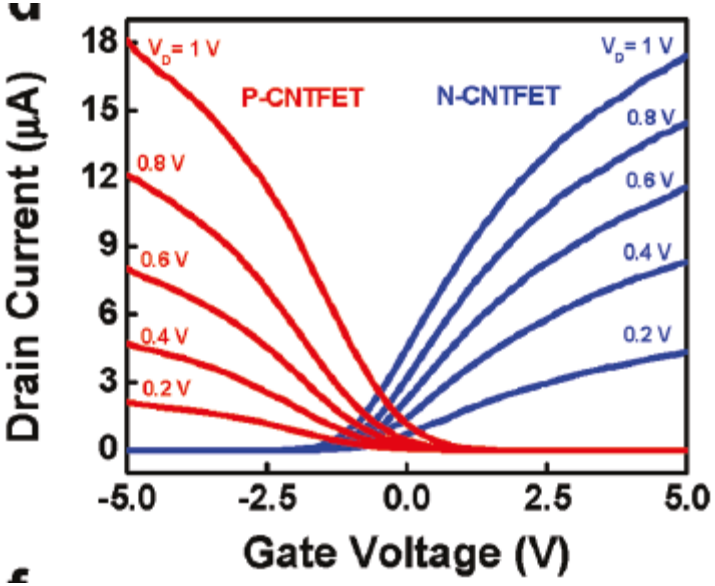
- **Mobility = 2-10 cm^2/V-s**
- **I_{ON}/I_{OFF} = 10^3 – 10^6**

- Both n- and p-type behavior demonstrated
- CMOS logic gates assembled and tested

CMOS Devices with HfO_2 Passivation

Chongwu Zhou Group, *ACS Nano* 5, 3284 (2011)





Transistor Performance

- **Mobility = ~5 cm^2/V-s**
- **I_{ON}/I_{OFF} = > 10^6**

→CMOS inverter demonstrated

→ High concurrent mobility and On/Off ratio

Conclusions

- s-SWNTs improve CNT-TFT performance

- Devices are nearly competitive with industry standards (μ ~ 5 cm^2 / V-s and I_{ON}/I_{OFF} ~ 10^6)

- Further improvements likely with additional material and device optimization

Thank You

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