CARBON NANOTUBES AND VAN DER WAALS MATERIALS FOR IoT ENERGY STORAGE AND SENSING APPLICATIONS

Katharine Dovidenko and Michael Shur

Rensselaer Polytechnic Institute

Troy, NY 12180, USA

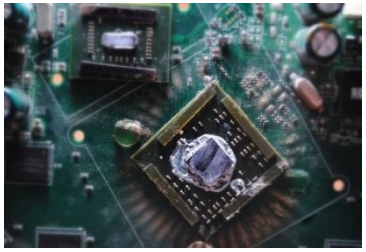
September 12, 2017

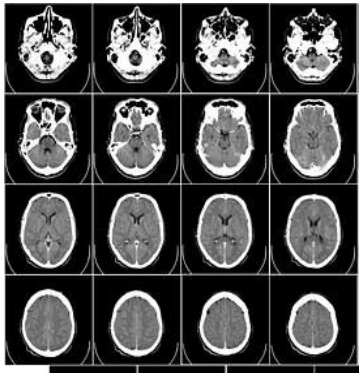
Presented at

The 14th U.S.-Korea Forum on Nanotechnology: Internet of Things (IoT) including Nanosensors and Neuromorphic Computing

IoT: applications and needs to be addressed

- Gas and humidity sensors, detectors
- Energy storage
- Bio-sensors and bio-markers, cell fluid delivery
- wearables

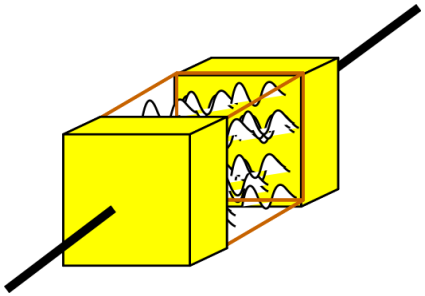




To be addressed:

- highly sensitive sensors
- off-grid, off battery operation
- low cost
- large scale applications

Our approach



- **Disordered 2D and 3Dnanotube arrays**

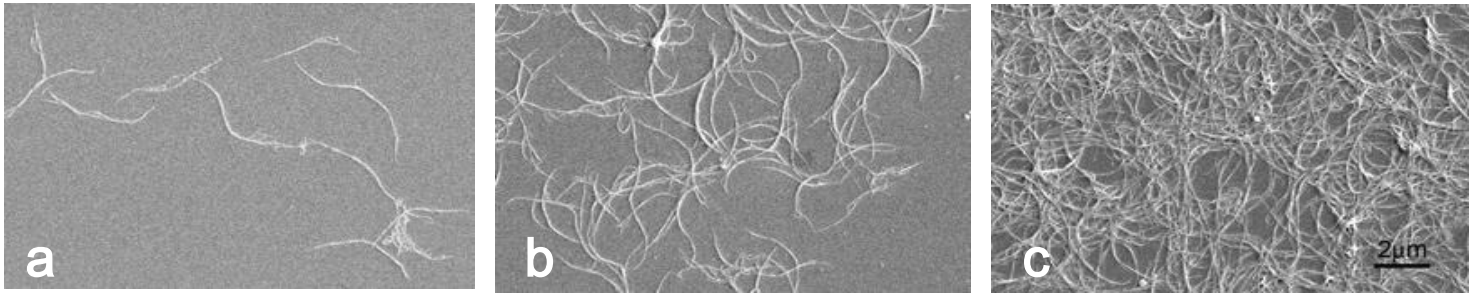
for manufacturability and ultra high energy storage capability

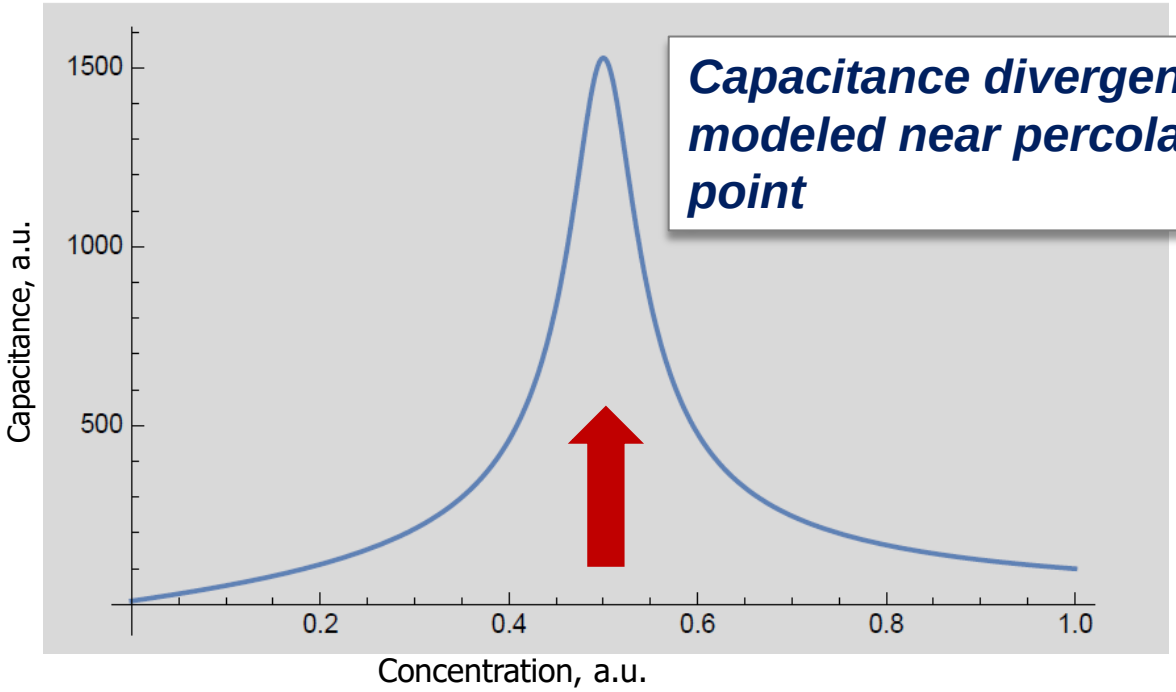
- **Divergent sensitivity near the percolation point**
- **Compatibility with Si VLSI and solar cells**
- **Embedding matrices for polarization doping**

✓ ***Predicted theoretically, modeling results***

✓ ***Initial experiments***

Supercapacitor near nanotube percolation point





Capacitance divergence modeled near percolation point

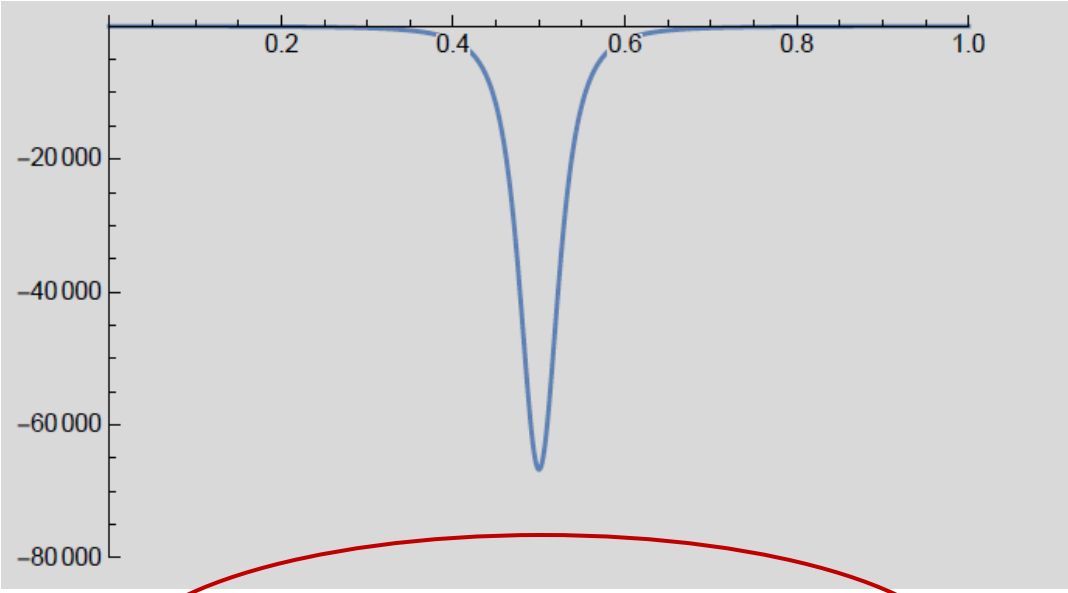
Carbon nanotube concentration study, SEM top-down images.

(a), (b) and(c) represent low-, medium-, and high concentrations of CNTs

S. L. Rumyantsev, M. S. Shur, G. Liu and A.A. Balandin, Low frequency noise in 2D materials: graphene and MoS2, INVITED, 2017 International Conference on: 20-23 June 2017 Vilnius, Lithuania, Lithuania

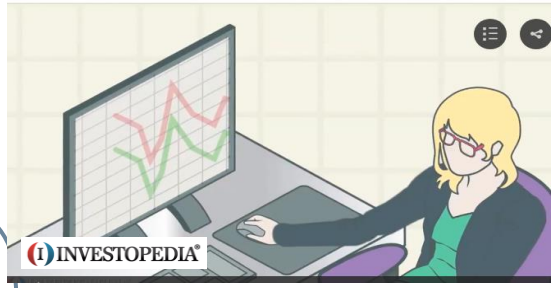
Divergent sensitivity near percolation point

Capacitance sensitivity to nano-tube concentration, a. u.

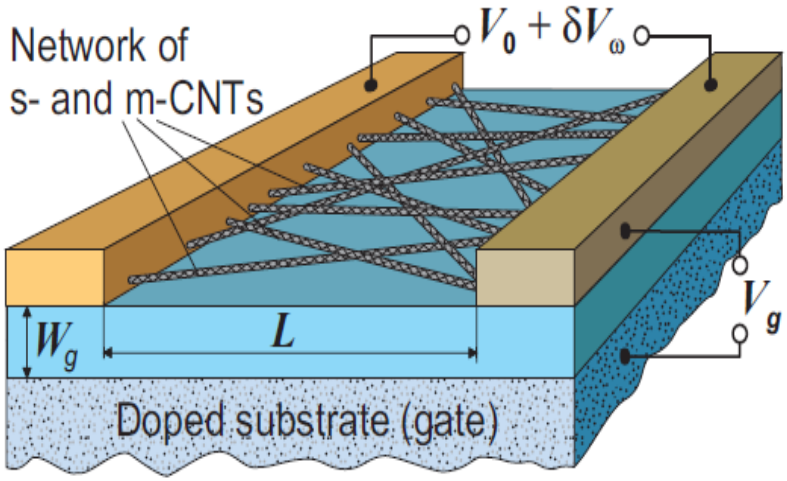


This is the system to invest in!

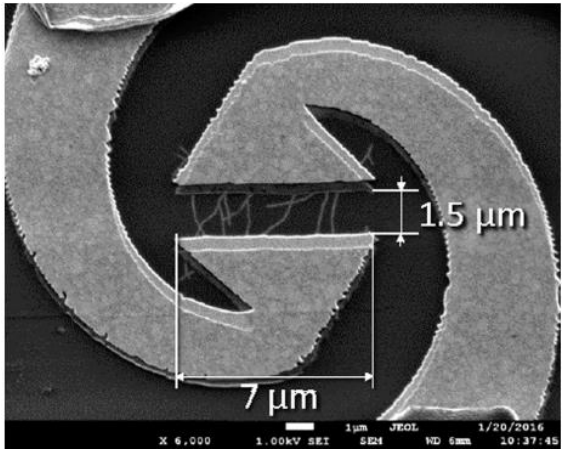
If only the stock market predictions were that clear … ☺



Experimental realization of CNT –Si MOSFET for THz sensing



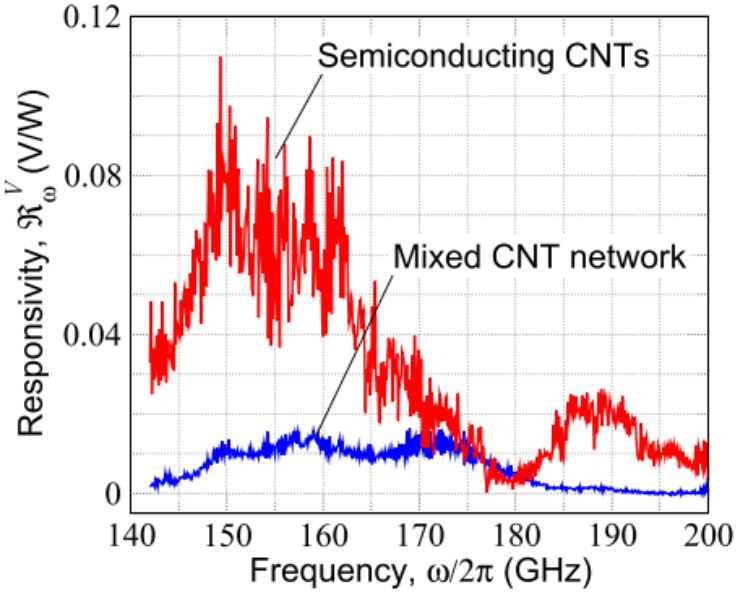
Schematic of the nano-tube network device structure



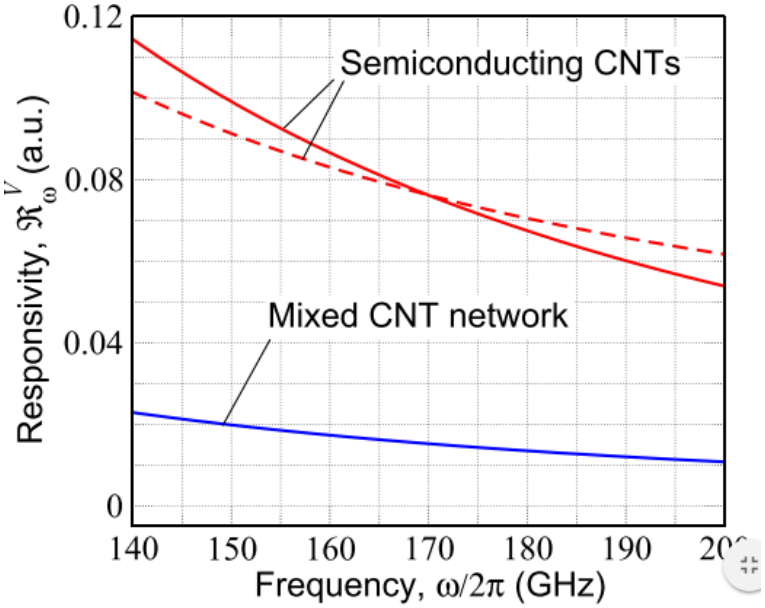
Fragment of the CNT-based device structure with a spiral antenna, SEM image

V. V. Ryzhii, T. Otsuji, M. Ryzhii, V. G. Leiman, G. Fedorov, G. N. Goltzman, I. A. Gayduchenko, N. Titova, D. Coquillat, D. But, W. Knap, V. Mitin, and M. S. Shur, "Two-dimensional plasmons in lateral carbon nanotube network structures and their effect on the terahertz radiation detection", J. Appl. Phys. 120(4) (2016) 044501

Sub-THz Sensing



Voltage responsivity versus radiation frequency, semiconducting and mixed semiconducting+metallic CNTs



Voltage responsivity versus radiation frequency calculated for low-density CNT detectors with CNT mixture and with primarily single-walled CNTs

V. V. Ryzhii, T. Otsuji, M. Ryzhii, V. G. Leiman, G. Fedorov, G. N. Goltzman, I. A. Gayduchenko, N. Titova, D. Coquillat, D. But, W. Knap, V. Mitin, and M. S. Shur, "Two-dimensional plasmons in lateral carbon nanotube network structures and their effect on the terahertz radiation detection", J. Appl. Phys. 120(4) (2016) 044501

Future Work

- Humidity sensor
- Radiation sensor
- CNT supercapacitors on grand scale
- VLSI integration
- Nanowires beyond CNT