USC University of Southern California

USC Viterbi School of Engineering

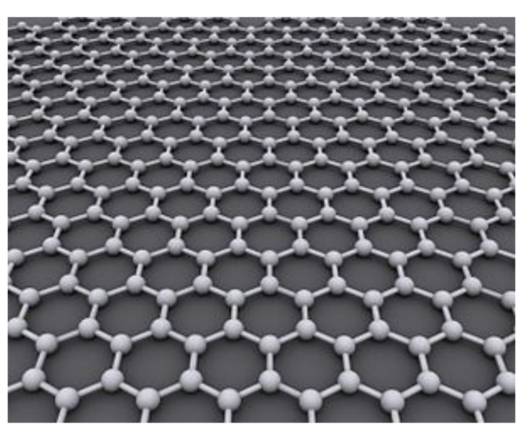
Ming Hsieh Department of Electrical Engineering

Graphene Nanoribbons for Electronic and Sensing Applications

Ahmad N. Abbas, Electrophysics- Chongwu Zhou group

Motivation

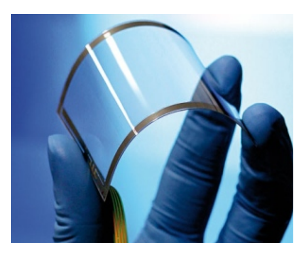
The Nobel Prize in Physics 2010



Graphene: a 2D sheet of carbon

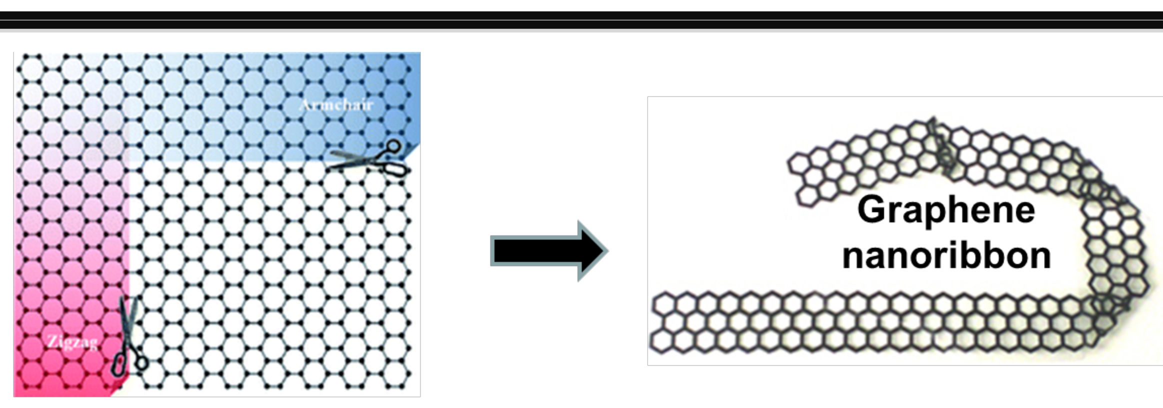
Property	Graphene	Silicon
Mobility (cm^2/V.s)	~10,000 – 10^6	~1000
Transparent	Yes	No
Flexible	Yes	No
Stretchable	Yes	No

Fig. Graphene on a plastic substrate (Source: Nature)



BUT graphene is a semimetal (with zero bandgap) and cannot be switched off in a transistor !!

Why Graphene Nanoribbons (GNRs) ?

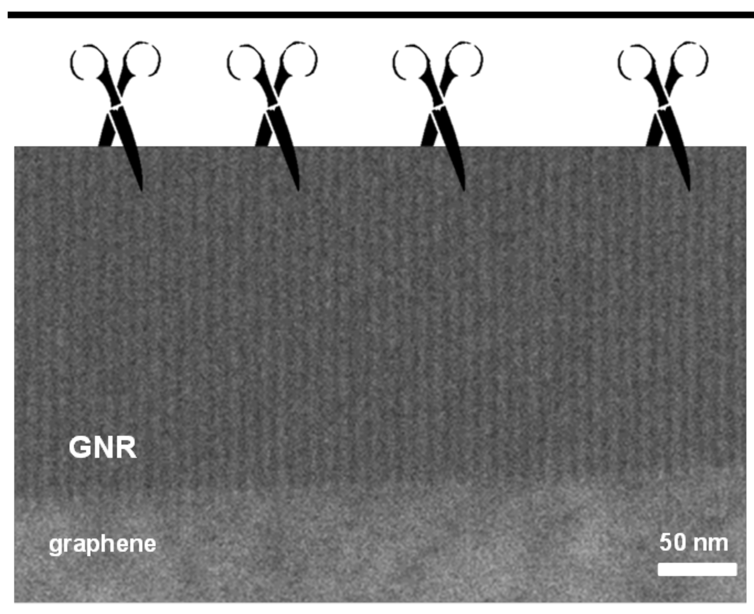


Because electrons are confined in the width direction, a bandgap appears, changing graphene from a semimetal to a semiconductor

- Graphene nanoribbons can be used as transistor channel material because they are semiconductors.
- Edge tunable electronic and optical properties.
- Can emit light and hence have potential in optoelectronic applications.

How to make GNRs?

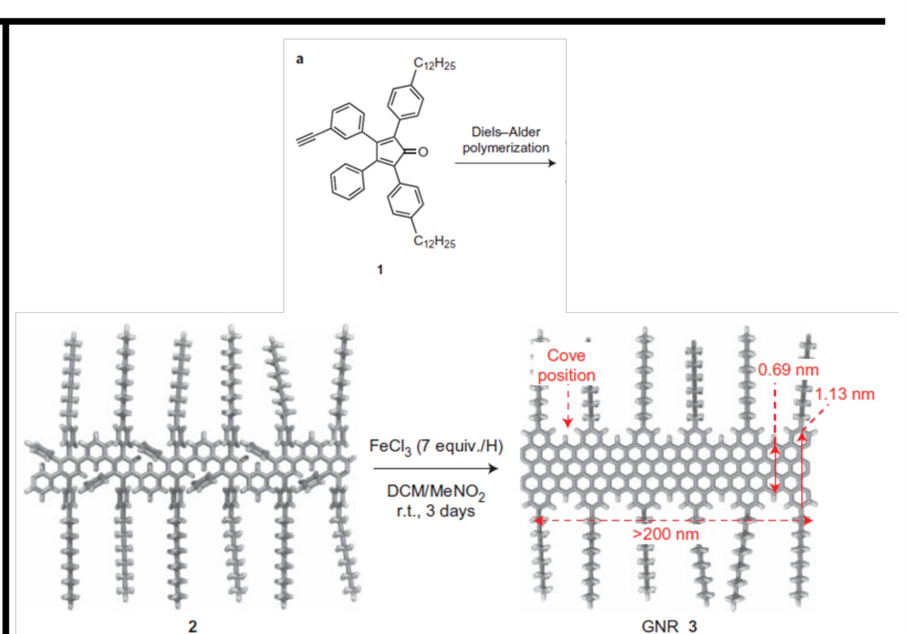
Top-down Fabrication



Scanning electron microscope image

Abbas *et al., ACS Nano* **2014**, *8*, 1538–1546.

Bottom-up Synthesis

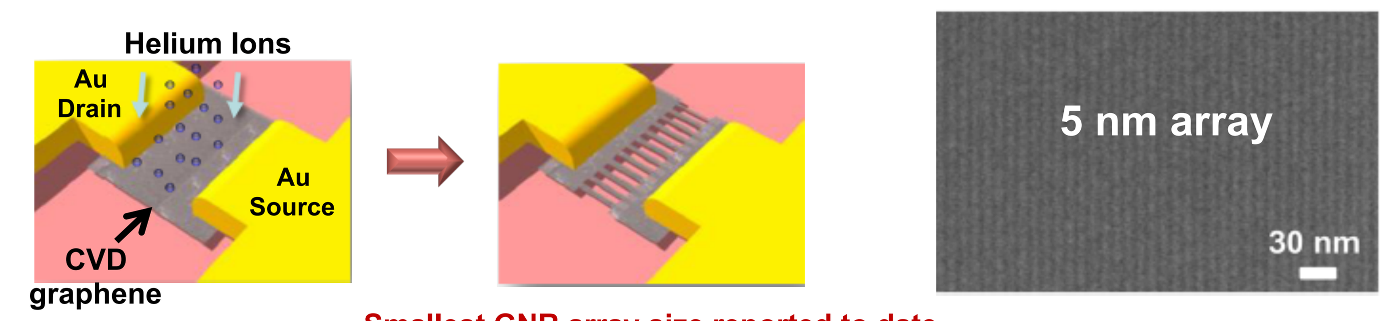


Narita *et al., Nat Chem* **2014**, *6* , 126-132

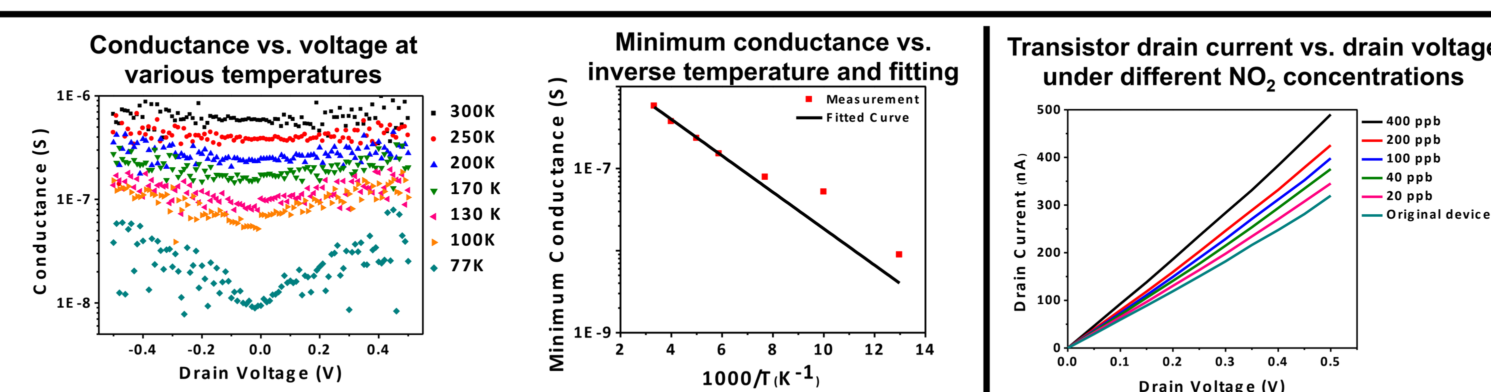
Accomplishment #1: Top-down graphene nanoribbon arrays down to 5 nm

➢ Challenge: One needs to fabricate sub-10 nm graphene nanoribbons to obtain bandgaps, and these sizes are beyond the resolution of most lithography techniques.

➢ Our Solution: Controlled patterning of graphene nanoribbon arrays down to 5 nm using helium ion beam lithography.



Smallest GNR array size reported to date



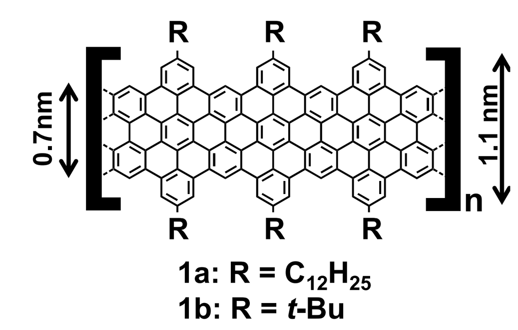
Field-effect transistor measurments at different low temperatures revealed a Bandgap > 88 meV

Most sensitive graphene-based NO_2 sensor (20 ppb)

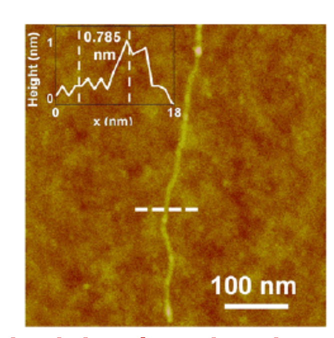
Accomplishment # 2: Bottom-up chemically synthesized graphene nanoribbon characterization

➢ Challenge: No one visualized and made transistors of such chemically synthesized graphene nanoribbons.

➢ Our solution: Chemically synthesized graphene nanoribbons up to 500 nm in length are obtained from our collaborator,

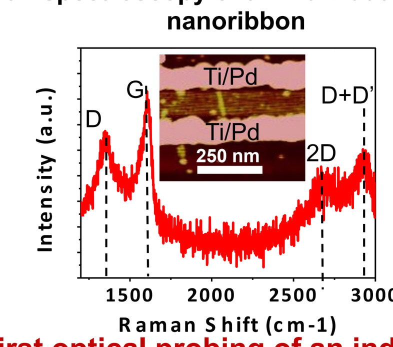


Atomic force microscope image



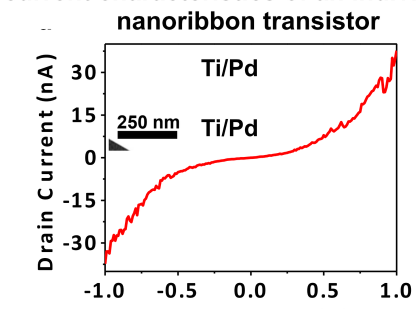
Method developed to deposit graphene nanoribbons

Raman spectroscopy of an individual graphene nanoribbon

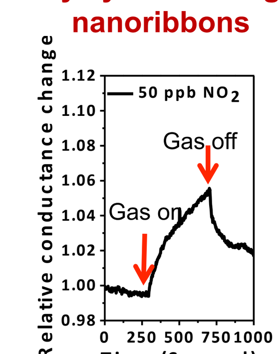


First optical probing of an individual chemically synthesized graphene nanoribbons

Voltage-current characteristics of an individual graphene nanoribbon transistor



First electronic probing of an individual chemically synthesized graphene nanoribbons (15 nm gap)

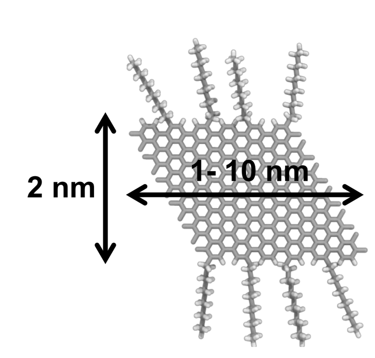


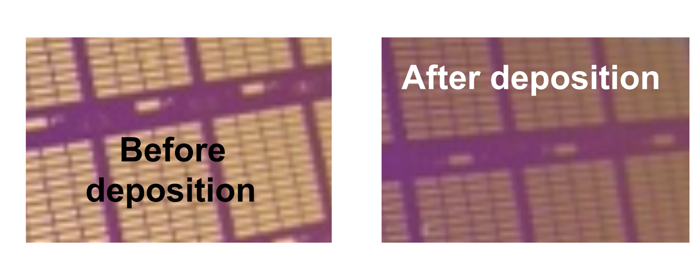
Synthesized GNR films field-effect transistors (FETs). Cheap, scalable and high sensitivity sensor.

Accomplishment # 3: Thin-Film Transistors based on bottom –up chemically synthesized graphene nanoribbons

➢ Challenge: Deposition of graphene nanoribbons controllably into films for various applications.

➢ Our Solution: Sublimation of short graphene nanoribbons using a vacuum-sealed glass tube.

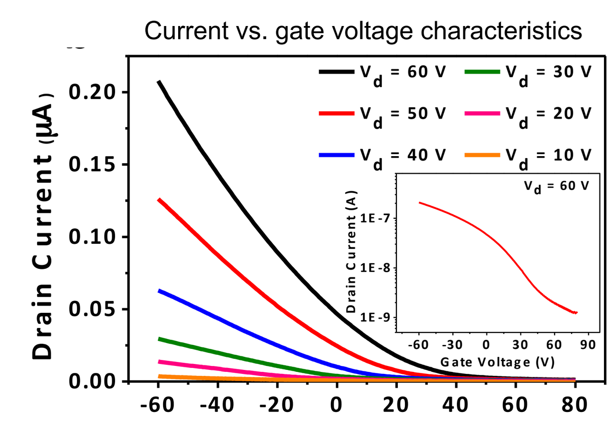




Conformal graphene nanoribbon coverage with thickness down to ~2 nm

Deposition of graphene nanoribbons using novel vacuum sublimation technology

Current vs. gate voltage characteristics



A well-operating transistor with On/Off ratio of ~200