Facile synthesis of high-quality graphene nanoribbons

Liying Jiao, Xinran Wang, Georgi Diankov, Hailiang Wang and Hongjie Dai

Department of Chemistry and Laboratory for Advanced Materials, Stanford University, Stanford, California 94305, USA.

nature nanotechnology

4 April 2010
DOI: 10.1038/NNANO.210.54

Robin John
Ph08d023
15 May 2010

graphene

- highest carrier mobility
- lowest dimensionality
- highest mechanical stability
- easiest system to understand the band structure

proposed uses

- alternative for Si in semiconductors FETs
- solar energy harvesting
- catalysis in fuel cells
- band controllable systems in optical detection
- high frequency detectors in the range of T Hz
- spin transport

issues

- not any easy method to tune the band gap
- difficult to have any well defined pattern as the growth is self governed
- proposed spin properties can be possible only with well well defined edge structures

background

- graphene nanoribbons – spin transport properties & tuneable band gap
- lithographic, chemical and sonochemical methods
- recently unzipping of MWNTs by a few chemical steps
- but heavily oxidised and defective nanoribbons
- masked gas-phase plasma etching of MWNTs –limited to the nanoribbons on substrate
- catalytic cutting and high current pulse burning – quality and quantity is limited.

present work

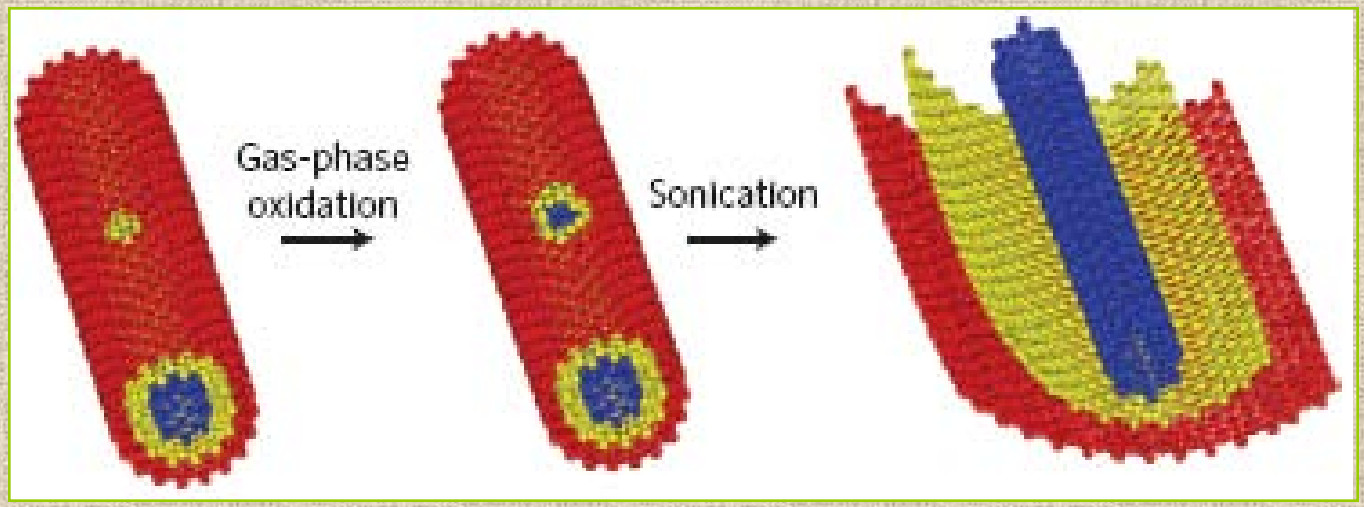
- pristine nanoribbons by unzipping MWNTs using mechanical sonication in organic solvents
- high quality ribbons with smooth edges and small I(D)/I(G)
- highest electrical conductance and highest mobility (1500 cm^2/Vs)
- at low temperatures show phase coherent transport and Fabry-Perote interference suggesting minimal defects and edge smoothness
- yield is 2 % from the raw soot arc discharge

method of preparation

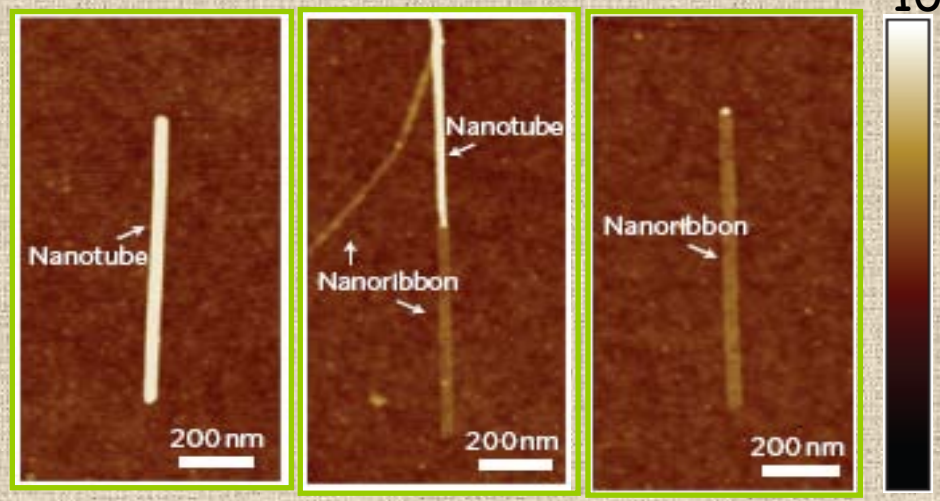
- raw soot from arc discharge which contains MWNTs were calcined in air at 500 ^{0}C – mild step which etches / oxidises only the defect site or ends

- dispersed in 1, 2 -dichloroethane organic solution of poly(*m*-phenylenevinylene-co-2.5-diotoxy-*p*-phenylenevinylene) and sonicated

- ultracentrifuged to remove CNTs and graphitic waste to form 60% GNRs in supernatent.

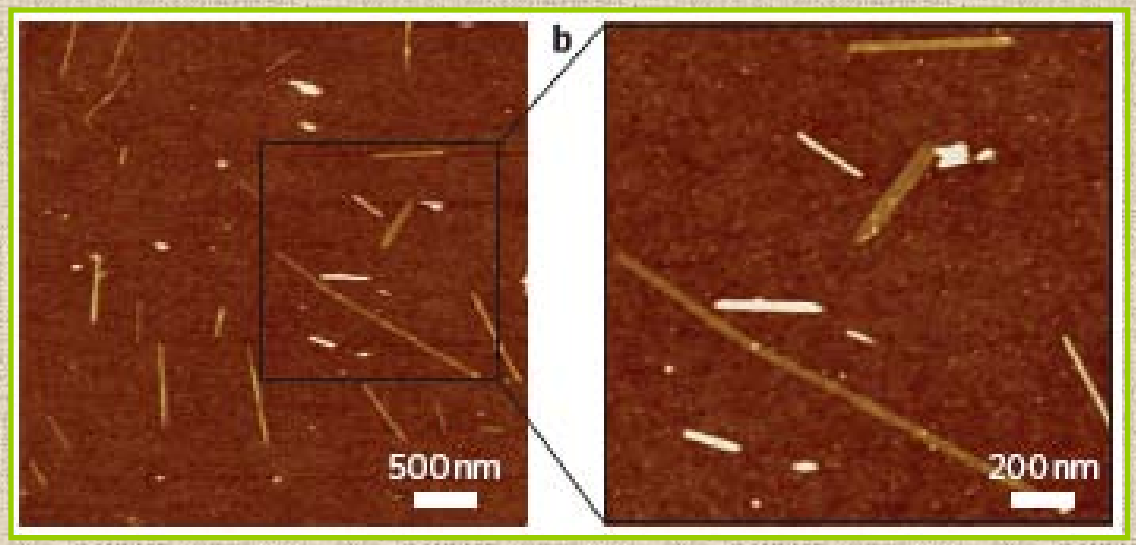


Atomic Force Micrograms



9 nm 1.4 nm 1.6 nm

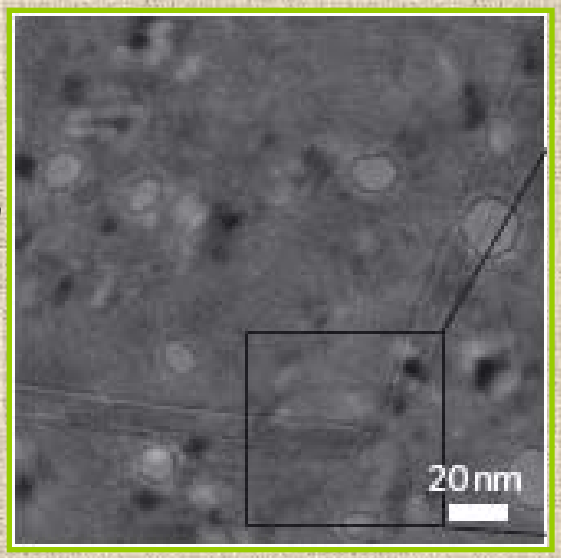
1.8 nm, 18 nm
1.4 nm, 48 nm
1.4 nm, 22 nm

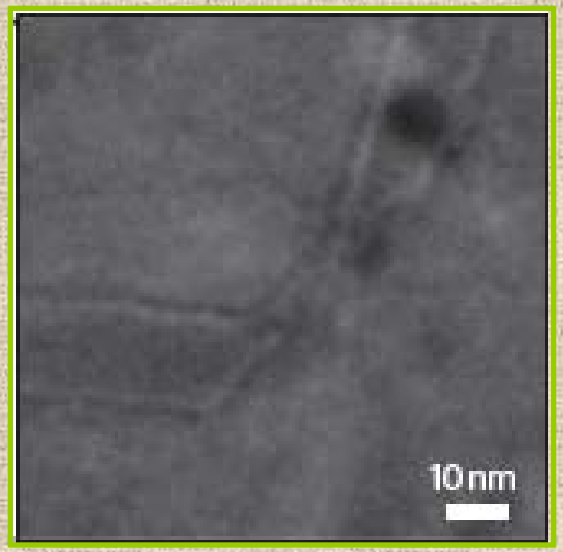


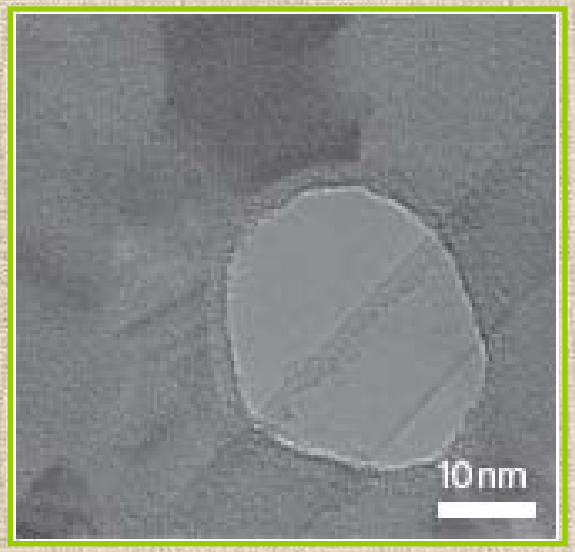
Transmission Electron Micrograph

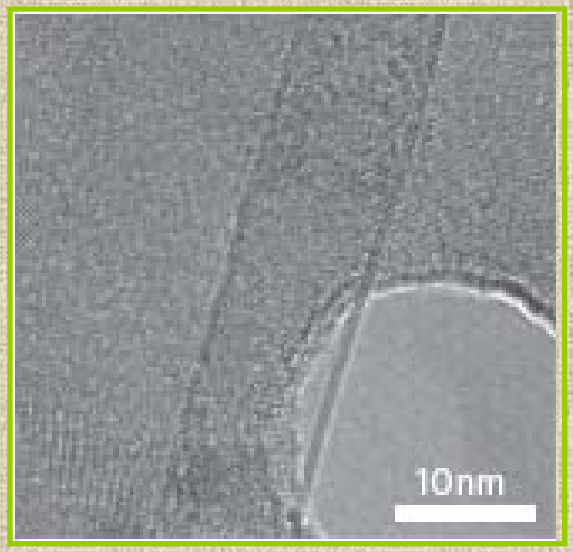
12 nm GNR
With a kink
due to folding

200 kV
Porous silicon
grid









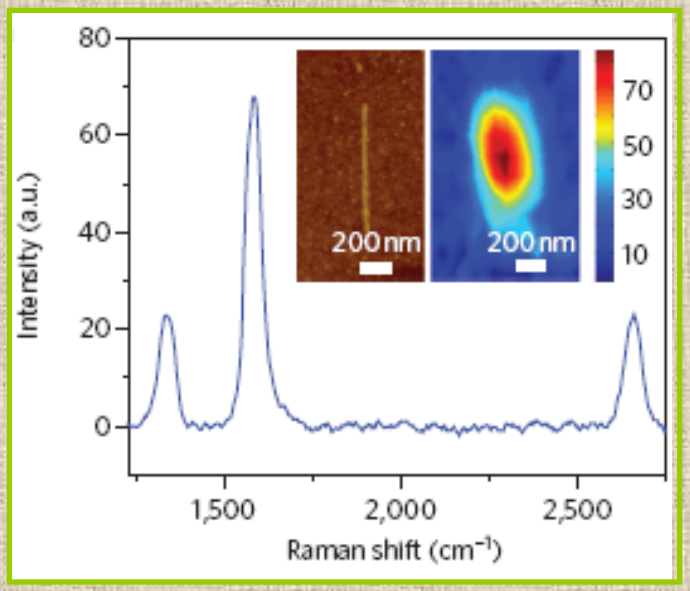
10 & 12 nm GNR

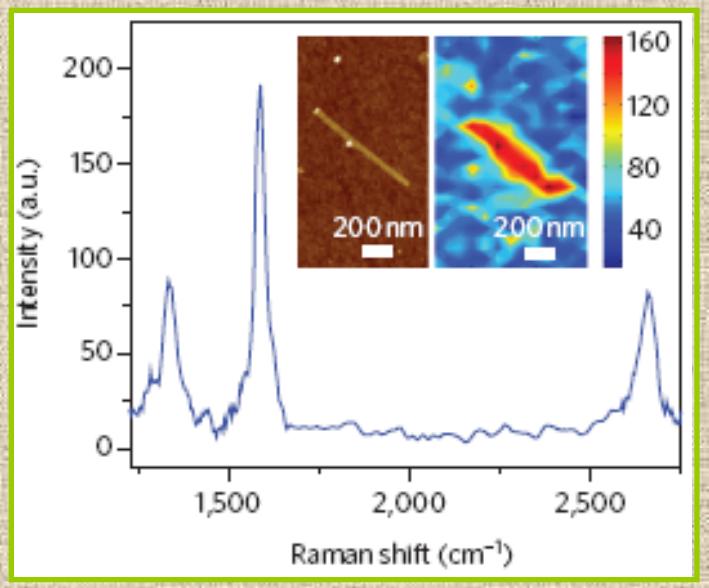
PmPV - attached

120 kV

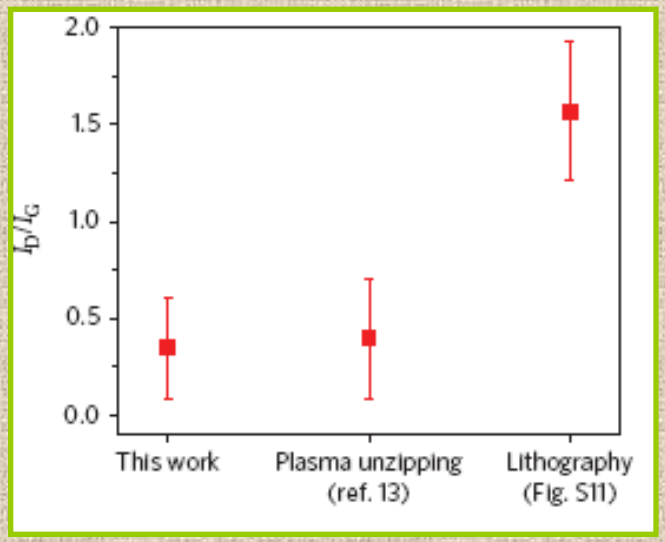
- no defects were created
- while calcination existing defects form etch pits and while sonication they get unzipped into GNRs
- the number of layers depend on the depth of etch pits forming single, bi and trilayer
- low oxidation was proved by low I(D) & XPS O1s was comparable to that of the MWNTs
- Sonochemistry and hot gas bubbles created during sonication causes the unzipping which proceeds along the tube axis
- resulting nanoribbons were seperated from the inner tubes and the edges were functionalised noncovalently by pi-stacking using PmPVs
- applicable to CVD grown MWNTs too

Inelastic Raman scattering





1.5 nm, 20 nm
I_D/I_G =0.3
bi layer

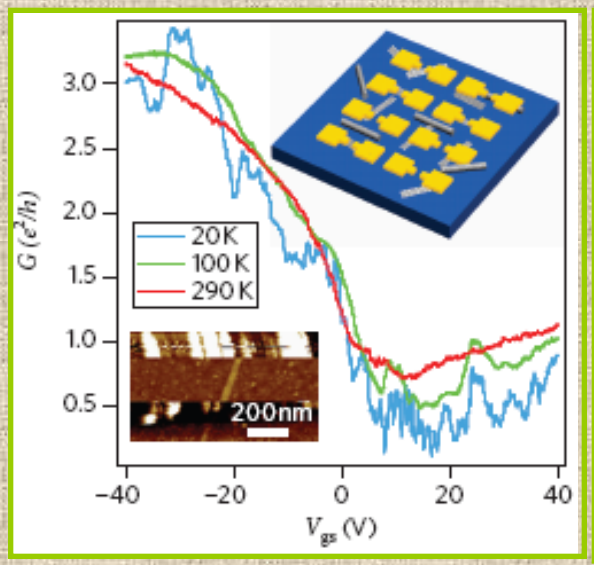


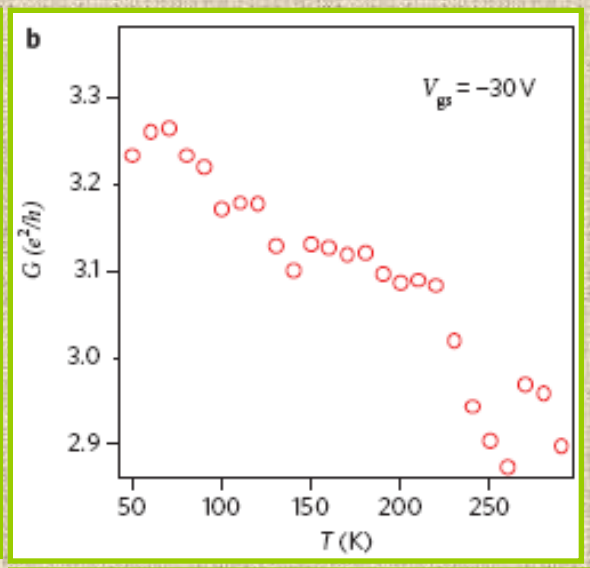
1.8 nm, 20 nm
I_D/I_G =0.5
tri layer

bi layer
average of 15 GNRs
of 20 nm width

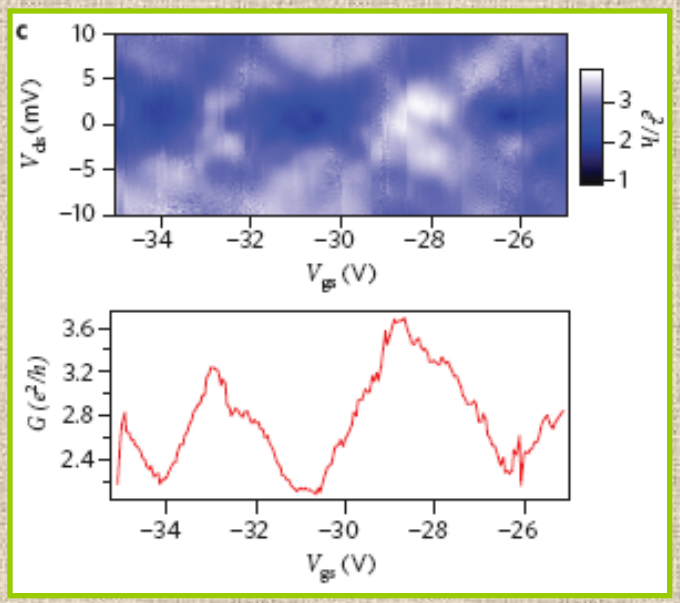
Electrical characterisation

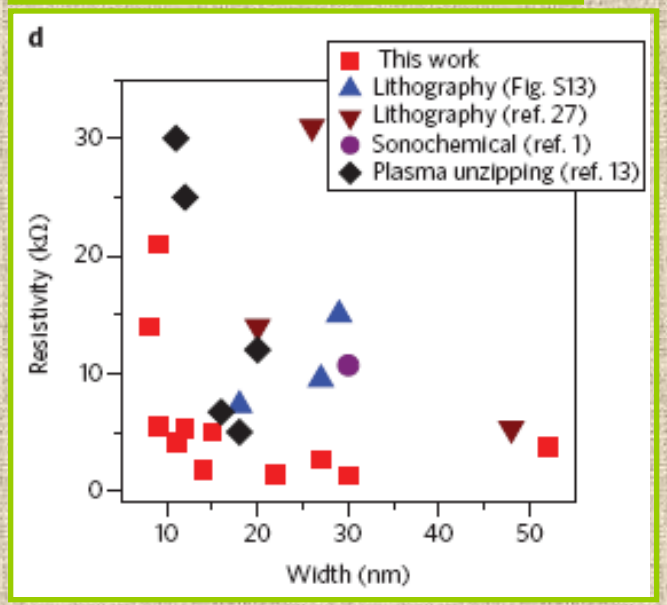
p channel conductivity increases with decrease in temperature





14 nm
1500 cm2/Vs





the bandgap of the nanoribbon was estimated to be Eg ≈ 10–15 meV by fitting the temperature dependence of minimum conductance to thermal activation over a barrier of Eg/2

conclusions

- prepared high quality GNRs of various widths 10-30 nm by mild gas-phase etching followed by sonication
- Imaged using AFM, TEM and Raman
- Transport measurements were done which shows high mibility and high conductivity
- obtained highest mobility and lowest resistivity for GNRs
- metallic beahvior of the valence band along with reduced phonon scattering at low temperatures
- Fabrey-perpt lilke conductivity characteristics suggests that the GNRs are of high quality with well defined edges

thank you all