Nanotechnology of graphene

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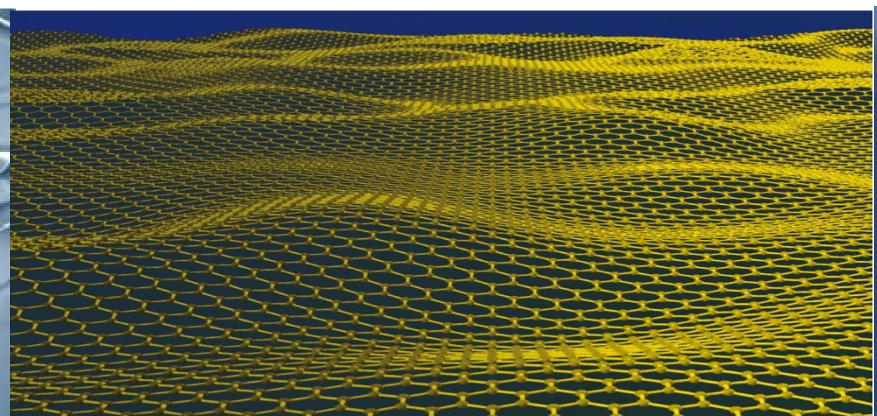
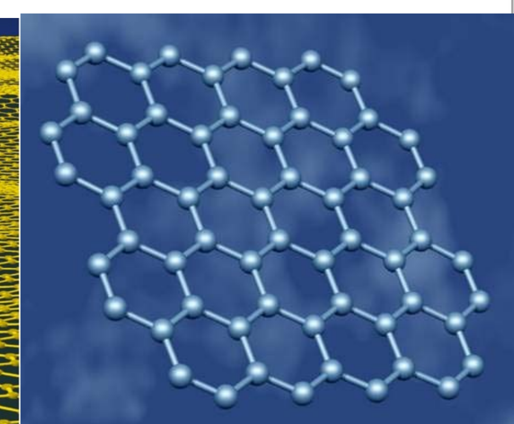
Korea Hungary Joint Laboratory for Nanosciences

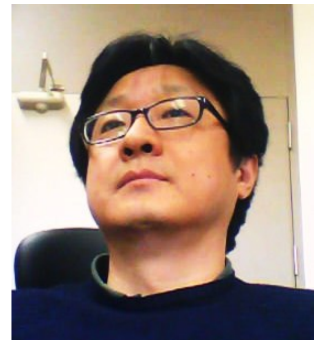




http://www.nanotechnology.hu/

Korean–Hungarian Joint Laboratory Team

Prof. László Péter Biró
Hungarian PI



Dr. Chanyong Hwang
Korean PI

Dr. Levente Tapasztó
Hungarian PI

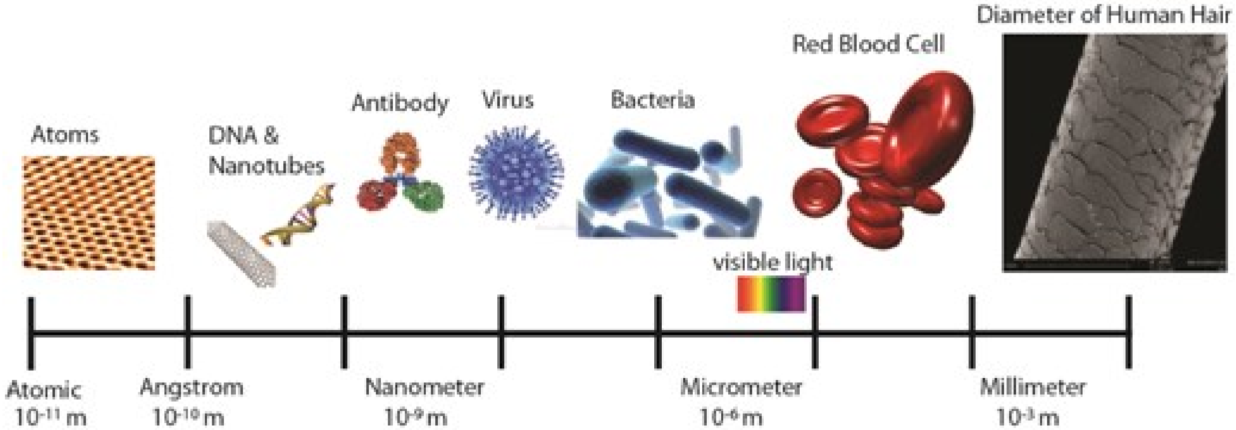
Dr. Yong-Sung Kim
KRISS - Korea

Gábor Magda
MTA-EK-MFA

Péter Vancsó
MTA-EK-MFA

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications."

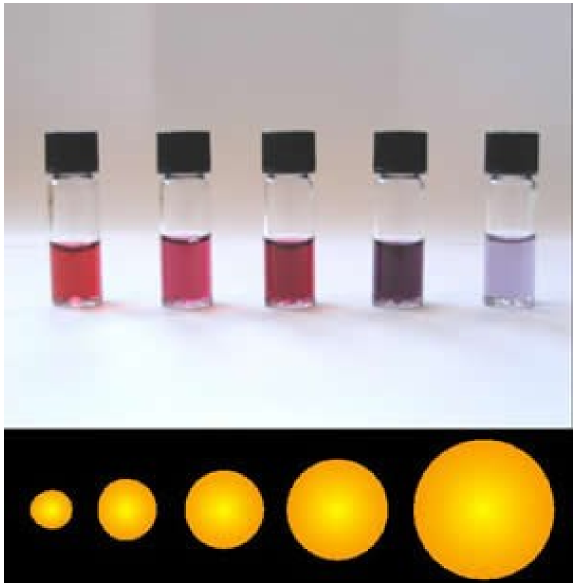
–National Nanotechnology Initiative



What's the BIG deal about something so SMALL?

It's not just about miniaturization.

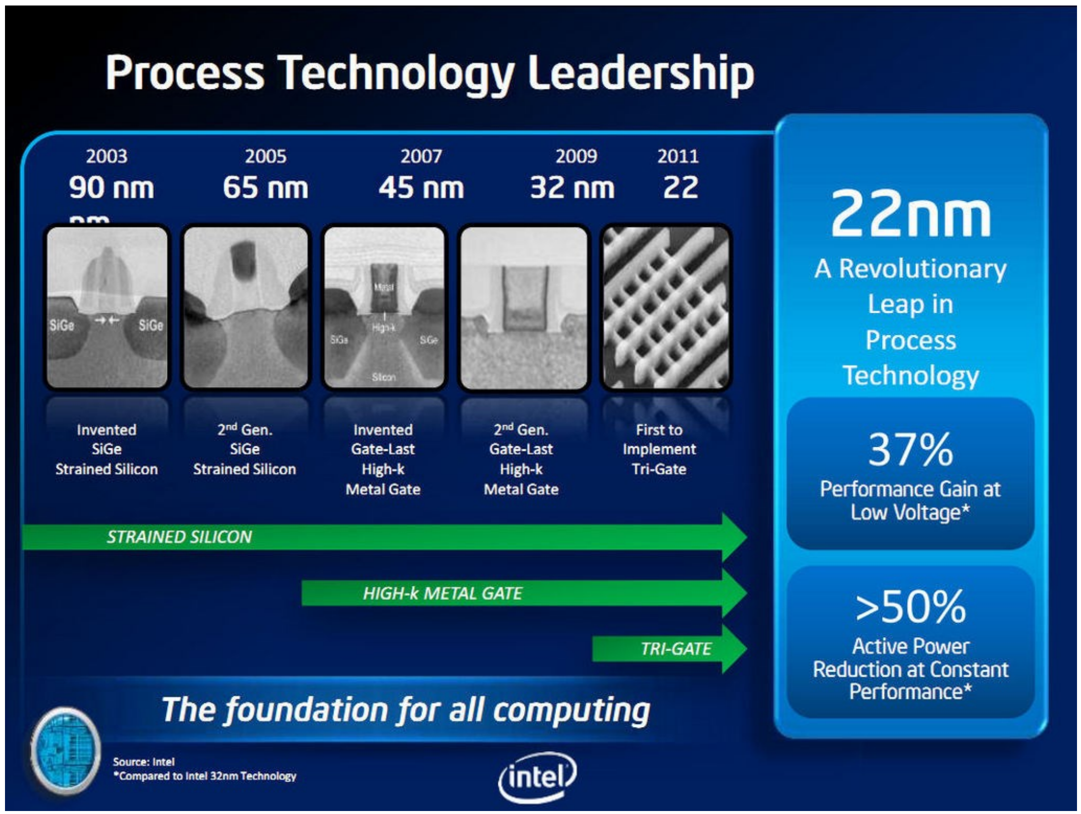
Gold nanoparticles



5 nm ... 15nm

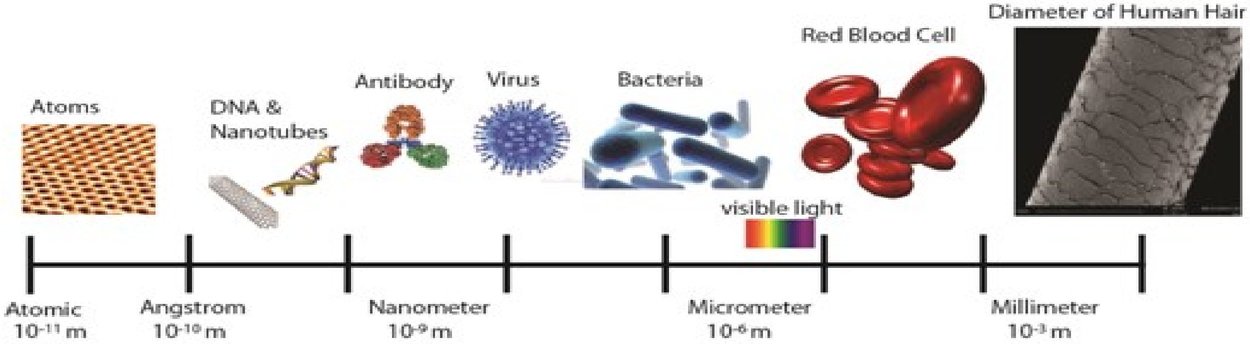
Materials behave differently at this scale – Quantum Mechanics – Size Effects

Are current electronic devices using nanotechnology?



Yes and No! Their size is nano, but the operation principles are classical not quantum. Nanotechnology is not simply miniaturization!

How can we access the nano-scale world?



Electron microscopy

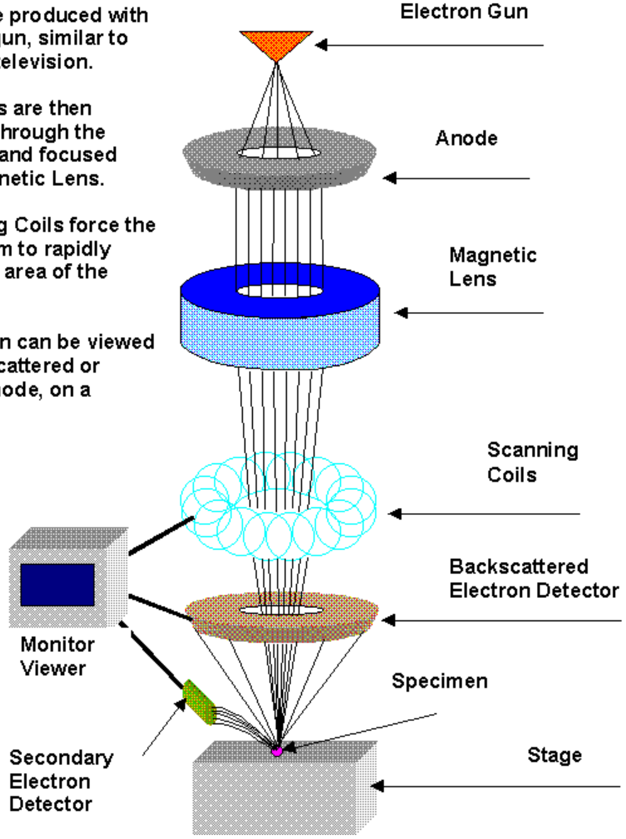
JEOL 3010

Electrons are produced with an electron gun, similar to the one in a television.

The electrons are then accelerated through the Anode plate and focused with the Magnetic Lens.

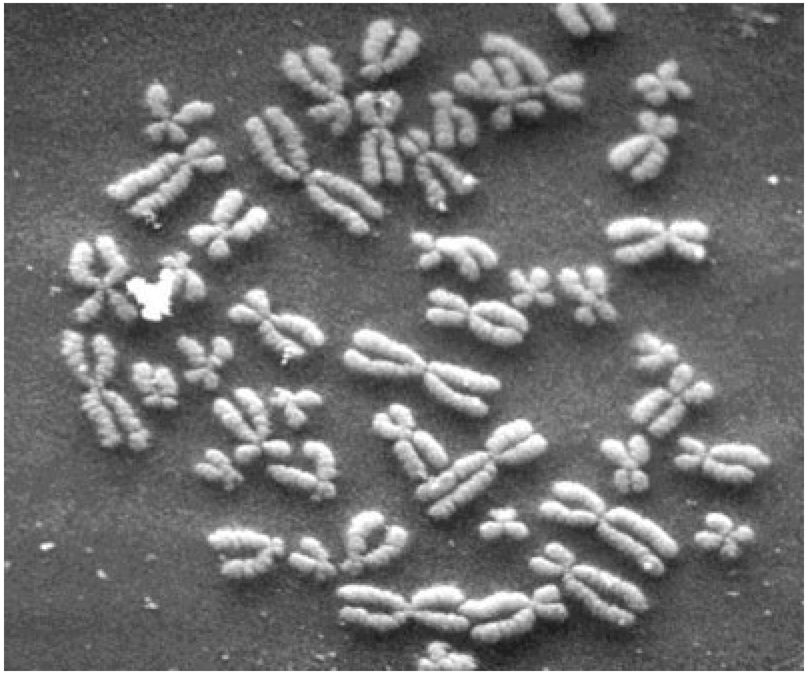
The Scanning Coils force the electron beam to rapidly scan over an area of the specimen.

The specimen can be viewed in the Backscattered or Secondary mode, on a monitor.

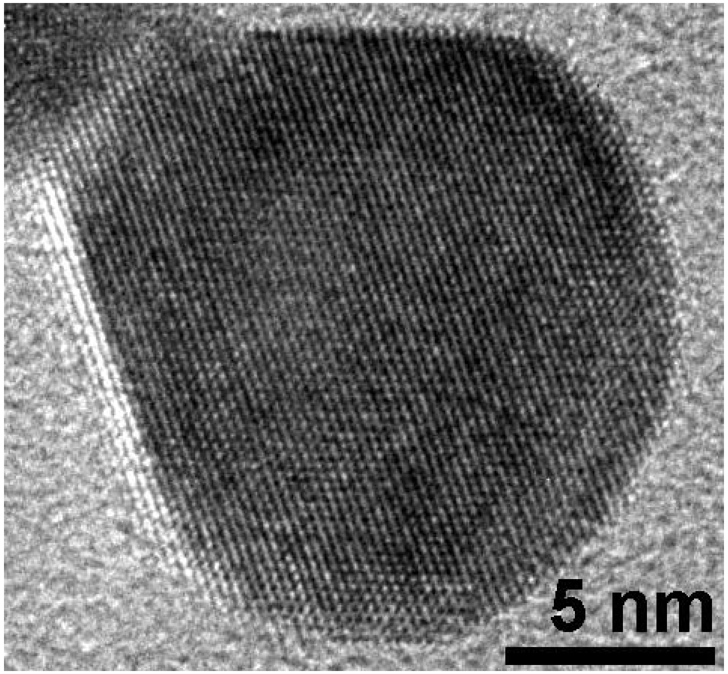


Electron microscopy

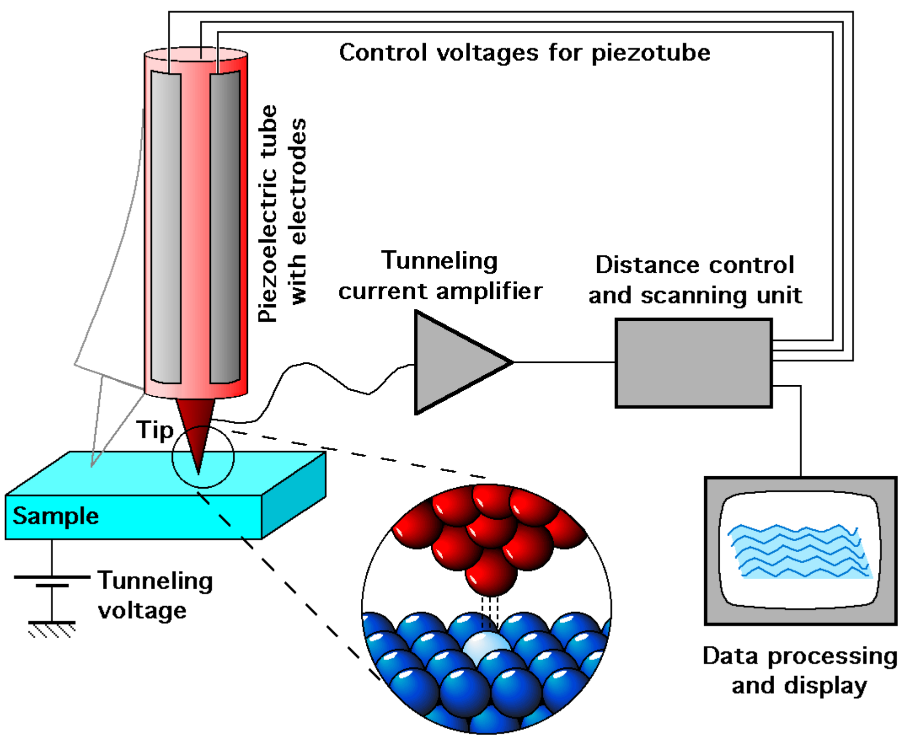
DNA



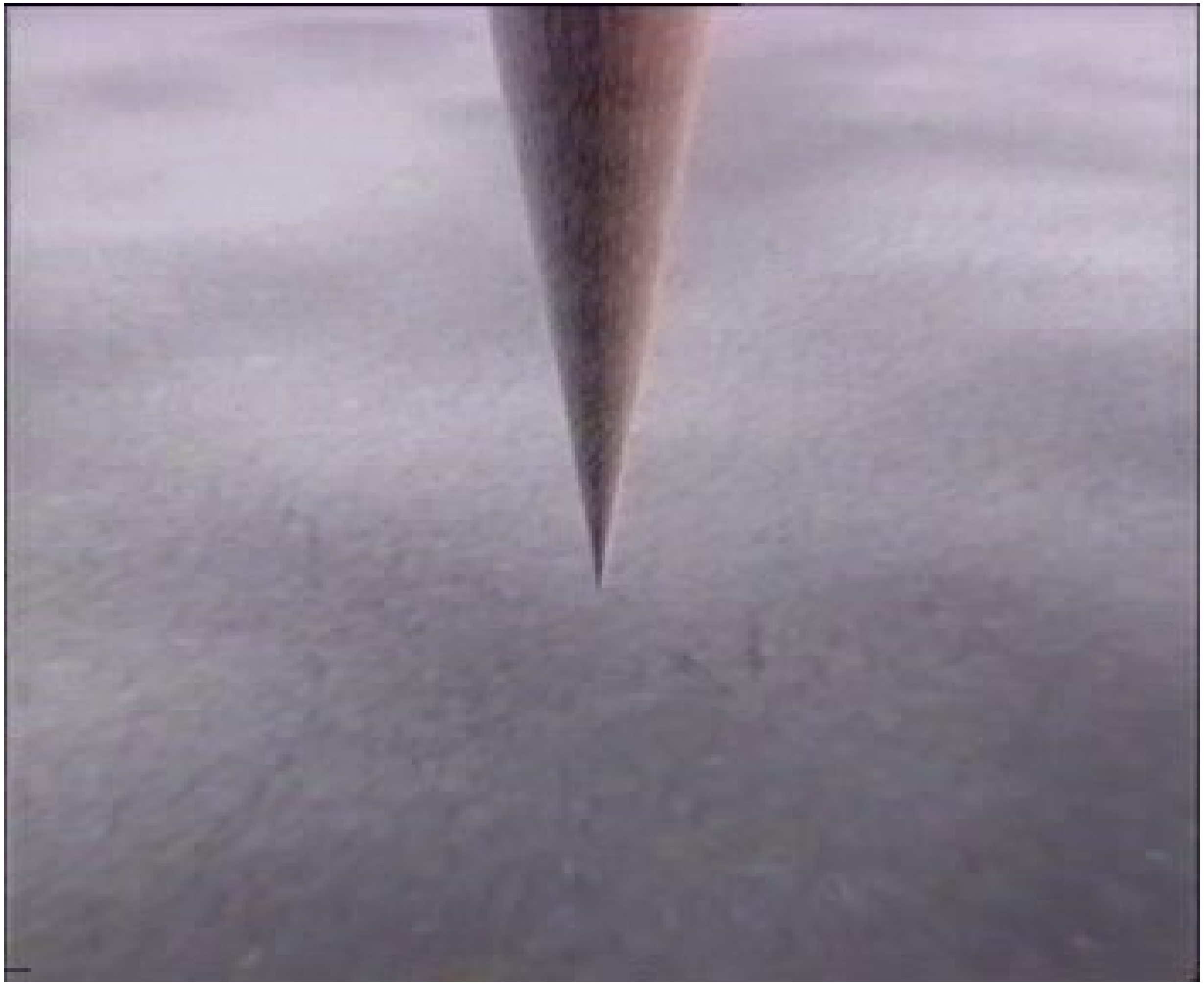
Gold nanoparticle



Scanning Tunneling Microscopy

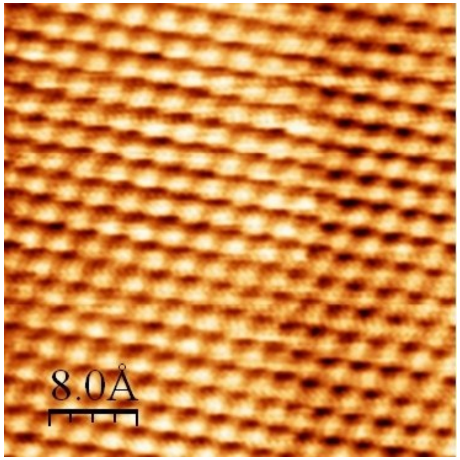


Scanning Tunneling Microscopy

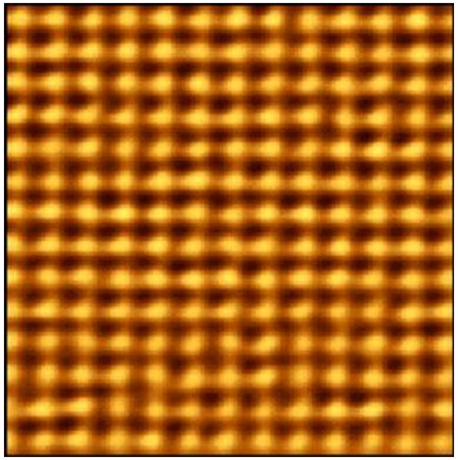


Scanning Tunneling Microscopy Imaging

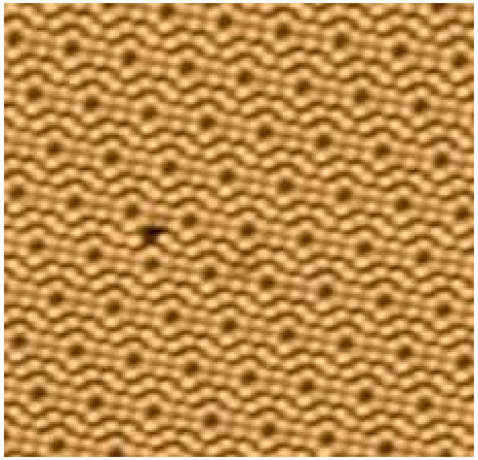
Gold

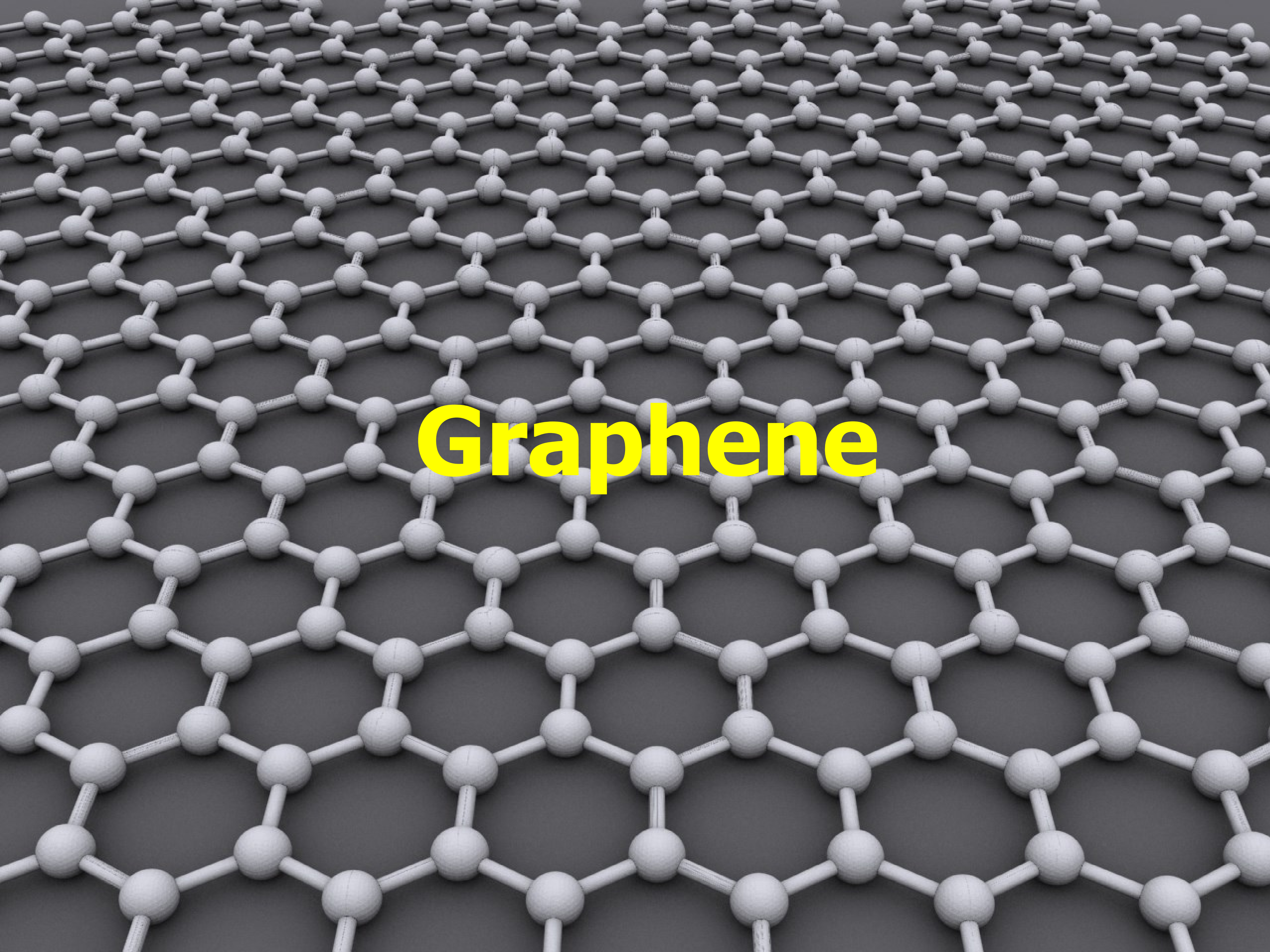


Copper



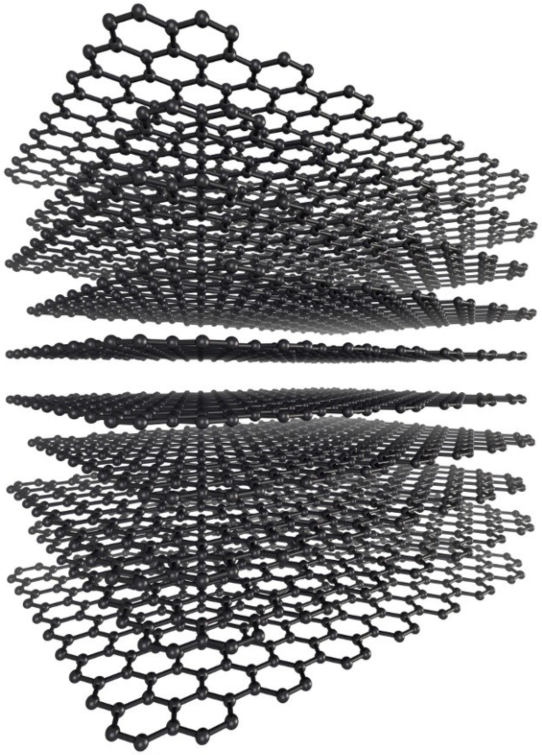
Silicon



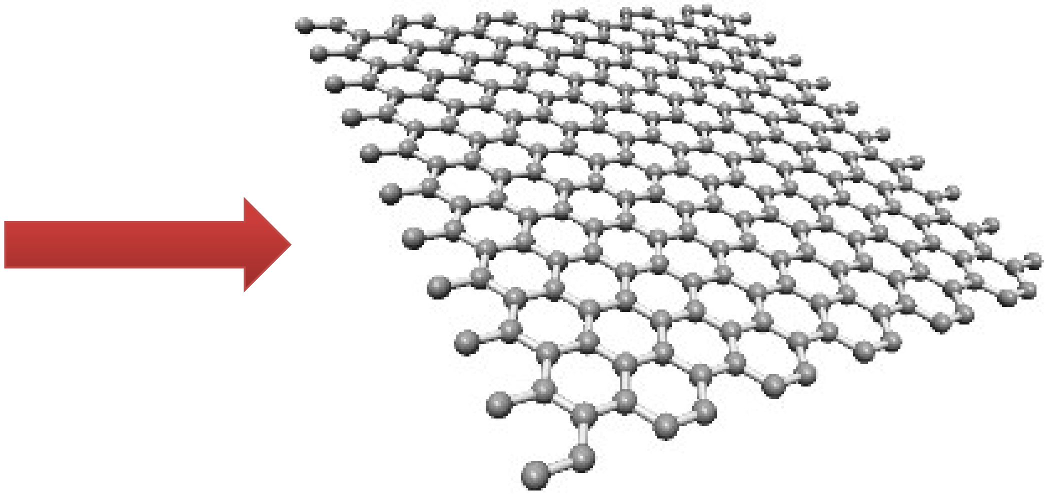

Graphene

What is Graphene ?

Graphite



Graphene



Physics Nobel Prize - 2010

Andre Geim   Kostya Novoselov

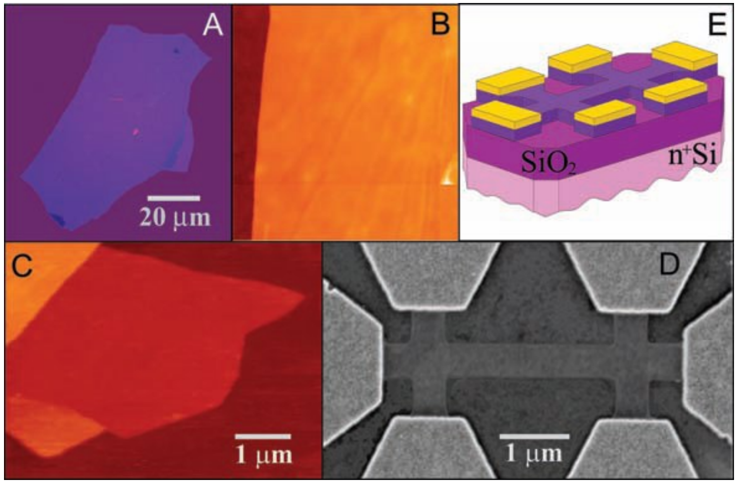
"for groundbreaking experiments regarding the two dimensional material graphene"

Electric Field Effect in Atomically Thin Carbon Films

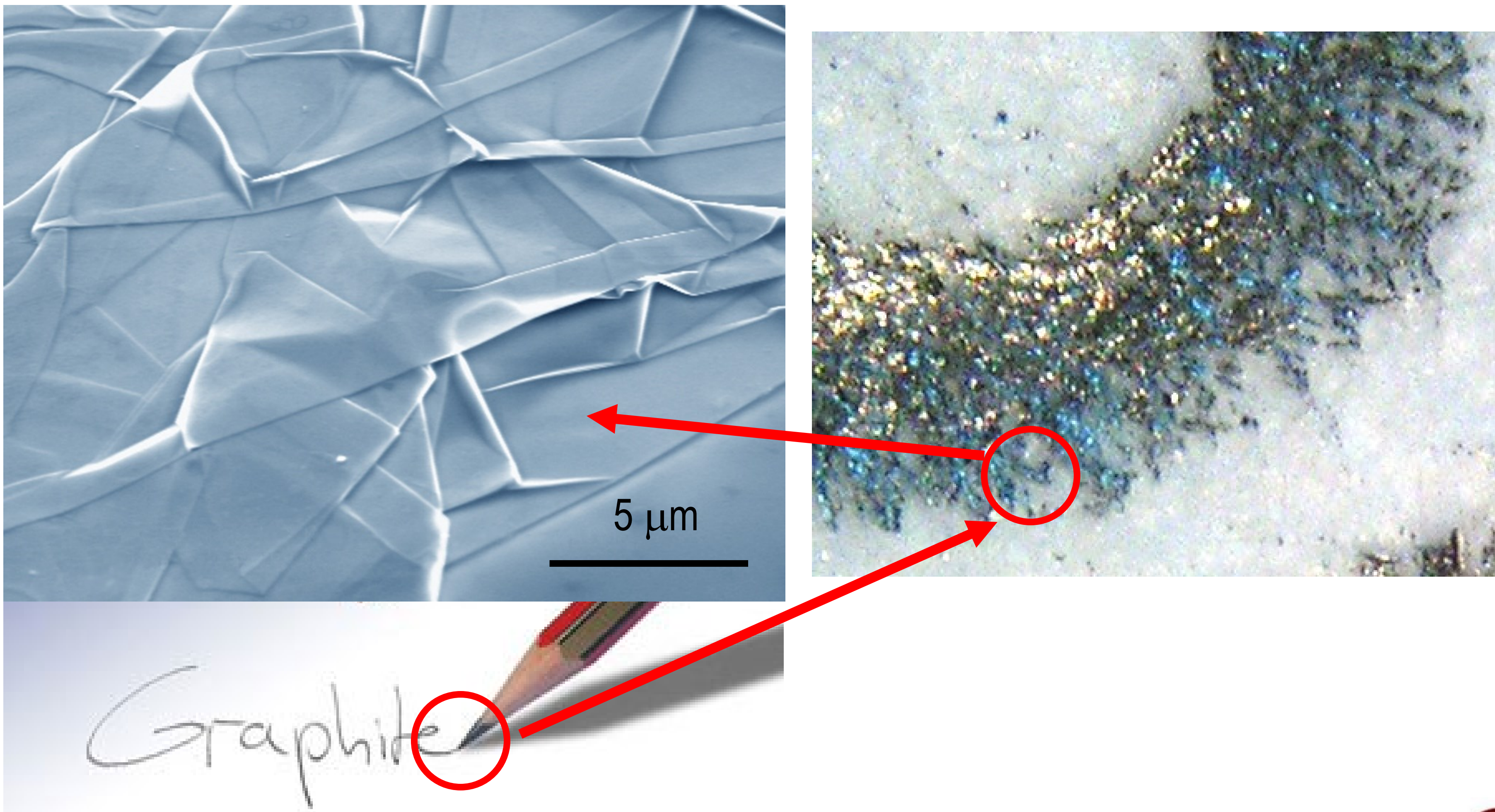
K. S. Novoselov,[1] A. K. Geim,[1*] S. V. Morozov,[2] D. Jiang,[1] Y. Zhang,[1] S. V. Dubonos,[2] I. V. Grigorieva,[1] A. A. Firsov[2]

We describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conductance bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room-temperature mobilities of ~10,000 square centimeters per volt-second can be induced by applying gate voltage.

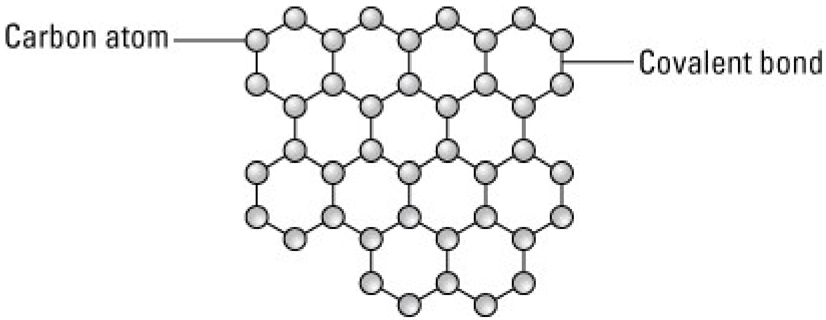
22 OCTOBER 2004 VOL 306 SCIENCE www.sciencemag.org

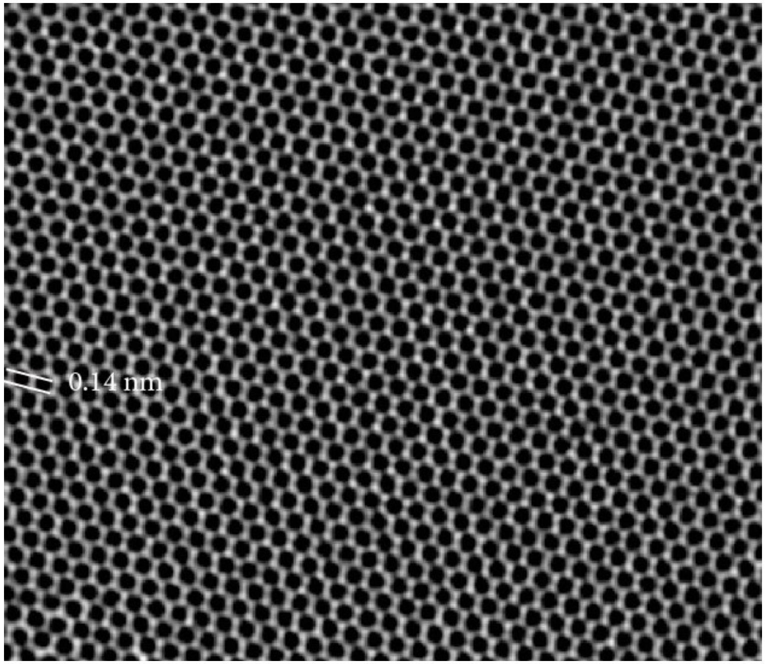


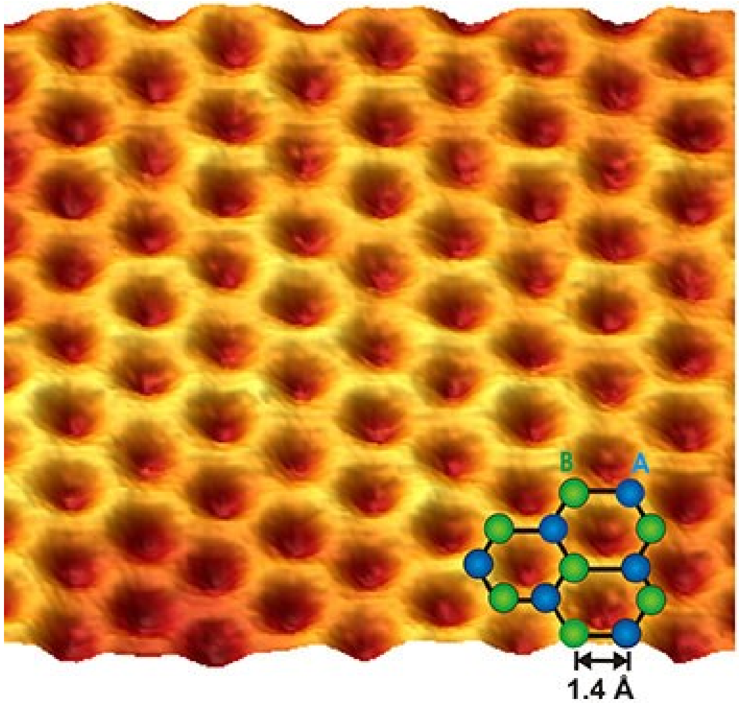
How is it made?



Imaging graphene



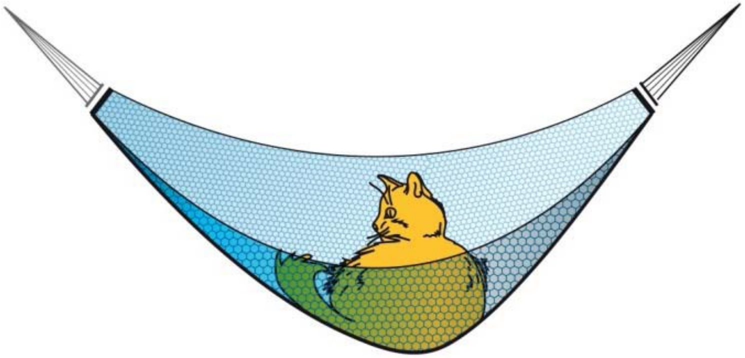




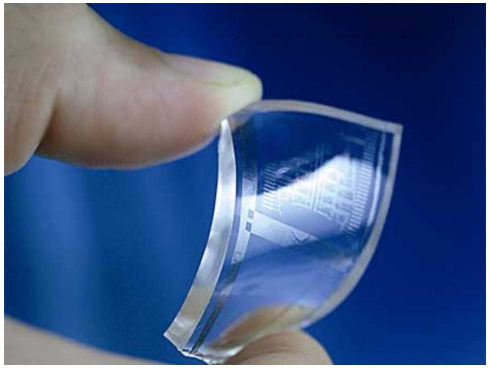
Electron microscopy

STM

Graphene the wonder material



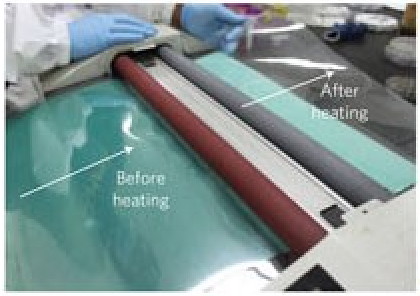
- ***The thinnest possible material***
- ***Mechanically stable***
- ***Elastically deformable by up to 20%***
- ***The strongest material ever measured (42 N m^{-1})***

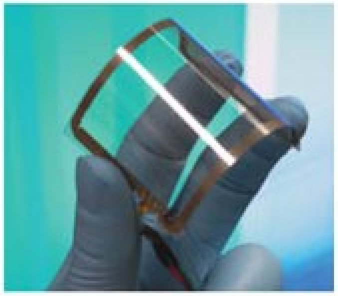


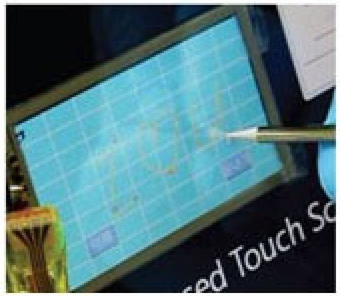
- Best conductor (1000x better than silicon)
- Excellent heat conductor (5000 $Wm^{-1}K^{-1}$)
- Transparent for all visible wavelength (2.7% absorption)

Graphene – applications

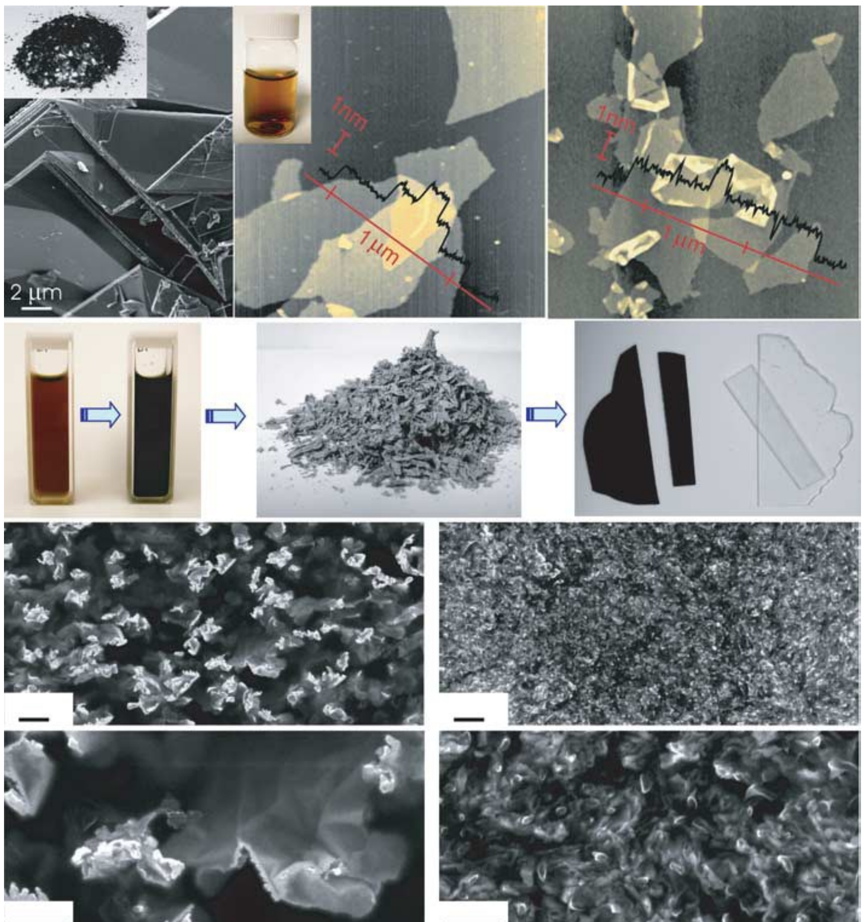
Flexible displays and touch screens, wearable solar cells

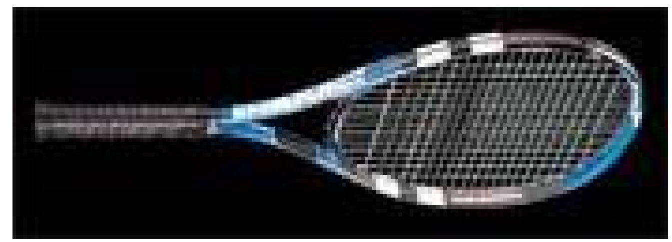






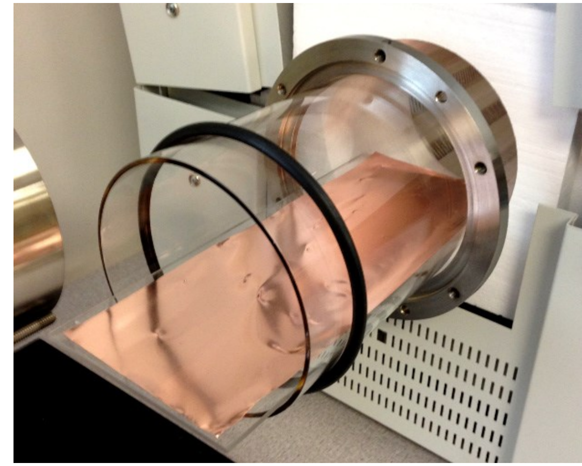
Graphene applications – composite materials

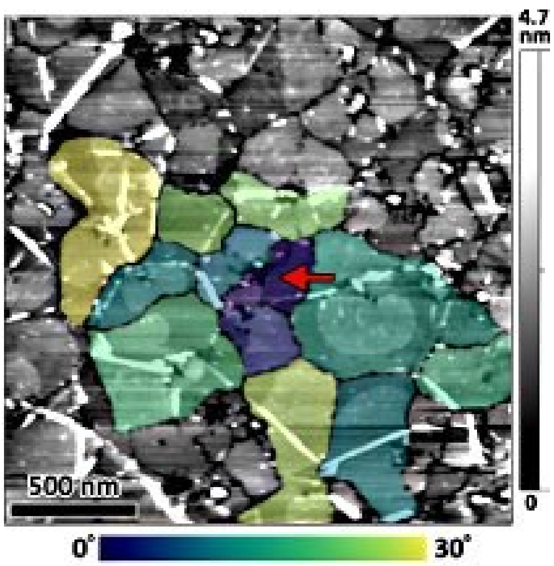




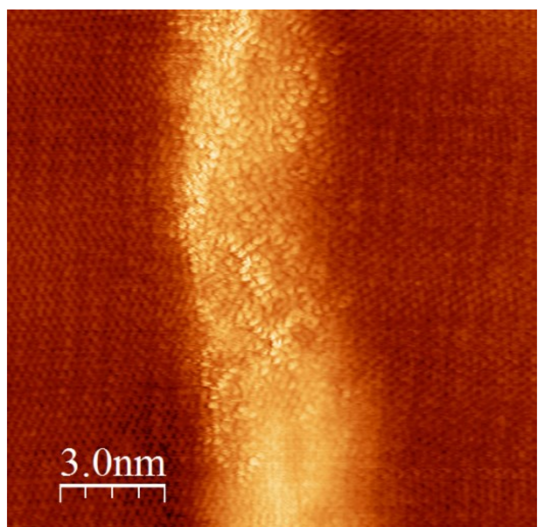
Achievements of the Korea Hungary Joint Laboratory for Nanosciences

CVD growth of graphene

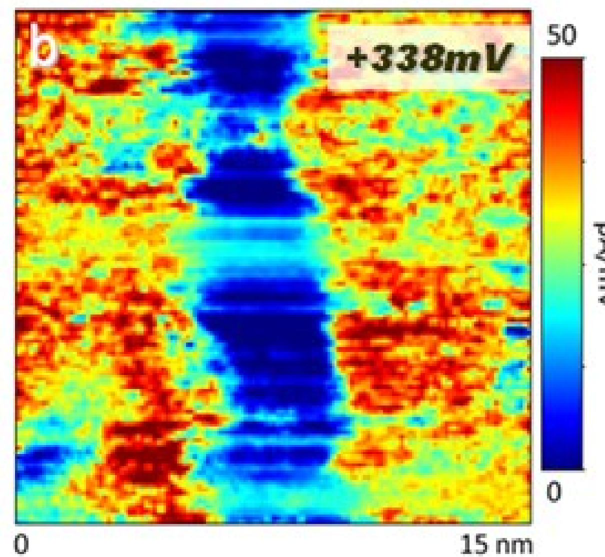




Topography

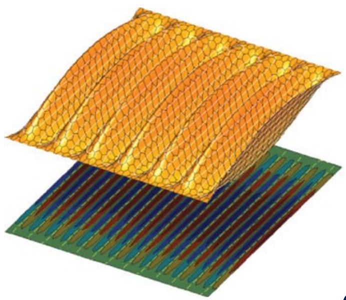


Conductivity

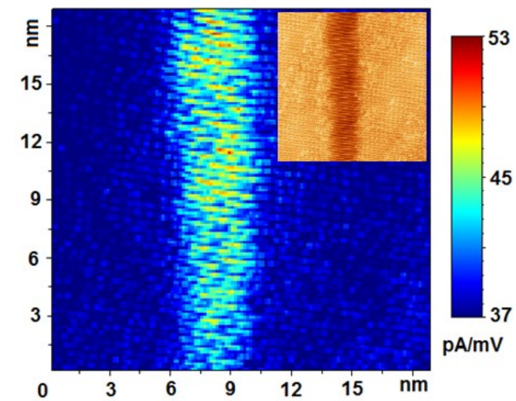


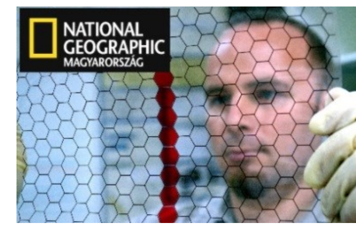
P. Nemes-Incze et al. Appl. Phys. Lett. 99, 23104 (2011) *L. Tapaszto et al. Appl. Phys. Lett. 100, 053114 (2012)*

Strain-engineering graphene superlattices with sub-nanometer precision

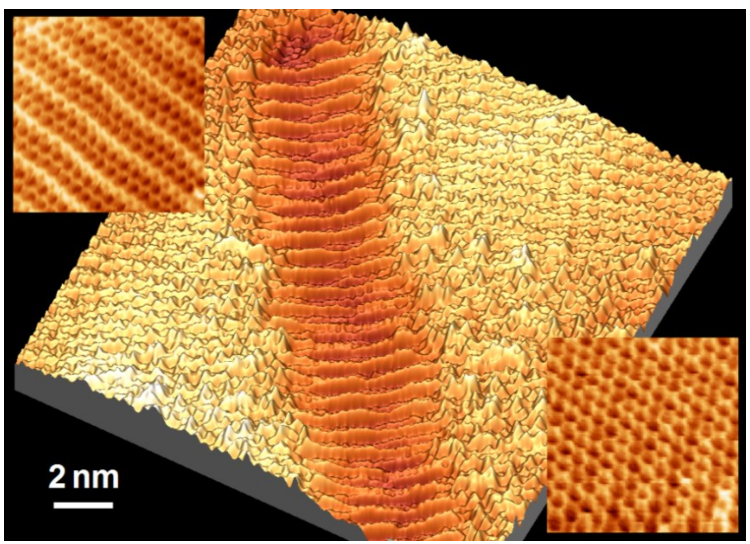


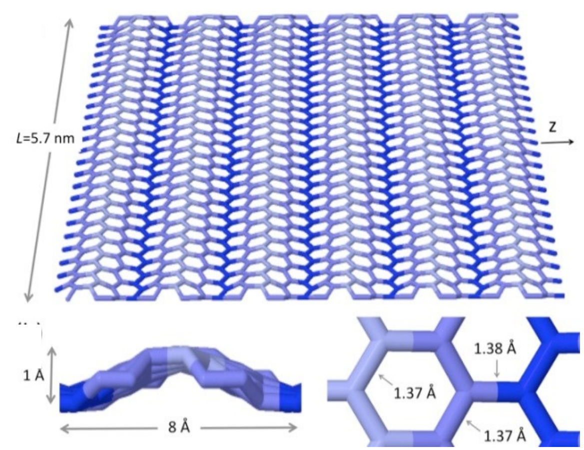
Electronic superlattice





STM image

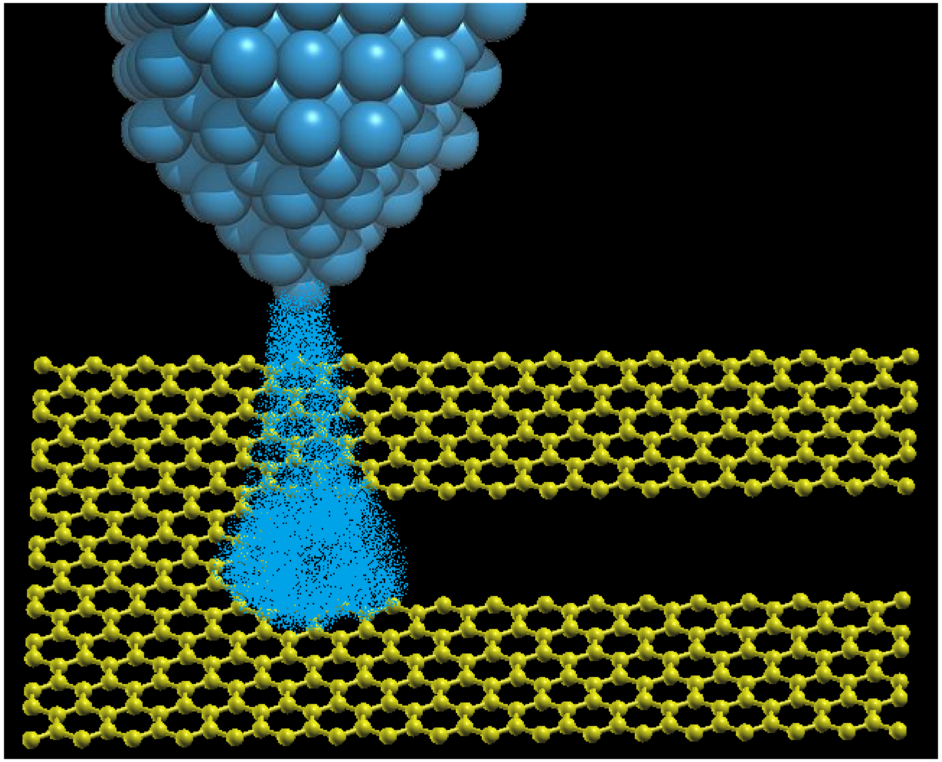




λ = 0.7 nm !!!

L. Tapasztó et al. ***Nature Physics*** 8, 739 (2012)

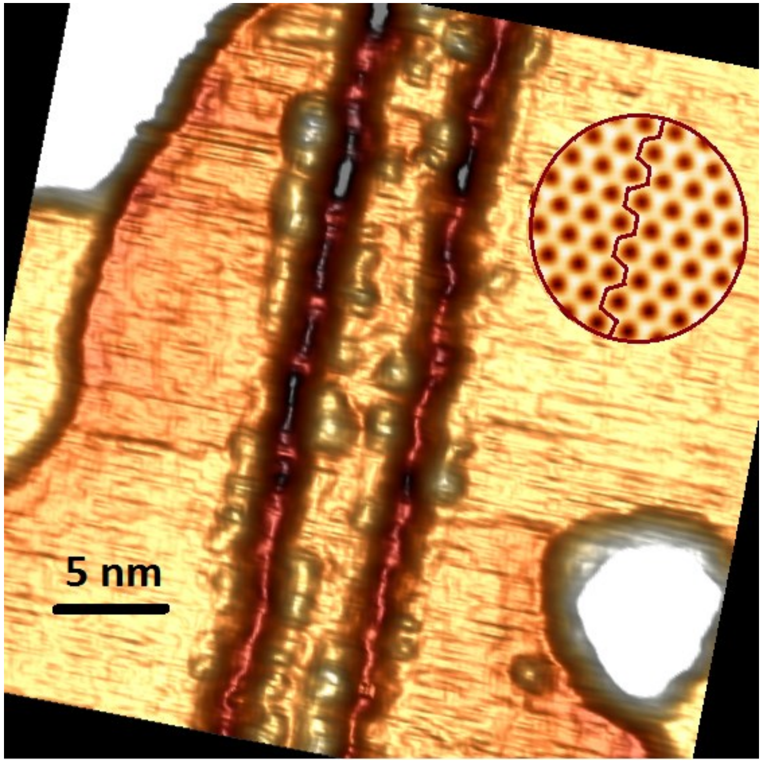
STM nanofabrication of graphene

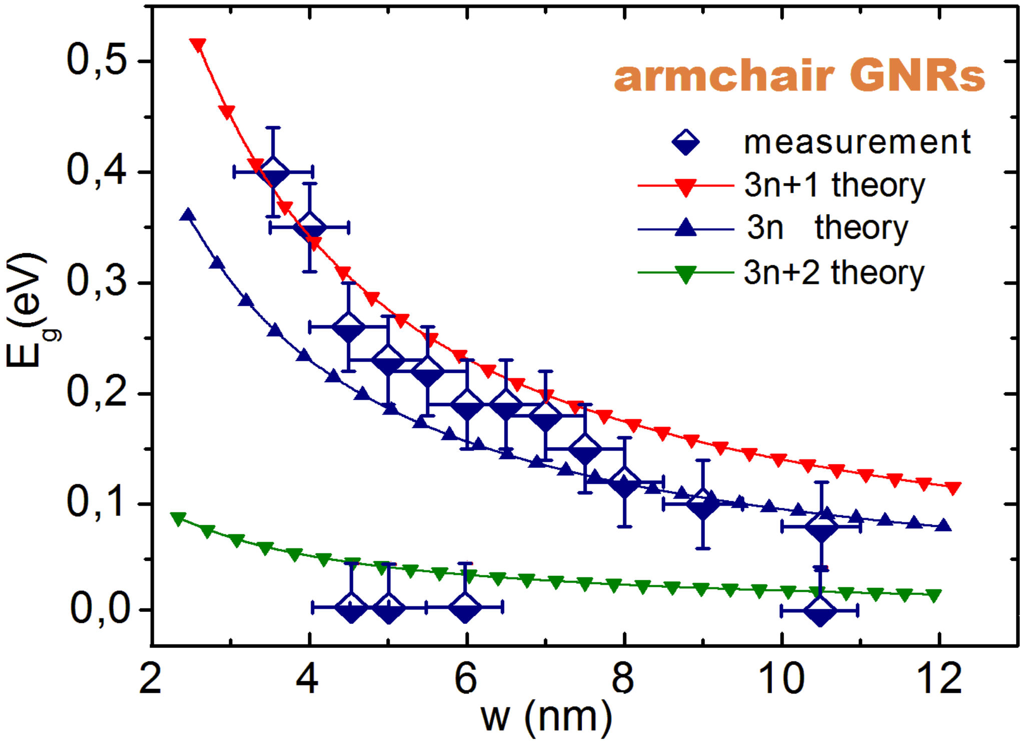


- Atomic resolution allows lattice orientation ✓
- Local modification - cutting ✓
- Sub-nanometer precision ✓
- Control over the crystallographic edge orientation ✓

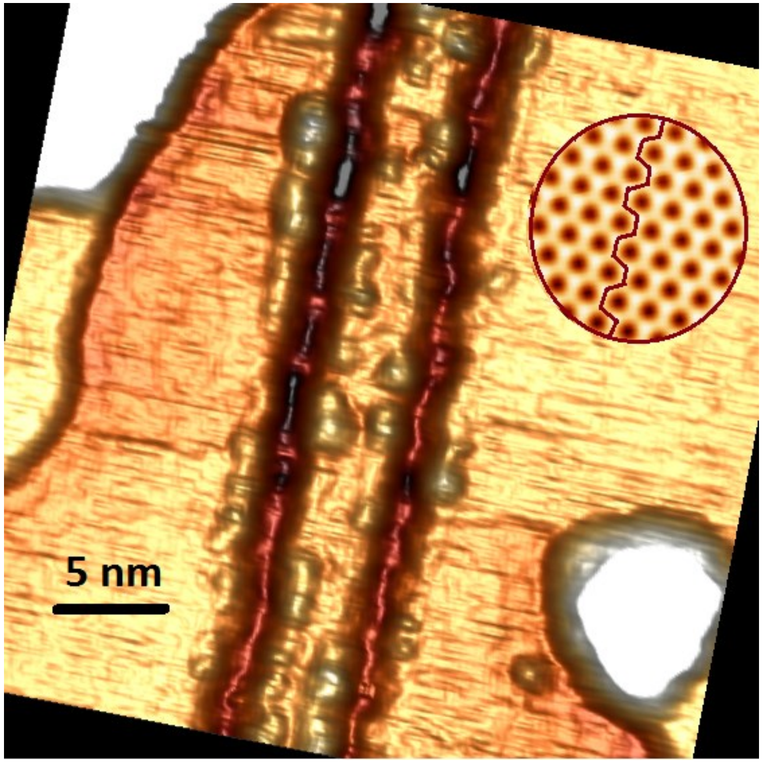
L. Tapasztó et al. Nature Nanotechnology 3, 397 (2008)

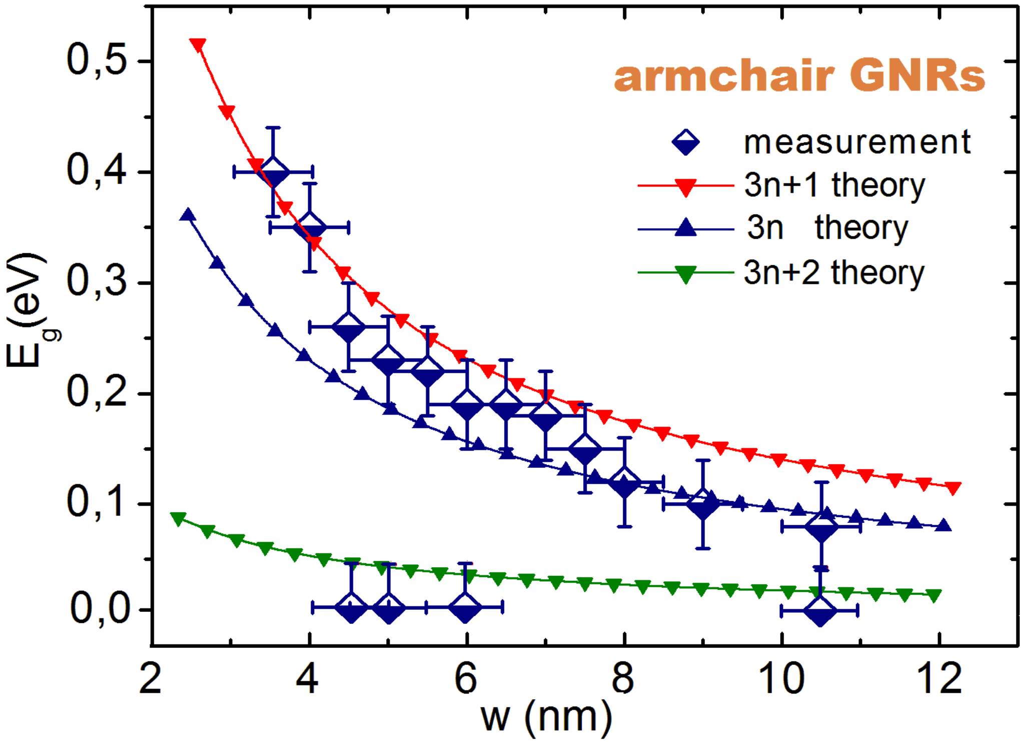
Engineering the electronic properties of grpahene



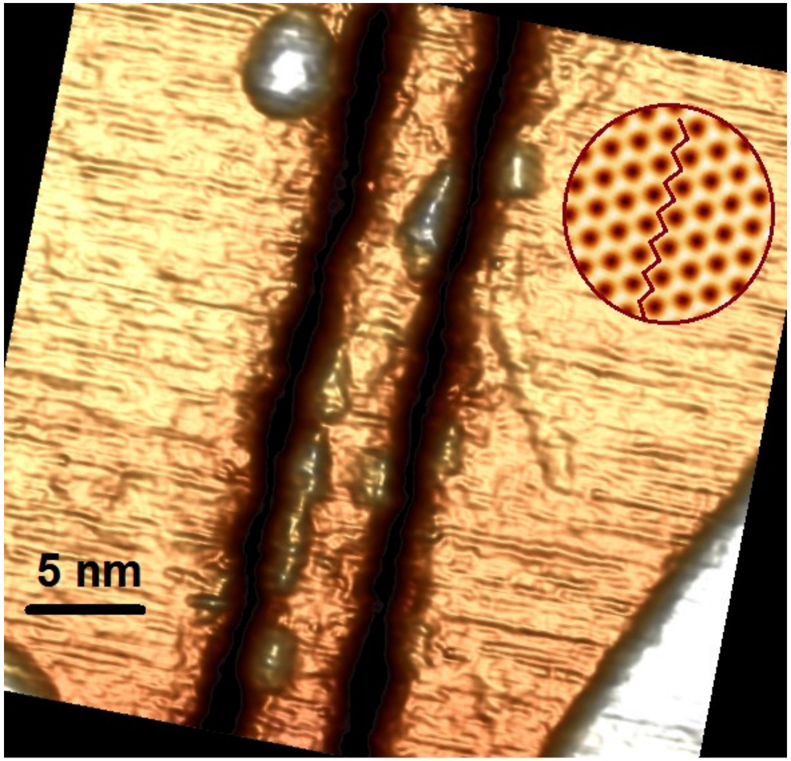


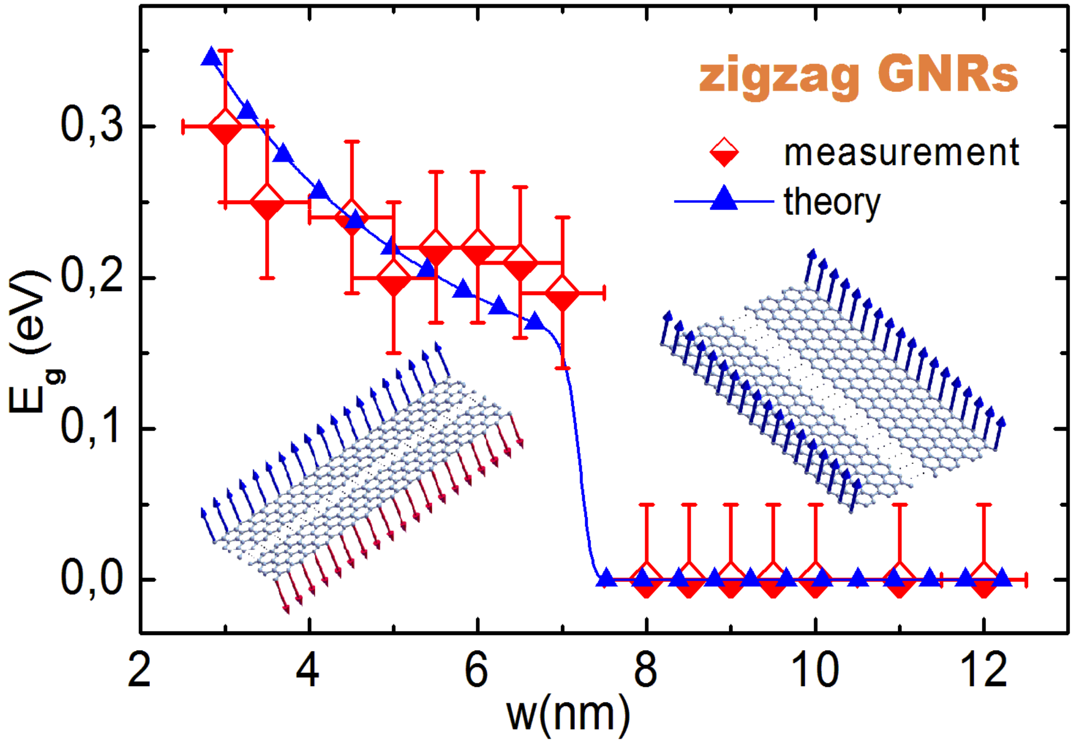
Engineering the electronic properties of grpahene





Engineering the magnetic properties of graphene





LETTER

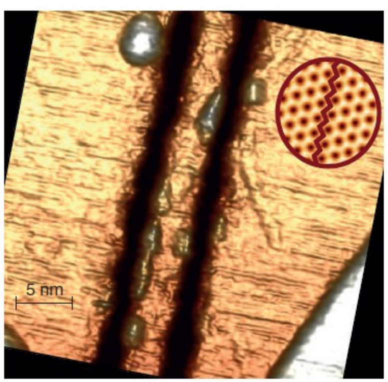
nature International weekly journal of science

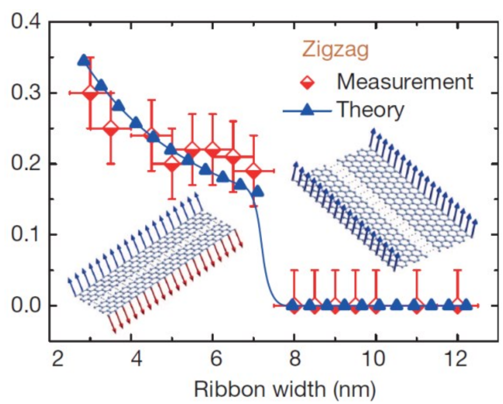
doi:10.1038/nature13831

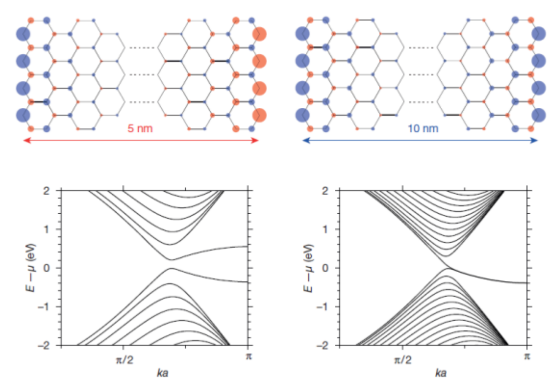
Room-temperature magnetic order on zigzag edges of narrow graphene nanoribbons

Gábor Zsolt Magda[1], Xiaozhan Jin[2], Imre Hagymási[3,4], Péter Vancsó[1], Zoltán Osváth[1], Péter Nemes-Incze[1], Chanyong Hwang[2], László P. Biró[1] & Levente Tapasztó[1]

The possibility that non-magnetic materials such as carbon could exhibit a novel type of *s*–*p* electron magnetism has attracted much attention over the years, not least because such magnetic order is predicted to be stable at high temperatures[1]. It has been demonstrated that atomic-scale structural defects of graphene can host unpaired spins[2,3], but it remains unclear under what conditions long-range magnetic order can emerge from such defect-bound magnetic moments. a considerable, nanometre-scale edge roughness, suppressing orientation effects[14]. Scanning tunnelling microscopy (STM) study of irregularly shaped graphene ribbons revealed that structures with more zigzag edges display smaller bandgaps than those with more armchair edges[15]. This is clearly indicative of edge-specific physics; however, the lack of orientation control did not allow a more systematic insight. In theory, there is a broad consensus that graphene nanoribbons with armchair

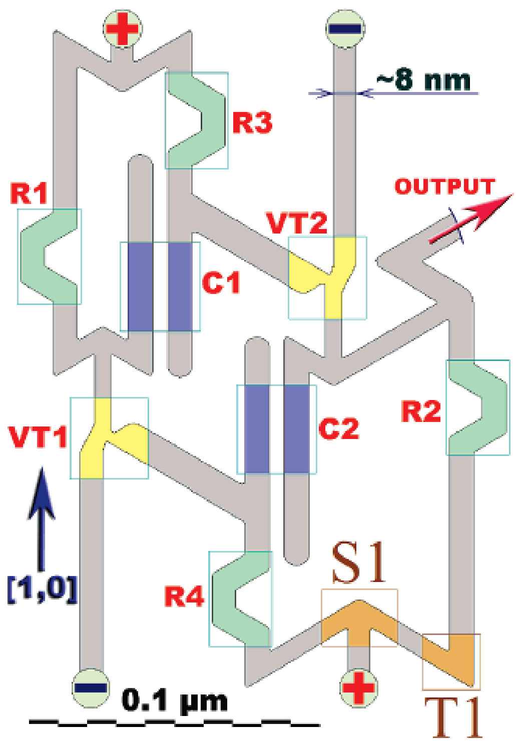


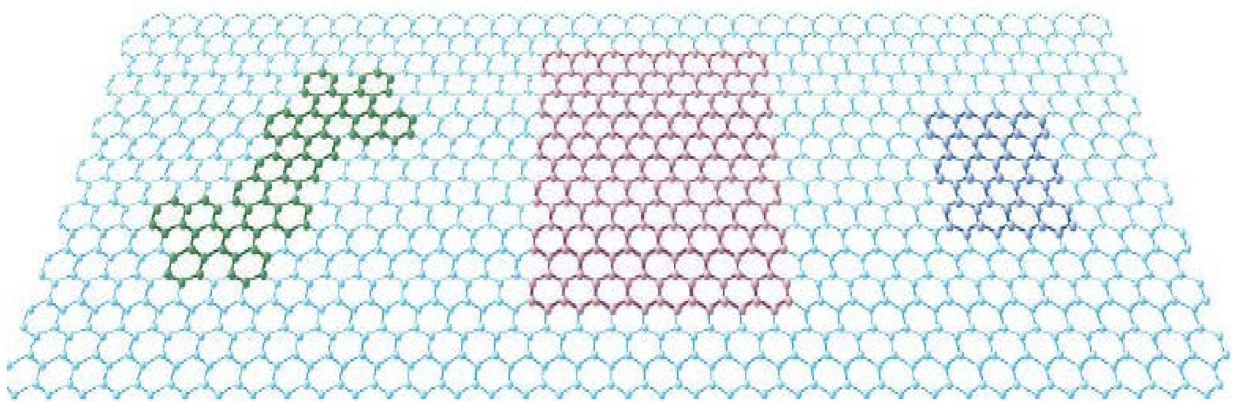




Received 14 April; accepted 1 September 2014.

Graphene nanoelectronics





- Ultrafast operation
- Ultra low power consumption

The next "Big Thing" is very, very, very small!

"Nanotechnology is an enabling technology that will change the nature of almost every human-made object in the next century."

-National Science and Technology Council –

Acknowledgements

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- Korea Hungary Joint Laboratory for Nanosciences Converging Research Center Program through the Ministry of Education, Science and Technology (2010K000980)
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- National Research Fund K 108753 és K 101599

Anmyun-do