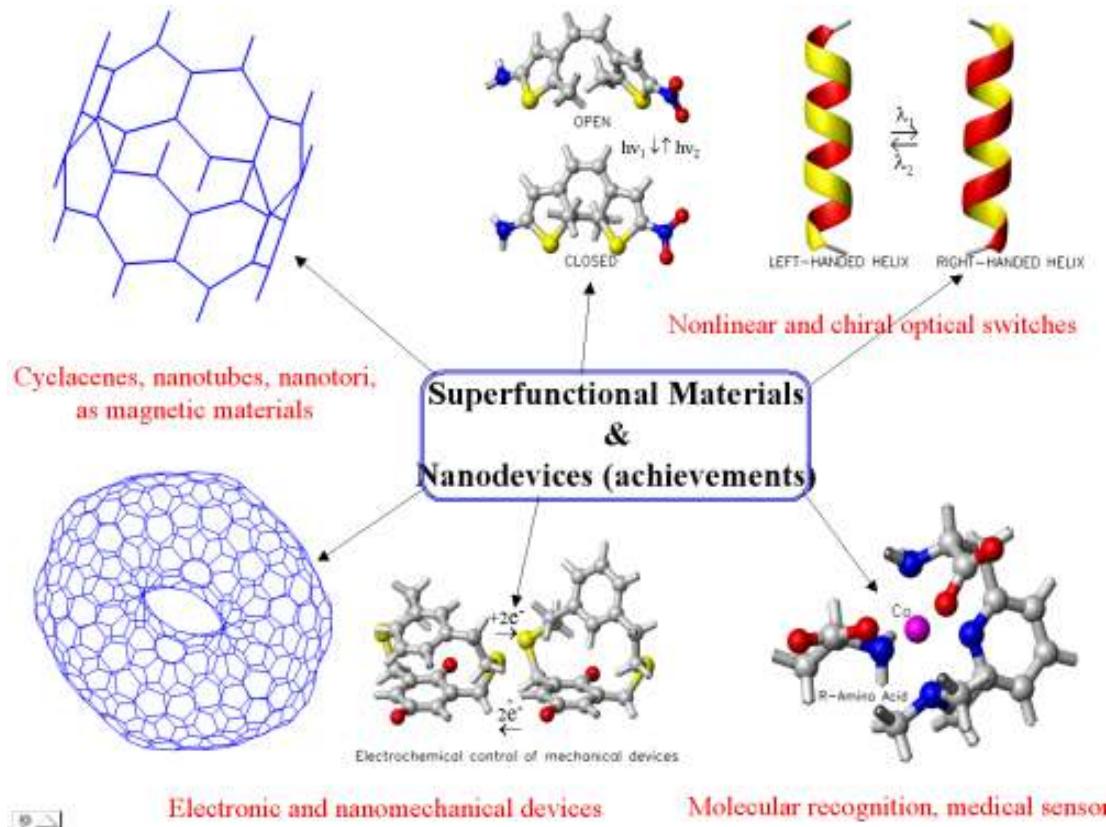


# Research Area

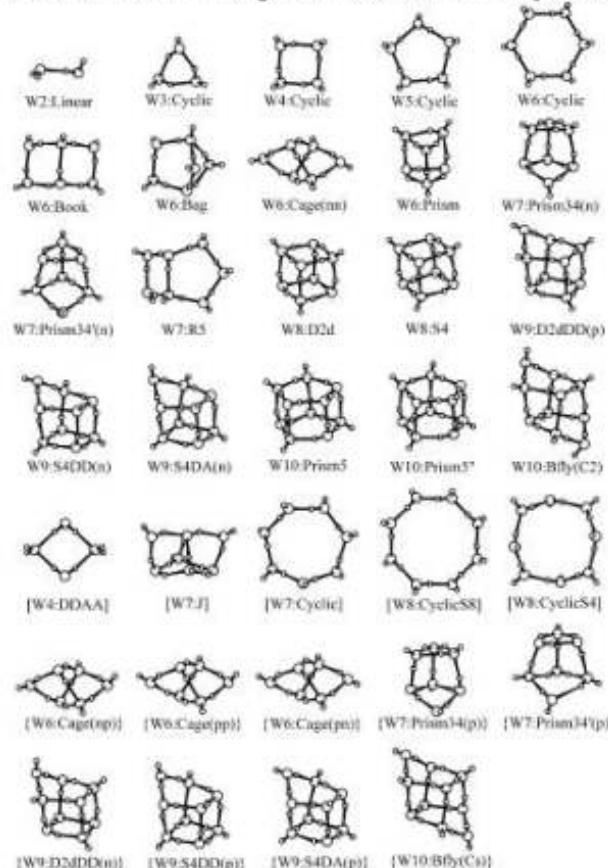
## Project #1 Superfunctional Materials and Nanodevices



# Research Area

## Project #2 Structure of Water Clusters

### Simple Molecular Assembly: Structure of Aqueous Clusters

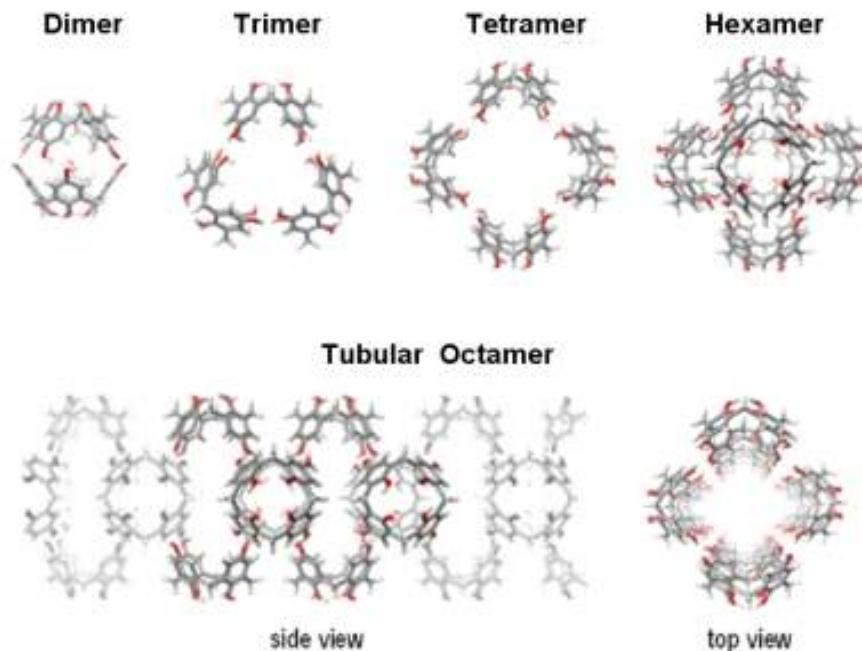


Chem. Phys. Lett. 131, 451 (1986). / J. Chem. Phys. 109, 5886 (1998); 110, 9128 (1999).  
J. Chem. Phys. 111, 18077 (1999). / Chem. Rev. 100, 4145 (2000).  
J. Chem. Phys. 112, 9759 (2000); 114, 3343 (2001).

# Research Area

## Project #3 Computer-Aided Design of Supramolecular Sturctures

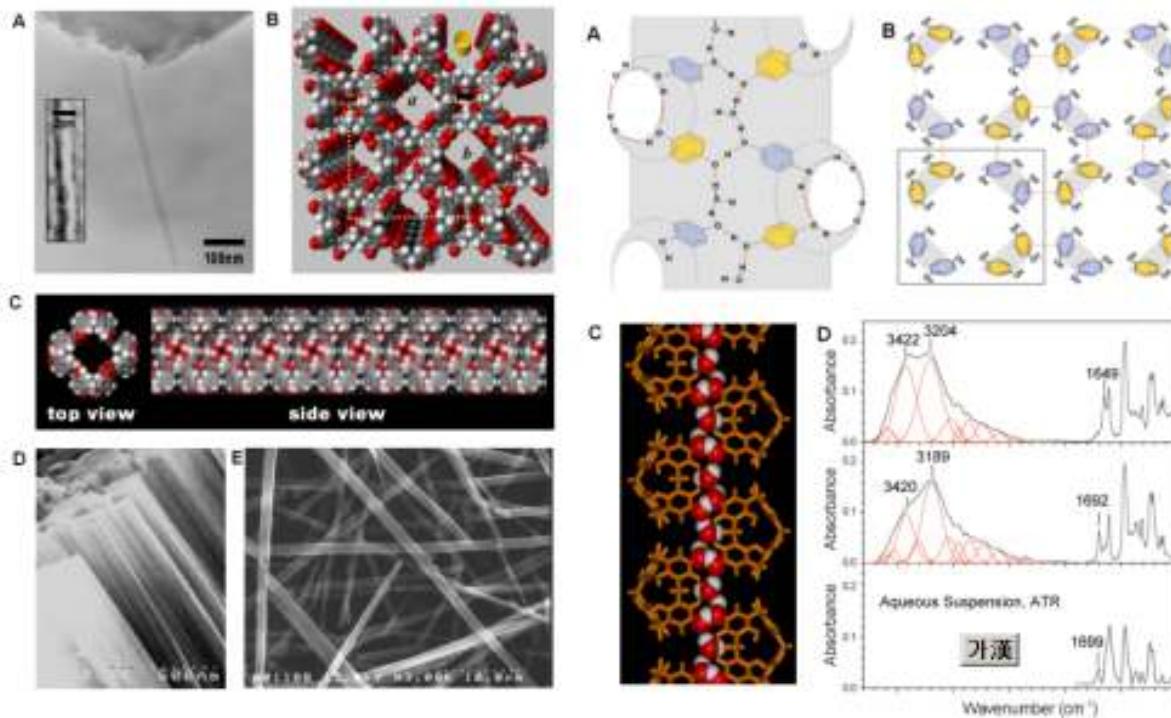
### Computer-Aided Design of Supramolecular Structures



## Research Area

### Project #4 Synthesis of Organic Nanotubes & 1-Dimensional Hydrogen Bond Chains

#### Self-Assembled Arrays of Organic Nanotubes with Infinitely Long One-Dimensional H-Bond Chains



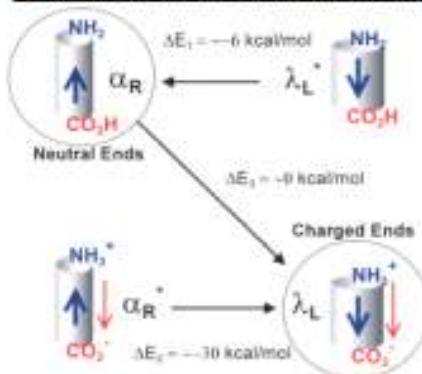
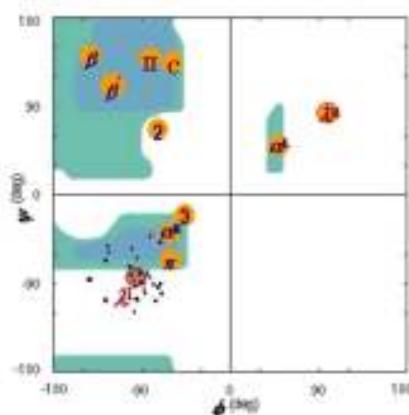
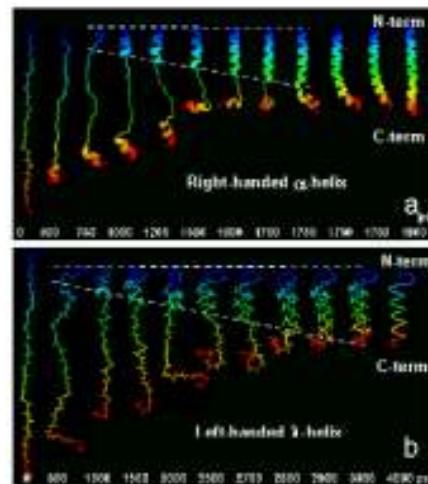
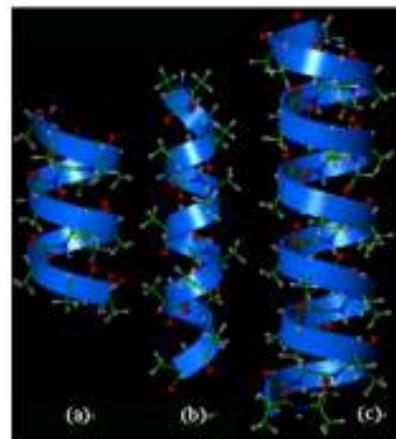
Kim, K. S et al. *J. Am. Chem. Soc.* **124**, 14268-14279 (2002).

Hong, B. H. et al. *J. Am. Chem. Soc.* **123**, 10748-10749 (2001).

# Research Area

## Project #5 Coil and De-coil of Poly-Alanine Peptide

### A New Type of Helix Pattern in Poly-Alanine Peptide

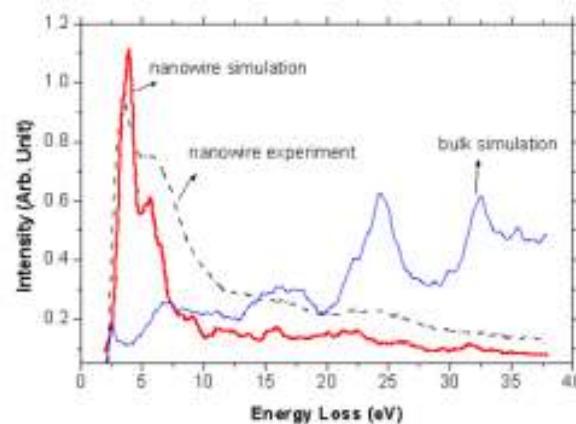
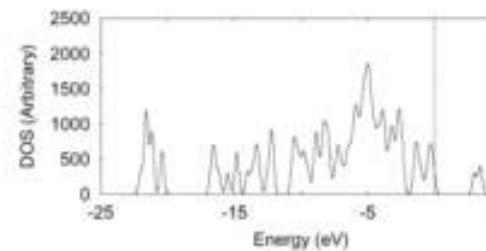
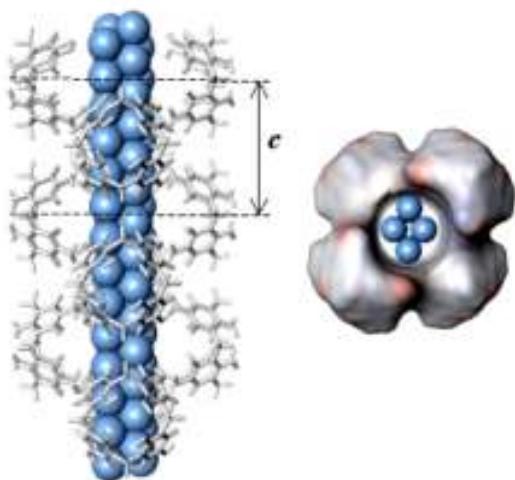


Son et al. *J. Am. Chem. Soc. (Comm.)* 123, 513 (2001).

# Research Area

## Project #6 Synthesis of Ultrathin Metallic Nanowire with Organic Nanotubes

### Ultrathin Single-Crystalline Silver Nanowire Arrays Formed in an Ambient Solution Phase

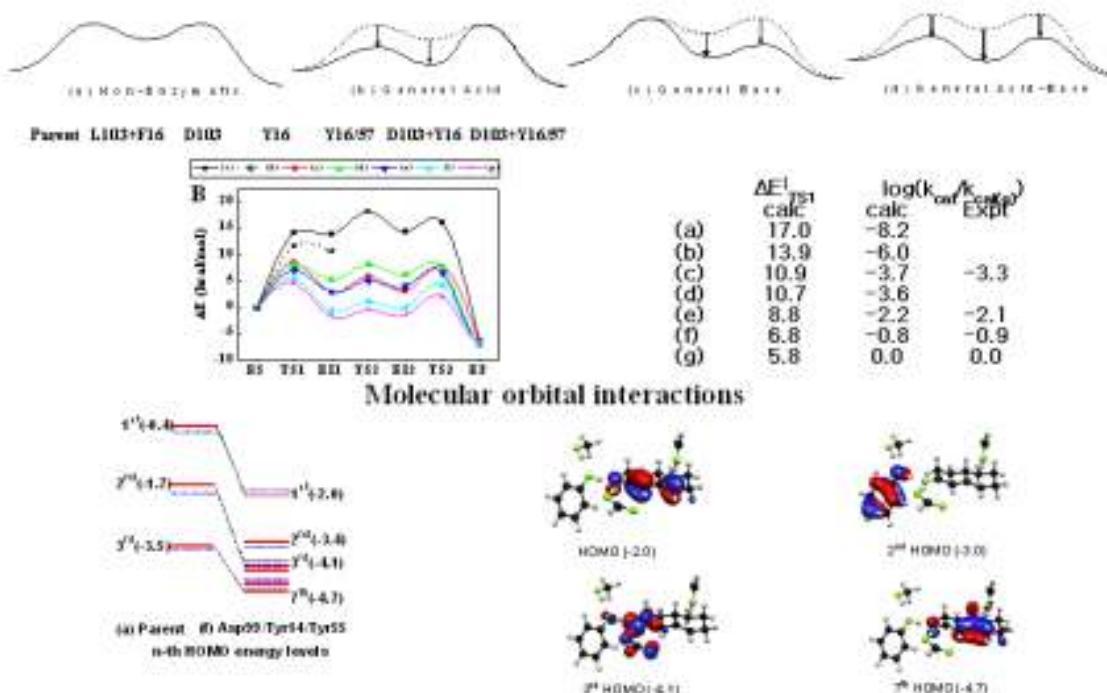


Hong, B.H., Bae, S.C., Lee, C.-W., Jeong, S. & Kim, K.S. Science 294, 348-351 (2001).

# Research Area

## Project #7 Study of Strong H-bonds, Pre-organization, Charge Buffering/Dissipation

### Strong H-bonds, Pre-organization, charge buffering/dissipation



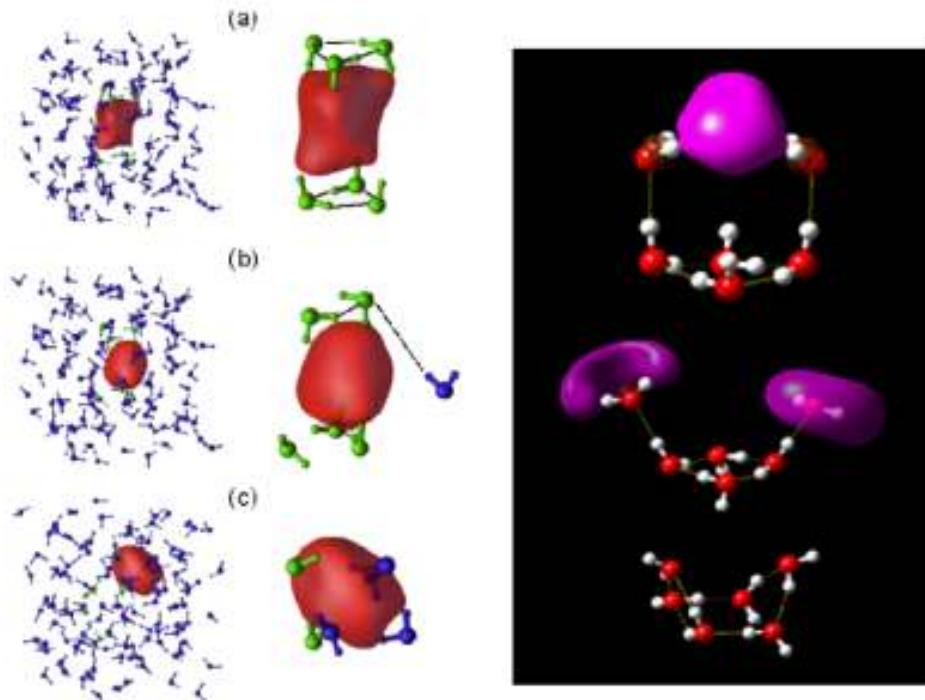
Kim et al, *Proc. Natl. Acad. Sci. USA*, **97**, 6373 (2000)

Kim et al, *Biochemistry* **41**, 5300 (2002)

Research Area

Project #8 Molecular Dynamics of Excess Electrons in Aqueous Solution

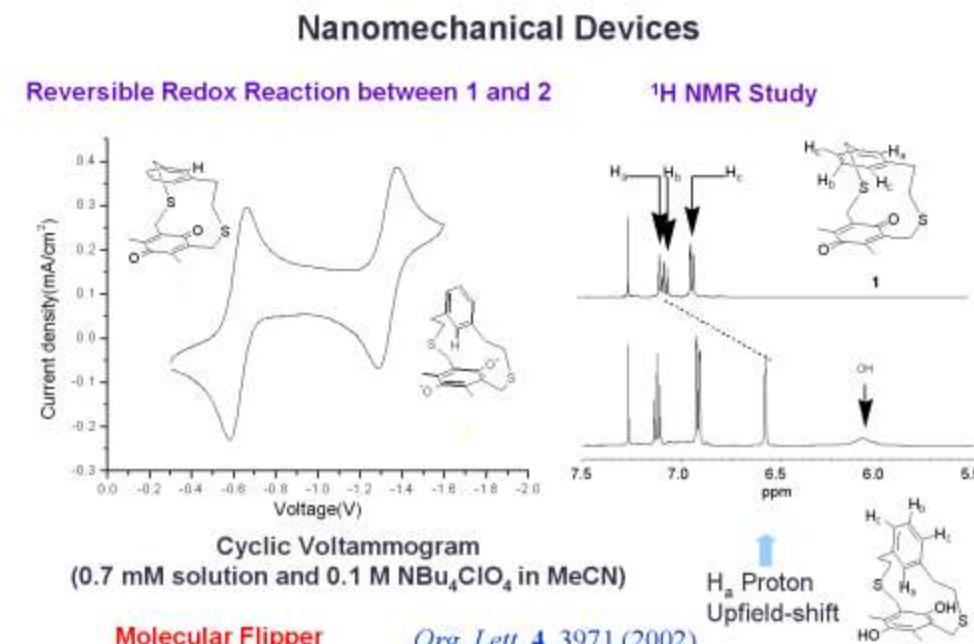
## Electron Carriers and Molecular Devices



Dynamical motion of electron charge density in water for every 10 fs.

# Research Area

## Project #9 Nanomechanical Devices: Molecular Flipper



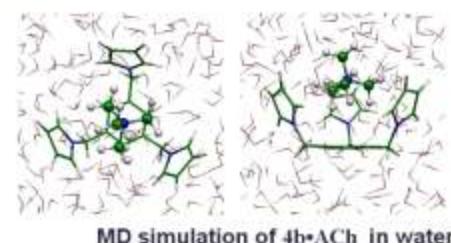
# Research Area

## Project #10 Denovo Design of Ionophores and Molecular Receptors

### Design of Ionophores and Receptors

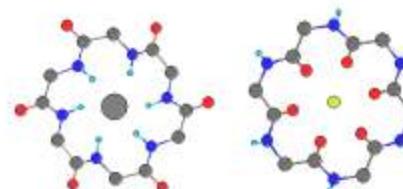


Calculated Structure of  $4b\text{-NMe}_4^+$  in Water by MD Simulation



- C-H---X H-Bonding Interaction
- Charge-Charge Interaction
- Charge-Dipole Interaction

Org. Lett. 4, 2897 (2002)



Amphi-ionophores

J. Phys. Chem. B 106, 2061 (2002); 102, 461 (1998)

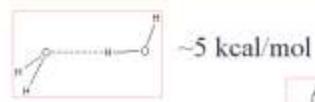


# Research Area

## Project #11 Comprehensive Study of Interaction Forces

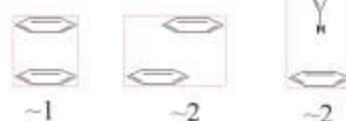
### Interaction Forces

#### 1. H-bonding



~5 kcal/mol

#### 2. $\pi-\pi$ interaction



~1

~2

~2

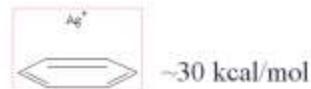
#### 3. $\pi-\text{H}_2\text{O}$ interaction



~2

~2

#### 4. Cation- $\pi$ interaction



~30 kcal/mol

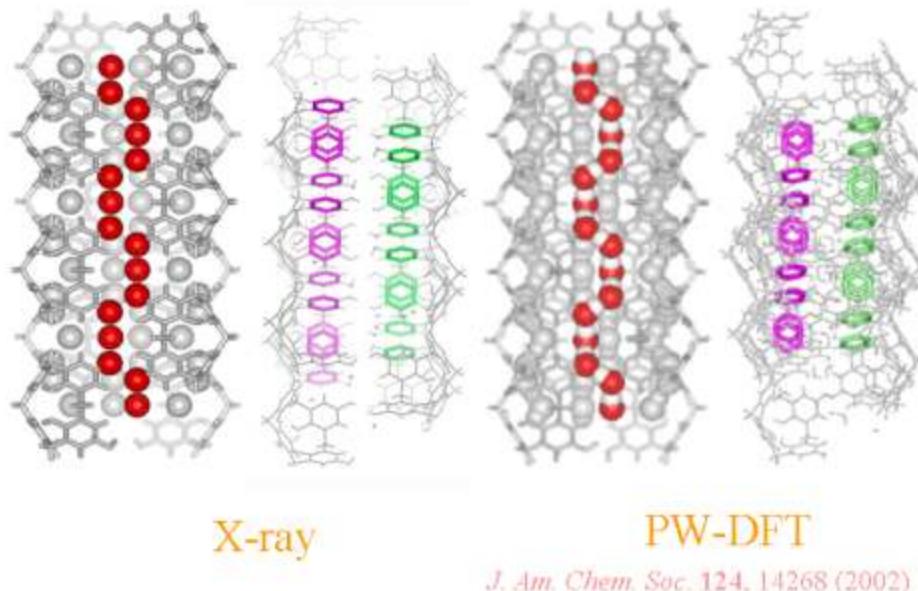
K. S. Kim, P. Tarakeshwar, J. Y. Lee, *Chem. Rev.* **100**, 4145 (2000)



## Research Area

### Project #12 Theoretical and Experimental Study of 1-Dimensional Arrays in Organic Nanotubes

#### 1D Short H-Bond Arrays vs. Displaced $\pi-\pi$ Stacks



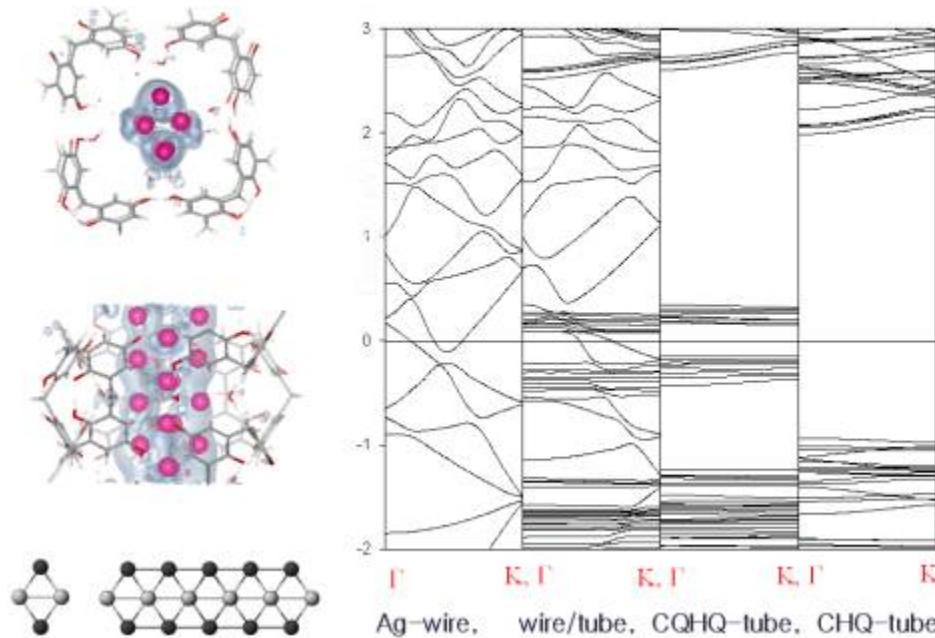
PW-DFT

*J. Am. Chem. Soc.* 124, 14268 (2002)

# Research Area

## Project #13 Electronic Band Structure of Nanotubes and Nanowires

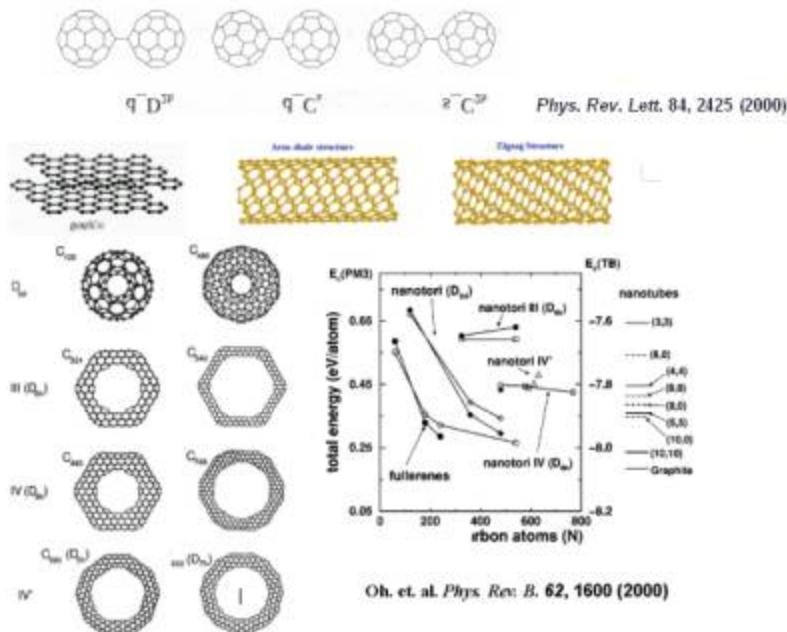
Electronic Band Structure of Nanotubes and Nanowires



# Research Area

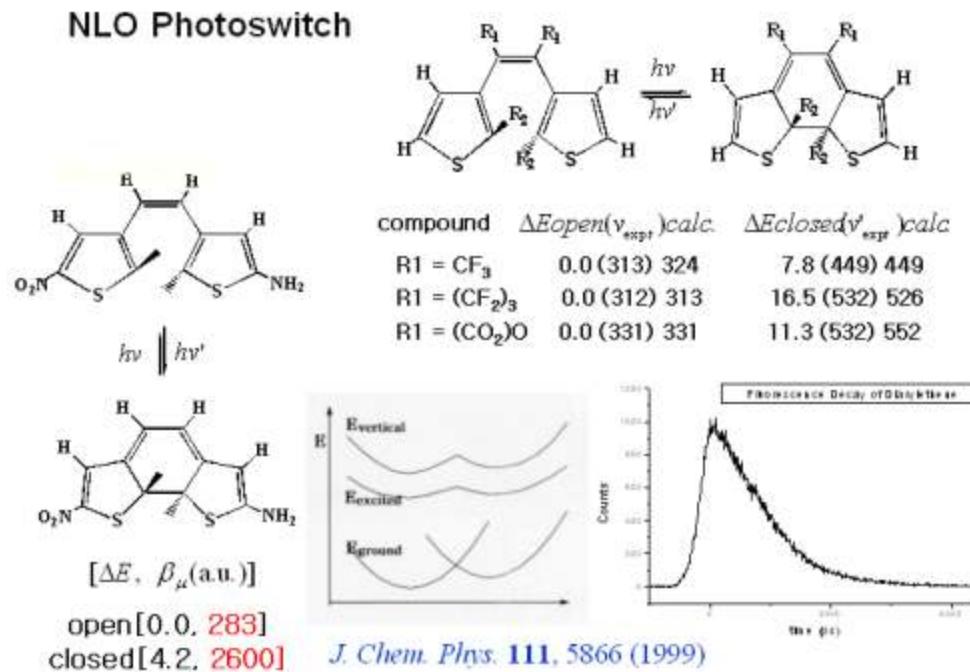
## Project #14 Synthesis of Carbon-based Nanoelectronic Materials

### Fullerenes, Nanotubes, Nanotubes



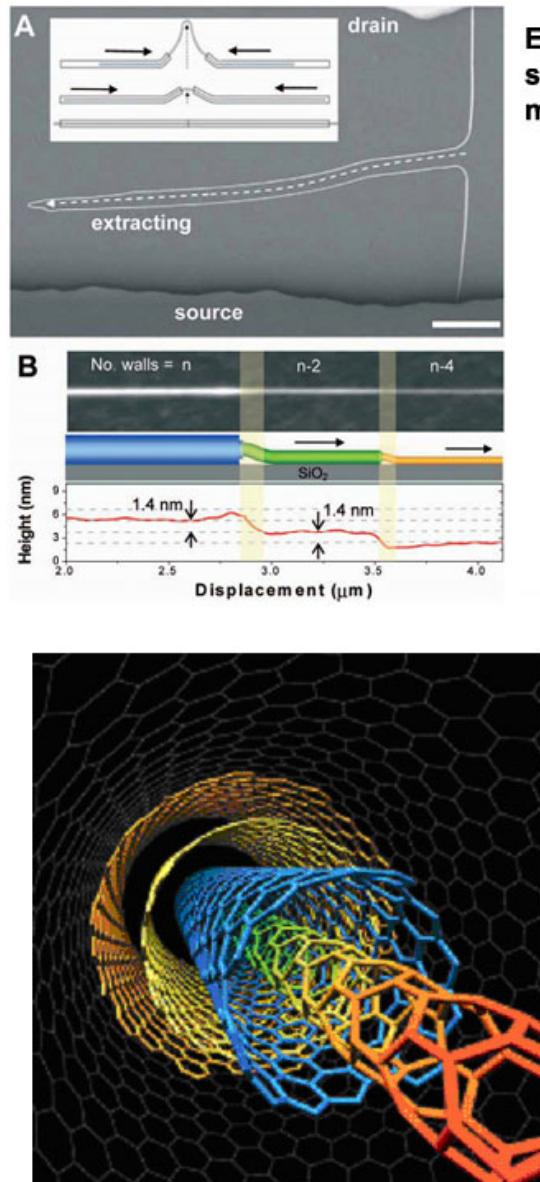
# Research Area

## Project #15 Nonlinear Optical Photoswitches

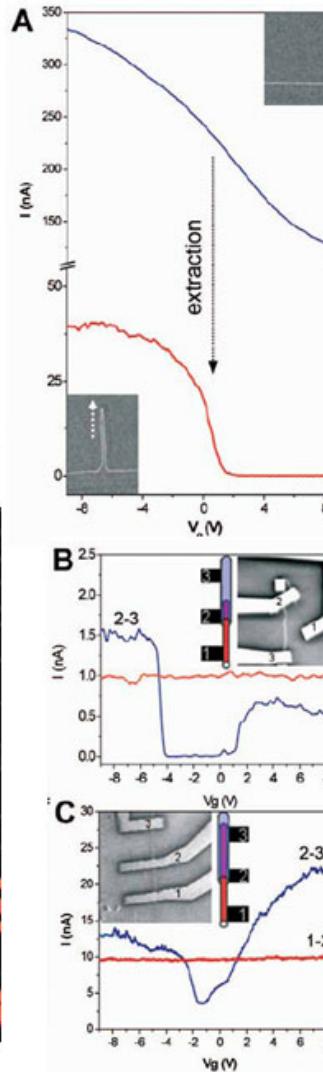


# Research Area

## Project #16 Carbon-based Nanoelectronic Devices : Extracting Single-wall Carbon Nanotubes



**Extracting subnanometer single shells from ultralong multiwalled carbon nanotubes**



# Research Area

## Project #17 Carbon-based Nanoelectronic Devices : Graphene in a spin



### featured highlight

#### Spintronics: Graphene in a spin

Published online 04 September 2008

Spintronics is the branch of electronics that exploits an electron's angular momentum—up or down 'spin state'—to encode data, rather than its charge. An important material for the future of spintronics is graphene—2D honeycomb sheet of carbon atoms.

Here, Kim and colleagues of Pohang University of Science and Technology, Korea<sup>1</sup> used first-principles computer simulations to determine the properties attainable in zigzag graphene nanoribbons, and found magnetoresistance values thousands of times larger than the largest value already reported.

The mechanical properties of graphene and its ability to transport electrons ballistically quickly make it of interest for both applications and fundamental studies. It has been shown experimentally that electron spin polarization is preserved for a long time when they are injected into graphene graphene, and that the spin is maintained for a long time within the material, which is important for spintronics.

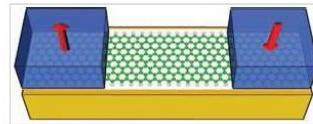


Fig. 1. The spin-valve set-up.

The researchers set up a 'spin valve' using a zigzag graphene nanoribbon by attaching both ends to electrodes, which were then independently subjected to external magnetic fields (Fig.1). When both ends of the electrodes were polarised in the same direction, electrons flowed easily along the ribbon. And, when both ends of the electrodes were polarised in different directions, the electrons needed to flip their spin to flow through the circuit, thus greatly increasing the resistance of the ribbon graphene. This susceptibility of the current and electrical resistance to external magnetic fields is known as magnetoresistance.

The researchers explained the very large change in the magnetoresistance to be due to the unique symmetry of the electron energy levels in the nanoribbons. Even larger values are expected to be attainable in narrower ribbons.

Kwang Kim says that "the mechanism of the magnetoresistance in the graphene nanoribbon device is different from that seen before. The huge magnetoresistance originates from both the orbital and spin symmetries of graphene zigzag nanoribbons."

Future plans include fabrication of devices through collaboration with experimental groups.

### Reference

1. Kim, W. Y. & Kim, K. S., Prediction of very large values of magnetoresistance in a graphene nanoribbon device. *Nature Nanotech.* 3, 408-412 (2008). | article |

### Author affiliation

WOO YOUN KIM<sup>1</sup> AND KWANG S. KIM<sup>1,2\*</sup>

<sup>1</sup>Department of Chemistry, Center for Superfunctional Materials, Pohang University of Science and Technology, San 31, Hyojadong, Namgu, Pohang, 790-784, Korea

<sup>2</sup>Department of Physics, Pohang University of Science and Technology, San 31, Hyojadong, Namgu, Pohang 790-784, Korea

\* kim@postech.ac.kr

### NPG Asia Materials

# Research Area

## Project #18 Carbon-based Nanoelectronic Devices : Pattern Growth of Graphene Films

The New York Times

[http://www.nytimes.com/2009/01/20/science/20obbend.html?\\_r=1](http://www.nytimes.com/2009/01/20/science/20obbend.html?_r=1)

OBSERVATORY

### With an Ultrathin Film, a Big Step Forward for Flexible Electronics

ARTICLE TOOLS

SPONSORED BY

By HENRY FOUNTAIN

Published: January 19, 2009

Flexible electronics — the kind that might be used in “smart” clothing, say, or in foldable displays that could make reading news online more like reading it in print — are still far from an everyday reality. But scientists in South Korea are reporting a significant advance toward the development of such devices.



Ji Hye Hor

Stretchable graphene electrode patterns transferred onto a silicon-based polymer.

#### Web Link

[Large-scale Pattern Growth of Graphene Films for Stretchable Transparent Electrodes \(Nature\)](#)

#### RSS Feed

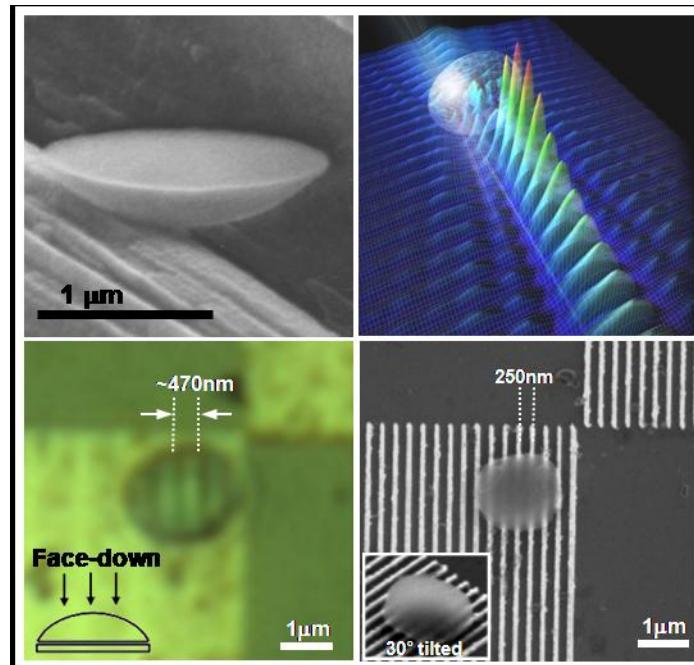
[Get Science News From The New York Times »](#)

---

K. S. Kim, Y. Zhao, H. Jang, S. Y. Lee, J. M. Kim, K. S. Kim, J.-H. Ahn, P. Kim, J.-Y. Choi, and B. H. Hong [Large-scale pattern growth of graphene films for stretchable transparent electrodes](#), *Nature* 457, 706-710 (2009).

## Research Area

### Project #19 Nano-optics : Synthesis of Organic Nanolenses and Theoretical Study of the Optical Properties



# Research Area

## Project #20 Fast DNA sequencing with a graphene-based nanochannel device



nature.com > journal home > archive > issue > letter > full text

NATURE NANOTECHNOLOGY | LETTER

### Fast DNA sequencing with a graphene-based nanochannel device

Seung Kyu Min, Woo Youn Kim, Yeonchoo Cho & Kwang S. Kim

Affiliations | Contributions | Corresponding author

Nature Nanotechnology 6, 162–165 (2011) | doi:10.1038/nnano.2010.283

Received 07 October 2010 | Accepted 22 December 2010 | Published online 06 February 2011

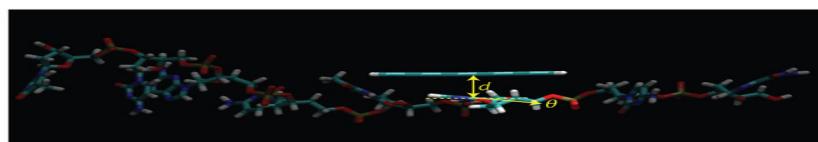
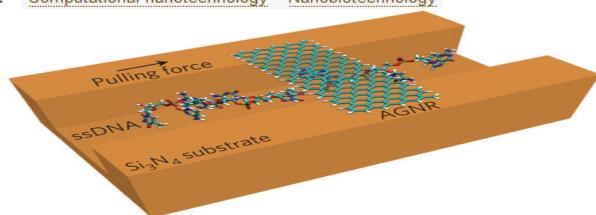
#### Abstract

Abstract • Main • Methods • References • Acknowledgements • Author information •

Supplementary information

Devices in which a single strand of DNA is threaded through a nanopore could be used to efficiently sequence DNA<sup>1, 2, 3, 4, 5, 6, 7, 8, 9</sup>. However, various issues will have to be resolved to make this approach practical, including controlling the DNA translocation rate, suppressing stochastic nucleobase motions, and resolving the signal overlap between different nucleobases<sup>4, 7</sup>. Here, we demonstrate theoretically the feasibility of DNA sequencing using a fluidic nanochannel functionalized with a graphene nanoribbon. This approach involves deciphering the changes that occur in the conductance of the nanoribbon<sup>10, 11</sup>, as a result of its interactions with the nucleobases via  $\pi-\pi$  stacking<sup>12, 13</sup>. We show that as a DNA strand passes through the nanochannel<sup>14</sup>, the distinct conductance characteristics of the nanoribbon<sup>15, 16</sup>, (calculated using a method based on density functional theory coupled to non-equilibrium Green function theory<sup>18–20</sup>) allow the different nucleobases to be distinguished using a data-mining technique and a two-dimensional transient autocorrelation analysis. This fast and reliable DNA sequencing device should be experimentally feasible in the near future.

- print
- email
- pdf options
- download citation
- order reprints
- rights and permissions
- share/bookmark



home > research highlight > DNA sequencing: Graphene bridges the gap  
Published online 09 May 2011

### DNA sequencing: Graphene bridges the gap

Simulations reveal that graphene nanoribbons make the difference for fast nanochannel-based DNA sequencing.

DNA sequencing using current techniques involves chopping up DNA strands into small pieces, followed by amplification, transcription and finally optical identification of the constituent nucleotides. Before personalized medicine based on genetic screening can become a reality, however, this laborious and expensive process must be made simpler and faster. Kwang Kim and co-workers at the Pohang University of Science and Technology in Korea<sup>1</sup> have now proposed a model for a high-speed device that can sequence entire DNA strands using a nanochannel structure in combination with graphene nanoribbons.

The use of conductive nanoscale pores, just wide enough for single DNA strands, for sequencing has been studied for over 15 years. The concept is relatively straightforward: DNA passing through the pores produces a distinctive electrical signature corresponding to its nucleotide composition. Researchers hope to one day develop inexpensive sequencing microchips based on this mechanism, but so far the nanopore scheme has been unable to achieve accurate single nucleotide resolution due to inadequate control of DNA movement.

Kim and his team designed a hypothetical nanochannel device that radically improves sequencing accuracy by introducing graphene nanoribbons — narrow strips of carbon just one atom thick. In this model (see image), a DNA strand flows down a silicon nitride nanochannel and passes beneath a narrow graphene nanoribbon bridge. Because graphene and nucleotides share similar benzene-like rings, attractive aromatic stacking forces can force the DNA to lie flat in the channel, preventing the random movements of the DNA strand that have previously impeded performance.

The simulations also showed that graphene's unique electronic properties allow for highly sensitive nucleotide detection. Electrons usually move with zero resistance through the graphene framework, but in the presence of DNA strands, the conductance of the graphene nanoribbon dips sharply following a pattern specific to each nucleotide. The researchers developed a sophisticated algorithm that turned the time-dependent conductance of the device into a precise, automatic read-out of the DNA sequence.

Importantly, the proposed device can be built using existing clean-room protocols, meaning that it may soon be in the hands of researchers. "Identifying a single nucleotide on a graphene nanoribbon would be a significant first step in this direction," says Kim.

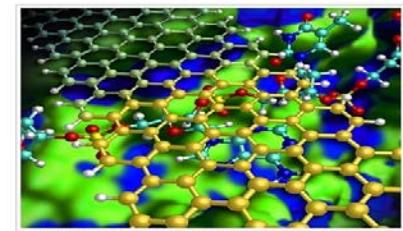


Illustration showing how a graphene nanoribbon (gold) helps to keep a DNA strand (red/blue) flat as it passes through a nanochannel (green/blue).

# Highlights

## 1 Left-handed polyalanine helix (JACS, 2001, 123, 514)

**C&EN**  
CHEMICAL & ENGINEERING NEWS

Click here

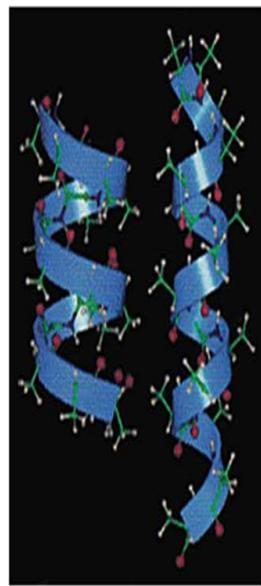
# Nanotechnology

C&EN Special Report

[Home](#) | [This Week's Contents](#) | [ACS Job Bank](#) | [Search C&EN Online](#)

### Left-handed polyalanine helix

Polyalanines can fold into a previously unknown left-handed helix depending on the charge of the terminal ends, according to Kwang S. Kim and coworkers at Pohang University of Science & Technology, South Korea. This new folding motif, named l-helix, has five residues per turn. It is adopted by polyalanines in which both terminal ends are charged:  $\text{NH}_3^+-(\text{alanine})_n-\text{COO}^-$  (at left in figure). Polyalanines with neutral terminal ends [ $\text{CH}_3-(\text{alanine})_n-\text{NH}_2$ , right] fold into the well-known right-handed  $\alpha$ -helix [J. Am. Chem. Soc., 123, 514 (2001)]. The results are based on calculations and simulations of polyalanines with different terminal charge conditions in the gas phase. They do not take into account solvent effects. The researchers suggest that manipulating the terminal ends can be used to control the handedness of a protein fold.



Go to

[Lipid bilayers stack up](#)

[Lost-wax method forms nanoparticles](#)

[Left-handed polyalanine helix](#)

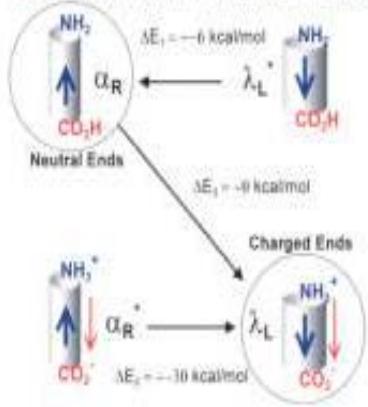
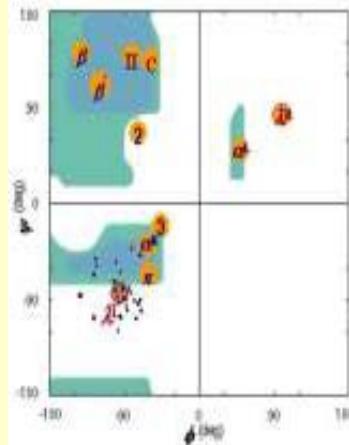
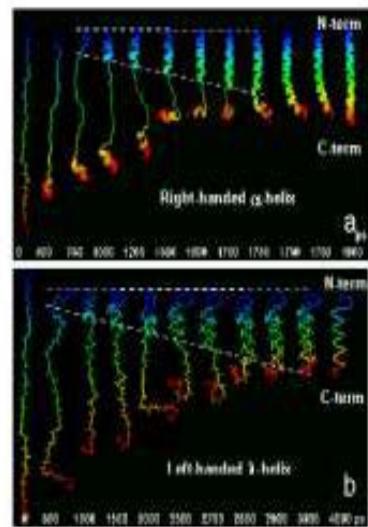
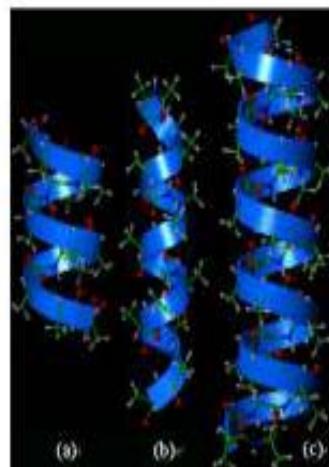
**SCIENCE &  
TECHNOLOGY  
ROUNDUP**

[E-mail this article to a friend](#)

[Print this article](#)

[E-mail the editor](#)

### A New Type of Helix Pattern in Poly-Alanine Peptide



Son et al. J. Am. Chem. Soc. (Comm.) 123, 513 (2001).

# Highlights

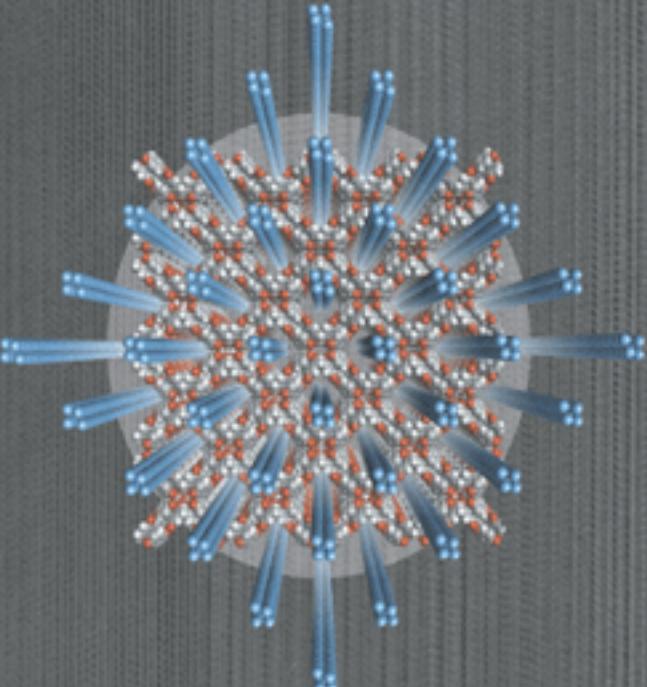
## 2 Ultra Single-Crystalline Silver Nanowire Arrays (Science, 2001, 294, 348, Cover)

UNDERPAID BUT SATISFIED? U.S. LIFE SCIENCES SALARIES PAGE 387

12 October 2001

# Science

Vol. 294 No. 5541  
Pages 253-464 \$9



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

C&EN  
CHEMICAL & ENGINEERING NEWS

[Table of Contents](#)  
[C&EN Classifieds](#)  
[News of the Week](#)  
[Cover Story](#)  
[Editor's Page](#)  
[Business](#)  
[Government & Policy](#)  
[Science/Technology](#)  
[Concentrates](#)  
 [Business](#)  
 [Government & Policy](#)  
 [Science/Technology](#)  
[Education](#)  
[ACS News](#)  
[Calendars](#)  
[Books](#)  
[Digital Briefs](#)  
[ACS Comments](#)  
[Career & Employment](#)  
[Special Reports](#)  
[Letters](#)  
[Newscripts](#)  
[Nanotechnology](#)  
[What's That Stuff?](#)  
[Pharmaceutical Century](#)  
  
[Hot Articles](#)  
[Safety Letters](#)  
[Chemoyclopedia](#)  
  
[Back Issues](#)

[Click here](#)

## Nanotechnology

C&EN Special Report

[Home](#) | [This Week's Contents](#) | [C&EN Classifieds](#)  
[Search C&EN Online](#)

## SCIENCE CONCENTRATES

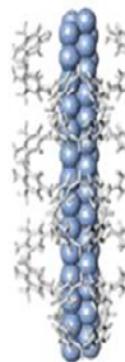
October 29, 2001

Volume 79, Number 44

CENEAR 79 44 p. 22

ISSN 0009-2347

Organic sheath protects silver nanowires



ADAPTED FROM  
SCIENCE © 2001

Metal nanowires less than a nanometer thick promise to be interesting and useful tools, particularly for nanoelectronics. But such wires are so fragile and so sensitive to oxidation that they tend to crumble seconds after being prepared. Now, chemistry professor Kwang S. Kim, director of the [Center for Superfunctional Materials](#) at Pohang University of Science & Technology in South Korea, and his colleagues have designed a sturdy organic framework to house and protect the nanowires. Kim's group has created self-assembled nanotube clusters from calix[4]hydroquinone units [[J. Am. Chem. Soc.](#), **123**, 10748 (2001)]. In mixtures of acetone and water, the calix[4]hydroquinones form "chessboardlike" arrays of rectangular pores, the authors write. They insert silver ions into the tubes, creating wires no more than 0.4 nm in diameter yet with micrometer-scale lengths [Science, **294**, 348 (2001)]. Unlike previous attempts, which required high vacuum or extreme temperatures and pressures, the nanowire arrays can be synthesized under mild conditions.



[Go To](#)  
[Organic sheath  
protects silver  
nanowires](#)

[Benzene-free  
synthesis of  
hydroquinone](#)

[Antispirals in  
chemical reaction  
system](#)

[Secrets of the  
mummy's tomb](#)

[E-mail this article to a  
friend](#)

# Highlights

## 3 Extracting single wall nanotube (PNAS, 2005, 102, 14155)

npg nature publishing group



Groundbreaking research

nature.com | about npg | news@nature.com | naturejobs | natureevents | help | site index

### materialsupdate

my account | e-alert | subscribe | register

SEARCH

go | advanced search

Friday 14 October 2005

#### nanozone news

13 Oct 2005

#### Unravelling the nanotube

**Multiwalled carbon nanotubes are assemblies of several nested nanoscale cylinders. These can be separated from one another simply by tugging.**

PHILIP BALL



Carbon nanotubes consisting of several concentric shells can be pulled open layer by layer, researchers in the USA and South Korea have shown.

They have used the needle tip of an atomic force microscope (AFM) to pull out the nested tubes like a retractable telescope. Because nanotubes are so long relative to their width, and because they don't break easily even when highly deformed, this telescoping extension means that the nanotubes can be reeled out over very long distances.

And because the nanotubes stay stuck to the AFM tip, they can be pulled across empty space to create bridging threads, or 'extruded' into crisscrossing patterns, rather like the strands of a spider's web being reeled out by the spider.

Kwang Kim of Pohang University of Science and Technology in Korea and his co-workers have found that their method also enables them to produce carbon nanotubes much thinner than those grown by conventional methods, by extruding the innermost shell from multiwalled structures. The thinnest of these are just 0.4 nm across — barely more than the spacing between each concentric layer — whereas single-walled carbon nanotubes grown by the usual methods tend to be no thinner than about 1 nm.

The key to opening up nanotubes this way is twofold. First, nanotubes deposited on a solid surface tend to be stuck there by intermolecular forces that, if the tube is long enough, impose strong frictional resistance to their being dragged, by an AFM tip say, over the surface. This means that a tip pushing against a nanotube at right angles to the long axis will deform and eventually break the outer shell(s), exposing inner layers.

Second, the friction between the concentric shells themselves is rather small. (This is often attributed to 'graphite-like' lubrication, although in fact graphite's lubrication properties owe more to intercalated gases between the sheets than to an intrinsic 'slidiness' of the sheets themselves.) This low friction means that the shells will readily telescope out from one another when pulled by the AFM tip.

Such inter-shell slipperiness in multiwalled carbon nanotubes (MWNTs) has

Physics

browse all publications

been exploited previously by Alex Zettl and John Cumings at the University of California at Berkeley to make nanodevices that rotate on nanotube bearings<sup>2</sup>. Zettl's group has also exposed the inner shells of a MWNT by peeling away the outer layers by vaporization<sup>3</sup>.

Kim and colleagues have now shown that the inner shells can be exposed without chemical modifications of this sort. They simply pull out a sharply kinked length of inner tubes from a break in the middle of a MWNT. They have extracted lengths of over tens or even hundreds of micrometres, for they have perfected a method of growing MWNTs more than 10 cm long.

When they perform the telescoping operation for MWNTs resting on a silica surface, the extruded tube becomes progressively thinner as each layer becomes impeded by friction once it gets long enough, so that it breaks afresh to release a further inner shell. These step-like decreases in width can be seen by measuring the nanotube height with an AFM. The steps are generally 1.4 nm high, indicating that the nanotube telescopes in a series of double-shell lengths (the inter-shell spacing is about 0.35 nm). Occasionally the researchers see single-shell ruptures (step heights of 0.7 nm).

Not only does this technique offer a way to make relatively wide hollow carbon 'nanopipes', by removing the inner layers of MWNTs, but it also ultimately frees the very narrow innermost tubes — 10 percent of them have diameters less than 0.7 nm. Kim and colleagues measured the electronic properties of these very narrow single-walled nanotubes and found that, out of 20 samples, all were metallic: none showed semiconducting behaviour.

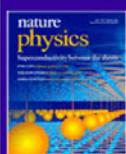
This is surprising. A nanotube's electronic behaviour depends on the precise structure of the helical bands of hexagonal carbon rings that wind along its wall, and in general two thirds of all single-walled carbon nanotubes are predicted to be semiconducting. So there seems to be some feature of the smallest-diameter nanotubes that enforces metallic conductivity — perhaps, say the researchers, the limited number of fullerene-like end caps for such small tubes imposes a certain helicity on the wall structure.

#### References

1. Hong B. H. et al. Extracting subnanometer single shells from ultralong multiwalled carbon nanotubes. *Proc. Natl. Acad. Sci. USA* **102**, 14155–14158 (2005) Article
2. Cumings J. & Zettl A. Low-friction nanoscale linear bearing realized from multiwall carbon nanotubes. *Science* **299**, 602–604 (2002) Article
3. Cumings J., Collins P. G. & Zettl A. Peeling and sharpening multiwall nanotubes. *Nature* **406**, 586 (2000) Article

**nature physics**

The first issue  
has arrived!



October and  
November  
issues available  
FREE online!

*Nature Physics* –  
bringing you  
the best in pure  
and applied  
physics research.

Home | News & features | Nanozone | Research & reviews

Advertising | About us | Contact us

© Nature Publishing Group 2005

Privacy policy

**NPG Resources**  
Nature  
Nature Materials  
Nature Biotechnology  
[news@nature.com](mailto:news@nature.com)  
Nature Physics  
Journal of Exposure Analysis & Environmental Epidemiology  
Naturejobs

**NPG Subject areas**  
Access material from all our publications in your subject area:

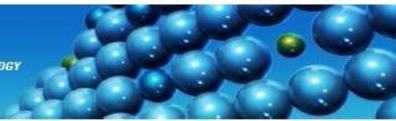
Biotechnology  
Cancer  
Chemistry  
Clinical Practice & Research NEW!  
Dentistry  
Development  
Drug Discovery  
Earth Sciences  
Evolution & Ecology  
Genetics  
Immunology  
Materials Science  
Medical Research  
Microbiology  
Molecular Cell Biology  
Neuroscience  
Pharmacology

# Highlights

## 4 Spintronics: Graphene in a spin (Nature Nanotech., 2008, 3, 408)



in association with  
TOKYO INSTITUTE OF TECHNOLOGY



### featured highlight

#### Spintronics: Graphene in a spin

Published online 04 September 2008

Spintronics is the branch of electronics that exploits an electron's angular momentum—up or down 'spin state'—to encode data, rather than its charge. An important material for the future of spintronics is graphene—2D honeycomb sheet of carbon atoms.

Here, Kim and colleagues of Pohang University of Science and Technology, Korea<sup>1</sup> used first-principles computer simulations to determine the properties attainable in zigzag graphene nanoribbons, and found magnetoresistance values thousands of times larger than the largest value already reported.

The mechanical properties of graphene and its ability to transport electrons ballistically quickly make it of interest for both applications and fundamental studies. It has been shown experimentally that electron spin polarization is preserved for a long time when they are injected into graphene graphene, and that the spin is maintained for a long time within the material, which is important for spintronics.

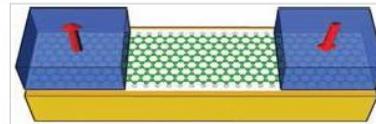


Fig. 1. The spin-valve set-up.

The researchers set up a 'spin valve' using a zigzag graphene nanoribbon by attaching both ends to electrodes, which were then independently subjected to external magnetic fields (Fig.1). When both ends of the electrodes were polarised in the same direction, electrons flowed easily along the ribbon. And, when both ends of the electrodes were polarised in different directions, the electrons needed to flip their spin to flow through the circuit, thus greatly increasing the resistance of the ribbon graphene. This susceptibility of the current and electrical resistance to external magnetic fields is known as magnetoresistance.

The researchers explained the very large change in the magnetoresistance to be due to the unique symmetry of the electron energy levels in the nanoribbons. Even larger values are expected to be attainable in narrower ribbons.

Kwang Kim says that "the mechanism of the magnetoresistance in the graphene nanoribbon device is different from that seen before. The huge magnetoresistance originates from both the orbital and spin symmetries of graphene zigzag nanoribbons."

Future plans include fabrication of devices through collaboration with experimental groups.

### Reference

1. Kim, W. Y. & Kim, K. S., Prediction of very large values of magnetoresistance in a graphene nanoribbon device. *Nature Nanotech.* 3, 408–412 (2008). | article |

### Author affiliation

WOO YOUN KIM<sup>1</sup> AND KWANG S. KIM<sup>1,2\*</sup>

<sup>1</sup>Department of Chemistry, Center for Superfunctional Materials, Pohang University of Science and Technology, San 31, Hyojadong, Namgu, Pohang, 790-784, Korea

<sup>2</sup>Department of Physics, Pohang University of Science and Technology, San 31, Hyojadong, Namgu, Pohang 790-784, Korea

\* kim@postech.ac.kr

# Highlights

## 5 Large-scale pattern growth of graphene films (Nature, 2009, 456, 706)

**The New York Times**

[http://www.nytimes.com/2009/01/20/science/20abbend.html?\\_r=1](http://www.nytimes.com/2009/01/20/science/20abbend.html?_r=1)

OBSERVATORY

### With an Ultrathin Film, a Big Step Forward for Flexible Electronics

ARTICLE TOOLS  
SPONSORED BY

By HENRY FOUNTAIN

Published: January 19, 2009

Flexible electronics — the kind that might be used in “smart” clothing, say, or in foldable displays that could make reading news online more like reading it in print — are still far from an everyday reality. But scientists in South Korea are reporting a significant advance toward the development of such devices.



Ji Hye Hong

Stretchable graphene electrode patterns transferred onto a silicon-based polymer.

#### Web Link

[Large-scale Pattern Growth of Graphene Films for Stretchable Transparent Electrodes \(Nature\)](#)

#### RSS Feed

[Get Science News From The New York Times >](#)

---

K. S. Kim, Y. Zhao, H. Jang, S. Y. Lee, J. M. Kim, K. S. Kim, J.-H. Ahn, P. Kim, J.-Y. Choi, and B. H. Hong. [Large-scale pattern growth of graphene films for stretchable transparent electrodes](#), *Nature* 457, 706-710 (2009).

# Highlights

## 6 Nanolenses: Beyond the limit (Nature, 2009, 460, 498)

npg nature asia-pacific  
npg asia materials in association with TOKYO INSTITUTE OF TECHNOLOGY

home reviews highlights about editorial committee advisory board register

home » featured highlight » Nanolenses: Beyond the limit

NPG Asia Materials featured highlight | doi:10.1038/asiamat.2009.18  
Published online 27 October 2009

### Nanolenses: Beyond the limit

One of the fundamental constraints on the maximum resolution in geometrical optics is the diffraction limit. While technologies such as fluorescence microscopy can overcome this limit, conventional optical microscopy on the nanoscale is a challenge. Researchers from Pohang University of Science and Technology in Korea, with colleagues from Sungkyunkwan University in Korea and Columbia University in the USA<sup>1</sup>, have now fabricated nanolenses capable of optical resolution beyond these limitations.

Miniature optical lenses are used for compact imaging and detection systems, and for focusing light onto tiny spots. However, these applications have been limited by diffraction to features larger than about half the wavelength of the light used. However, the situation changes when the lens size itself approaches the wavelength of light. "The resolution we achieved is much better than the diffraction limit, because the lens size is comparable to the wavelength, which leads to extremely short focal lengths," says Kwang Kim, leader of the team.

The researchers fabricated the tiny lenses using an organic molecule — calix[4]hydroquinone (CHQ) — that self-assembles into nanostructures such as nanotubes, nanospheres and nanolenses. Plano-spherical geometry was obtained by covering the structures with a thin CHQ film. Any material released from the nanostructures accumulated underneath the thin film, growing in a direction away from the substrate such that the plano-spherical lenses thus formed could be easily released.

The nanolenses had extremely small focal lengths, which made it possible to clearly resolve stripe patterns with a line spacing of only 250 nm (Fig. 1). Features of this small size cannot be resolved by conventional optical microscopes. As the wavelength of light used for the optical microscopy was 472 nm, the imaging of features of smaller than 220 nm clearly demonstrates that the researchers had overcome the limit of classical optics, which is 260 nm for this experimental configuration.

The nanolenses may be used in a number of applications ranging from optical lithography and imaging to memory devices, for which the technology could increase the storage density of optical disks. This new approach developed by Kim and his team marks the birth of a truly nanoscale optical microscope.



Recommend article ▶

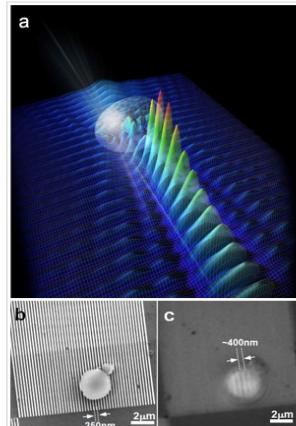


Fig. 1: (a) Simulation illustrating the ultra short focal length of the nanolenses. (b) Scanning electron microscope image of 250 nm-wide stripes. (c) The stripes are resolved using the nanolens, but not by conventional optical microscopy.

### current reviews

- ▶ The electronic properties of graphene and carbon nanotubes
- ▶ The future of plastic optical fiber
- ▶ Technical evolution of liquid crystal displays

### site resources

- ▶ recommend article
- ▶ RSS feed
- ▶ share article

### search & explore

#### search

 GO

#### explore

- photonic crystal
- crystal
- ferrite films

▶ more keywords



### news & events

#### Nano Materials for the Future, 24th November 2009

Tokyo Institute of Technology GCOE for Program for the Education and Research Center for Materials Innovation...

#### 3rd AEARU Advanced Materials Science

Workshop, POSCO International Center,

POSTECH, Korea, 11-13th November 2009

AEARU, the Association of

East Asian Research

Universities presents a

workshop to exchange information...

### Reference

1. Lee, J.Y.,<sup>1</sup> Hong, B.H.,<sup>1,2</sup> Kim, W.Y.,<sup>1</sup> Min, S.K.,<sup>1</sup> Kim, Y.,<sup>1</sup> Jouravlev, M.V.,<sup>1</sup> Bose, R.,<sup>3</sup> Kim, K.S.,<sup>2</sup> Hwang, I.-C.,<sup>1</sup> Kaufman, L.J.,<sup>4</sup> Wong, C.W.,<sup>3</sup> Kim, P.<sup>5</sup> & Kim, K.S.<sup>1\*</sup> Near-field focusing and magnification through self-assembled nanoscale spherical lenses. *Nature* **460**, 498 (2009). | article □

# Highlights

## 7 Fast DNA sequencing with a graphene-based nanochannel device, *Nature Nanotechnology* (*Nature*, 2009, 460, 498) and *NPG Asia Materials*

nature asia-pacific

npg asia materials in association with TOKYO INSTITUTE OF TECHNOLOGY

home current content reviews highlights archive about editorial committee advisory board

home » research highlight » DNA sequencing: Graphene bridges the gap

NPG Asia Materials research highlight | doi:10.1038/asiamat.2011.72

Published online 09 May 2011

### DNA sequencing: Graphene bridges the gap

**Simulations reveal that graphene nanoribbons make the difference for fast nanochannel-based DNA sequencing.**

DNA sequencing using current techniques involves chopping up DNA strands into small pieces, followed by amplification, transcription and finally optical identification of the constituent nucleotides. Before personalized medicine based on genetic screening can become a reality, however, this laborious and expensive process must be made simpler and faster. Kwang Kim and co-workers at the Pohang University of Science and Technology in Korea<sup>1</sup> have now proposed a model for a high-speed device that can sequence entire DNA strands using a nanochannel structure in combination with graphene nanoribbons.

The use of conductive nanoscale pores, just wide enough for single DNA strands, for sequencing has been studied for over 15 years. The concept is relatively straightforward: DNA passing through the pores produces a distinctive electrical signature corresponding to its nucleotide composition. Researchers hope to one day develop inexpensive sequencing microchips based on this mechanism, but so far the nanopore scheme has been unable to achieve accurate single nucleotide resolution due to inadequate control of DNA movement.

Kim and his team designed a hypothetical nanochannel device that radically improves sequencing accuracy by introducing graphene nanoribbons — narrow strips of carbon just one atom thick. In this model (see image), a DNA strand flows down a silicon nitride nanochannel and passes beneath a narrow graphene nanoribbon bridge. Because graphene and nucleotides share similar benzene-like rings, attractive aromatic stacking forces can force the DNA to lie flat in the channel, preventing the random movements of the DNA strand that have previously impeded performance.

The simulations also showed that graphene's unique electronic properties allow for highly sensitive nucleotide detection. Electrons usually move with zero resistance through the graphene framework, but in the presence of DNA strands, the conductance of the graphene nanoribbon dips sharply following a pattern specific to each nucleotide. The researchers developed a sophisticated algorithm that turned the time-dependent conductance of the device into a precise, automatic read-out of the DNA sequence.

Importantly, the proposed device can be built using existing clean-room protocols, meaning that it may soon be in the hands of researchers. "Identifying a single nucleotide on a graphene nanoribbon would be a significant first step in this direction," says Kim.

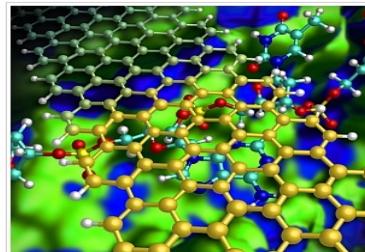


Illustration showing how a graphene nanoribbon (gold) helps to keep a DNA strand (red/blue) flat as it passes through a nanochannel (green/blue).

Full text access provided to Pohang University

nature nanotechnology

nature.com ► journal home ► archive ► issue ► letter ► full text

NATURE NANOTECHNOLOGY | LETTER

### Fast DNA sequencing with a graphene-based nanochannel device

Seung Kyu Min, Woo Youn Kim, Yeonchoo Cho & Kwang S. Kim

Affiliations | Contributions | Corresponding author

*Nature Nanotechnology* 6, 162–165 (2011) | doi:10.1038/nnano.2010.283

Received 07 October 2010 | Accepted 22 December 2010 | Published online 06 February 2011

#### Abstract

Abstract • Main • Methods • References • Acknowledgements • Author information •

Supplementary information

Devices in which a single strand of DNA is threaded through a nanopore could be used to efficiently sequence DNA.<sup>1, 2, 3, 4, 5, 6, 7, 8, 9</sup> However, various issues will have to be resolved to make this approach practical, including controlling the DNA translocation rate, suppressing stochastic nucleobase motions, and resolving the signal overlap between different nucleobases.<sup>4, 7</sup> Here, we demonstrate theoretically the feasibility of DNA sequencing using a fluidic nanochannel functionalized with a graphene nanoribbon. This approach involves deciphering the changes that occur in the conductance of the nanoribbon<sup>10, 11</sup> as a result of its interactions with the nucleobases via  $\pi-\pi$  stacking<sup>12, 13</sup>. We show that as a DNA strand passes through the nanochannel<sup>14</sup>, the distinct conductance characteristics of the nanoribbon<sup>15, 16</sup>, calculated using a method based on density functional theory coupled to non-equilibrium Green function theory<sup>18–20</sup>, allow the different nucleobases to be distinguished using a data-mining technique and a two-dimensional transient autocorrelation analysis. This fast and reliable DNA sequencing device should be experimentally feasible in the near future.

Subject terms: Computational nanotechnology • Nanobiotechnology

- print
- email
- pdf options
- download citation
- order reprints
- rights and permissions
- share/bookmark