El grafeno y sus propiedades únicas

F. Guinea

imdea nanociencia

EXCELENCIA SEVERO OCHOA 2017 - 2021

AGENCIA ESTATAL DE INVESTIGACIÓN

A. Castro-Neto (Boston U.), N. M. R. Peres (U. Minho, Portugal), E. V. Castro, J. dos Santos (Porto), J. Nilsson (Boston U, Göteborg.), A. Morpurgo (Delft), M. I. Katsnelson (Nijmegen), D. Huertas-Hernando (Trondheim, Norway), D. P. Arovas, M. M. Fogler (U. C. San Diego), J. González, F. G., G. León, M. P. López-Sancho, T. Stauber, J. A. Vergés, M. A. H. Vozmediano, B Wunsch (CSIC, Madrid), A. K. Geim, K. S. Novoselov (U. Manchester), A. Lanzara (U. C. Berkeley), M. Hentschel (Dresden), E. Prada, P. San-José (Karlsruhe, Lancaster), J. L. Mañes (U. País Vasco, Spain), F. Sols (U. Complutense, Madrid), E. Louis (U. Alicante, Spain), A. L. Vázquez de Parga, R. Miranda, M. M. Ugeda, I. Brihuega, J. M. Gómez-Rodríguez (U. Autónoma, Madrid), B. Horovitz (Beersheva), P. Le Doussal (ENS, Paris), A. K. Savchenko (Exeter), F. von Oppen (Berlin), A. Akhmerov (Leyden), M. Wimmer (Regensburg, Leyden), T. Low (Purdue), V. Parente, A. Tagliacozzo (Naples), D. Rainis, F. Taddei, M. Polini (Pisa), V. I. Fal'ko (Lancaster), M. F. Crommie (UC Berkeley)..

Residencia de Estudiantes

Resumen

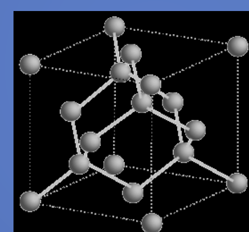
- Historia del grafeno
- Las propiedades especiales del grafeno
- Aplicaciones del grafeno

Residencia de Estudiantes, Madrid, 16 Noviembre 2018

La física de la materia condensada

De los átomos (10^{-9} metros, 1 nanometro) a los materiales macroscópicos (escala humana, $\sim$ 1 metro).

> The fundamental laws necessary for the mathematical treatment of a large part of physics and the whole of chemistry are thus completely known, and the difficulty lies only in the fact that application of these laws leads to equations that are too complex to be solved.
>
> Paul Dirac (1929)



Silicio

Física de altas energías

Matemáticas

Química

Física de la materia condensada

Ingeniería

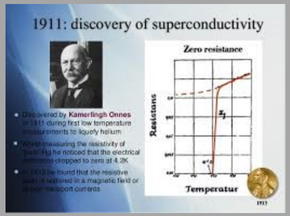
Biología

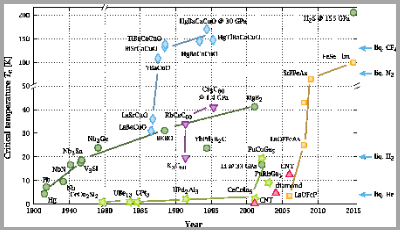
La física de la materia condensada

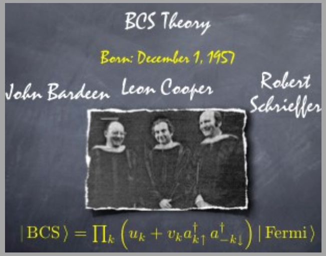
Transistor

Las ecuaciones de Maxwell justifican la financiación de la investigación básica por al menos doscientos años,
P. M. Etxenike, DIPC, San Sebastián.

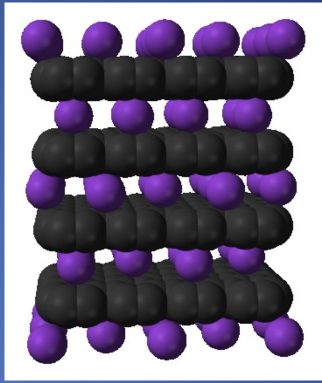
Superconductividad







Materiales similares

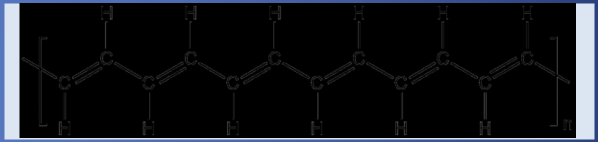


Compuestos intercalares de grafito:

Planos de grafeno y planos metálicos.

Superconductores a baja temperatura.

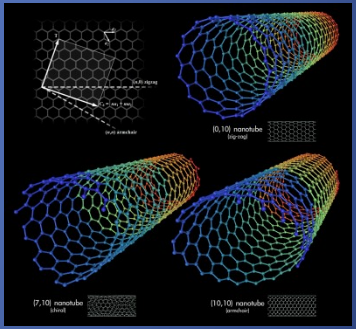
Poliacetileno:



Cadena de átomos de carbono.

Primer polímero unidimensional metálico

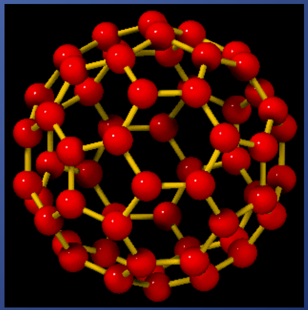
A. J. Heeger, A. G. MacDiarmid, H. Shirakawa, reciben el premio Nobel en química en 2000



Nanotubos de carbono:

Duros, flexibles, pueden ser metálicos o semiconductores.

Fullerenos:



Esfera de átomos de carbono con forma de balón de fútbol.

R. F. Curl Jr., H. W. Kroto, R. E. Smalley, , reciben elpremio Nobel en química en 1994

Some early visionaries

The universe (which others call the Library) is composed of an indefinite and perhaps infinite number of hexagonal galleries

The idealists argue that the hexagonal rooms are a necessary form of absolute space or, at least, of our intuition of space. They reason that a triangular or pentagonal room is inconceivable.

The library of Babel, Jorge Luis Borges

Quino

El comienzo

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.

The ability to control electronic properties of a material by externally applied voltage is at the heart of modern electronics. In many cases, it is the electric field effect that allows one to vary the carrier concentration in a semiconductor device and, consequently, change an electric current through it. As the semiconductor industry is nearing the limits of performance improvements for the current technologies dominated by silicon, there is a constant search for new, nontraditional materials whose properties can be controlled by the electric field. The most notable recent examples of such materials are organic conductors (*1*) and carbon nanotubes (*2*). It has long been tempting to extend the use of the field effect to metals [e.g., to develop all-metallic transistors that could be scaled down to much smaller sizes and would consume less energy and operate at higher frequencies than traditional semiconducting devices (*3*)]. However, this would require atomically thin metal films, because the electric field is screened at extremely short distances (<1 nm) and bulk carrier concentrations in metals are large compared to the surface charge that can be induced by the field effect. Films so thin tend to be thermodynamically unstable, becoming discontinuous at thicknesses of several nanometers; so far, this has proved to be an insurmountable obstacle to metallic electronics, and no metal or semimetal has been shown to exhibit any notable (>1%) field effect (*4*).

We report the observation of the electric field effect in a naturally occurring two-dimensional (2D) material referred to as few-layer graphene (FLG). Graphene is the name given to a single layer of carbon atoms densely packed into a benzene-ring structure, and is widely used to describe properties of many carbon-based materials, including graphite, large fullerenes, nanotubes, etc. (e.g., carbon nanotubes are usually thought of as graphene sheets rolled up into nanometer-sized cylinders) (*5*–*7*). Planar graphene itself has been presumed not to exist in the free state, being unstable with respect to the formation of curved structures such as soot, fullerenes, and nanotubes (*5*–*14*).

[1]Department of Physics, University of Manchester, Manchester M13 9PL, UK. [2]Institute for Microelectronics Technology, 142432 Chernogolovka, Russia.

*To whom correspondence should be addressed. E-mail: geim@man.ac.uk

666 22 OCTOBER 2004 VOL 306 SCIENCE www.sciencemag.org

Monocapa de carbono.
Se puede añadir carga eléctrica.

Two-dimensional atomic crystals

K. S. Novoselov*, D. Jiang*, F. Schedin*, T. J. Booth*, V. V. Khotkevich*, S. V. Morozov†, and A. K. Geim*‡

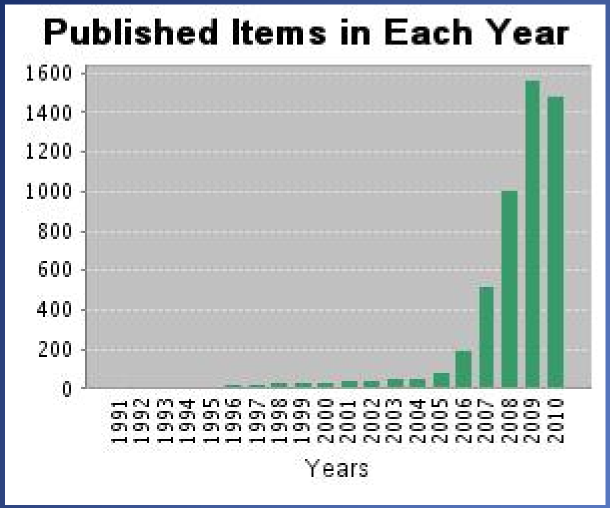
*Centre for Mesoscience and Nanotechnology and School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom; and †Institute for Microelectronics Technology, Chernogolovka 142432, Russia

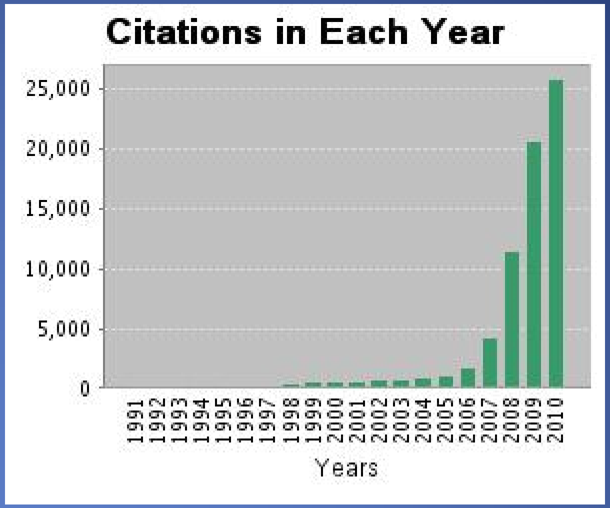
Edited by T. Maurice Rice, Swiss Federal Institute of Technology, Zurich, Switzerland, and approved June 7, 2005 (received for review April 6, 2005)

www.pnas.org/cgi/doi/10.1073/pnas.0502848102 PNAS | July 26, 2005 | vol. 102 | no. 30 | 10451–10453

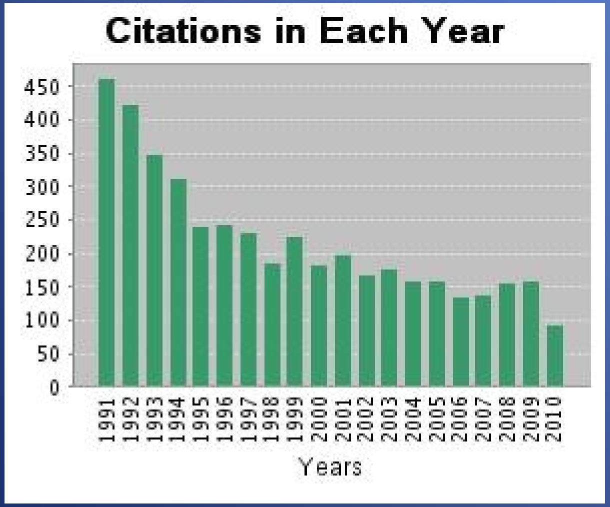
Fabricación de grafeno

+





Grafeno (sin incluir los nanotubos de carbono)



Citas a:
Possible High-Tc Superconductivity in the Ba-La_Cu-O System, J. G. Bednorz and K. A. Müller, Zeits. für Phys. **64**, 189 (1986)

The Big Bang Theory, Feb. 2010

Stockholm, May 2010

Stockholm, Dec. 2010

esy of M. A. H.
ediano

A. K. Geim, interview less than one hour after the announcement

[AS] No, no, it's ok. I mean, for a start, the isolation of graphene using Scotch tape seems beautifully non-Boffin-like and wonderfully accessible. It gives hope to all.

[AG] Yeah, it's a great educational experiment. In a sense not that it's isolation of graphene: **it shows people that, in fact, you don't need to be in a Harvard or Cambridge, in one of the universities which collect the smartest people and the best equipment. You can be in the second or even third rated universities in terms of facilities and, whatever, prestige, but you still can do something amazing** and something which, I hope, this is an example, which brings more enthusiasm to young generation of inspiring scientists, that they can do something without being at the best place at the best time.

[AS] Hmm, hmm, that's a nice message. The trick in having this approach of playing with new things while finishing off old things must be getting the balance right. You have to learn to find new areas while not neglecting the one's you're working on.

[AG] Yeah, balance is important. **And, putting long hours because nothing comes for free. If you ... It's extremely hard, it's extremely hard.** First of all, not all the experiments I mentioned – levitating frog, gecko tape, graphene – were originally funded by anyone, ok. And, only graphene later got some research grants to continue this work on another level. But, essentially, you have your work for which you are paid and, yeah, you have not to neglect this work. So, at the same time, you want to start a new subject and, it requires a lot of hours to find the previous literature because, if you are not an expert, you have to look through the literature not to invent the wheel again. And, this is the hardest one.

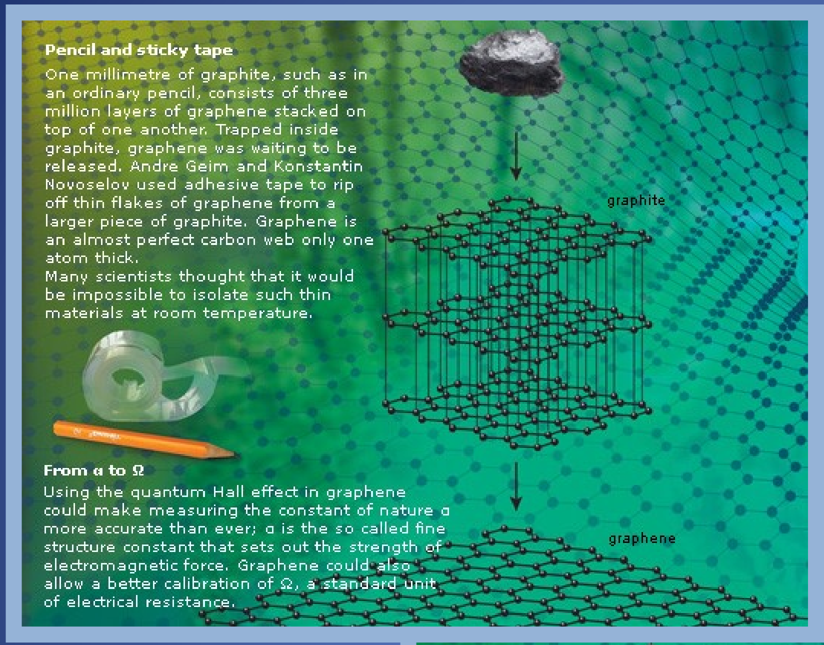
And, in addition, OK, balance is not as important as courage. Because ... Courage is really important because you stumble on something, ok, which you are still not confident. You feel, ok, sort of you feel secure within your own research area and what you are doing. If you are doing something new, you always can be considered as a fool, inventing the wheel, as I said. Or, you can just be wasting your time. So, the courage is not social courage. The courage is about, ok, investing your time into something which might turn out like a blip.

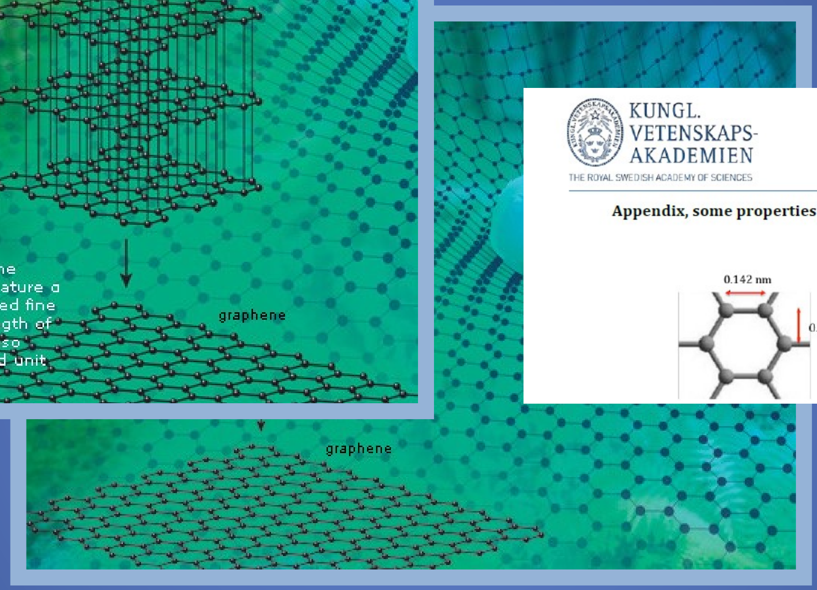
Andre Geim, entrevista en la radio pública sueca una hora después de conocer que había recibido el premio Nobel

… Ello muestra a la gente que, de hecho, no es necesario estar en Harvard o Cambridge, en una de las universidades que coleccionan a la gente más brillante o los mejores equipos. Tú puedes estar en una universidad de segunda o hasta tercera categoría en términos de medios, y, de lo que sea, prestigio, y aún así, hacer cosas impresionantes, …..

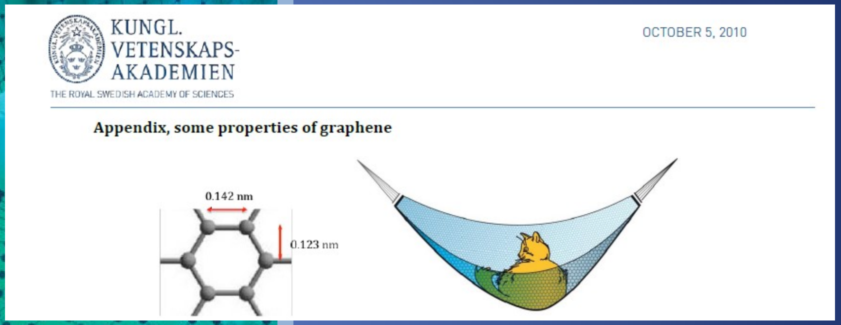
… y poniendo muchas horas, porque nada es gratis, … Es difícil, es muy difícil, …

Grafeno, la red cristalina perfecta

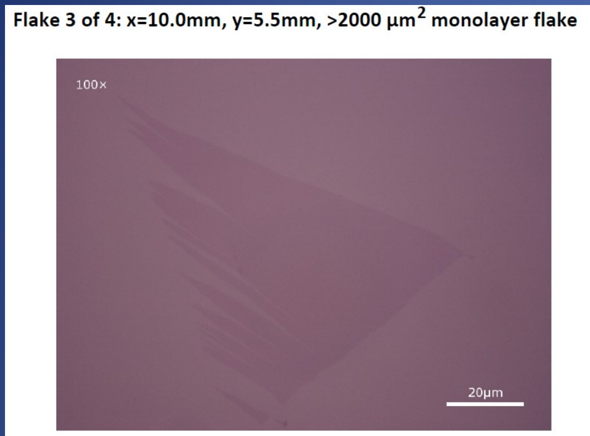




De la nominación al premio Nobel, Real Academia Sueca de Ciencias, octubre 2010



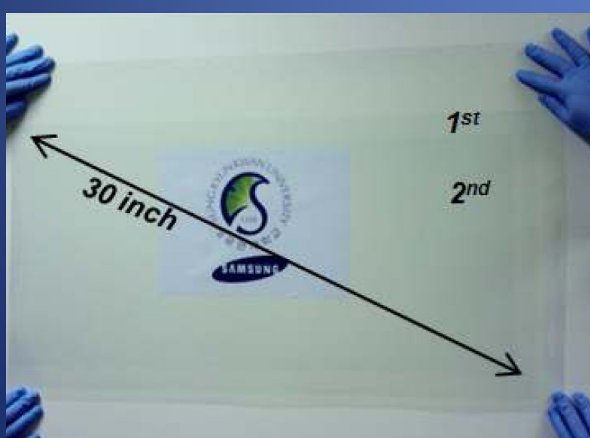
El grafeno tiene un átomo de grosor



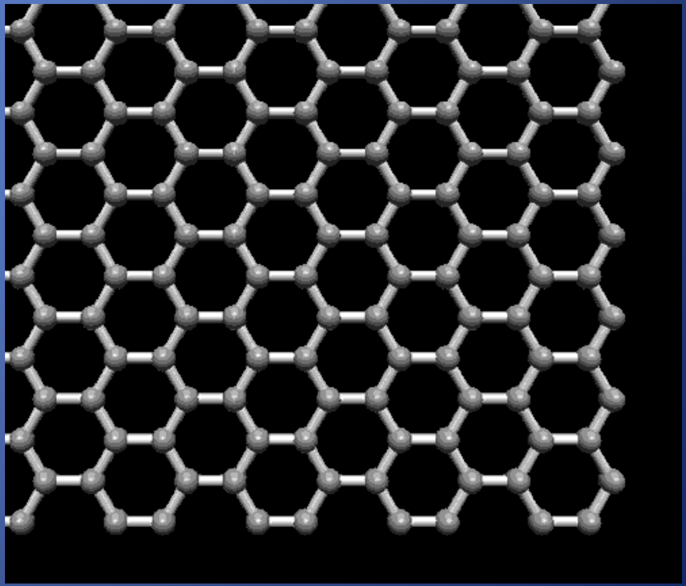
Muestra a la venta por Graphene Industries, Manchester
Precio de cuatro trozos: 1.100 £
Precio aproximado por gramo: 10^{14}€ (EU, USA GDP/yr 1.5×10^{15}€)

Extraordinariamente resistente
Pocos defectos
Fácil de manipular

Contiene un solo elemento, carbono
Enlaces σ muy robustos
Cuatro electrones de valencia



Muestra por CVD hecha
por SKKU, Corea



¿Porqué hay cristales bidimensionales?

STATISTICAL PHYSICS

by

L. D. LANDAU AND E. M. LIFSHITZ

INSTITUTE OF PHYSICAL PROBLEMS,
U.S.S.R. ACADEMY OF SCIENCES

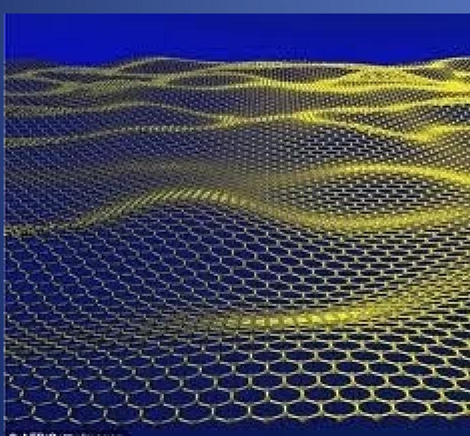
Volume 5 of *Course of Theoretical Physics*

PART 1

THIRD EDITION, REVISED AND ENLARGED
by E. M. LIFSHITZ and L. P. PITAEVSKII

ered). It is easy to see, however, that the thermal fluctuations "smooth out" such a crystal, so that ϱ = constant is the only possibility: the mean

Fluctuaciones térmicas: $$\langle \vec{u}(L)\vec{u}(0)\rangle \approx \frac{k_B T}{B}\log\left(\frac{L}{d}\right)$$



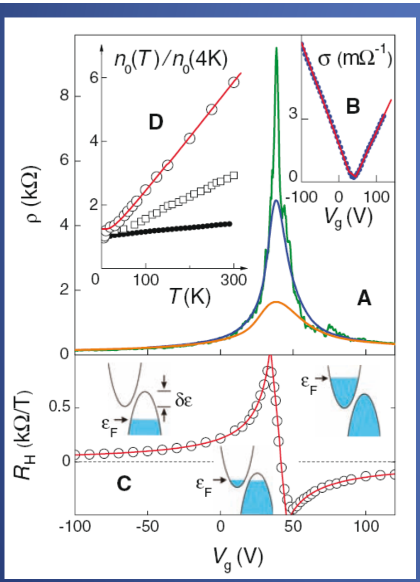
$B_{grafeno}$ =22 eV Å^{-2} = 352 N/m
$B_{diamante}$ x d=52.4 N/m

$$T = 300\ K$$
$$L = 1\ Km$$
$$\langle \vec{u}(L)\vec{u}(0)\rangle \approx 0.03\ \overset{0}{\text{A}}$$

El grafeno es metálico

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]



$$\vec{v}_d = \mu \vec{E}$$

μ_{gr}=30.000 – 1.000.000 $cm^2V^{-1}s^{-1}$

$|n_{min}|=10^8\ cm^{-2}$, $|n_{max}|=10^{13}\ cm^{-2}$

Dispositivo típico de silicio a temperatura ambiente:

μ_{Si} ≈ 1.400 $cm^2V^{-1}s^{-1}$

Las propiedades electrónicas del grafeno pueden ser variadas en un rango muy amplio.

Other two dimensional compounds: BN, silicene?

El grafeno no es ni un metal ni un aislante convencional

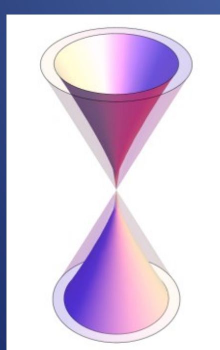
Teoría

ELSEVIER
Nuclear Physics B424 [FS] (1994) 595–618
NUCLEAR PHYSICS B [FS]

Non-Fermi liquid behavior of electrons in the half-filled honeycomb lattice
(A renormalization group approach)

J. González [a], F. Guinea [b], M.A.H. Vozmediano [c]
[a] Instituto de Estructura de la Materia, CSIC, Serrano 123, E-28006 Madrid, Spain
[b] Instituto de Ciencia de Materiales, CSIC, Cantoblanco, E-28049 Madrid, Spain
[c] Departamento de Ingeniería, Universidad Carlos III de Madrid, Avda. Mediterráneo s / n, E-28913 Leganés (Madrid), Spain

Screening processes are anomalous.
The Fermi velocity is renormalized, as for relativistic elementary particles

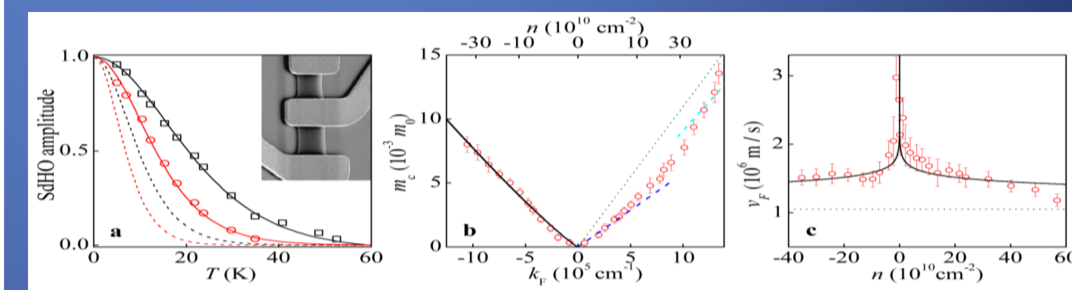


nature physics
LETTERS
PUBLISHED ONLINE: 24 JULY 2011 | DOI: 10.1038/NPHYS2049

Dirac cones reshaped by interaction effects in suspended graphene

D. C. Elias[1], R. V. Gorbachev[1], A. S. Mayorov[1], S. V. Morozov[2], A. A. Zhukov[3], P. Blake[3], L. A. Ponomarenko[1], I. V. Grigorieva[1], K. S. Novoselov[1], F. Guinea[4]* and A. K. Geim[1,3]

Experimentos



Algunas propiedades básicas

- El grafeno es una membrana de un átomo de espesor.
- Es un metal, cuyas propiedades se pueden variar.
- Es el material más duro conocido.
- Es inerte químicamente, e impermeable a casi todos los elementos.
- Los electrones en el grafeno no tienen masa, como ciertas partículas elementales.

Electrones y deformaciones del cristal

Teoría

VOLUME 69, NUMBER 1 PHYSICAL REVIEW LETTERS 6 JULY 1992

Continuum Approximation to Fullerene Molecules

José González,[1] Francisco Guinea,[2],[a] and M. Angeles H. Vozmediano[1]
[1]*Instituto de Física Fundamental, Consejo Superior de Investigaciones Científicas, Serrano 123, 28006 Madrid, Spain*
[2]*The Harrison M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109-1120*

PHYSICAL REVIEW B **77**, 075422 (2008)

Midgap states and charge inhomogeneities in corrugated graphene

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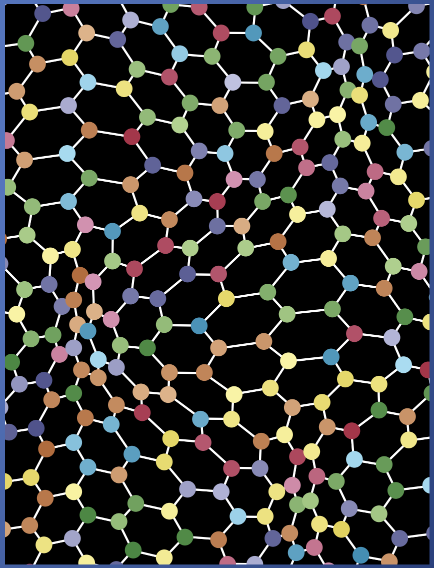
M. A. H. Vozmediano
Instituto de Ciencia de Materiales de Madrid (CSIC), Cantoblanco, Madrid 28049, Spain

LETTERS
PUBLISHED ONLINE: 27 SEPTEMBER 2009 | DOI: 10.1038/NPHYS1420
nature physics

Energy gaps and a zero-field quantum Hall effect in graphene by strain engineering

F. Guinea[1]*, M. I. Katsnelson[2] and A. K. Geim[3]*

Las tensiones modifican las propiedades electrónicas y simulan un campo magnético



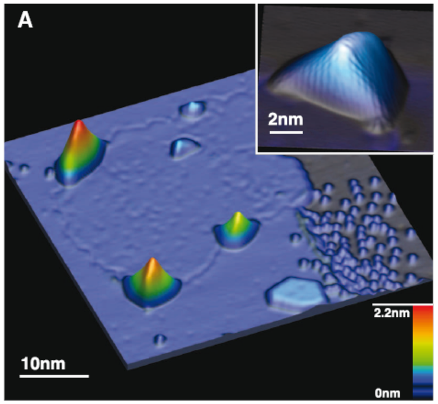
Electrones y defomaciones cristalinas

Experimentos

Strain-Induced Pseudo–Magnetic Fields Greater Than 300 Tesla in Graphene Nanobubbles

N. Levy,[1,2*†] S. A. Burke,[1*‡] K. L. Meaker,[1] M. Panlasigui,[1] A. Zettl,[1,2] F. Guinea,[3] A. H. Castro Neto,[4] M. F. Crommie[1,2§]

30 JULY 2010 VOL 329 SCIENCE



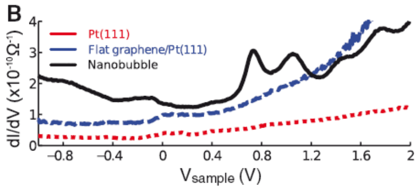


Fig. 1. STM images and STS spectra taken at 7.5 K. (**A**) Graphene monolayer patch on Pt(111) with four nanobubbles at the graphene-Pt border and one in the patch interior. Unreacted ethylene molecules and a small hexagonal graphene patch can be seen in the lower right ($I_{tunneling}$ = 50 pA, V_{sample} = 350 mV, 3D z-scale enhanced 4.6×). (Inset) High-resolution image of a graphene nanobubble showing distorted honeycomb lattice resulting from strain in the bubble ($I_{tunneling}$ = 50 pA, V_{sample} = 200 mV, max z = 1.6 nm, 3D z-scale enhanced 2×). (**B**) STS spectra of bare Pt(111), flat graphene on Pt(111) (shifted upward by 3×10^{-11} ohm^{-1}), and the center of a graphene bubble (shifted upward by 9×10^{-11} ohm^{-1}). V_{mod} = 20 mV.

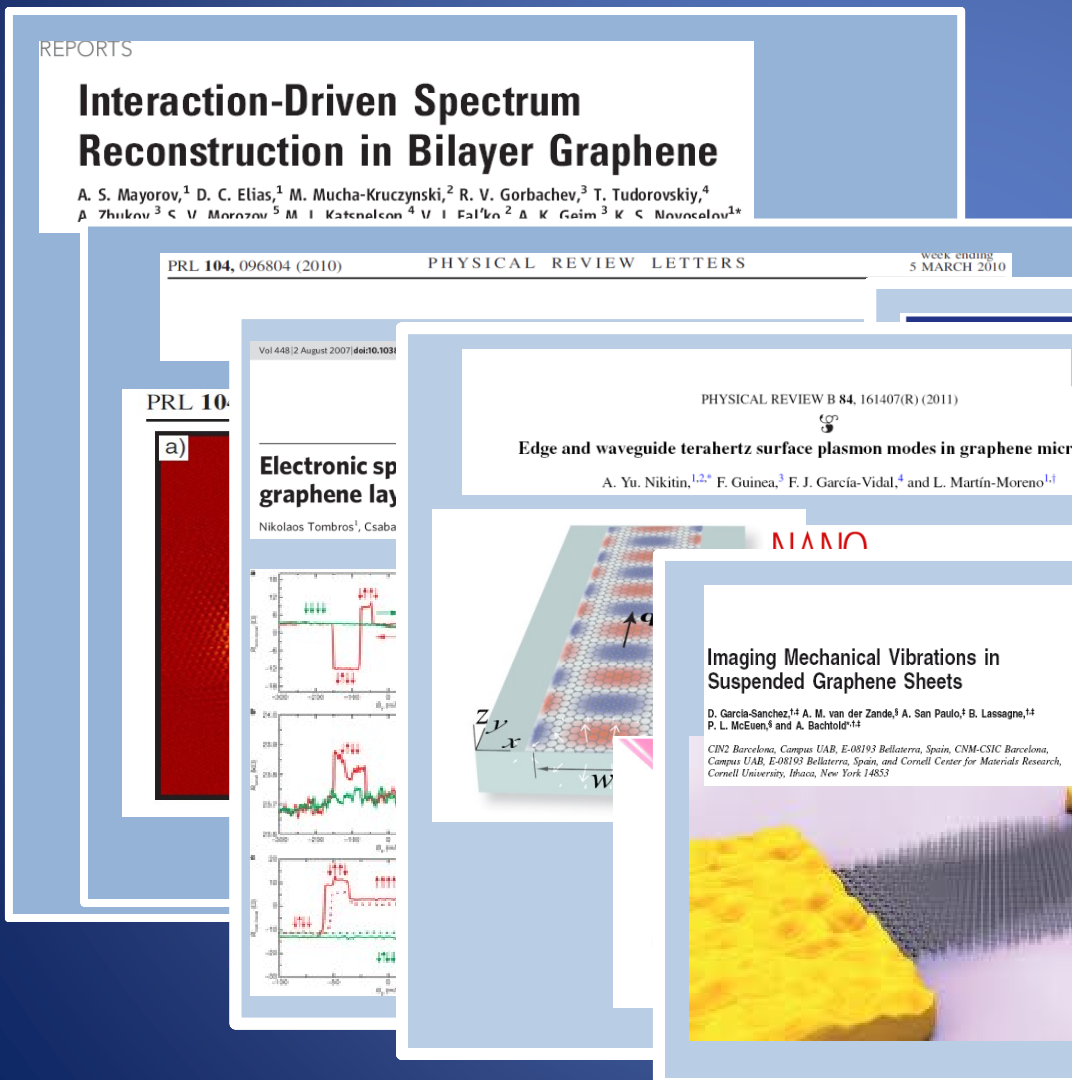
¿Ingeniería de tensiones?

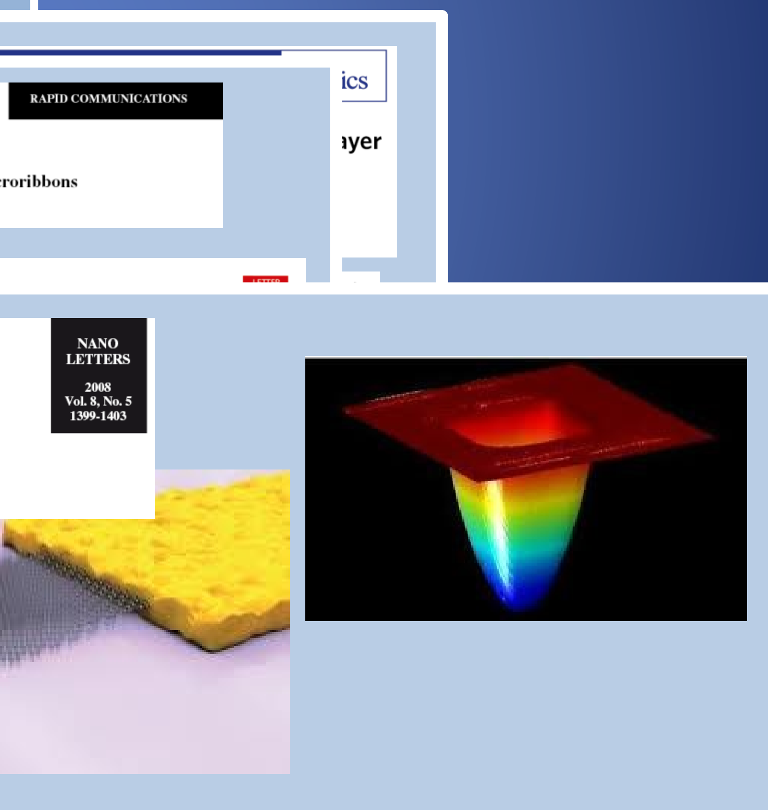
LOS SUPERLATIVOS DEL GRAFENO

- El material más delgado imaginable
- Mayor relación superficie/volumen (~2,700 m^2 por gramo)
- El material más irrompible medido nunca (límite teórico)
- Material más duro (constantes elásticas mayores que el diamante)
- Material más deformable (hasta un 20% elásticamente)
- Conductividad térmica record (también mejor que el diamante)
- Mayor densidad de corriente a temperatura ambiente (100 veces la del cobre)
- Completamente impermeable (incluso los átomos de helio son detenidos)
- La movilidad electrónica más elevada (100 veces mayor que el silicio)
- Conduce electricidad en ausencia de electrones
- Los portadores de carga más ligeros (masa igual a cero)
- Recorrido libre medio más largo a temperatura ambiente (micras)

Más propiedades sorprendentes

- Nuevas fases en bicapas de grafeno
- Defectos y magnetismo
- Transporte de espín
- Estructuras híbridas
- Óptica y plasmónica del prafeno
- Osciladores cuánticos, …





Superconductivity in graphene. American Physical Society March Meeting, Los Angeles 2018

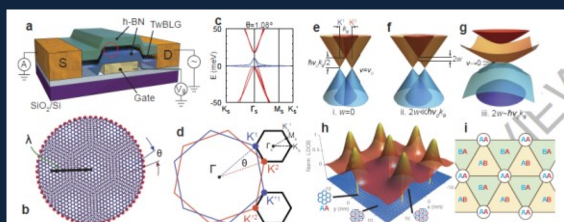

nature Accelerated Article Preview

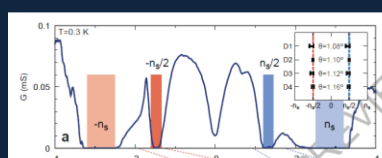
LETTER

doi:10.1038/nature26154

Correlated insulator behaviour at half-filling in magic-angle graphene superlattices

Yuan Cao, Valla Fatemi, Ahmet Demir, Shiang Fang, Spencer L. Tomarken, Jason Y. Luo, J. D. Sanchez-Yamagishi, K. Watanabe, T. Taniguchi, E. Kaxiras, R. C. Ashoori & P. Jarillo-Herrero





Pablo Jarillo-Herrero @ MIT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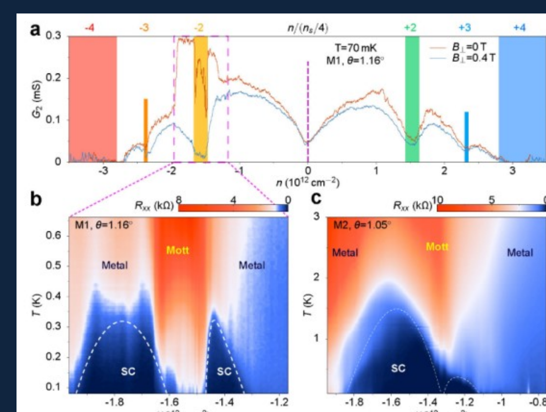
ARTICLE

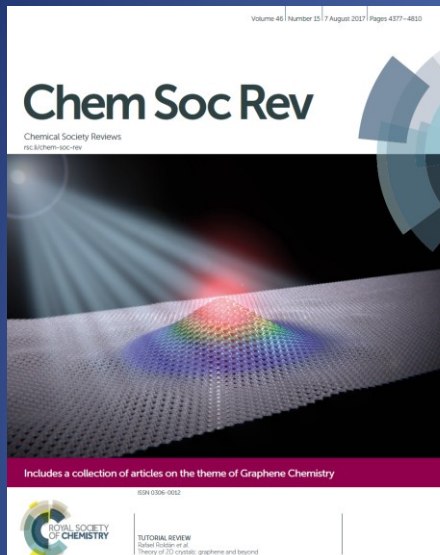
doi:10.1038/nature26160

Unconventional superconductivity in magic-angle graphene superlattices

Yuan Cao, Valla Fatemi, Shiang Fang, Kenji Watanabe, Takashi Taniguchi, Efthimios Kaxiras & Pablo Jarillo-Herrero



Many new two dimensional materials



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Theory of 2D crystals: graphene and beyond

Rafael Roldán,[*a] Luca Chirolli,[b] Elsa Prada,[c] Jose Angel Silva-Guillén,[b] Pablo San-Jose[a] and Francisco Guinea[bd]

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rsc.li/chem-soc-rev

This tutorial review presents an overview of the basic theoretical aspects of two-dimensional (2D) crystals. We revise essential aspects of graphene and the new families of semiconducting 2D materials, like transition metal dichalcogenides or black phosphorus. Minimal theoretical models for various materials are presented. Some of the exciting new possibilities offered by 2D crystals are discussed, such as manipulation and control of quantum degrees of freedom (spin and pseudospin), confinement of excitons, control of the electronic and optical properties with strain engineering, or unconventional superconducting phases.

1 Introduction

Graphene is the first truly 2D crystal that has been isolated in a controlled manner, initiating a field of research known as "2D materials".[1] 2D crystals are materials of atomic thickness that, as a result of their reduced dimensionality, exhibit unique physical and chemical properties that strongly differ from their 3D counterparts. If the crystalline structure of a 3D crystal is preserved as its thickness is reduced down to atomic scales, as happens with layered materials, it typically exhibits dramatic changes in its physical properties. For example, only when graphene is isolated from 3D graphite into its one-atom-thick form, do its carriers behave as massless relativistic electrons. Another example is MoS_2, which in its monolayer form presents a direct band gap and spin-polarized valleys, two key features that make this 2D semiconductor much better suited for photonics and optoelectronics than its 3D version. From a fundamental point of view, moreover, 2D is a critical dimensionality for

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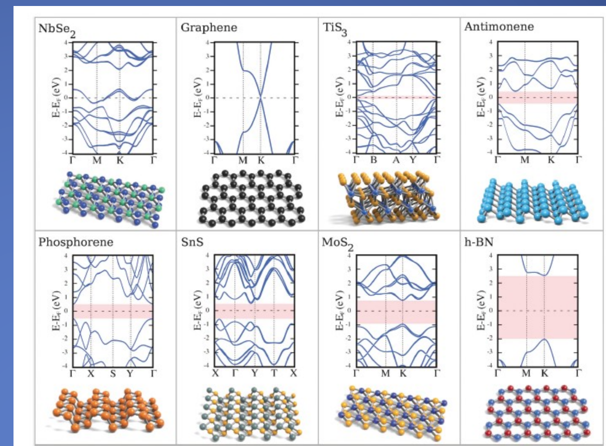
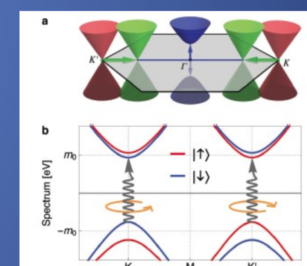
From left to right: Jose Angel Silva-Guillén, Pablo San-Jose, Rafael Roldán, Elsa Prada, Francisco Guinea and Luca Chirolli

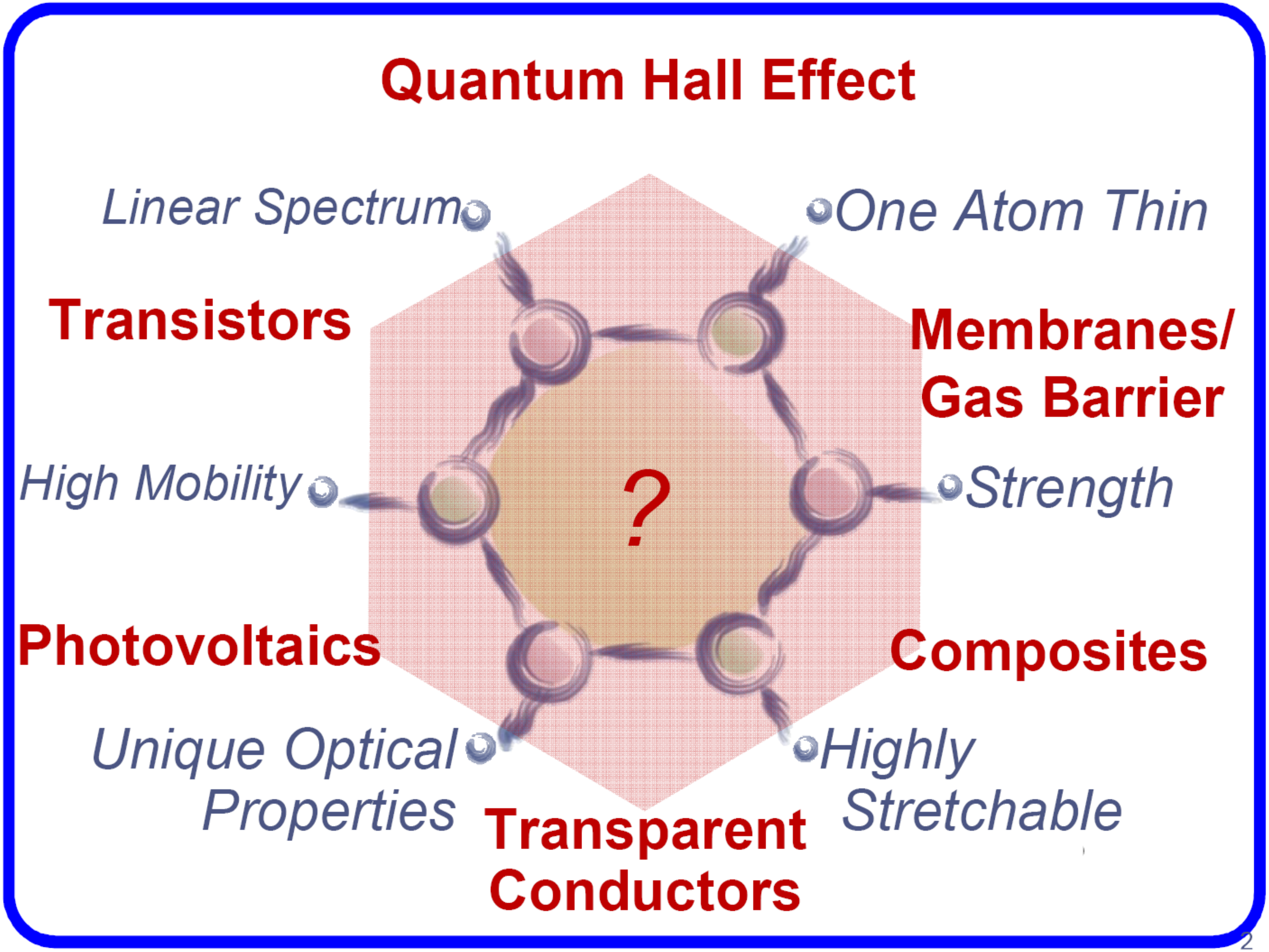
Our group involves three different institutions within the Cantoblanco Campus in Madrid (Autónoma University, ICMM-CSIC and IMDEA Nanociencia). During the last decade we have collaborated extensively on the theory of 2D crystals, in particular graphene and transition metal dichalcogenides. Amongst other aspects, we have studied in detail the modification in this class of systems of electronic, optical and transport properties through several manipulation schemes, such as the application of strain, also known as strain engineering, or by folding and wrinkling ('origami' electronics). We have also studied the properties of monolayers as anharmonic membranes, and the physics of multilayers, such as the formation of moiré patterns and stacking solitons. The group has also a great expertise in the physics of spin and spin-orbit coupling, the emergence of topological phases of matter, the electronic properties of 2D and topological superconductors, the role of electronic interactions, exciton physics, and correlations in low dimensions. We apply a wide variety of theoretical techniques, including ab initio simulations, large scale quantitative tight-binding modelling, and effective field-theoretical descriptions. The group includes two tenured members (F. G. and P. S-J.), two on a tenure track (E. P. and R. R.) and two postdocs (J. A. S.-G. and L. C.).

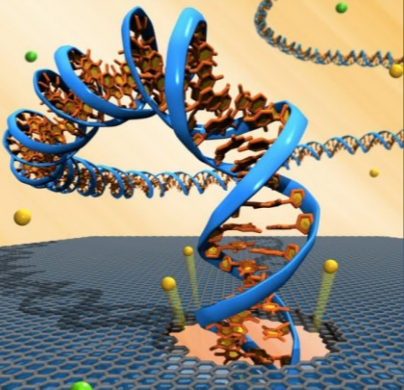


- Semiconductors
- Superconductors
- Ferromagnetic



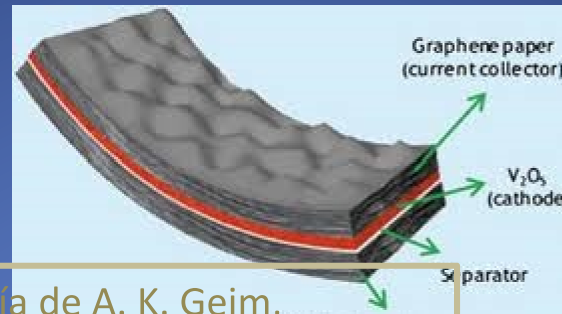
Novel topological properties

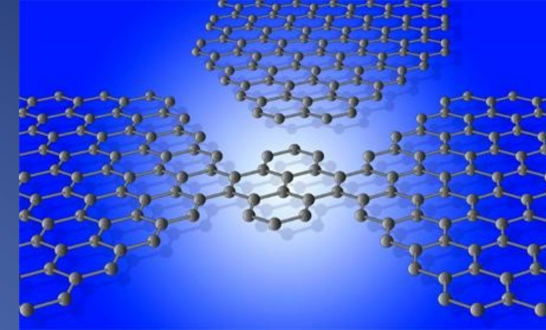

Quantum Hall Effect
Linear Spectrum
One Atom Thin
Transistors
Membranes/
Gas Barrier
High Mobility
?
Strength
Photovoltaics
Composites
Unique Optical
Properties
Highly
Stretchable
Transparent
Conductors



medical applications: drug delivery; lab-on-chip; DNA sequencing

batteries; supercapacitors conductive inks; etc.

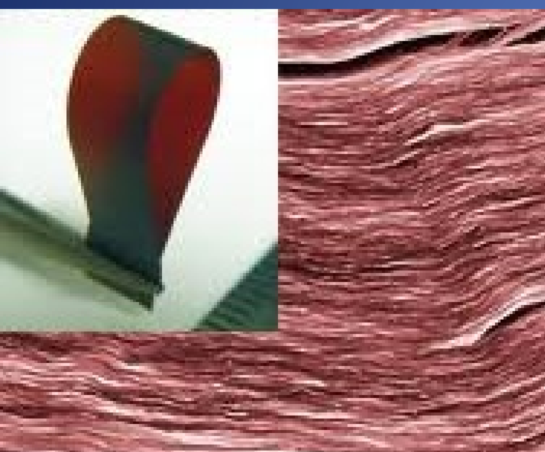




graphene as next Si

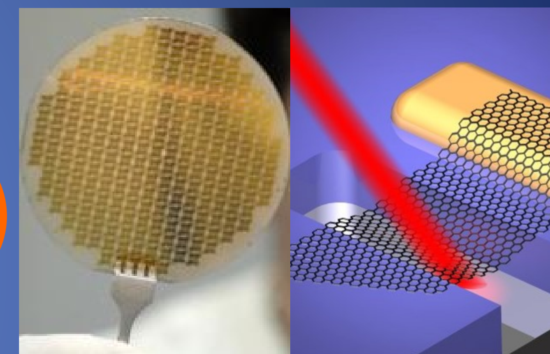
Cortesía de A. K. Geim, Bruselas, Marzo 2011

composites; barrier films



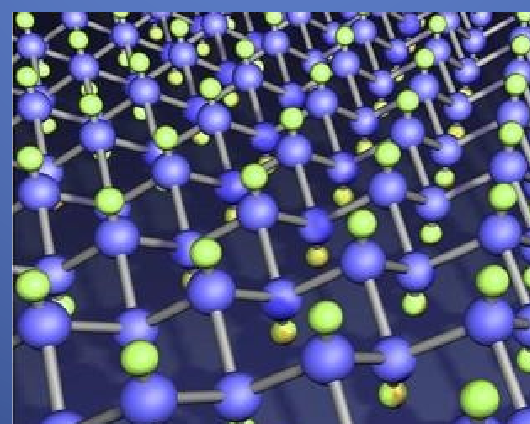
graphene applications

word graphene covers many different materials as word plastic does



ultra-high frequency electronics; optoelectronics

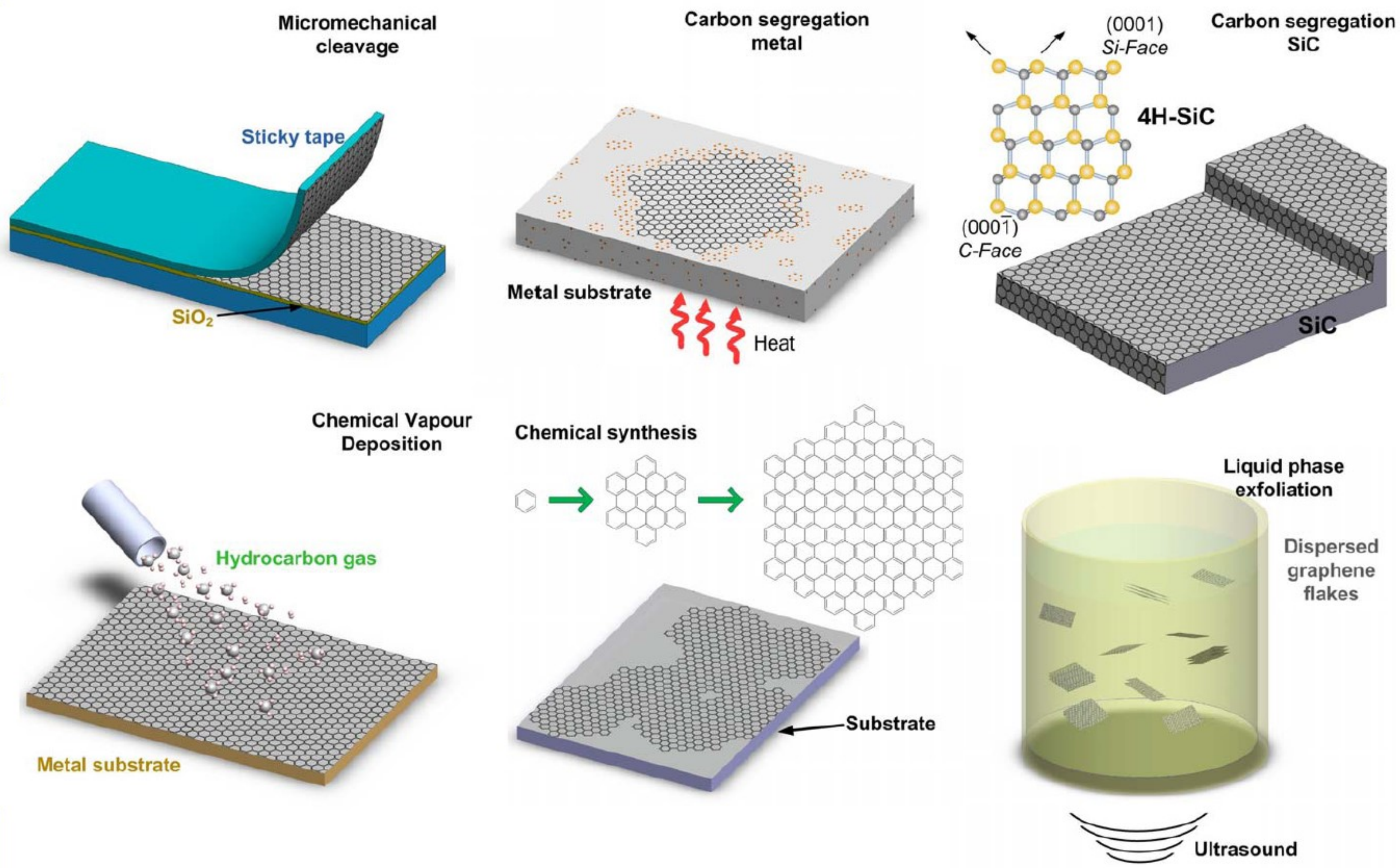
MEMS; various sensors



graphene derivatives; e.g., 2D analogue of Teflon

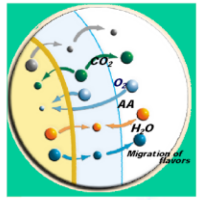
flexible LCD and LED wall lightning

Graphene Production

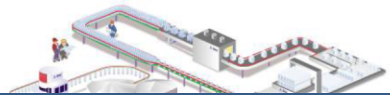


Gas Diffusion Barrier

- ▪Gas barrier diffusion properties
  - ▪Barrier to oxygen
  - ▪Barrier to CO_2 gas



- ▪Industrial specifications



  - ▪co
    pr
  - ▪fe
- ▪Pack
  - ▪Re
  - ▪fo

FILLER FOR PLASTICS

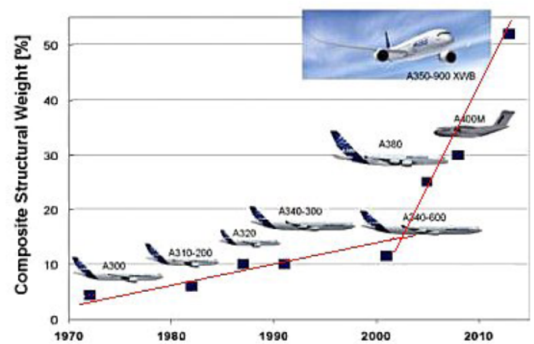
production: > 100 tons per year

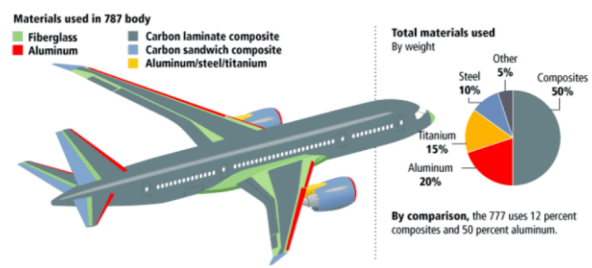
st

bo

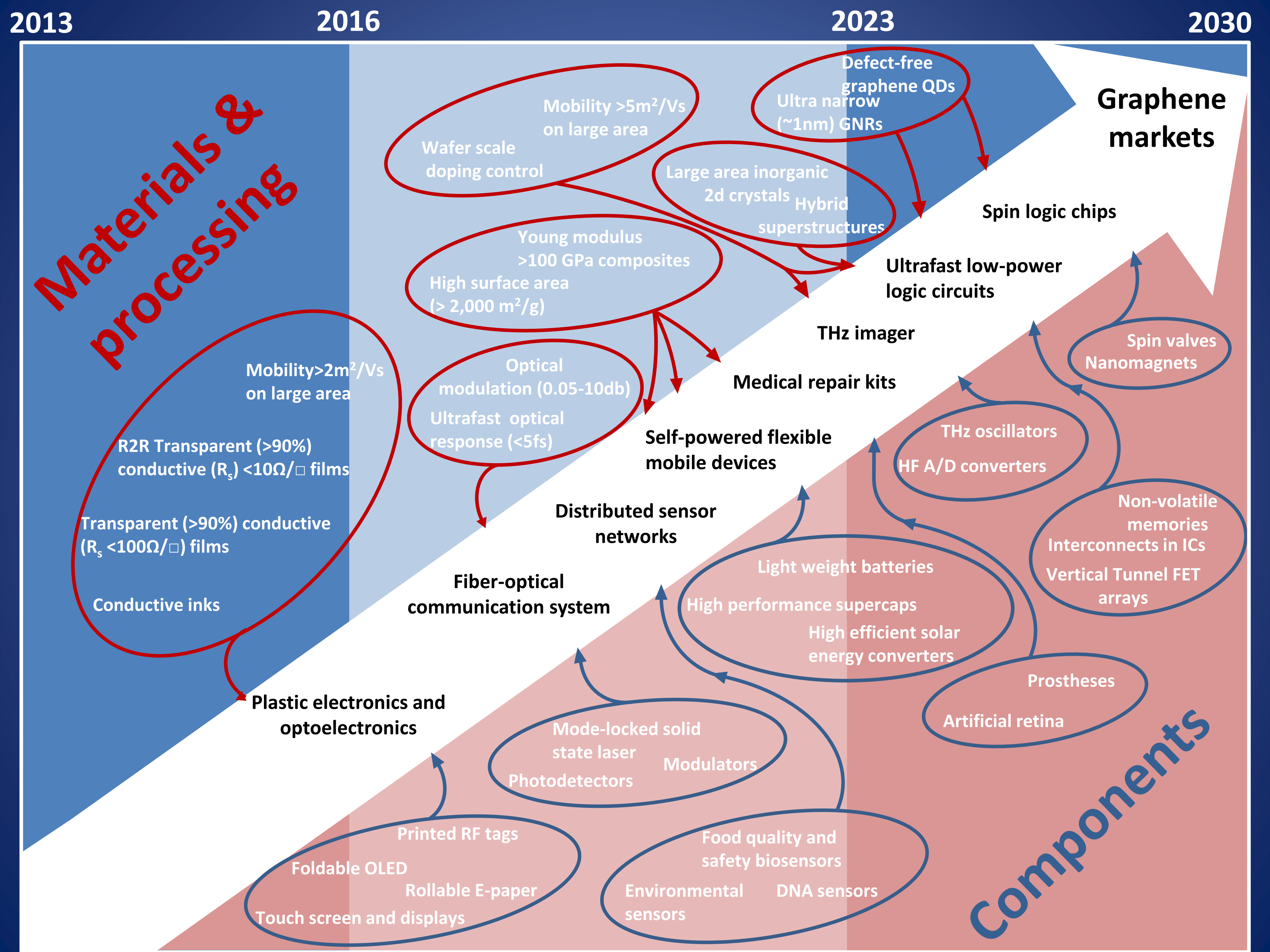
m
co

Composites





Strain Sensor


2013
2016
2023
2030
Materials & processing
Graphene markets
Defect-free graphene QDs
Ultra narrow (~1nm) GNRs
Mobility >5m²/Vs on large area
Wafer scale doping control
Large area inorganic 2d crystals
Hybrid superstructures
Young modulus >100 GPa composites
High surface area (> 2,000 m²/g)
Optical modulation (0.05-10db)
Ultrafast optical response (<5fs)
Mobility>2m²/Vs on large area
R2R Transparent (>90%) conductive (Rs) <10Ω/□ films
Transparent (>90%) conductive (Rs <100Ω/□) films
Conductive inks
Spin logic chips
Ultrafast low-power logic circuits
THz imager
Medical repair kits
Self-powered flexible mobile devices
Distributed sensor networks
Fiber-optical communication system
Plastic electronics and optoelectronics
Spin valves
Nanomagnets
THz oscillators
HF A/D converters
Non-volatile memories
Interconnects in ICs
Vertical Tunnel FET arrays
Light weight batteries
High performance supercaps
High efficient solar energy converters
Prostheses
Artificial retina
Mode-locked solid state laser
Modulators
Photodetectors
Printed RF tags
Foldable OLED
Rollable E-paper
Touch screen and displays
Food quality and safety biosensors
Environmental sensors
DNA sensors
Components

El grafeno en la economía

IBM

NOKIA
Connecting People

PHILIPS
PHILIPS

ST Electronics
A company of ST Engineering

Alcatel·Lucent

VOLVO

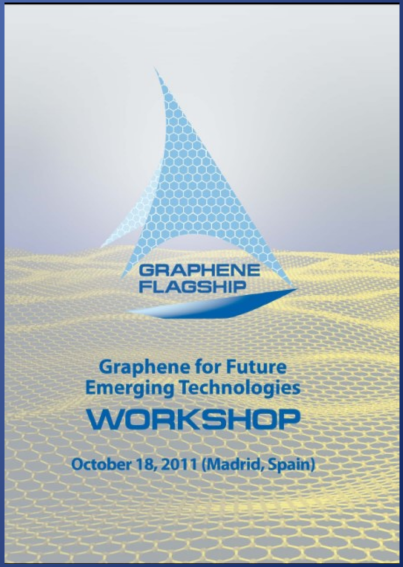
SAMSUNG

BASF
The Chemical Company

RENAULT

TOSHIBA

TEXAS INSTRUMENTS



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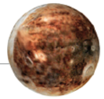
THIS WEEK



EDITORIALS

The long game

Graphene is not a miracle material, just a very promising one. It will take restraint and sustained interest to deliver its potential.

¿Es posible que un campo de la ciencia se mueve demasiado rápido? Quizá. Aquellos que trabajan en la forma de carbono llamada grafeno, lo han visto dispararse como un cohete desde ser la nueva cosa importante a un material milagroso, en menos tiempo que el que necesita un artículo de investigaión para ser aceptado y publicado. Sin embargo, aunque la carrera hacia aplicaciones que exploten las propiedades asombrosas del grafeno ha comenzado, el trabajo necesario para conocer como se puede controlar permanece inacabado.

remarkable properties, the work necessary to find out how it could best be harnessed remains incomplete.

Relevancia de algunos premios Nobel de Física

Cortesía de T. Palacios,
Austria, Abril 2011

Kroemer's Lemma of New Technologies:
"The *principal* applications of any sufficiently new and innovative technology always have been – and will continue to be – applications *created* by that technology."

Lema de Kroemer de nuevas tecnologías:
"las aplicaciones ***principales*** de cualquier nueva e innovadora tecnología siempre ha sido – y continuará siéndolo – aplicaciones ***creadas*** por esa tecnología"