

GrapheneStakeholders
Association

Graphene Development & Commercialization

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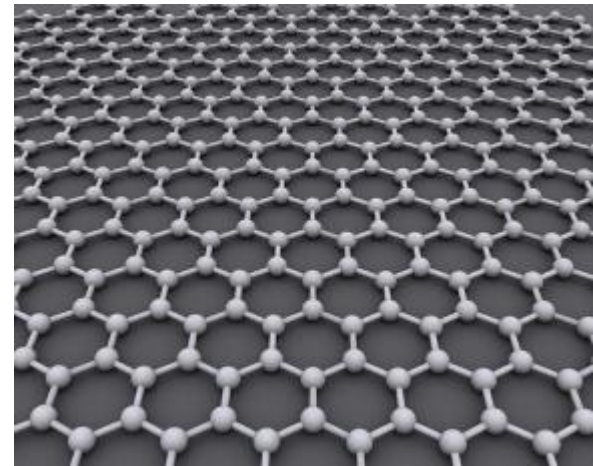
www.graphenestakeholders.org

Topics

- A little background
- The Graphene Stakeholders Association
- Today's Talks



Graphene Technologies / NMIC

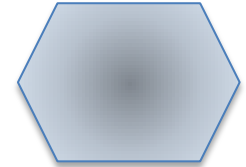
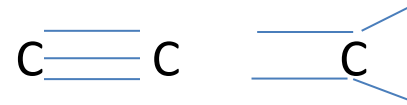


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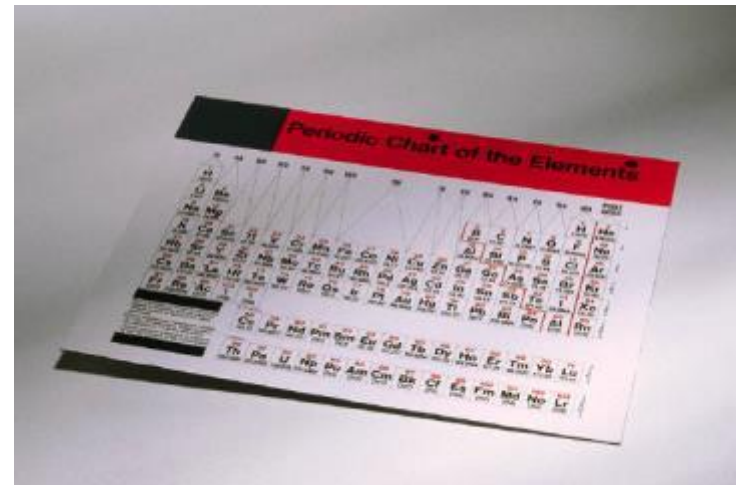
2-D Chemistry

- Carbon – graphene, graphyne, graphdiyne...oh my!

– Planar / linear sp, sp² bonds



- Silicene
- MoS₂, MoO₂
- WS₂, WSe₂
- BN
- ...



Graphene Properties

(Novoselev et al)

- High electron mobility and current carrying ability
- High Youngs Modulus $>1\text{TPa}$
- Strength 130GPa
- Thermal conductivity $>3000\text{WmK}^{-1}$
- Impermeable to gases
- Readily chemically modified

Graphene's Bright Future

Graphene is flexible, transparent, strong, and electrically and thermally conductive.

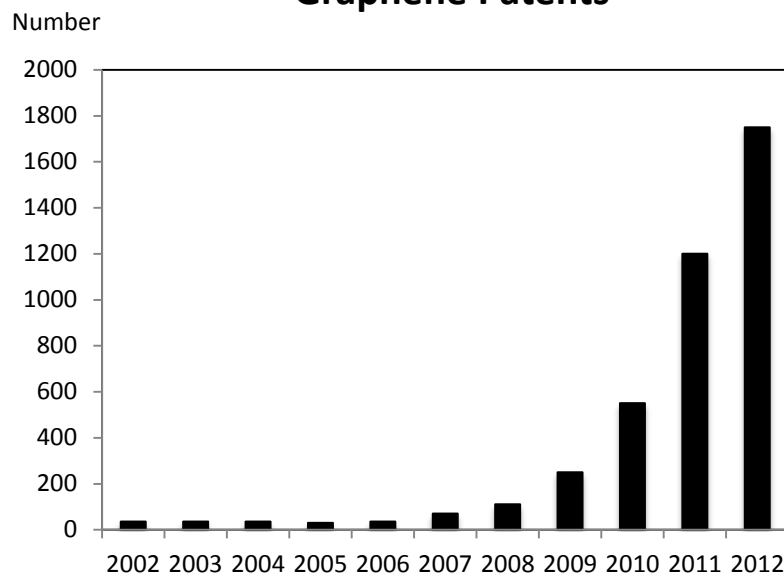
Researchers and engineers have identify a host of key applications for graphene, including:

- Semiconductors
- Wearable computers
- Flexible displays
- Communications
- Photovoltaics
- Medical diagnostics and health care

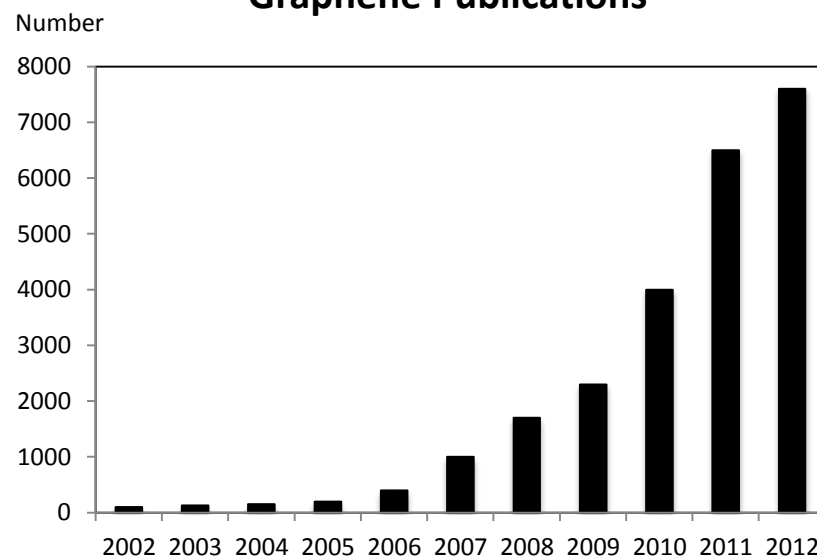


Growing Interest

Graphene Patents



Graphene Publications



Graphene-related patents and publications indicate growing interest in graphene research and development activity

Global Interest



China has published more graphene patents than any other country, at 2,204, ahead of 1,754 for the U.S., 1,160 for South Korea, and 54 for the U.K.

South Korea's Samsung has more graphene patents than any single company.

Nokia is part of the 74-company Graphene Flagship Consortium that is receiving a €1 billion (\$1.35 billion) grant that the E.U. announced in January 2013.

Nokia, Philips, U.K. invention stalwart Dyson, weapons and aerospace company BAE Systems, and others have committed £13 million (\$20.5 million) to a graphene development center at Cambridge University, to go along with £12 million (\$18.9 million) from the British government.

But...graphenes are not alike!

(adapted from "A Roadmap for Graphene), Novoselev et al, Nature,490,192-200, 2012)

| Method | Crystallite Size μm | Mobility $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ | Application |
|-----------------------------|--------------------------------|--|--|
| Mechanical exfoliation | >1000 | >20000 | Research |
| Chemical exfoliation | <0.1 | 100 | Coatings, paint/ink, composites, TC, energy, bio |
| Chemical via graphene oxide | ~100 | 1 | Coatings, paint/ink, composites, TC, energy, bio |
| CVD | 1000 | 10000 | Photonics, nano electronics, TC, sensor, bio |
| SiC | 50 | 10000 | HF transistors, electronics |

THE NATIONAL

ACADEMIES

**TRIENNIAL REVIEW OF THE
NATIONAL NANOTECHNOLOGY
INITIATIVE**

By

The Committee on Triennial Review of the National Nanotechnology
Initiative: Phase II

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

Specific

2D Commercialization Challenges

- Lux Research Report LRM-R-12-4 December 2012 – the title says it all
 - “Is Graphene the Next Silicon...Or Just the Next Carbon Nanotube” (ouch!)
 - Lux Populi summary forecasts just \$126M, 2020
- Barriers include
 - Initial high cost - Wright’s law (volume goes up, cost goes down)
 - HSE / environmental complexity
 - IP confusion
 - Technical issues
 - Lack of standards – ISO TC 229, IEC TC 113 and others grappling with this
 - Competition from other materials – especially CNT
 - The sheer time it takes to get commercial traction
 - Graphene 2004, CNT ~1970-1990
 - Lead-free solder 15 years, base metal capacitors 40 years
 - MEMS – neither of the biggest current applications (airbag sensors and smartphone accelerometers) were envisioned when MEMS devices were first proposed in 1965 by Harvey Nathanson at Westinghouse
 - Fitting graphene into the industrial infrastructure – inks, polymer fillers, films etc.
 - Led to...



GrapheneStakeholders
Association

GSA Mission



The Graphene Stakeholders Association (GSA) is a non-profit organization based in the U.S. that was created in 2013 to promote the responsible development of graphene and graphene-enabled technologies.

The GSA seeks to foster education, collaboration and commercialization through diverse membership of researchers, universities, government agencies and corporations.

GSA Foundation



The GSA's co-founders are:

- Keith Blakely, CEO, The InVentures Group
- Stephen Waite, Managing Partner, SoundView Technology Group
- Dr. Alan Rae, CEO, NanoMaterials Innovation Center
- Vincent Caprio, Executive Director, NanoBusiness Commercialization Association

Each co-founder brings decades of experience to the GSA

GSA Mandate



- To promote the responsible development of graphene products by supporting standards activities and fostering education.
- To develop standard definitions, standard metrology and HSE standards with international, national and industry-based standards organizations through collaboration.
- To facilitate commercialization activities through networking and partnerships.
- To monitor progress and develop action plans through regular web conferences and meetings.
- To communicate the benefits and progress of the industry as a whole to public and private thought leaders and influencers including, where appropriate, governmental agencies and regulatory bodies.

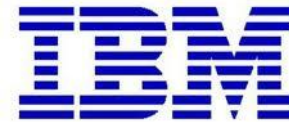
Commercialization



Graphene developers will continue to refine and scale-up their production processes, squeezing cost reductions out of economies of scale and automation.

However, one of the major keys for further commercial growth of the material will be expanding partnership networks between start-ups and their corporate strategic partners.

The GSA seeks to play a key role in helping to foster collaboration and partnerships in the corporate sector.



i n v e n t

Challenges

Processing, Cost, Competition, Regulatory

- Graphene is prohibitively expensive to make today. Graphene nanoplatelets (GNPs) average about \$150/kg today while monolayer graphene films are \$100/000/m².
- Researchers are working on methods to reduce the cost of manufacturing and help make graphene a ubiquitous fabrication material. Reliable low-cost process key.
- Graphene film companies face major commercialization hurdles, including reducing costs, scaling-up the substrate transfer process, overcoming current deposition area limitations, and besting other emerging material solutions.
- Environmental, Health and Safety-related issues.

GSA Leadership



The Graphene Stakeholders Association seeks to get out in front of the key issues associated with graphene by working closely with standards organizations, including ISO, national standards organizations and industry-based standards groups including SEMI, IEC and IPC in the electronics industry as well as UL and ASTM.

The topics will be primarily definitions, nomenclature, metrology, analytical methods, and health / safety / environment (HSE) concerns.

GSA Activities



The GSA will work primarily by regular web conferences timed for the convenience of members and will hold at least one plenary conference per year to review progress and develop action plans.

The GSA intends to collaborate closely with the NanoBusiness Commercialization Association and to organize meetings and presentations around certain of their events to enable our members to make the most efficient use of their time with respect to technical and business conference meetings.

GSA Membership



The GSA seeks broad membership that includes key graphene stakeholders:

- Researchers
- Universities
- Government labs and agencies
- Emerging and established corporations





For more information on the GSA, please visit our website:
www.graphenestakeholders.org

For inquires on membership, please send email to:
info@graphenestakeholders.org

or contact:

Keith Blakely: keith@graphenestakeholders.org

Steve Waite: steve@graphenestakeholders.org

Today's Talks

- Developing Graphene: Standards, Tools, Nomenclature (Moderator: Alan Rae)
 - Dr. Andrew Pollard (NPL)
 - Dr. Toby Sainsbury (NPL)
 - (Dr. Angela Hight Walker (NIST))
- Graphene Production: Recipes for Success (Moderator: Keith Blakely)
 - Dr. Elena Polyakova (Graphene Labs)
 - Ray Gibbs (Haydale)
 - John Biondi (Xolve)
- Graphene Roadmap – Innovation and Commercialization Prospects (Moderator – Steve Waite)
 - Mike Patterson (Graphene Frontiers)
 - Jon Myers (Graphene Technologies)