Graphene: Wonder material for electronics, computers and beyond

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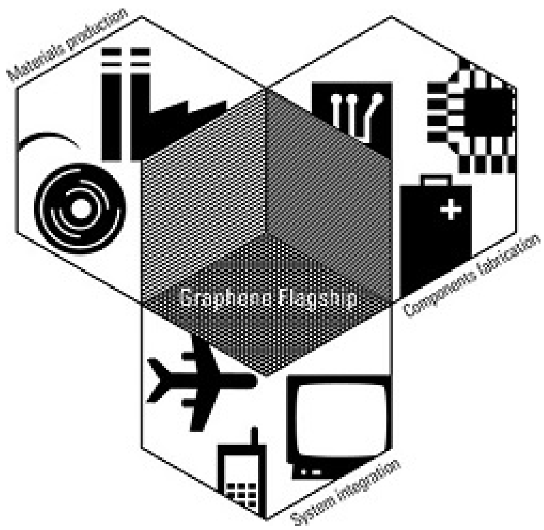

You might think that such a new 'wonder material' would lie outside your everyday experience, but graphene is the exception. When you write or draw with a pencil, the graphite (the 'lead' of the pencil) slides off in thin layers to leave a trail - the line on the paper. Carbon's ability to form a thin layer of molecules is what makes graphene special - and scientists are starting to explore the possibilities for electronics and computing of carbon grids that are just one molecule thick.

The semiconductor industry is the basis of today's high-tech economy, directly supporting over 100,000 jobs in Europe, and indirectly even more. This has been achieved through continued miniaturisation in 'Complementary metal-oxide-semiconductor' (CMOS) technology, based on silicon. But this model will only last for 10 or 15 more years.

The major challenge for the ICT industry is to find alternatives for information processing and storage beyond the limits of existing CMOS. There are good indications that graphene is a prime candidate for "Beyond CMOS" components, and is, despite its revolutionary nature, complementary to conventional CMOS technologies.

Graphene has been the subject of a scientific explosion since the ground-breaking experiments on this novel material less than 10 years ago, recognised by the Nobel Prize in Physics in 2010 awarded to Professor Andre Geim and Professor Kostya Novoselov, at the University of Manchester. The remarkable electrical properties of graphene may overcome the physical limits silicon faces as transistors shrink to ever-smaller sizes - providing solutions for the "Beyond CMOS" era, needed to meet the challenges of global competition.

Bringing together multiple disciplines and addressing research across a whole range of issues, from the fundamental understanding of material properties to graphene production, the GRAPHENE Flagship was launched in October 2013. The proposed research includes electronics, spintronics, photonics, plasmonics and mechanics - all based on graphene.

Led by Professor Jari Kinaret, from Sweden's Chalmers University, the Flagship involves over 126 academic and industrial research groups in 17 European countries, with 136 principal investigators, including four Nobel laureates. With an initial 30-month budget of EUR 54 million, the GRAPHENE consortium will grow to include another 20-30 groups through an open call for project proposals in November , worth up to a total of EUR 9 million.

'Graphene production is obviously central to our project,' said Prof. Kinaret at the launch, but key applications to be looked at include fast electronic and optical devices, flexible electronics, functional lightweight components and advanced batteries. Examples of new products enabled by graphene technologies include fast, flexible and strong consumer electronics, such as electronic paper and bendable personal communication devices, as well as lighter and more energy-efficient aeroplanes. In the longer term, graphene is expected to give rise to new computational paradigms and revolutionary medical applications, such as artificial retinas.

Setting sail: Graphene as FET flagship

Described by European Commission Vice-President Neelie Kroes as a 'daring venture', the 'Future and emerging technologies' (FET) flagships are visionary, large-scale, science-driven research initiatives which tackle scientific and technological challenges across scientific disciplines. These new instruments in EU research funding foster coordinated efforts between the EU and its Member States' national and regional programmes, are highly ambitious, and rely on cooperation among a range of disciplines, communities and programmes - requiring support for up to 10 years. Following the start-up phase, running until March 2016 under the EU's current 'Seventh Framework Programme' for research (FP7), the work will continue under the next programme, 'Horizon 2020', with an expected EUR 50 million per year for the Flagship project.

Graphene was chosen as a flagship following a competition between six pilot projects to investigate the areas with the greatest potential for sustained investment. As Mrs Kroes has said: 'Europe's position as a knowledge superpower depends on thinking the unthinkable and exploiting the best ideas. This multi-billion competition rewards home-grown scientific breakthroughs and shows that when we are ambitious we can develop the best research in Europe.'

The Flagship pilot for graphene, the GRAPHENE-CA project, looked at how developments in this carbon-based material could revolutionise ICT and industry. The pilot project established a comprehensive scientific and technological roadmap to serve as the basis for the research agenda of the GRAPHENE Flagship - covering electronics, spintronics, photonics, plasmonics and mechanics, and supporting areas such as graphene production and chemistry. And this was the basis on which it was selected.

Now the Flagship is up and running, it already comprises a research team of dizzying scope. There are universities from Louvain in Belgium, Aalto in Finland, Lille and Strasbourg in France, Bremen, Chemnitz, Dresden and Hamburg in Germany, Ioannina in Greece, Dublin in Ireland, Trieste in Italy, Minho in Portugal, Barcelona and Castilla-La Mancha in Spain, Basel, Geneva and Zurich in Switzerland, Delft and Groningen in the Netherlands, and Cambridge, Manchester and Oxford in the United Kingdom. These are complemented by polytechnics and institutes of technology from Austria, Denmark, France, Germany, Greece, Italy, Poland, Spain, Sweden and Switzerland. In addition, there are industrial partners such as Nokia, Thales, Alcatel Lucent, Philips Technology, Airbus and ST Microelectronics. And this list accounts for only part of the participating organisations.

Their mission is to take graphene, and related layered materials, from the academic laboratories to society - revolutionising multiple industries and creating economic growth and new jobs in Europe.

'The Commission, and all the academic and industrial partners of the Graphene Flagship, are all in this together. It is an unusually long-term commitment, and there will be challenges, let's be clear about that,' said Carl-Christian Buhr, member of the Cabinet of Mrs Kroes. 'We need to bring in industry in such a way that ideas are taken up and lead to new products and markets. That's the whole idea of the Flagship.'

Indeed, it includes a comprehensive set of complementary activities to achieve this, such as:

An ERA-NET type of project, FLAG-ERA, to support the Flagship in the coordination of national research initiatives on graphene.

- A range of initiatives focused on spreading knowledge about graphene to the wider world. The Graphene Week , for example, is an annual forum bringing together hundreds of researchers to share their latest developments across disciplines - the next will be held in Gothenburg, Sweden, in June 2014. It aims to be a 'gathering of the graphene tribe', where discussions of fundamental science can meet exciting new applications.
- Graphene Connect is an interaction platform for academia and businesses promoting scientists to think outside the box and industries to develop end-user products based on graphene - this will include a number of industrial workshops, and sessions for business angels, entrepreneurs and venture capitalists to discuss potential graphene investment opportunities.
- Graphene Study is a European winter school on graphene that will help build a new generation of graphene researchers, as well as new direct communication channels between young researchers and academia-industry players. The first will be held in the Austrian Alps, on 2-7 February 2014.

Early results

Some of the EU's previously funded graphene research is already delivering. The GRAND (4) project, which ended in December 2010, looked at whether graphene would still work its wonders when integrated with the silicon CMOS process.

Led by AMO in Germany, the project team set out to assess whether graphene really could bring conventional semiconductor technology into the "Beyond CMOS" era. The GRAND consortium developed ways of fabricating 2-dimensional graphene nanostructures (with widths of only 5 nm across) for use in electronics components. It was important to show that not only could such components function, but that they could be fabricated in a way that could be scaled up to industrial quantities.

As a result, the team designed a new type of transistor - with the concept published in the renowned journal *Applied Physics Letters* - that could open new routes for graphene-based high-speed electronic and optoelectronic devices.

As part of the GRAND project, graphene has also been integrated into a non-volatile memory device that could be reduced to molecular sizes - a graphene memory measuring just 1x1 nm that retains the information stored in it even when power is turned off. The team fabricated more than 10 such devices - indicating their scalability.

Led by the Chalmers University of Technology, Sweden, the CONCEPTGRAPHENE project set out to unlock the potential of depositing a thin layer of graphene on to a silicon carbide (SiC) base - aiming to develop scalable electronics with potential applications in 'spintronics' and ultra-accurate measuring devices. The team worked on fabricating large-scale graphene wafers that would allow for high-density electronic devices to be manufactured on a single silicon wafer. This type of technology will be needed for full-scale industrial manufacture of graphene-based components and devices in a way that is compatible with current industry techniques.

Having ended in September 2013, the project launched a start-up company that will produce graphene wafers. Graphensic AB is located in Linköping, Sweden. The company is a spin-off from Linköping University and produces high-quality, highly uniform, graphene on silicon carbide (SiC) using a patented 'High-temperature graphene process' - a growth method which produces a thin layer of graphene, even a single layer of atoms, on SiC.

More where that came from

But graphene is not the only innovative material that could transform electronics - the 2D-NANOLATTICES project, ending in May 2014, is working on other graphite-like molecular-lattice structures based on different elements. These 'nanolattices' also have great potential to pave the way to ever-smaller, and more powerful, nano-electronic devices. In particular, 'silicene' (or 'germanene'), the silicon or germanium equivalent of graphene, if they exist, may offer better compatibility with silicon processing.

Led by the National Center for Scientific Research 'Demokritos', in Greece, the project team aims to find ways to induce and stabilise the silicon and germanium and prove for the first time that silicene has a physical existence. By producing alternating layers weakly bonded between one another, each consisting of a single layer of atoms, this new material could serve as the elements of gates and other components in new, miniaturised 2D semiconductors.

Perhaps we are still in the early stages, but these look to be the first steps in a transformation of the way electronics devices are made - and in their abilities - with the potential to similarly transform the European high-tech industry and economy.

More information: cordis.europa.eu/projects/rcn/109691_en.html

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