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S'pore edges ahead in graphene research

NUS centre working to harness the power of this super material for commercial use

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Doctoral student Candy Lim examining a diamond plate. She was part of the team which found that bonding graphene onto such a diamond plate could make water cut diamond at high temperatures. The research was recently published in Nature Communications.

Professor Antonio Castro Neto whips out a transparent flat case slightly bigger than a namecard. It works like a regular touchscreen panel, but take a sledgehammer to it and it won't crack, he says.

Then, he picks up a slim slice of honeycomb sponge light as a feather and soft as velvet.

The porous material is ideal for producing super batteries, and is a favoured substrate for growing stem cells.

Meet graphene – the ingredient scientists in Singapore used to create the touchscreen's protective coating, and the special foam.

If materials could be superheroes, graphene would be Mr Invincible.

So tough that a sheet as thin as cling film could hold an elephant, it is the thinnest and strongest substance known to science. It is also as stretchy as rubber, almost transparent, and conducts electricity and heat better than anything.

Comprising pure carbon sheets just an atom thick, graphene is one of the world's few two-dimensional materials and could potentially be used in anything from foldable computers you can wear to artificial skin and cheap and speedy DNA sequencers and radioactive waste cleaners.

Billions of dollars are being pumped into graphene research by institutes and companies, and scientists worldwide are locked in battle to come out ahead in the field, which is forecast to develop into a US$600 billion (S$750 billion) industry in the next 20 years.

But long before it became the darling of the scientific community and won its discoverers Andre Geim and Konstantin Novoselov of Manchester University the 2010 Nobel prize in physics, scientists in Singapore were already showing interest in it.

"Many of us have been working with graphene since it was discovered in 2004," said National University of Singapore (NUS) dean of science Andrew Wee.

"We recognised its potential early, put in a proposal for a centre and it took off. In science you have to do things early because after a few years everybody is doing it."

The effort is paying off, he points out: NUS and Nanyang Technological University are respectively ranked second and third worldwide in terms of graphene publications, behind only the Chinese Academy of Sciences – a multi-institutional organisation, and ahead of the likes of the Massachusetts Institute of Technology and the Russian Academy of Sciences. Ranked by country, Singapore is No. 7 worldwide.

Now, the main player here – the $40 million Graphene Research Centre at NUS which began operations in 2010 – has 26 principal investigators plus many PhD students and research fellows, and is involved in research funding to the order of $100 million, and 50 patent applications.

Its director, Prof Castro Neto, said: "We have some of the best people in the world, and the best equipment for the complete innovation cycle; from synthesising the material to making the devices.

"We have everything in place to be the best in the world."

Prof Castro Neto, known as the godfather of graphene to his colleagues because of his seminal work in the field, has been involved in such research "from Day One", and worked closely with graphene's discoverers, professors Geim and Novoselov.

Another pioneer who came to set up the first graphene laboratory from scratch is Assistant Professor Barbaros Oezyilmaz. He gave up offers from top American institutions after completing his postdoctoral research at Columbia University to come to Singapore in 2008.

Now with a prestigious Nature Physics paper fresh off the press, his latest work shows the impact that graphene – with added hydrogen – can have in the field of spintronics. This is an emerging form of electronics which uses the magnetic state (spin) of electrons to encode and process data, rather than using electric charge.

"This is the first time that spin-based magnetic applications with graphene seem feasible," said Prof Oezyilmaz, who has also just won a $10 million grant from the National Research Foundation to scale up graphene production for industrial use.

"When you combine the flexible electronics enabled by graphene with the power-saving ability of spintronics, it means every computer can be replaced with something lightweight you can wear, which doesn't have to be charged constantly," he said.

"Five years ago, no one had heard of Singapore in this field, now things are very different. The work we're doing shows that none of these concepts is crazy."

Also making waves is Professor Loh Kian Ping, who combined his research interests in both diamond and its carbon-based sister graphene.

He and his team have managed to cut diamonds with water.

By bonding graphene onto diamond and heating it to high temperatures of 1,000 deg C, the water molecules trapped inside – unable to escape or evaporate – reach a "supercritical" phase where the boundary between liquid and gas disappears, causing the water to become corrosive and etch the diamond, he explained.

"Most chemical reactions are limited by the boiling point of the solvent. This made us realise that water is not what it seems, and we can do the same with other fluids to see how they react."

The discovery, published this month in the journal Nature Communications, has wide-ranging industrial applications, from using supercritical water to treat organic wastes to laser-assisted etching of semiconductor films.

Doctoral student Candy Lim, who was part of the research team, said: "This is an exciting discovery and we've had many different ideas for applications along the way."

Standing behind the local effort are the two Nobel laureates, professors Geim and Novoselov, both scientific advisers to the graphene centre. Prof Geim also spends a month here every year as visiting professor.

In Singapore in 2009, he had lamented the pace of graphene research in the West, and called on NUS to pick up the slack. He said at the time: "I feel so sour that we know so much about its properties but are so slow in utilising them."

Now, he says, the graphene centre has a dynamic, fast-moving team, with information flowing between Manchester and Singapore, including a continual exchange of postdoctoral researchers.

"The NUS centre is still gearing up and I am getting more and more interested in this collaboration," he said.

"For me, it was an amazing journey from an empty place at the NUS three years ago to one of the world leading centres in graphene research."

He added: "Importantly, graphene is not a blip on the screen. It is now clear that the subject will continue for many decades, as graphene comes again and again in different reincarnations.

"The progress at the NUS continues and, with catching up being no longer necessary, one can clearly see where the NUS will be in a few years' time. I certainly want to remain associated with such a star performer."

Speaking to The Sunday Times from Manchester, Prof Novoselov said that he was impressed by the calibre of talent at the NUS graphene centre.

"This is up to the point of jealousy, I'd like to steal some of their people, I'm serious," he said. "It was really a brave lot that joined first, and now that the centre has critical mass and Singapore is on the map, the hope would be to maintain this momentum."

Prof Novoselov's lab is also collaborating with the Singapore centre on several fronts.

The projects being tackled at NUS cover a broad portfolio, ranging from the deepest science to those close to commercialisation, he added.

He cautioned, however, against focusing on applied technology at the expense of basic science.

"Developing technology is a good thing, but it can be a little dangerous as technology is becoming so complicated that it needs a boost from science. You need to do both."

Bottlenecks remain in research – nobody has been able yet to produce graphene on an industrial scale, for instance. Even being able to manipulate material an-atom thick is a science in itself.

But Prof Castro Neto is confident that graphene will have a big impact commercially in five to 10 years.

The lowest hanging fruit – composite materials built to be stronger and more flexible – have already gone to market in the form of graphene tennis rackets.

"We hope not just to have an impact on the science, this we're already doing," said Prof Castro Neto, who took leave as professor of physics at Boston University in the US to helm the Singapore centre.

"We want to make a big impact on society and the world, and return the investments this country has made.

"Wouldn't it be wonderful if Singapore could be known as the graphene island?"

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SUPER STRONG, SLIM AND FLEXIBLE

Graphene, which comes from graphite – the stuff in pencils – is a single layer of carbon atoms a million times thinner than a strand of human hair.

Touted as a next-generation super material, it is nearly transparent, stronger than diamond, the best conductor of heat and electricity, and as flexible as rubber.

Graphene could also be used in anything from super strong composite materials in satellites, planes and cars, to flexible solar panels, mobile phones and bionic implants.

Since its discovery in 2004, more than 2,200 graphene patents have been filed worldwide, and the industry is predicted to be worth US$600 billion (S$756 billion) in the next 20 years.

Professors Andre Geim and Konstantin Novoselov of Manchester University extracted graphene from graphite with the help of sticky tape.

To do so, they used the tape to peel off a layer of graphite from its block and then repeatedly stuck and peeled back the tape.

For their discovery, they won the Nobel Physics Prize in 2010.

Products already or soon-to-be on the market:

- Tennis and squash rackets made with the graphene composites are already on the market.
  They are said to be easier to swing and allow players to make more powerful shots.
- Conductive graphene ink used in circuit boards for electronic devices such as security tags and mobile phones.
  Graphene ink is cheaper than the ink currently used in printed circuit boards and more flexible.
  The ink can be printed on many different materials including paper and polymer film, and the resulting board can be twisted or folded with no damage.