Electronics at the nano-limit

S ANANTHANARAYANAN EXPLAINS WHAT WORKING WITH ASSEMBLIES OF ATOMS IN SHEETS THAT ARE JUST ONE ATOM THICK IS ALL ABOUT

Miniaturisation was at first the progress of finer and finer workmanship, like wrist-watches, or model ships, or desktop-size working versions of the steam locomotive. The integrated circuit or the microchip, where thousands of electronic components fit on a sliver the size of a postage stamp, is perhaps the ultimate leap forward. But nanotechnology uses the crystal structure of materials and the bulk behaviour of groups of atoms to create devices that cannot be assembled manually.

If we go further and work at the level of individual atoms themselves, we are usually in the domain of chemistry and we create new compounds, not atom-size devices. Just short of this may be working with assemblies of atoms in sheets that are just one atom thick. This is what Chul-Ho Lee, Gwan-Hyoung Lee, Arend M van der Zande, Wenchao Chen, Yilei Li, Minyong Han, Xu Cui, Ghidewon Arefe, Colin Nuckolls, Tony F Heinz, Jing Guo, James Hone and Philip Kim from Korea University and Yonsei University at Seoul and at Columbia and University of Florida report in their paper in the journal *Nature Nanotechnology*.

Atoms are three-dimensional things, with a nucleus surrounded by electrons in shells and shaped more like a ball than like a plate. Atoms, or even groups of them, like compounds, hence usually form bonds, using the outer electrons, with other atoms or compounds, in three dimensions. Or, even if they lay themselves out in small groups, as a sheet, they strongly influence other atoms on either side of the sheet, which loses a purely two-dimensional character. But there are elements like carbon, which form very stable 3-D crystals, like the diamond, but can also keep all bonds within one plane and form extended sheets that freely slide over one another.

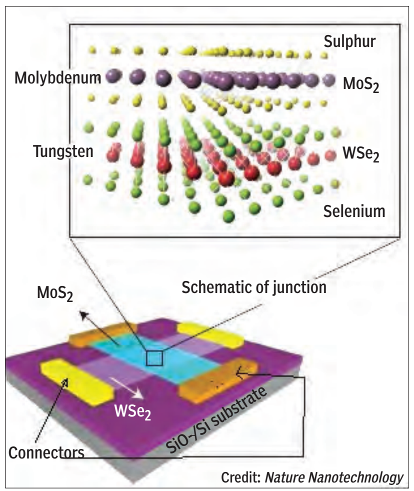
Graphite is the classic example and it is the property of sheets sliding smoothly that is used to make marks on paper, when graphite is used in pencil lead. But the main thing about this structure is that the sheets of atoms, which slide over other sheets, in this case called *graphene*, are each only one atom thick. Graphene, or other similar forms of carbon, in the form of nano-tubes, or balls in a geodesic dome structure, also have interesting electrical properties, with prospects of application as connectors in micro-electronics.

The bonds between atoms, in the 2-D sheet structure, are because of an exchange or sharing of electrons and these are stable and strong; in fact, very strong. But between two adjacent layers of this kind there are no electronic bonds, just a mild attraction, like the forces between neutral atoms in a gas, which tend to slightly reduce the pressure that the speed of the gas molecules exert on the walls of a container. These forces are called *van der Waals forces* and materials that consist of one-atom layers held together by such forces are *van der Waals materials*.

While graphene was the first such material that forms mono-layers, as the structure was called, that was studied, attention in the last few years has moved to other materials. The material of interest is a category of compounds that contain atoms of metals that have unfilled inner shells in their electronic structure, which allows them to form a plurality of kinds of links with other atoms. These atoms combine with atoms of elements of the class of sulphur, selenium, tellurium. These later elements, which are like oxygen, need, for stability, to form a pair of bonds with the atoms of the metal with which they combine. The result is that in these compounds, the electronic structure and the masses are suitable for mutual combination in the form of a mat, or a sheet, where all bonds are satisfied along a single plane and there is no need to seek bonds in the third dimension, for stability.

Sandwich of mono-layers

These other materials, hence, also form mono-layers, like graphene. But in these materials, where there is more complexity in the structure of the mono-layer sheet, it is possible to control how they conduct electricity, in the way that can be done with bulk silicon, which is the basis of semiconductor technology, diodes, transistors and all of modern electronics. Specifically, these materials could be insulators in the pure form, but become conductors, called *semiconductors*, if some of the atoms in their structure were replaced by others that have one more or one less outer electron in their electronic structure. These newcomers then land up with either one extra electron, or with a "gap" where there should have been an electron. And this anomaly, of an extra or a missing electron, is free, in the assemblage, to carry an electric current. If there is a junction of these two kinds of conducting materials, then we have a case where the "extra" electrons can cross over, but there is no way a "gap" can cross, which means the junction is a *one-way gate* for an electric current. It is with such junctions that electronic circuits can allow or prevent the passage of a current, a property that is used to record data, carry out calculations and the other wonders of electronics.



Credit: *Nature Nanotechnology*

Not only can junctions of composite mono-layers be bestowed with semiconductor properties, they can be even be tweaked to respond to light. The response can be to change from insulator to conductor or the other way about, for use as a light operated switch, or to throw out electrons and develop a charge for use as a detector. Inversely, the junctions can emit photons when charged with electricity, which would enable their use in display. Different compositions of the mono-layer material would lead to different levels of response, and the response could even be controlled by using external electric or magnetic fields.

Another feature of these mono-layer junctions is that the interface of two layers is of a pair of layers that are smooth at the atoms level and, when placed in contact, they are linked by *van der Waals forces*. This ensures a high quality interface, without the limitations inherent in conventional fabrication and the structure created is fundamentally different and more flexible.

The authors of the paper in *Nature Nanotechnology* report that they used a mono-layer of tungsten diselenide (WSe_2) as the layer with the "gaps" or the *holes* and a mono-layer of molybdenum disulphide (MoS_2) as the layer with free electrons, to create the junction of the two kinds of semiconductors. The two mono-layers consist of hexagonally packed layers of tungsten or molybdenum atoms, sandwiched between two planes of selenium or sulphur atoms, as the case may be.

The mono-layers were deposited, in contact by *van der Waals forces*, on a silica/silicon base and the layers were provided with electrical contacts. The base was also charged, as this charge affects the density of available current carriers, that is, the holes or the electrons, in the mono-layers. Trials then showed that the junction worked effectively as a one-way gate for an electric current, and the current flowing could be controlled by the charge applied to the base. Further trials with exposure of the junction to white light or light of specific colours, again showed that the mono-layers were induced to emit electrons, which, naturally, had to flow in one direction only and hence charge one side of the junction, like in a normal photocell. To improve the collection of the photocurrent, the junction was also sandwiched between mono-layers of graphene.

Analyses of the response of the junction to the different parameters show that the mechanism of working in mono-atomic layers is fundamentally different from conventional devices. But the work represents a first creation of an atomically thin junction of semiconductor layers that "will lead to unique material platforms for novel, high-performance electronic and optoelectronic devices", the authors say.

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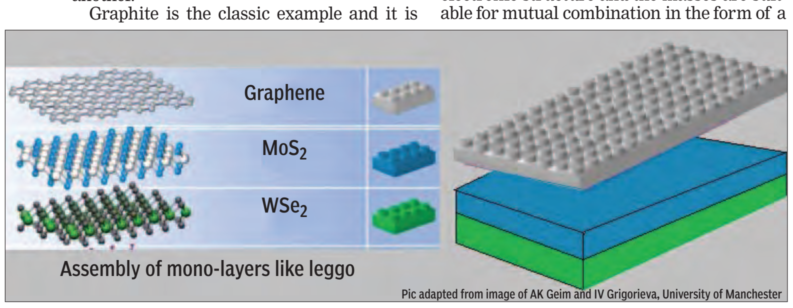

Assembly of mono-layers like leggo
Pic adapted from image of AK Geim and IV Grigorieva, University of Manchester

KILLERS IN DISGUISE

MUSHROOMS OF THE GENUS *AMANITA* RESEMBLE THE EDIBLE VARIETIES SAVE FOR SMALL TELLTALE SIGNS THAT ARE OFTEN OVERLOOKED, WRITES **RIDDHI DATTA**

'This dish of mushrooms changed the destiny of Europe," said Voltaire in his famous book, *Mémoires de M. de Voltaire*. It was 1740 and an unfortunate case of mushroom poisoning emptied the royal throne of Rome. Holy Roman Emperor Charles VI suffered from indigestion after eating sautéed mushrooms, illness followed and 10 days later he was dead. Whether this was a case of assassination or accidental poisoning is not known, but the villain was a deadly mushroom, *Amanita phalloides*. Since Charles VI didn't leave a male heir to the throne, his sudden death led to the War of Austrian Succession. Several renowned historical figures, including Roman Emperor Claudius, Pope Clement VII and Russian tsaritsa Natalia Naryshkina are thought to have lost their lives to *Amanita* poisoning.

The genus comprises around 600 species, including some of the most toxic species known to cause fatal results across the globe. About 95 per cent of the fatalities have been attributed to *Amanita* while *Amanita phalloides* accounts for 50 per cent. The latter is popularly known as the "Death Cap".

These are commonly seen beneath pines, oaks, dogwoods and other trees between September and November. The cap can be up to 15 cm wide and the stalk up to five inches tall. The cap can be yellowish, brownish, whitish, or greenish and is often sticky to touch.

The gills are whitish and there is a noticeable skirt-like floppy ring (*annulus*) a little below the gills on the stalk. At the base of the stalk is a white cup (*volva*) and this species is tremendously poisonous. About 30 gm or half a cap is enough for death and toxicity is not reduced even on cooking, drying or freezing. The most threatening fact about this toadstool is that it resembles several edible mushrooms.

Amanita ocreata, commonly known as the Western North American Destroying Angel, is another dangerous species under the genus *Amanita* associated with countless cases of mushroom poisoning. It is extensively found in the Pacific Northwest and California floristic provinces under oak trees. It resembles several edible mushrooms when immature, save that it has a ring that sets it apart from the edible variety. This toadstool is extremely poisonous and consumption of even half a cap can lead to death.


The Death Cap in its natural habitat.


The deadly *Amanita ocreata*.


The European Destroying Angel at a young stage.


The poisonous *Ananita verna*.

Another deadly member of the genus is the European Destroying Angel or *Amanita virosa*, commonly seen in European deciduous and coniferous forests during the summer and autumn. This immature mushroom resembles several edible varieties but it's not till its caps have opened and its gills become visible that one can identify it. Fool's Mushroom or *Amanita verna* is another deadly member of the genus found in these forests during the spring.

This all-white mushroom has a cap about five to 10 cm wide and the stalk has a membranous ring and a bag-like *volva*. It also resembles several edible mushrooms but has a *volva* that the others don't possess and about 30 gm can prove fatal. Concumption of an even smaller amount is highly risky. The victim does not feel any symptoms till 10-14 hours after intake. The symptoms start with vomiting, diarrhoea and cramps and then there is a subsidence. After three to fours days come more severe effects that include jaundice, diarrhoea, delirium and coma as a result of fulminant hepatic failure and attendant hepatic encephalopathy. Renal failure and coagulopathy may appear during this stage, leading to death within six to 16 days after poisoning.

The lethal effect of the death caps has been attributed to a couple of toxins, amatoxins and phallotoxins produced by these mushrooms. Most of the phallotoxins are highly toxic to cells but are not absorbed through the gut. Hence, they do not significantly contribute to poisoning. Among the amatoxins, amanitin is the dominant and most toxic.

After being absorbed in the gastrointestinal tract, the toxin molecules can travel through the blood stream and affect many organs, causing damage to the liver, kidney and heart and, ultimately, death. Amatoxins damage the cells of these organs, causing perforations in the cell membrane that lead to a leakage of cytoplasmic organelles into the extracellular matrix. Because amatoxins also inhibit RNA polymerase, the organ cannot repair the damage and cells disintegrate.

While mushrooms of the edible variety have been identified as extremely nutritious, with their high protein and low fat and carbohydrate content, most cases of poisoning worldwide occur because of misidentification by amateur mushroom hunters. So if you have even the slightest discomfort after a mushroom meal, immediately visit a physician. Poisoning can be cured if detected early.

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End of the world? Hardly

JACK SIMPSON REPORTS ON ALL YOU NEED TO KNOW ABOUT A SUPERMOON

Last Sunday night, a supermoon lit up the sky, closer to earth than it has been in over 20 years. It was 14 per cent bigger and 30 per cent brighter than usual. So what is a supermoon. The scientific name is a perigee moon, perigee meaning "closest point to earth". It refers to the phenomenon when the moon is in its "full moon" stage, and at its closest point to earth during its yearly orbit. With the moon being closer, it appears far bigger and far brighter.

Sunday's supermoon was the second in a trio of supermoons this time of year, with one having happened on 12 July and the next one due to appear on 9 September. To have three in such close proximity is very rare and it is not expected that this will happen again until 2034. In general, supermoons occur on average every 13 months.

According to astronomers, Sunday saw the moon closer to earth than ever before in the last 20 years. For just 26 minutes, it reached its full perigee stage, taking it to within 221,765 miles of earth. It also coincided with the Perseid meteor shower, a yearly occurrence that saw more than 100 meteors appear in our skies over the weekend.

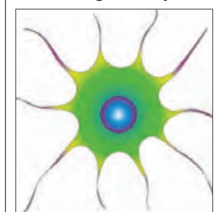
Could the supermoon bring about the end of life as we know it? No, and this depite *The Daily Express* reporting that the "rare lunar event could bring about the end of the world". We're still spinning and I wouldn't start planning for a post-apocalyptic existence just yet. Future supermoons are expected on 9 September 2014, 28 September 2015, 14 November 2016 and 2 January 2018.

THE INDEPENDENT

PLUS POINTS

Vital brainwave

A gamma wave is a rapid, electrical oscillation in the brain and a scan of academic literature shows that waves of this nature may be involved with learning memory and attention — and, when perturbed, may play a part in schizophrenia, epilepsy, Alzheimer's, autism and Attention Deficit Hyperactivity Disorder. That's quite a list and one of the reasons these brainwaves, cycling at 25-80 times per second, persist as an object of fascination to neuroscientists.



Despite lingering interest, much remains elusive when trying to figure out how gamma waves are produced by specific molecules within neurons — and what the oscillations do to facilitate communication along a human brain's trillions and trillions of connections. A collaboration at the Salk Institute in La Jolla, California, has looked beyond the pre-eminent brain cell — the neuron — to achieve new insights. With contributions from the laboratories of Terrence Sejnowski, Inder Verma and Stephen Heinemann, the experiments showed that a rise in calcium within astrocytes preceded the onset of gamma waves in slices of tissues from the hippocampus, a structure in the brain involved in memory formation.

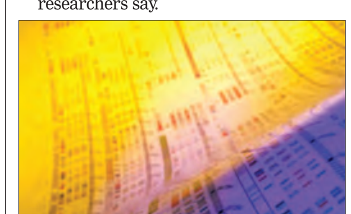
The researchers then went on to seek firmer proof that astrocytes play a pivotal role in generating the gamma waves. They engineered into mice a genetic switch that could turn off — and then reactivate — the release of neurotransmitters from the astrocyte.

The neurotransmitter is discharged after levels of calcium within the cell have risen to a certain level, hinder the release of the neurotransmitter glutamate and prevent astrocytes from communicating with nearby cells. The shutdown weakened the gamma waves in a mouse's brain. Their ability to flip the switch and observe the change in oscillations suggests a strong cause-and-effect relationship between astrocytes' signalling and the resulting strength of the gamma waves. The work was published in a recent edition of the *Proceedings of the National Academy of Sciences*.

Malarial barcode

The discovery of a new "genetic barcode" capable of tracking drug-resistant strains of the malaria parasite has spurred Indian scientists to assist prevention efforts by collecting the entire genome of local parasite varieties.

"Whole genome sequencing" is a relatively new technique that unravels the genetic code of assorted DNA sequences in different parts of cells — for example, in mitochondria as well as the nucleus. Genetic markers found this technique could be used to monitor the spread of strains of malaria, including drug-resistant varieties, and help develop disease-control strategies tailored to specific locations, the researchers say.



But because the technique is new, there are certain regions where scientists have yet to collect data on local strains of *Plasmodium falciparum*, a malaria parasite, according to Cally Roper, a malaria genetics researcher at the London School of Hygiene and Tropical Medicine, in the UK. These areas include much of the Indian subcontinent plus Nigeria and the Democratic Republic of Congo, she says.

Aparup Das, a researcher at the National Institute of Malaria Research in New Delhi, says India faces an additional hurdle in collecting whole genome data because national law prohibits foreign scientists from working on the blood samples they need from infected Indian citizens unless they collaborate with local scientists. But a study authored by Roper and published in *Nature Communications* on 13 June shows that DNA from a little-studied component in the cells of malaria parasites — an apicoplast — can act like a "genetic barcode" and be used to monitor the spread of various strains.

Das, who was not involved in the study, says he and Roper have now agreed to collaborate on the whole genome sequencing of Indian samples. "Our work together will add Indian samples to the available data and fill the obvious gap."

The study's authors say genetic markers that tracked the spread of polio were an invaluable tool in tackling that disease and have "enormous potential" in the fight against malaria, too.

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