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THE NEXT DISRUPTIVE TECHNOLOGY IN ELECTRONICS: GRAPHENE TRANSISTORS

Arjun Subramanian P

A breakthrough in graphene-based transistor technology was reported in an editorial recently in the *Indian Express* by a team working on the technology at the Indian Institute of Science (IISc), Bangalore.[1] The author explains the immense application of the graphene based technology in electronics and communication. This is a major achievement and the application of this technology has high potential to revolutionise the electronic industry (integrated circuits manufacturing). Graphene was first isolated in 2004 by two researchers: Prof Andre Geim and Prof Kostya Novoselov at the University of Manchester, for which they were later awarded the Nobel Prize in Physics.[2] Ever since, various researches have been 'On' to use graphene for various applications including in integrated circuits.

The key aspect here is that the breakthrough in this technology will continue the relevance of Moore's Law for some more time. Some experts have opined that Moore's Law's physical limitation will be reached by 2017[3] while some claim it will last till 2026. With graphene transitors, the deadline will be extended further by several years. However, the coming of the graphene transistor might bring the actual end of Moore's Law closer, as it is understood that the limitation will arrive once transistors can be produced as small as the atomic particles.[4] It is to be noted that graphene is just one atom thick.[5]

The simplified version of Moore's Law is:

The overall processing power of computers will double every two years.[6]

To further simplify it,

The number of transistors on an affordable CPU would double every two years.[7]

Silicon and other materials like germanium, gallium-arsenide semiconductors have a limitation in size – they cannot be reduced beyond a certain point where the materials will lose their structural stability. Moreover, the resistance to electron flow is quite high compared to graphene. Here is where the use of graphene comes into play.

Graphene:

It is an allotrope of carbon just like diamond and graphite. But unlike diamond and other allotropes of carbon, graphene and graphite are two dimensional in structure and the important thing is that both are stable in this form. Further, graphene has a hexagonal lattice much like graphite, but there is just a single layer.[8] Though graphene has several amazing properties, i.e. it is nearly transparent, stronger (due to stronger covalent bonds) than steel, etc., only the properties relevant to this article will be discussed here.

Electronic properties of graphene

1. It has very high electrical conductivity as for each graphene atom one electron is free (the remaining 5 bond with three neighbouring atoms)[9] for conduction.

2. In addition, the electron mobility is very high – in fact higher than any known material. Electron mobility is the speed at which electrons move when a potential difference is created in the material.[10]

This property is the most important of all which makes it desirable to be used in electronics. This is also defined as high ballistic transport, which happens as a result of very little resistance to electron flow. A research has achieved mobility of 200,000 $cm^2 V^{-1} s^{-1}$ at electron densities of ~2 $\times 10^{11} cm^{-2}$ by suspending a single layer of graphene.[11]

Usually, there are two methods to increase the electron mobility of a conducting material: one, by reducing the impurities to extremely low levels; and two, by reducing the temperature to sub-zero conditions which stops impurity oscillations. The second method is the preferred method for achieving super-conductivity. However, the unique electric property of graphene offers this at room temperature.

These two properties of graphene along with its thin structure (the thinnest material known[12]), make it a highly desired material for making superfast and extremely small transistors. Firstly, the high electron mobility increases the speed of electronic operation (flip-flop) manyfold. Graphene transistors are said to have the potential to operate at speeds over 400 GHz.[13] Secondly, the thin nature enables cutting it to atom size transistor which means that more number of transistors can be packed in a given area, which further increase the processing power to tremendous proportions.

However, graphene transistor technology is not yet a complete reality and is still under research with varying levels of success. There are two primary hurdles in using graphene for producing transistors. One, Graphene does not have a band gap.[14] Two, as Mr. Mayank Shrivastava and team in IISc puts it: the unique electronic property of graphene is lost once it comes in contact with other three- dimensional metals.[15] These are the two major hurdles in using graphene as transistor material.

The first characteristic, 'no band gap', is nothing but the absence of an energy state/level which exists between the valence band and conduction band in an atom (above the outer most electron shell). Hence, there is no extra energy required to push the electron from the valence band to the conduction band; this poses a big problem in controlling flow of electrons, which electronic components are all about. Several institutes have come up with solutions like doping (impurities; this is also done in the existing semiconductor Bipolar Junction Transistor (BJT) like PNP and NPN[16]), applying electric fields, stretching and squeezing the material. But results have been with moderate success only with none managing to achieve the required 1 eV band gap.[17] So far no efficient solutions have been found for this problem. For the second hurdle of non-compatibility with three dimensional materials, the IISc Bangalore team claims to have solved the problem.

In addition to its electric properties, the other unique properties of graphene, i.e. its tensile strength, transparency and flexibility, will find application in several fields like biomedical, sensors, composites, energy, etc. Already, the material is being used to manufacture flexible (foldable) display screens.[18] Several researches are underway at present and soon they can be expected to emerge as products in the market – probably making graphene the next most sought-after crystallised carbon after the diamond.

(Disclaimer: The views and opinions expressed in this article are those of the author and do not necessarily reflect the position of the Centre for Air Power Studies [CAPS])

NOTES

[1] Mayank Srivastava and team, "Breaking the graphene barrier", Indian Express, Available at: http://indianexpress.com/article/technology/science/breaking-the-graphene-barrier-4465396/ , 9 January 2017

[2] "The story of graphene", University of Manchester, http://www.graphene.manchester.ac.uk/explore/the-story-of-graphene/ , accessed on 16th January 2017

[3] "Moore's Law", http://www.investopedia.com/terms/m/mooreslaw.asp, accessed on 15th January 2017

[4] "Moore's Law",http://www.mooreslaw.org/, accessed on 15th January 2017

[5] "Graphenomenon Graphene: Super Material", http://www.graphenomenon.com/ , accessed on 16 January 2017

[6] No.4

[7] Ibid

[8] Joseph Scott Bunch, "Mechanical and Electrical Property of Graphene Sheets", May 2008, p. 40-41 Available at: http://www.mceuengroup.lassp.cornell.edu/sites/mceuen/files/publications/Thesis_Bunch.pdf

[9] "Graphene Properties", http://www.understandingnano.com/graphene-properties.html, accessed on 17th January 2017

[10] Ibid

[11] K.I. Bolotin, K.J. Sikes, Z.Jiang, M.Klima, G.Fudenberg, J.Hone, P.Kim, H.L. Stormer, "Ultrahigh electron mobility in suspended graphene", February 2008, http://www.sciencedirect.com/science/article/pii/S0038109808001178 , accessed on 17 January 2017

[12] No.1

[13] "How to save the troubled graphene transistor", MIT Technology Review, https://www.technologyreview.com/s/518426/how-to-save-the-troubled-graphene-transistor/, 20 August 2013

[14] Ibid

[15] No.1

[16] Bipolar Junction Transistors have two junctions. For example the NPN and PNP both have two junctions. In the NPN, a single p-type material is sandwiched between two n-type materials. In the PNP transistor, it is the exact opposite. The difference between p-type and n-type lies in the difference in impurity doping. In p-type the doping creates an electron deficiency creating an excess hole (+ve) while in the n-type the doping creates an excess electron.

[17] No.13

[18] "Bendable smartphones are coming! Devices with screen made from graphene are so flexible they can be worn like a bracelet", http://www.dailymail.co.uk/sciencetech/article-3607191/Bendable-smartphones-coming-Devices-screens-graphene-flexible-worn-like-BRACELET.html , 24 May 2016