I.B.M. Releases New Graphene Circuits

I.B.M. researchers said Thursday that they had designed high-speed circuits from graphene, an ultra-thin material that has a host of promising applications, from high-bandwidth communication to a new generation of low-cost smart phone and television displays.

The researchers reported their findings in the journal *Science*, and concluded that a wafer-scale graphene circuit was demonstrated in which all circuit components, including graphene field-effect transistor and inductors, were monolithically integrated on a single carbide wafer. The integrated circuit operates as a broadband radio-frequency mixer at frequencies up to 10 gigahertz. These graphene circuits exhibit outstanding thermal stability with little reduction in performance (less than 1 decibel) between 300 and 400 kelvin. These results open up possibilities of achieving practical graphene technology with more complex functionality and performance.

The I.B.M. advance, therefore, is fundamentally a circuit known as a broadband frequency mixer that was built on a wafer of silicone. Widely used in all kinds of communications products, the circuits shift signals from one frequency to another. In the *Science* paper, the I.B.M. researchers describe a demonstration in which they deposited several layers of graphene on a silicone wafer, then created circuits based on graphene transistors and components known as inductors. They demonstrated frequency mixing up to speeds of 10 gigahertz.

In the past I.B.M. has created stand-alone graphene transistors, but not complete electronic circuits.

Scientists began making flakes of graphene, an atomic-scale lattice of carbon atoms, in the 1970s. They have gradually refined the process so they can now produce films of the material that are just a single atom thick. The film arranges itself in a hexagon-shaped array of carbon atoms and has the advantages of being flexible, transparent and inexpensive to manufacture.

But it is not yet a candidate to replace today’s CMOS transistors, the basis for the microprocessors and computer memories in consumer electronics systems. Graphene does not have the same physical properties as semi-conducting materials and cannot be used to completely switch on and off in the way that logic transistors are meant to do.

That has not tempered the industry’s excitement over potential applications for the material. In Europe and Asia, government and corporate investments are running far in advance of those in the United States, said Phaedon Avouris, an I.B.M. chemical physicist who is a leader of the company’s research effort. “Outside the U.S. there is a lot of interest,” he said.

Both the European Union and South Korea have recently started $1.5 billion efforts to build industrial-scale efforts using graphene as a next-generation display material, he said. Singapore has also recently started a major investment in the material.

In addition, American taxpayer funds are, sadly, being used towards the development of graphene development, in the form of corporate welfare doled out to I.B.M. from the Defense Department budget. I.B.M.’s research has been supported by a more modest effort financed by the Defense Advanced Research Projects Agency, the Pentagon office that supports futuristic science and technology. (Graphene is being explored as a substitute for materials like gallium arsenide, used in high-frequency military communications equipment.) In fact, the latest research released on the efficacy of graphene use was made possible through grant money from the Pentagon’s Defense Advanced Research Projects Agency.

To make the integrated graphene circuit, the IBM team first heated a silicone carbide wafer to desorb, or release, silicone and form a layer of graphene on its surface. The graphene film was allowed to grow to two or three layers in thickness, and then the silicone surface was heated to 1,400 degrees Celsius. Top-gated dual-fingered field-effect transistors were then integrated with aluminum inductors. Following this, the wafer was spin-coated with a thin polymer, and a layer of hydrogen silsesquioxane was applied to create active channels. The active channels were then carved by e-beam lithography, the excess graphene was removed with an oxygen plasma laser, and the circuit was cleaned with acetone. Hydrogen silsesquioxane is a negative tone electron-beam resist. Photoresists are used in the fabrication of printed circuit boards.

What is the future of Graphene?

CMOS (complementary metal oxide semiconductor) technology, which is currently used in integrated circuits, is rapidly approaching the limits of what it can do, and graphene is one of the alternatives being eyed as a replacement. However, the technology to produce graphene circuits is still in its infancy, and more work needs to be done to iron out the wrinkles. Among other things, the device yield rate needs to be improved, and using graphene in electrodes is the application that's probably closest to commercialization.

However, there are many other potential uses of graphene because of its uniqueness. Graphene is transparent like plastic but conducts heat and electricity better than metal, it is an elastic thin film, it's an impermeable membrane, and it is chemically inert and stable.

Ironically, in spite of American taxpayer support for the development of graphene products, I.B.M. says that will remain the preferred material of choice in the development of computer circuits. I.B.M. has revealed that graphene cannot fully replace inside CPU's (according to the United Kingdom-based computer hardware analyst firm Bit-tech. The reason is that graphene transistors cannot actually be completely switched off, which researchers had obviously failed to consider.

Yu Ming Lin from I.B.M. Research (Nanometer Scale and Science and Technology Committee) has even gone on record as saying that graphene as it is "will not replace the role of in the digital computing regime," in spite of the high conductivity (and other intriguing properties) inherent in graphene. Lin says that "there is an important distinction between the graphene transistors that we demonstrated, and the transistors used in a CPU. Unlike silicone, 'graphene does not have an energy gap, and therefore, graphene cannot be "switched off," resulting in a small on/off ratio." However, he also says that this does not mean the end for graphene as a suitable material of choice in CPU's and in other technological uses. Lin said that it may complement silicone in the form of a hybrid circuit to enrich the functionality of computer chips such as those used in Radiofrequency (RF) circuits since they aren't dependent on a large on/off ratio.

Intel's director of components research, Mike Mayberry said that 's properties make it a nearly ideal material. "The industry has so much experience with it that there are no plans to move away from as the substrate for chips." Graphene, in its current research state, may not replace as the main material for building CPUs, but continued research should eventually lead it to a strong foothold in the future of nanoelectronics. The Department of Defense and other government agencies have also not recently announced any efforts or plans to fund any further graphene research and development programs.