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A Conversation with Deji Akinwande

Mark Peplow

The nanotechnology researcher discusses recent achievements in making electronics out of atom-thin materials.


Credit: Texas ECE

Deji Akinwande, professor of electrical and computer engineering at the University of Texas, Austin, develops electronic devices that rely on atom-thin sheets known as two-dimensional (2-D) materials. While the carbon material graphene has received the lion's share of attention in this field, analogous materials such as silicene, phosphorene, and molybdenum disulfide are increasingly being tapped for applications such as wireless communications and low-power computing. Mark Peplow spoke to Akinwande and reports back from the frontiers of flatland.

How many 2-D materials are there?

This has become like counting grains of sand, there are so many. The definition of 2-D materials is expanding to include a range of synthetic materials, even polymers that tile on surfaces.

Graphene is the prototypical 2-D material, but it really lacks one key property for electronics: a bandgap. Without this energy barrier, one cannot switch graphene on or off like silicon or other conventional semiconductors. Materials like molybdenum disulfide and phosphorene are very exciting, because they not only have a sizable bandgap, they also have mobile electrons. That allows them to switch at very high frequencies, so they can process information from a wireless communication antenna, for example. Earlier this year we made what is basically a flexible phosphorene radio, as a proof of concept for a flexible wireless communication system.

I was at the Consumer Electronics Show in Las Vegas last year, and the big theme was wearable electronics. Phosphorene may be the ideal candidate for these applications, because it has the best features of both graphene and molybdenum disulfide. Unfortunately, phosphorene is not inherently stable, because it likes to attract moisture. But we have a coating that can make it last for many months, effectively indefinitely.

You made the first silicene transistor this year. Why was that such a milestone?

Until recently, there was a widespread belief that a silicene transistor would be impossible to realize experimentally. Silicene is unstable, but we've found that you can coat it with other materials to protect it. That's not so different from silicon—one of the reasons silicon has been so successful is that it is passivated with a surface layer of silicon oxide.

2-D materials like silicene, germanene, and stannene have the potential to create electronics with very low energy consumption. They are predicted to be topological insulators, a state of matter in which electrons travel without being scattered by defects in the material's structure. Conventional transistors consume quite a lot of energy as electrons scatter, dissipating it as heat.

Your group also reported a gigahertz-frequency transistor made from molybdenum disulfide. What advantages does that material offer?

Molybdenum disulfide has a very large bandgap, which reduces current leakage dramatically when the transistor is off. That sort of power loss is a big problem in today's devices.

Although gigahertz frequencies are not unusual for a transistor, they are unusually high for molybdenum disulfide. These frequencies open up an application space for molybdenum

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disulfide and related materials for low-power radio frequency electronics.

The next thing is to demonstrate simple prototype systems, where we put many transistors together into circuits. I think this is what's needed for companies to be interested in commercialization.

Can 2-D materials be produced at a sufficient scale for commercial applications?

Graphene is already manufacturable at a very large scale. When I go to conferences I'm always proud to show a smartphone made in China that uses a graphene touchscreen. More than 50,000 of these phones have been sold already.

The idea now is that we can leverage this infrastructure and knowledge and apply it to molybdenum disulfide—developing a universal technique to manufacture all of these 2-D materials.

Semiconductor electronics is a very mature industry, and there's a lot of inertia to change, so the prospects of displacing silicon in the next 10 years is pretty low. But flexible electronics is a nascent field, with lots of small, agile companies willing to adopt new methods and materials. So it's much more promising for 2-D materials to progress in those kinds of commercial applications in the next decade.

What other applications of 2-D materials are you working on?

We've just received a grant to pioneer studies of 2-D materials for brain electronics. Part of the challenge with understanding the brain is reading its electrical signals, and flexible 2-D materials are the ideal platform for that.

We hope to use sandwiched layers of graphene, molybdenum disulfide, and hexagonal boron nitride to make amplifiers—active electrodes—so you can read brain signals directly from the forehead.

They're flexible, so they can fit closely to your head. These materials also have just the right electrochemical impedance to receive electrical signals from brain activity.

Most similar electrodes are passive. But these will be active: They will record the signal from the brain and then amplify it in the Mo_2S layer. We'll have the first truly active electrode for reading brain signals.

Mark Peplow is a freelance contributor to Chemical & Engineering News, the weekly news magazine of the American Chemical Society. Center Stage interviews are edited for length and clarity.

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