

Penciled-in Electronics

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Materials Research Society | Published: 28 January 2014



Flexible toy pencils deposit a polymer/graphite composite to make a chemical vapor sensor. Figure courtesy of Jiaxing Huang. Click image to enlarge.

We use pencils so often in our everyday lives that we don't normally think about the science inside them. A group of students in a class at Northwestern University taught by [Professor Jiaxing Huang](#) are using pencils to do what they were literally made to do: deposit graphite onto paper. Except they aren't taking notes. They're fabricating strain gauges and chemiresistors from commercially bought pencils and printing paper. The team, including students Cheng-Wei Lin and Zhibo Zhao and their TA Jaemyung Kim, published their findings in the *Nature* - family, open-access journal *Scientific Reports*.

"It started as a joke in my class. I was telling students that there's a new material called graphene and people say if you use pencils to draw a line you may have already drawn graphene sheets. After class a student came up to me and asked if we could do something with that graphene," Huang said.

Huang teaches an Introduction to Conducting Polymers course where, as a final project, he has the students develop an idea relating to conducting polymers or, more broadly speaking, π -conjugated systems. The idea can be anything from a proof of concept to a consumer application. The only catch is that it has to be novel. A clever group of students used Huang's graphene joke as a starting point for actual innovation.

"I think this is a rather new model for teaching," said University of Cincinnati Professor Andrew Steckl. "It is very time intensive and somewhat expensive. But when [the students] are done with all of this, they have such terrific background knowledge, and they develop, very early on, an intuition of the subject. And that's what I think successful research is about: intuition."

The "lead" in a pencil is typically made of fine graphite powders held together by an inorganic clay consisting of silicon, aluminum, magnesium, and oxygen. Softer lead has a higher percent of graphite and tends to write darker, while hard lead has less graphite and writes lighter. A pencil line is really a thin film of graphite networked by the binder, which means it can be conductive.

The pencil line's conductance is sensitive to bending the paper. When bent upwards in a u shape, the line is compressed, carbon networks are connected, and conductance increases. When bent downwards in an n shape, the network is stretched and conductance lowers. The students found that lines drawn with pencils of medium hardness exhibit high sensitivity to compression and stretching. The HB pencil, which lies in the middle of a surprisingly large scale, had the largest response. Harder pencils failed to meet the percolation threshold, meaning there wasn't enough graphite to connect the carbon networks, and the devices didn't respond to bending.

The real innovation came using toy pencils that twist and bend without snapping, which Huang discovered at the Reagan airport. He bought the pencil out of curiosity and, while bending it back and forth on the plane, he realized that the binder is made of organic polymers rather than brittle inorganics as in traditional pencils. Intrigued by the possibilities, he gave the souvenir to his students.

Already, polymer/carbon composites are used to make electronic noses that sniff out hazardous volatile chemicals. Vapors of volatile solvents can swell the polymer binder, decreasing the graphite contacts and generating a change in its electrical signal. The students drew up an "all-pencil device" that could detect certain solvent vapors. Once the vapors evaporated, the device could be reused.

"People normally make such polymer composites using specialized processing techniques and novel materials -nanotubes, metal particles, etc.-but our students demonstrated this principle by just drawing a line with a flexible toy pencil," Huang said.

The devices based on graphite lines, whether networked with stiff inorganics or flexible polymer, are endless. "My students have proposed many ideas such as pencil drawn touch pads or keyboards," Huang said. "It is probably only limited by our imagination and creativity." The method is simple, cheap, disposable, and environmentally friendly. But more exciting is the course format Huang illustrates, where students are encouraged to perform research-level projects and contribute to the scientific literature.

"If my student didn't ask me that question none of this would have happened," Huang said. "I use this as an example to tell students to keep up the curiosity and pay attention to the things around you. That's how you come up with great ideas."

Read the abstract in *Scientific Reports* [here](#).