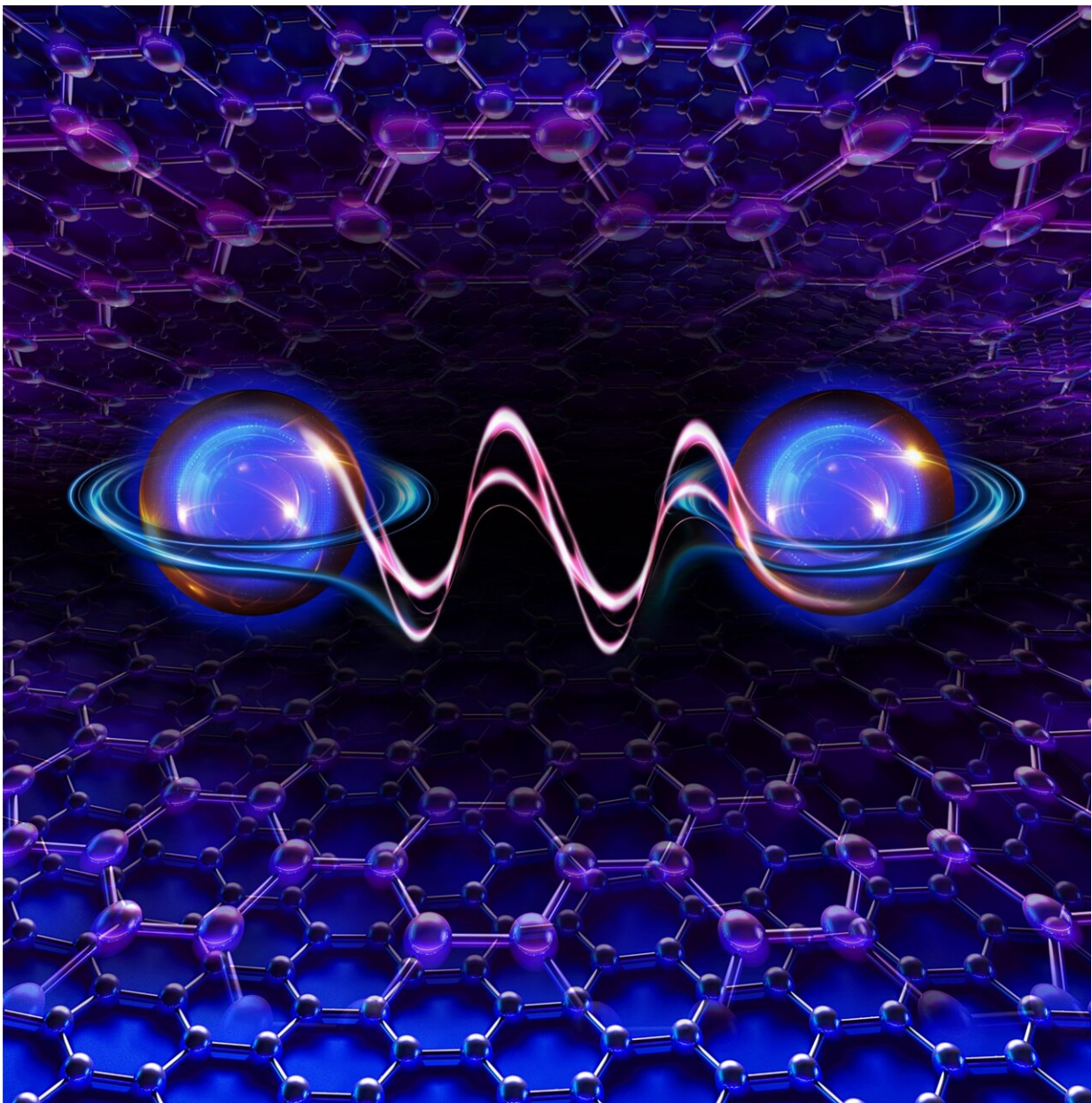


Physicists turn pencil lead into metaphorical 'gold'

October 30 2023, by Elizabeth A. Thomson



Artist's rendition of the electron correlation, or ability of electrons to talk with each other, that can occur in a special kind of graphite (pencil lead). Credit: Sampson Wilcox, MIT Research Laboratory of Electronics

MIT physicists and colleagues have metaphorically turned graphite, or pencil lead, into gold by isolating five ultrathin flakes stacked in a specific order. The resulting material can then be tuned to exhibit three important properties never before seen in natural graphite.

"It is kind of like one-stop shopping," says Long Ju, an assistant professor in the MIT Department of Physics and leader of the work, which is reported in the [Nature Nanotechnology](#). "In this case, we never realized that all of these interesting things are embedded in graphite."

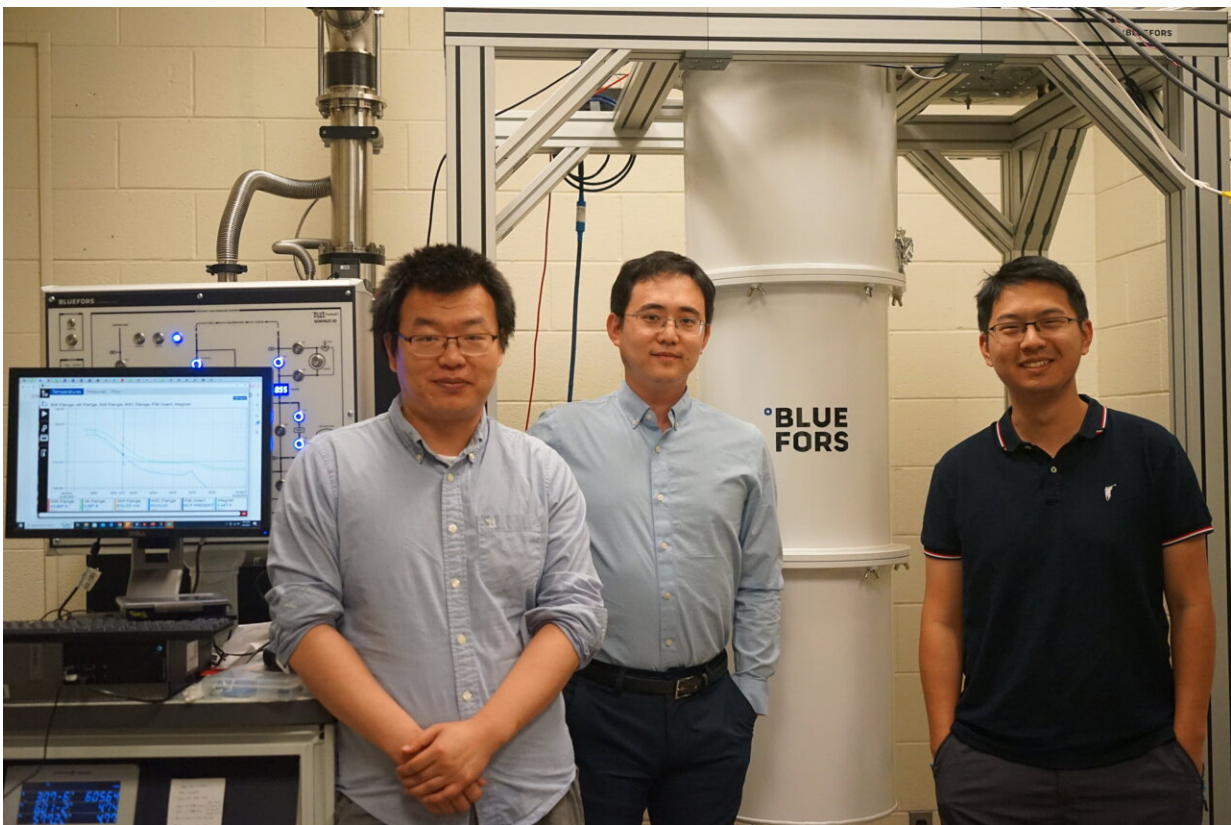
Further, he says, "It is very rare to find materials that can host this many properties."

Graphite is composed of graphene, which is a single layer of carbon atoms arranged in hexagons resembling a honeycomb structure. Graphene, in turn, has been the focus of intense research since it was first isolated about 20 years ago. Then about five years ago researchers including a team at MIT discovered that stacking individual sheets of graphene, and twisting them at a slight angle to each other, can impart new properties to the material, from superconductivity to magnetism. The field of "twistronics" was born.

In the current work, "we discovered interesting properties with no twisting at all," says Ju, who is also affiliated with the Materials Research Laboratory.

He and colleagues discovered that five layers of graphene arranged in a certain order allow the electrons moving around inside the material to talk with each other. That phenomenon, known as electron correlation, "is the magic that makes all of these new properties possible," Ju says.

Bulk graphite—and even single sheets of graphene—are good electrical conductors, but that's it. The material Ju and colleagues isolated, which they call pentalayer rhombohedral stacked graphene, becomes much more than the sum of its parts.



MIT Postdoctoral Associate Zhengguang Lu, Assistant Professor Long Ju, and Graduate Student Tonghang Han in the lab. The three are authors, with seven others, of a paper in *Nature Nanotechnology* about a special kind of graphite (pencil lead). Credit: Ju lab, MIT

Novel microscope

Key to isolating the material was a [novel microscope](#) Ju built at MIT in 2021 that can quickly and relatively inexpensively determine a variety of important characteristics of a material at the nanoscale. Pentlayer rhombohedral stacked graphene is only a few billionths of a meter thick.

Scientists including Ju were looking for multilayer graphene that was stacked in a very precise order, known as rhombohedral stacking. Says Ju, "there are more than 10 possible stacking orders when you go to five layers. Rhombohedral is just one of them." The microscope Ju built, known as Scattering-type Scanning Nearfield Optical Microscopy, or s-SNOM, allowed the scientists to identify and isolate only the pentlayers in the rhombohedral stacking order they were interested in.

Three in one

From there, the team attached electrodes to a tiny sandwich composed of boron nitride "bread" that protects the delicate "meat" of pentlayer rhombohedral stacked graphene. The electrodes allowed them to tune the system with different voltages, or amounts of electricity. The result: they discovered the emergence of three different phenomena depending on the number of electrons flooding the system.

"We found that the material could be insulating, magnetic, or topological," Ju says. The latter is somewhat related to both conductors and insulators. Essentially, Ju explains, a topological material allows the unimpeded movement of electrons around the edges of a material, but not through the middle. The electrons are traveling in one direction along a "highway" at the edge of the material separated by a median that makes up the center of the material. So the edge of a topological material is a perfect conductor, while the center is an insulator.

"Our work establishes rhombohedral stacked multilayer [graphene](#) as a highly tunable platform to study these new possibilities of strongly correlated and topological physics," Ju and his co-authors conclude.

In addition to Ju, authors of the paper are Tonghang Han and Zhengguang Lu. Han is a graduate student in the Department of Physics; Lu is a postdoctoral associate in the Materials Research Laboratory. The two are co-first authors of the paper.

More information: Tonghang Han et al, Correlated insulator and Chern insulators in pentalayer rhombohedral-stacked graphene, *Nature Nanotechnology* (2023). [DOI: 10.1038/s41565-023-01520-1](https://doi.org/10.1038/s41565-023-01520-1)

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