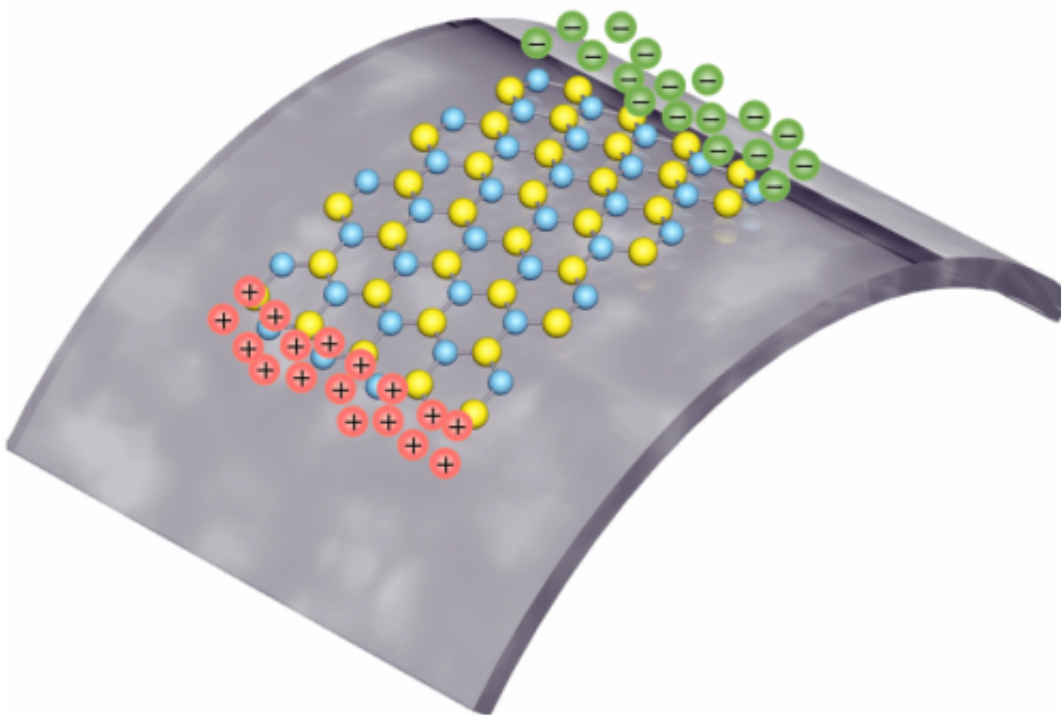


Researchers develop world's thinnest electric generator

October 15 2014



This is a cartoon showing positive and negative polarized charges are squeezed from a single layer of atoms of molybdenum disulfide (MoS₂), as it is being stretched. Credit: Lei Wang/Columbia Engineering

Researchers from Columbia Engineering and the Georgia Institute of Technology report today that they have made the first experimental observation of piezoelectricity and the piezotronic effect in an

atomically thin material, molybdenum disulfide (MoS₂), resulting in a unique electric generator and mechanosensation devices that are optically transparent, extremely light, and very bendable and stretchable.

In a paper published online October 15, 2014, in *Nature*, research groups from the two institutions demonstrate the mechanical generation of electricity from the two-dimensional (2D) MoS₂ material. The [piezoelectric](#) effect in this material had previously been predicted theoretically.

Piezoelectricity is a well-known effect in which stretching or compressing a material causes it to generate an electrical voltage (or the reverse, in which an applied voltage causes it to expand or contract). But for materials of only a few atomic thicknesses, no experimental observation of piezoelectricity has been made, until now. The observation reported today provides a new property for two-dimensional materials such as molybdenum disulfide, opening the potential for new types of mechanically controlled electronic devices.

"This material—just a single layer of atoms—could be made as a wearable device, perhaps integrated into clothing, to convert energy from your body movement to electricity and power wearable sensors or medical devices, or perhaps supply enough energy to charge your cell phone in your pocket," says James Hone, professor of mechanical engineering at Columbia and co-leader of the research.

"Proof of the piezoelectric effect and piezotronic effect adds new functionalities to these two-dimensional materials," says Zhong Lin Wang, Regents' Professor in Georgia Tech's School of Materials Science and Engineering and a co-leader of the research. "The materials community is excited about molybdenum disulfide, and demonstrating the piezoelectric effect in it adds a new facet to the material."

Hone and his research group demonstrated in 2008 that graphene, a 2D form of carbon, is the strongest material. He and Lei Wang, a postdoctoral fellow in Hone's group, have been actively exploring the novel properties of 2D materials like graphene and MoS₂ as they are stretched and compressed.



Researchers from the Georgia Institute of Technology and Columbia Engineering have made the first experimental observation of piezoelectricity and the piezotronic effect in an atomically thin material, molybdenum disulfide (MoS₂). Shown is a sample of the material that was tested as part of the research. The material could be the basis for unique electric generator and mechanosensation devices that are optically transparent, extremely light, and very bendable and stretchable. Credit: Rob Felt/Georgia Tech

Zhong Lin Wang and his research group pioneered the field of piezoelectric nanogenerators for converting mechanical energy into

electricity. He and postdoctoral fellow Wenzhuo Wu are also developing piezotronic devices, which use piezoelectric charges to control the flow of current through the material just as gate voltages do in conventional three-terminal transistors.

There are two keys to using [molybdenum disulfide](#) for generating current: using an odd number of layers and flexing it in the proper direction. The material is highly polar, but, Zhong Lin Wang notes, so an even number of layers cancels out the piezoelectric effect. The material's crystalline structure also is piezoelectric in only certain crystalline orientations.

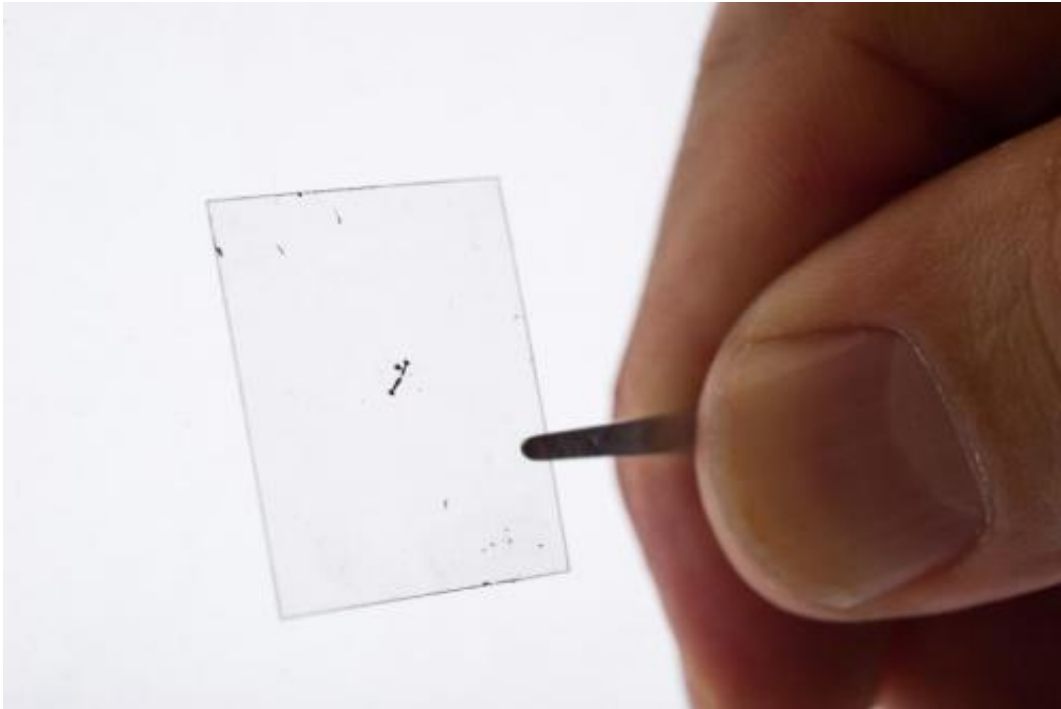
For the *Nature* study, Hone's team placed thin flakes of MoS₂ on flexible plastic substrates and determined how their crystal lattices were oriented using optical techniques. They then patterned metal electrodes onto the flakes. In research done at Georgia Tech, Wang's group installed measurement electrodes on samples provided by Hone's group, then measured current flows as the samples were mechanically deformed. They monitored the conversion of mechanical to electrical energy, and observed voltage and current outputs.

The researchers also noted that the output voltage reversed sign when they changed the direction of applied strain, and that it disappeared in samples with an even number of atomic layers, confirming theoretical predictions published last year. The presence of piezotronic effect in odd layer MoS₂ was also observed for the first time.

"What's really interesting is we've now found that a material like MoS₂, which is not piezoelectric in bulk form, can become piezoelectric when it is thinned down to a single atomic layer," says Lei Wang.

To be piezoelectric, a material must break central symmetry. A single atomic layer of MoS₂ has such a structure, and should be piezoelectric.

However, in bulk MoS₂, successive layers are oriented in opposite directions, and generate positive and negative voltages that cancel each other out and give zero net [piezoelectric effect](#).



Researchers from the Georgia Institute of Technology and Columbia Engineering have made the first experimental observation of piezoelectricity and the piezotronic effect in an atomically thin material, molybdenum disulfide (MoS₂). Shown is a sample of the material that was tested as part of the research. The material could be the basis for unique electric generator and mechanosensation devices that are optically transparent, extremely light, and extremely bendable and stretchable. Credit: Rob Felt/Georgia Tech

"This adds another member to the family of piezoelectric materials for functional devices," says Wenzhuo Wu.

In fact, MoS₂ is just one of a group of 2D semiconducting materials

known as transition metal dichalcogenides, all of which are predicted to have similar piezoelectric properties. These are part of an even larger family of 2D materials whose [piezoelectric materials](#) remain unexplored. Importantly, as has been shown by Hone and his colleagues, 2D materials can be stretched much farther than conventional materials, particularly traditional ceramic piezoelectrics, which are quite brittle.

The research could open the door to development of new applications for the material and its unique properties.

"This is the first experimental work in this area and is an elegant example of how the world becomes different when the size of material shrinks to the scale of a single atom," Hone adds. "With what we're learning, we're eager to build useful devices for all kinds of applications."

Ultimately, Zhong Lin Wang notes, the research could lead to complete atomic-thick nanosystems that are self-powered by harvesting mechanical energy from the environment. This study also reveals the piezotronic effect in two-dimensional materials for the first time, which greatly expands the application of layered materials for human-machine interfacing, robotics, MEMS, and active flexible electronics.

Provided by Columbia University School of Engineering and Applied Science

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