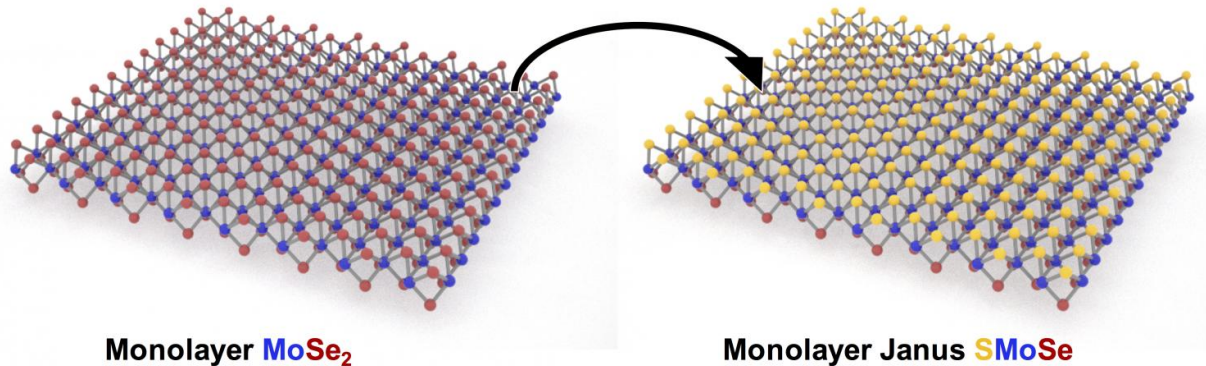


2-faced 2-D material is a first at Rice

August 14 2017



Rice University materials scientists replace all the atoms on top of a three-layer, two-dimensional crystal to make a transition-metal dichalcogenide with sulfur, molybdenum and selenium. Credit: Jing Zhang/Rice University

Like a sandwich with wheat on the bottom and rye on the top, Rice University scientists have cooked up a tasty new twist on two-dimensional materials.

The Rice laboratory of [materials](#) scientist Jun Lou has made a semiconducting transition-metal dichalcogenide (TMD) that starts as a monolayer of molybdenum diselenide. They then strip the top layer of the lattice and replace precisely half the selenium atoms with sulfur.

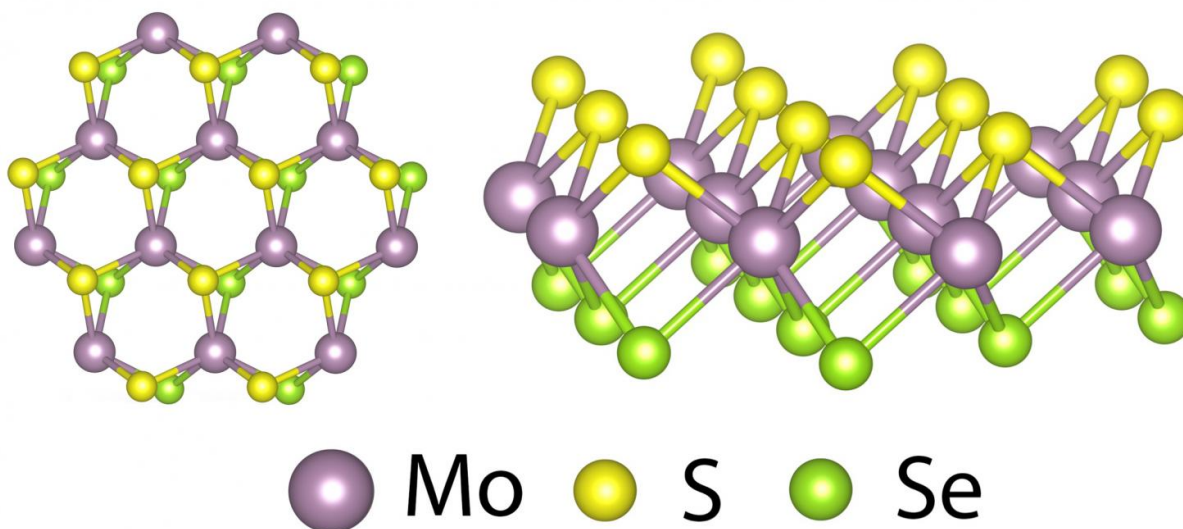
The new material they call Janus sulfur molybdenum selenium (SMoSe) has a crystalline construction the researchers said can host an intrinsic

electric field and that also shows promise for catalytic production of hydrogen.

The work is detailed this month in the American Chemical Society journal *ACS Nano*.

The two-faced material is technically two-dimensional, but like molybdenum diselenide it consists of three stacked layers of atoms arranged in a grid. From the top, they look like hexagonal rings a la graphene, but from any other angle, the grid is more like a nanoscale jungle gym.

Tight control of the conditions in a typical chemical vapor deposition furnace—800 degrees Celsius (1,872 degrees Fahrenheit) at atmospheric pressure—allowed the sulfur to interact with only the top layer of selenium atoms and leave the bottom untouched, the researchers said. If the temperature drifts above 850, all the selenium is replaced.



This image shows top (left) and side views of Janus sulfur molybdenum selenium created at Rice University. Careful control of heating allows sulfur to replace

just the top plane of selenium atoms in the new two-dimensional material.
Credit: Jing Zhang/Rice University

"Like the intercalation of many other molecules demonstrated to have the ability to diffuse into the layered materials, diffusion of gaseous sulfur molecules in between the layers of these Van der Waals crystals, as well as the space between them and the substrates, requires sufficient driving force," said Rice postdoctoral researcher Jing Zhang, co-lead author of the paper with graduate student Shuai Jia. "And the driving force in our experiments is controlled by the reaction temperature."

Close examination showed the presence of [sulfur](#) gave the material a larger band gap than molybdenum diselenide, the researchers said.

"This type of two-faced structure has long been predicted theoretically but very rarely realized in the 2-D research community," Lou said. "The break of symmetry in the out-of-plane direction of 2-D TMDs could lead to many applications, such as a basal-plane active 2-D catalyst, robust piezoelectricity-enabled sensors and actuators at the 2-D limit."

He said preparation of the Janus material should be universal to layered materials with similar structures. "It will be quite interesting to look at the properties of the Janus configuration of other 2-D materials," Lou said.

More information: Jing Zhang et al, Janus Monolayer Transition-Metal Dichalcogenides, *ACS Nano* (2017). [DOI: 10.1021/acsnano.7b03186](#)

Provided by Rice University

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