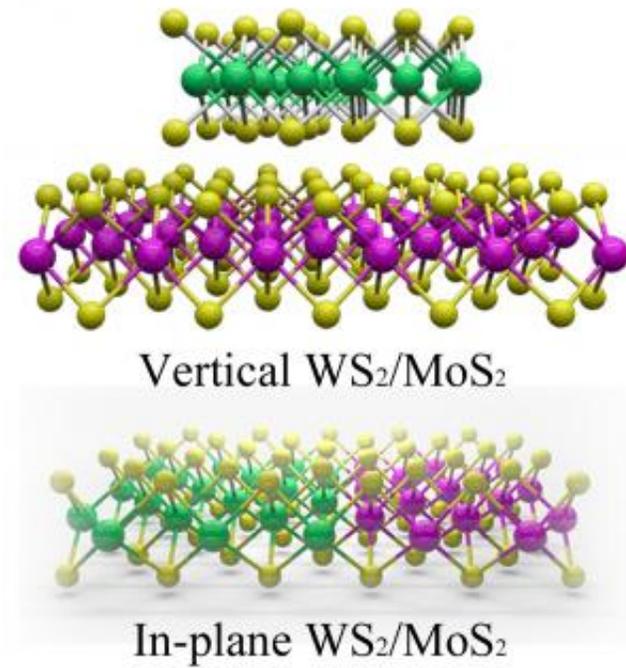


'Pixel' engineered electronics have growth potential

September 29 2014, by Mike Williams



Stacked (top) and in-plane nanomaterials self-assemble in two ways, depending on the temperature at which they're grown, according to Rice University researchers who led the project. The semiconducting materials show promise for a new generation of "pixel" electronics. In the illustration, green spheres are tungsten, purple are molybdenum and yellow are sulfur. Credit: Ajayan Group/Rice University

(Phys.org) —A little change in temperature makes a big difference for

growing a new generation of hybrid atomic-layer structures, according to scientists at Rice University, Oak Ridge National Laboratory, Vanderbilt University and Pennsylvania State University.

Rice scientists led the first single-step growth of self-assembled hybrid layers made of two elements that can either be side by side and one-atom thick or stacked atop each other. The structure's final form can be tuned by changing the growth temperature.

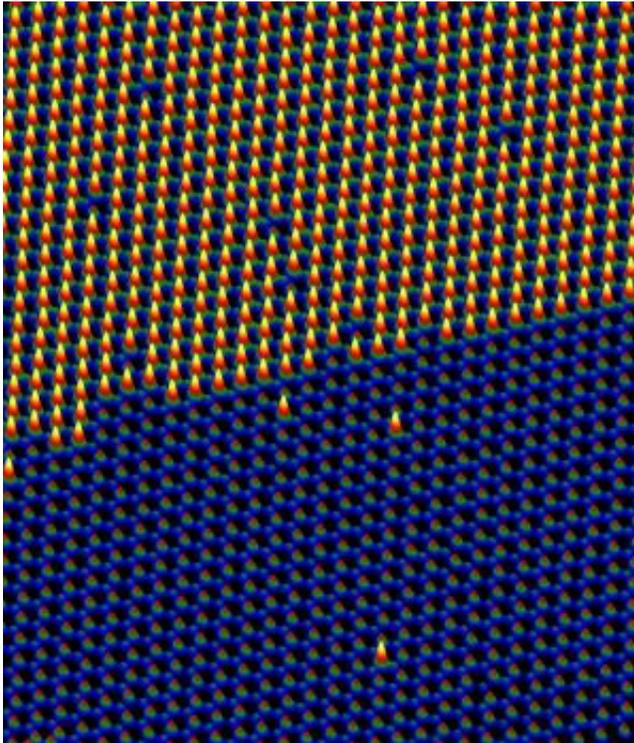
The discovery reported online this week in *Nature Materials* could lead to what Rice [materials](#) scientist Pulickel Ajayan calls "pixel engineering": atomically thin semiconductors with no limit to their potential for use in optoelectronic devices.

The researchers led by Ajayan and Wu Zhou, a materials scientist at Oak Ridge, discovered the interesting new composites when they combined the growth of two-dimensional [molybdenum disulfide](#) and tungsten disulfide through [chemical vapor deposition](#). In this process, specific gases are heated in a furnace, where their atoms gather in an orderly fashion around a catalyst to form the crystalline material.

High-temperature growth – about 850 degrees Celsius (1,563 degrees Fahrenheit) – yielded vertically stacked bilayers, with tungsten on top. At lower temperatures, about 650 degrees C (1,202 degrees F), the crystal lattices preferred to grow side by side. The interfaces in either material are sharp and clean, as seen under a scanning electron microscope and in spectroscopic studies.

"With the advent of 2-D layered materials, people are trying to build artificial structures using graphene and now dichalcogenides as building blocks," Ajayan said. Because graphene is atomically thin and flat and dichalcogenides like molybdenum disulfide are not quite that flat, there is some incompatibility when these are grown together—but two

dichalcogenides with different compositions could be compatible. "We show that depending on the conditions, we can combine two dichalcogenides to grow either in-plane hybrid or in stacks."

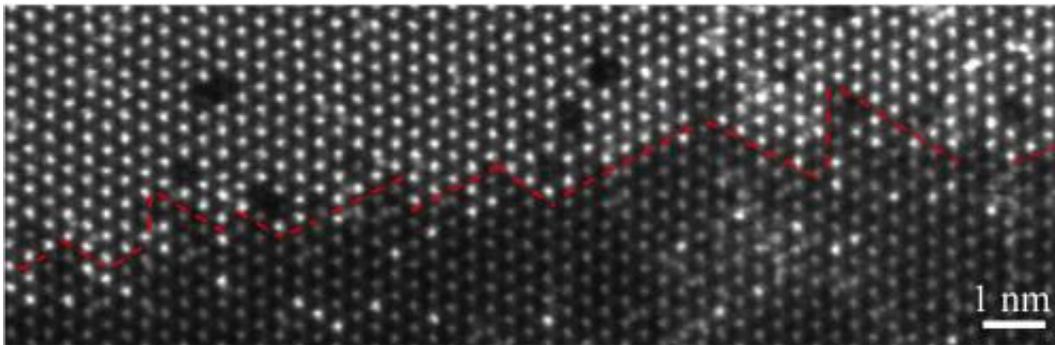


This image shows the interface between elements of the in-plane material created by scientists at Rice University and their colleagues. Tungsten disulfide (orange) and molybdenum disulfide (blue) molecules self assemble into either single- or multiple-layer materials, depending on growth temperature. Credit: Yongji Gong and Junhao Lin

The monolayer composites have small but stable band gaps, while the stacked composite layers show modified [electronic properties](#) such as enhanced photoluminescence, which will be useful for electronics that rely on optical signals.

"What's even more interesting is that the layered structure has a particular lock-in stacking order," Zhou said. "When you stack 2-D materials by transferring layers, there's no way to control their orientation to one another. That impacts their electronic properties. In this paper, we demonstrate that in a certain window, we can get a particular stacking order during growth, with a particular orientation."

The new materials could be used for vertically stacked field-effect transistors as well as electronic devices only a few atoms thick, he said.

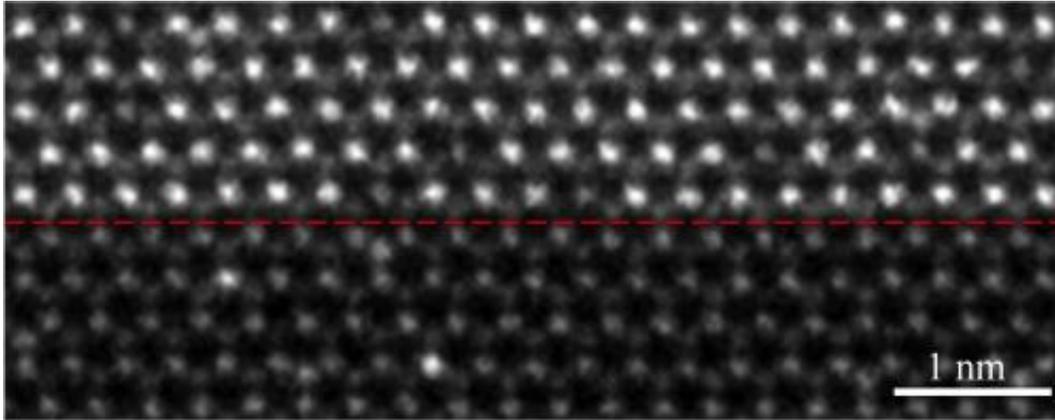


This atomic-resolution image shows the sharp line between tungsten disulfide (brighter) and molybdenum disulfide (darker) in a new material made in a collaboration led by Rice University. The two-dimensional material shows promise for nanoelectronic applications. Credit: Oak Ridge National Laboratory

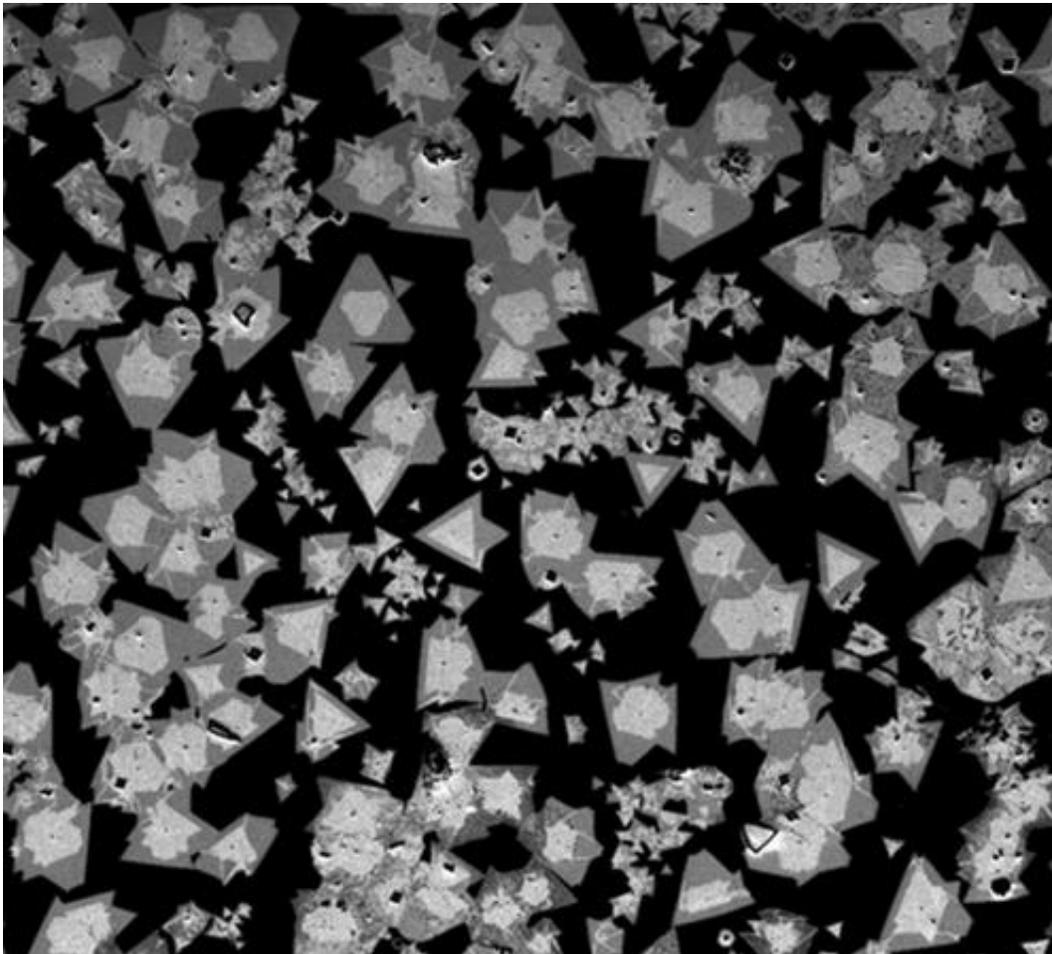
"We should be able to tweak certain regions to control certain functions, like light or terahertz emission," said Robert Vajtai of Rice, a co-author of the study. "The whole idea, really, is to create domains with different electronic characters within a single layer."

"Our goal is to build fully functional [electronic devices](#) on a single plane, or maybe a few layers," added Mauricio Terrones, a co-author from Penn State. "What we've accomplished means that pretty much any

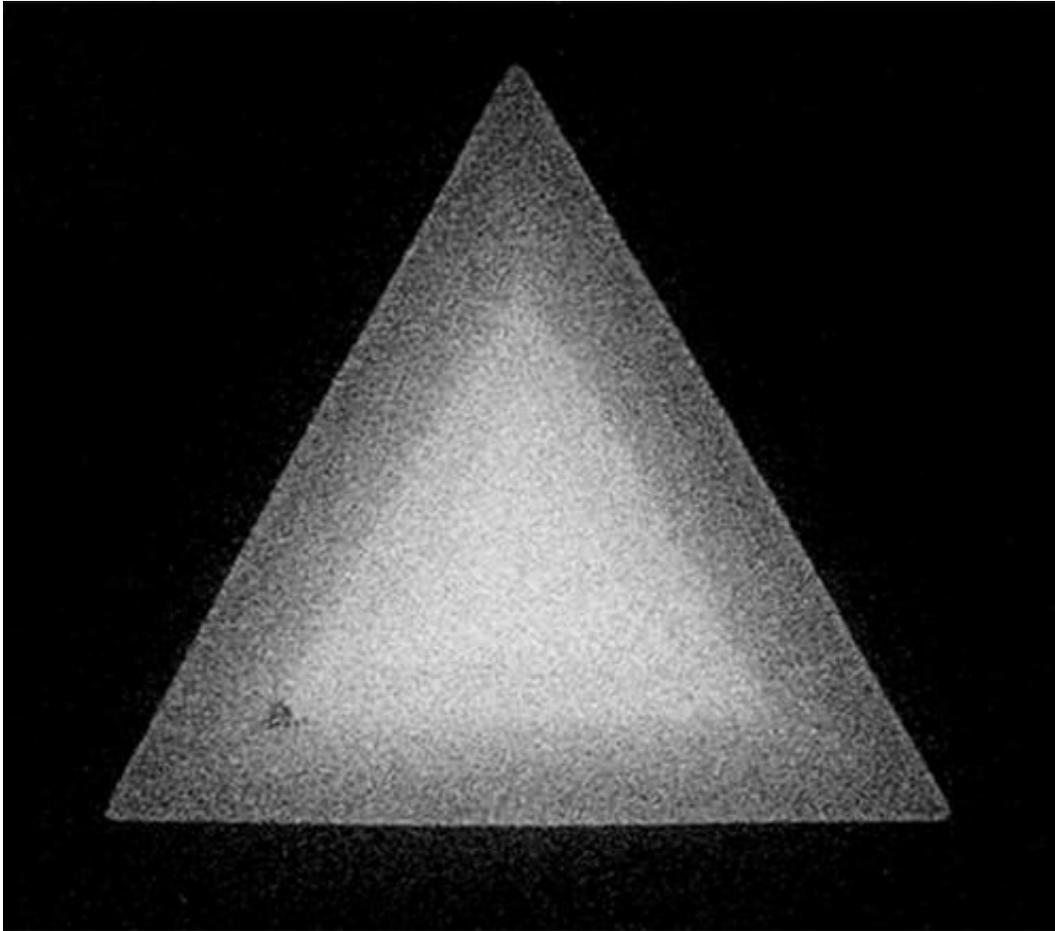
architecture for devices is now possible on a single atomic layer. And that's remarkable."



This atomic-resolution image shows the sharp line between tungsten disulfide (brighter) and molybdenum disulfide (darker) in a new material made in a collaboration led by Rice University. The two-dimensional material shows promise for nanoelectronic applications. Credit: Oak Ridge National Laboratory



Stacked heterostructures of tungsten disulfide and molybdenum disulfide were grown in experiments at Rice University. The form of the structures depends on the growth temperature: Higher temperatures resulted in stacked structures, while lower temperatures produced in-plane structures. The material may be useful for nanoelectronic applications. Credit: Ajayan Group/Rice University



An image of an in-plane heterostructure of tungsten disulfide and molybdenum disulfide, created in an experiment at Rice University. The structures self assemble in a furnace at 650 degrees Celsius. Higher temperatures formed stacked heterostructures. The structure is about 20 microns across. Credit: Ajayan Group/Rice University

More information: "Vertical and in-plane heterostructures from WS₂/MoS₂ monolayers." Yongji Gong, et al. *Nature Materials* (2014)
[DOI: 10.1038/nmat4091](https://doi.org/10.1038/nmat4091)

Provided by Rice University

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