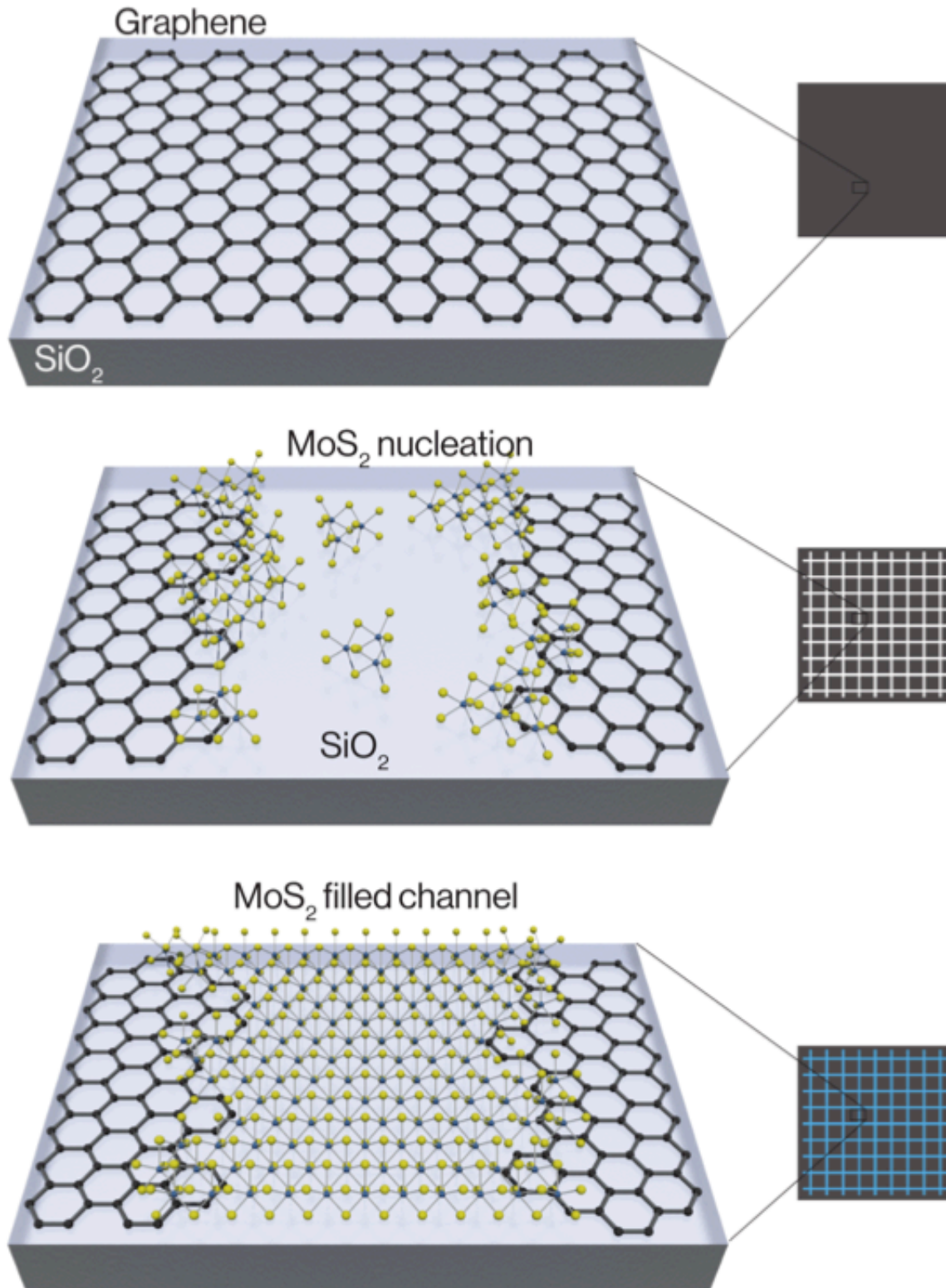


# **Scientists grow atomically thin transistors and circuits**

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This schematic shows the chemical assembly of two-dimensional crystals. Graphene is first etched into channels and the TMDC molybdenum disulfide ( $\text{MoS}_2$ ) begins to nucleate around the edges and within the channel. On the

edges, MoS<sub>2</sub> slightly overlaps on top of the graphene. Finally, further growth results in MoS<sub>2</sub> completely filling the channels. Credit: Berkeley Lab

In an advance that helps pave the way for next-generation electronics and computing technologies—and possibly paper-thin gadgets—scientists with the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) developed a way to chemically assemble transistors and circuits that are only a few atoms thick.

What's more, their method yields functional structures at a scale large enough to begin thinking about real-world applications and commercial scalability.

They report their research online July 11 in the journal *Nature Nanotechnology*.

The scientists controlled the synthesis of a transistor in which narrow channels were etched onto conducting graphene, and a semiconducting material called a transition-metal dichalcogenide, or TMDC, was seeded in the blank channels. Both of these materials are single-layered crystals and atomically thin, so the two-part assembly yielded electronic structures that are essentially two-dimensional. In addition, the synthesis is able to cover an area a few centimeters long and a few millimeters wide.

"This is a big step toward a scalable and repeatable way to build atomically thin electronics or pack more computing power in a smaller area," says Xiang Zhang, a senior scientist in Berkeley Lab's Materials Sciences Division who led the study.

Zhang also holds the Ernest S. Kuh Endowed Chair at the University of

California (UC) Berkeley and is a member of the Kavli Energy NanoSciences Institute at Berkeley. Other scientists who contributed to the research include Mervin Zhao, Yu Ye, Yang Xia, Hanyu Zhu, Siqu Wang, and Yuan Wang from UC Berkeley as well as Yimo Han and David Muller from Cornell University.

Their work is part of a new wave of research aimed at keeping pace with Moore's Law, which holds that the number of transistors in an integrated circuit doubles approximately every two years. In order to keep this pace, scientists predict that integrated electronics will soon require transistors that measure less than ten nanometers in length.

Transistors are electronic switches, so they need to be able to turn on and off, which is a characteristic of semiconductors. However, at the nanometer scale, [silicon transistors](#) likely won't be a good option. That's because silicon is a bulk material, and as electronics made from silicon become smaller and smaller, their performance as switches dramatically decreases, which is a major roadblock for future electronics.

Researchers have looked to two-dimensional crystals that are only one molecule thick as alternative materials to keep up with Moore's Law. These crystals aren't subject to the constraints of silicon.

In this vein, the Berkeley Lab scientists developed a way to seed a single-layered semiconductor, in this case the TMDC molybdenum disulfide (MoS<sub>2</sub>), into channels lithographically etched within a sheet of conducting graphene. The two atomic sheets meet to form nanometer-scale junctions that enable graphene to efficiently inject current into the MoS<sub>2</sub>. These junctions make atomically thin transistors.

"This approach allows for the chemical assembly of electronic circuits, using two-dimensional materials, which show improved performance compared to using traditional metals to inject current into TMDCs," says

Mervin Zhao, a lead author and Ph.D. student in Zhang's group at Berkeley Lab and UC Berkeley.

Optical and electron microscopy images, and spectroscopic mapping, confirmed various aspects related to the successful formation and functionality of the two-dimensional transistors.

In addition, the scientists demonstrated the applicability of the structure by assembling it into the logic circuitry of an inverter. This further underscores the technology's ability to lay the foundation for a chemically assembled atomic computer, the scientists say.

"Both of these two-dimensional crystals have been synthesized in the wafer scale in a way that is compatible with current semiconductor manufacturing. By integrating our technique with other growth systems, it's possible that future computing can be done completely with atomically thin crystals," says Zhao.

**More information:** Large-scale chemical assembly of atomically thin transistors and circuits, *Nature Nanotechnology*, [DOI: 10.1038/nnano.2016.115](https://doi.org/10.1038/nnano.2016.115)

Provided by Lawrence Berkeley National Laboratory

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