# A new technique for making 2D transistors from dual-phase TMD crystals

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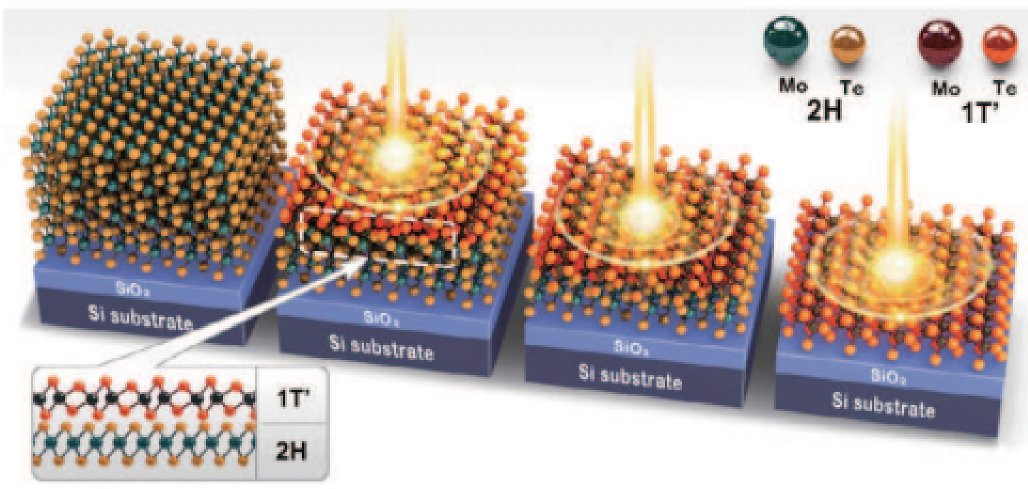



A simulation of the process of converting the 2H-$MoTe_2$ into 1T'-$MoTe_2$ with laser-irradiation

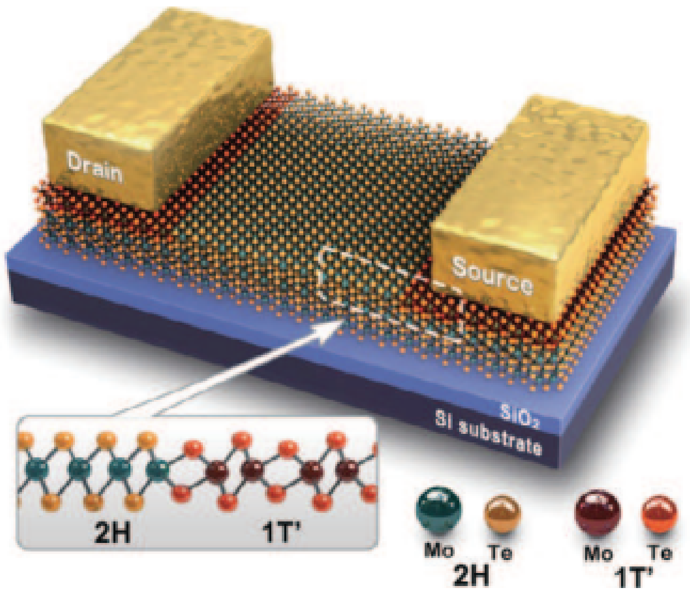
Molybdenum ditelluride ($MoTe_2$) is a crystalline compound that, if pure enough, can be used as a transistor. Its molecular structure is an atomic sandwich made up of one molybdenum atom for every two tellurium atoms. It was first made in the 1960s via several different fabrication methods, but until last year, it had never been made in a pure enough form to be suitable for electronics.

Last year, a multidisciplinary Korean research team devised a fabrication method for the creation of pure $MoTe_2$. Not only did they succeed in making $MoTe_2$ in pure form, they were able to make two types of it—a semiconducting variety called 2H-$MoTe_2$ (2H because of its hexagonal shape) and a metallic variety called 1T'-$MoTe_2$ (1T' because it has an octahedral shape) — which are both stable at room temperature.

Making $MoTe_2$ in a pure form was very difficult and it was seen by some as a black sheep of the transition metal dichalcogenides (TMD) family and purposefully ignored. TMDs are molecules that can be made exceedingly thin, only several atomic layers, and have an electrical property called a band gap, which makes them ideal for making electrical components, especially transistors.

A TMD crystal follows an MX2 format: there is one transition metal, represented by M (M can be Tungsten, Molybdenum, etc.) and two chalcogenides, the X2 (Sulfur, Selenium, or Tellurium). These atoms form a thin molecular sandwich with the one metal and two chalcogenides, and depending on their fabrication method, can exist in several differently shaped atomic arrangements.

The overwhelming majority of current microchips are made from silicon, and they work extremely well. However, as devices get smaller, there is an increasing demand to shrink the size of the logic chips that make those devices work. As the chips approach single- or several-atom thickness, (commonly referred to as two-dimensional), silicon no longer works as well as it does in a larger 3D scale. As the scale approaches two dimensions (2D), the band gap of silicon changes (higher band gap than that of its 3D form) and the contact points with metal connections on silicon are no longer smooth enough to be used efficiently in electrical circuits.




the 2H-$MoTe_2$ and 1T'-$MoTe_2$ transition line and metal electrodes attached to the 1T'-$MoTe_2$

This is the perfect opportunity to employ new, exotic TMD materials. The IBS research team was able to exploit the two versions of $MoTe_2$ and make one 2D crystal that was composed of the semiconducting 2H-$MoTe_2$ and the metallic 1T'-$MoTe_2$. This configuration is superior to using silicon or other 2D semiconductors because the boundary where the semiconducting (2H) and metallic (1T') $MoTe_2$ meet have what's called am ohmic homojunction. This is a connection that forms at the boundary between two different structural phases in a single material. Despite one $MoTe_2$ state being a semiconductor and one being metallic, the team was able to create an ohmic homojunction between them, making an extremely efficient connection.

To do this, the team started with a piece of their pure 2H-$MoTe_2$ which was several atoms thick. They directed a 1 μm wide laser (a human hair is 17 to 181 μm) at the 2H-$MoTe_2$ which locally heated the sample and changed the affected area into 1T'-$MoTe_2$. With this method, the team was able to create a 2D transistor that utilized an amalgamation of both the semiconducting properties of the 2H-$MoTe_2$ material as well as the high conductivity of the 1T'-$MoTe_2$.

This is a clever solution to several problems that have hindered scientists and engineers in the past. By using only one material in the device channel and the metal-semiconductor junction, it is more energy efficient since the joints between the two phases of the $MoTe_2$ are fused seamlessly realizing an ohmic contact at the joints. Because 1T'-$MoTe_2$ is such a good conductor, metal electrodes can be applied to it directly, saving any additional work of finding a way to attach metal leads. This new fabrication technique is a hyper-efficient way of utilizing the available $MoTe_2$ without any wasted or extraneous parts.

When asked about its potential for future use, Professor Heejun Yang of SKKU said, "There are many candidates for 2D semiconductors, but $MoTe_2$ has a band gap of around 1 eV which is similar to silicon's band gap and it allows an ohmic homojunction at the semiconductor-metal junctions." This means that $MoTe_2$ can replace silicon without much change in the current voltage configurations used with today's silicon technologies. The dual-phase $MoTe_2$ transistor looks promising for use in new electronic devices as demand for components increases for materials that are small, light and extremely energy efficient.

**More information:** Suyeon Cho, Sera Kim, Jung Ho Kim, Jiong Zhao, Jinbong Seok, Dong Hoon Keum, Jaeyoon Baik, Duk-Hyun Choe, K. J. Chang, Kazu Suenaga, Sung Wng Kim, Young Hee Lee, Heejun Yang (2015), Phase patterning for ohmic homojunction contact in MoTe2, *Science*, DOI: dx.doi.org/10.1126/science.aab3175

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