Researchers produce first 2-D field-effect transistor made of a single material

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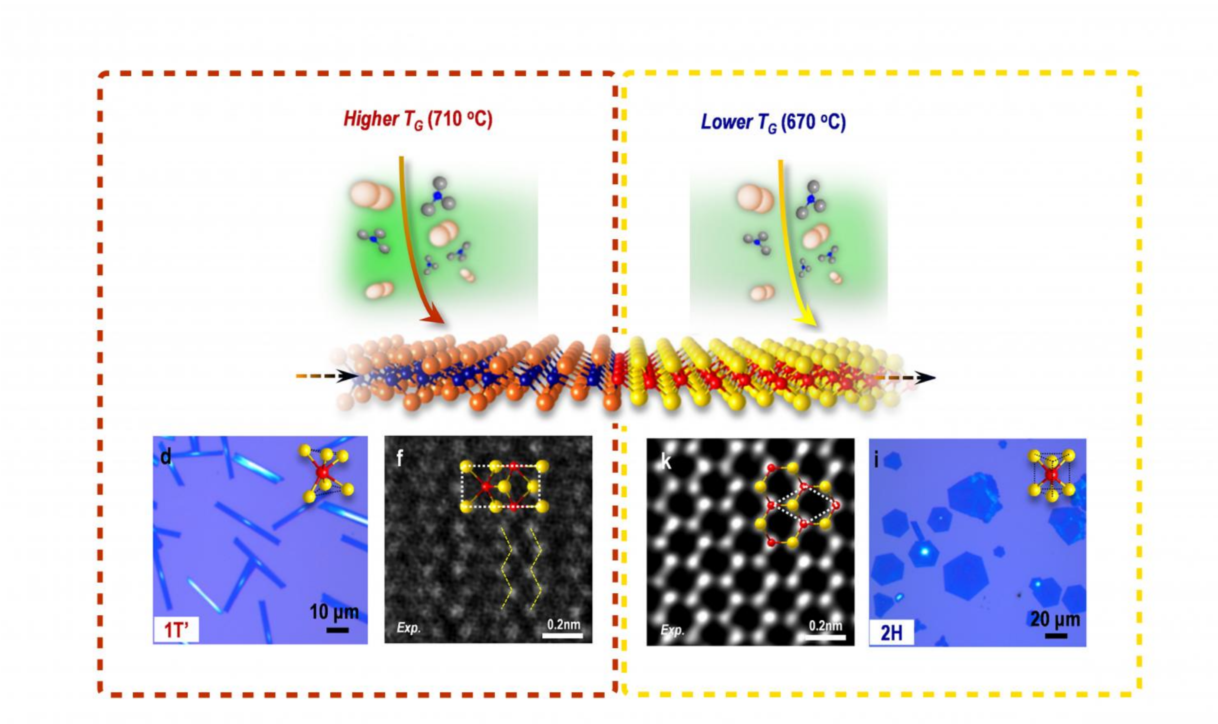
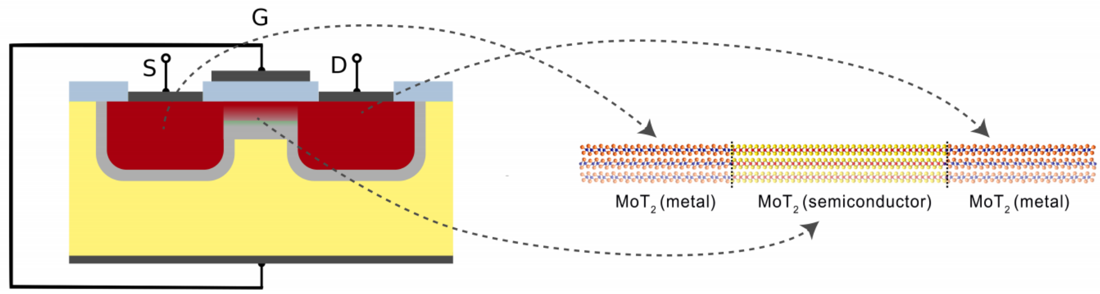


Metallic (right) and semiconducting (left) MoTe2 crystals are obtained side by side on the same plane. Rectangular crystals represent metal MoTe2, while hexagonal crystals are the characteristic feature of semiconducting MoTe2. Credit: *Nature Nanotechnology*

Modern life would be almost unthinkable without transistors. They are the ubiquitous building blocks of all electronic devices, and each computer chip contains billions of them. However, as the chips become increasingly small, the current 3-D field-electronic transistors (FETs) are reaching their efficiency limit. A research team at the Institute for Basic Science (IBS) has developed the first 2-D electronic circuit (FET) made of a single material. Published in *Nature Nanotechnology*, this study shows a new method to make metallic and semiconducting polymorphs from the same material in order to manufacture 2-D FETs.

In simple terms, FETs can be thought of as high-speed switches, composed of two metal electrodes and a semiconducting channel in between. Electrons (or holes) move from the source electrode to the drain electrode, flowing through the channel. While 3-D FETs have been scaled down to nanoscale dimensions successfully, their physical limitations are starting to emerge. Short semiconductor channel lengths lead to a decrease in performance—some electrons are able to flow between the electrodes even when they should not, causing heat and efficiency reduction. To overcome this performance degradation, transistor channels have to be made with nanometer-scale thin materials. However, even thin 3-D materials are not good enough, as unpaired electrons, part of the so-called "dangling bonds" at the surface interfere with the flowing electrons, leading to scattering.

Using 2-D FETs rather than 3-D FETs can overcome these problems and offers new, attractive properties. "FETs made from 2-D semiconductors are free from short-channel effects because all electrons are confined in naturally atomically thin channels, free of dangling bonds at the surface," explains Ji Ho Sung, first author of the study. Moreover, a single- and few-layer form of layered 2-D materials have a wide range of electrical and tunable optical properties, atomic-scale thickness, mechanical flexibility and large bandgaps (1~2 eV).

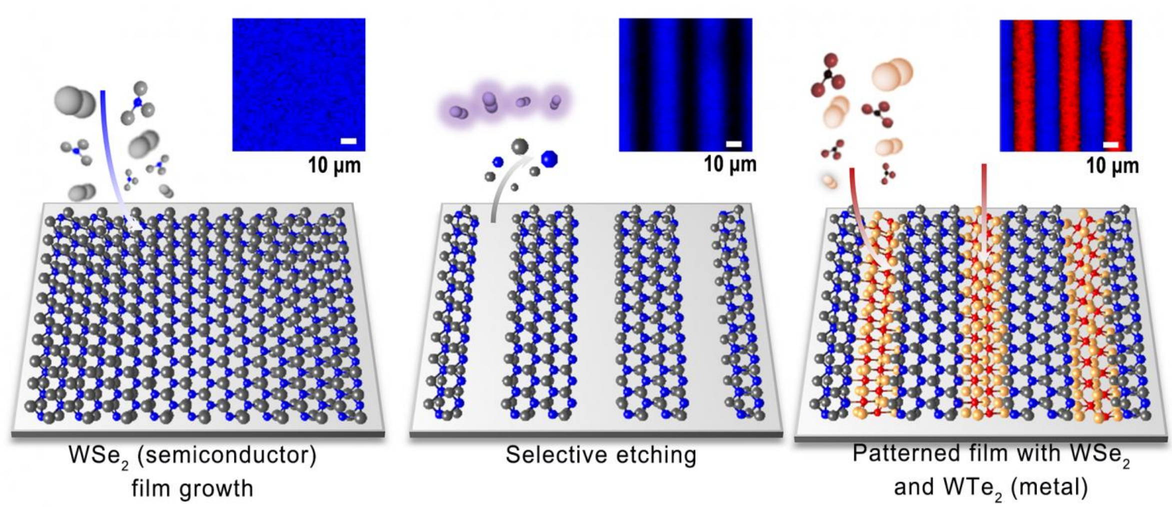


The standard 3-D FET has two electrodes (source and drain, S and D) made of doped silicon and a semiconducting channel in between. When the transistor is on, the electrons move from the source to the drain passing through the channel. The 2-D FET featured in this study uses MoTe2 for both metal (red) and semiconductor (yellow), reducing off-current effects and dangling bonds which are becoming a problem with the smaller 3-D transistors. Credit: IBS

The major issue for 2-D FET transistors is the existence of a large contact resistance at the interface between the 2-D semiconductor and any bulk metal. To address this, the team devised a new technique to produce 2-D metal transistors with semiconduction made of molybdenum telluride ($MoTe_2$). It is a polymorphic material, meaning that it can be used both as a metal and as a semiconductor. Contact resistance at the interface between the semiconductor and metallic $MoTe_2$ is shown to be very low. Barrier height was lowered by a factor of 7, from 150 meV to 22 meV.

IBS scientists used the chemical vapor deposition (CVD) technique to build high-quality metallic or semiconducting $MoTe_2$ crystals. The polymorphism is controlled by the temperature inside a hot-walled quartz-tube furnace filled with NaCl vapor at 710° C to obtain metal, and 670° C for a semiconductor.

The scientists also manufactured larger scale structures using stripes of tungsten diselenide (WSe_2) alternated with tungsten ditelluride (WTe_2). They first created a thin layer of semiconducting WSe_2 with chemical vapor deposition, then scraped out some stripes and grew metallic WTe2 on its place.



Step by step method, which starts with a film of semiconducting WSe2, followed by selective etching and growth of metal WTe2. Credit: *Nature Nanotechnology*

It is anticipated that in the future, it would be possible to realize an even smaller contact resistance, reaching the theoretical quantum limit, which is regarded as a major issue in the study of 2-D materials, including graphene and other transition metal dichalcogenide materials.

More information: Ji Ho Sung et al, Coplanar semiconductor–metal circuitry defined on few-layer MoTe2 via polymorphic heteroepitaxy, *Nature Nanotechnology* (2017). DOI: 10.1038/NNANO.2017.161

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