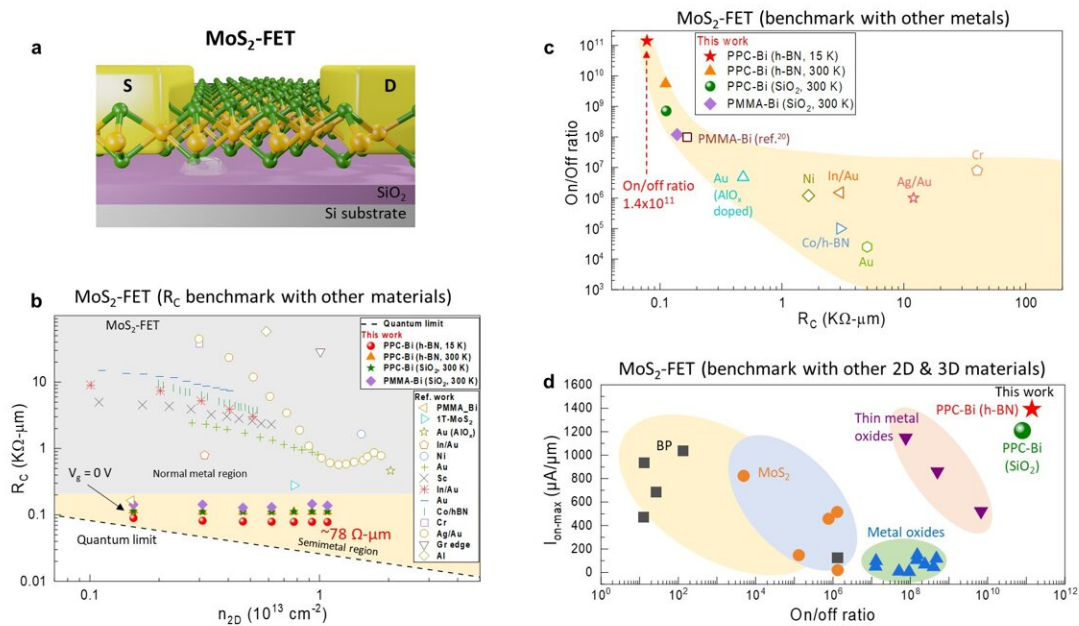


Pioneering beyond-silicon technology via residue-free field effect transistors

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Benchmark of ultra-clean large-area monolayer MoS₂-FET. (a) MoS₂ FET device schematic. (b) Benchmark of RC vs. n_{2D} in MoS₂ FET using different metal contacts for various semiconductor technologies. (c) Benchmark of on/off ratio vs. RC in MoS₂ FET compared to different metal contacts used in semiconductor technologies. (d) Benchmark of the maximum on-current (I_{on-max}) vs. on/off ratio of the MoS₂ FET for PPC-Bi contact compared to reports described in the literature. Credit: Institute for Basic Science

A revolution in technology is on the horizon, and it's poised to change

the devices that we use. Under the leadership of Professor Lee Young Hee, a team of researchers from the Center for Integrated Nanostructure Physics within the Institute for Basic Science (IBS), South Korea, has unveiled a new discovery that can greatly improve the fabrication of field-effect transistors (FET).

Their research is published in *Nature Nanotechnology*.

A high-performance field-effect transistor (FET) is an essential building block for next-generation beyond-silicon-based semiconductor technologies. Current 3-dimensional silicon technology suffers from degradation of FET performances when the device is miniaturized past sub-3-nm scales.

To overcome this limit, researchers have studied one-atom thick (~0.7 nm) two-dimensional (2D) [transition metal dichalcogenides](#) (TMDs) as an ideal FET platform over the last decade. Nevertheless, their practical applications are limited due to the inability to demonstrate integration at the wafer-scale.

A major problem is the residues that occur during fabrication. Traditionally, polymethyl methacrylate (PMMA) is used as a supporting holder for device transfer. This material is notorious for leaving insulating residues on TMD surfaces, which often generates mechanical damage to the fragile TMD sheet during transfer.

As an alternative to PMMA, several other polymers such as polydimethylsiloxane (PDMS), polyvinyl alcohol (PVA), polystyrene (PS), polycarbonate (PC), ethylene vinyl acetate (EVA), polyvinylpyrrolidone (PVP) and [organic molecules](#) including paraffin, [cellulose acetate](#), naphthalene have all been proposed as a supporting holder. Nevertheless, residues and mechanical damages are inevitably introduced during transfer, which leads to degradation of FET

performances.

The IBS researchers addressed this problem and have made an intriguing breakthrough by successfully harnessing polypropylene carbonate (PPC) for residue-free wet transfer. Using PPC not only eliminated residue but also allowed for the production of wafer-scale TMD using chemical vapor deposition. Previous attempts at manufacturing large-scale TMDs often resulted in wrinkles, which occur during the transfer process. The weak binding affinity between the PPC and the TMD not only eliminated residues but wrinkles as well.

Mr. Ashok Mondal, the first author of the study said, "The PPC transfer method we chose enables us to fabricate centimeter-scale TMDs. Previously, TMD was limited to being produced using a stamping method, which generates flakes that are only 30-40 μm in size."

The researchers built a FET device using a semimetal Bi contact electrode with a monolayer of MoS_2 , which was transferred by the PPC method. Less than 0.08% of PPC residue was found to remain on the MoS_2 layer. Thanks to the lack of interfacial residues, the device was found to have an ohmic contact resistance of $R_C \sim 78 \Omega\text{-}\mu\text{m}$, which is close to the quantum limit. An ultrahigh current on/off ratio of $\sim 10^{11}$ at 15 K and a high on-current of $\sim 1.4 \text{ mA}/\mu\text{m}$ were also achieved using the h-BN substrate.

This finding was the first in the world that demonstrated wafer-scale production and transfer of CVD-grown TMD. The state-of-the-art FET device produced in this way was found to have electrical properties that far exceed that of previously reported values. It is believed that this technology can be easily implemented using the currently available integrated circuit manufacturing technology.

Dr. Chandan Biswas, the co-corresponding author of the study said, "It is

hoped that our success in the [residue](#)-free PPC transfer technique will encourage other researchers to develop further improvements in various TMD devices in the future."

More information: Ashok Mondal et al, Low Ohmic contact resistance and high on/off ratio in transition metal dichalcogenides field-effect transistors via residue-free transfer, *Nature Nanotechnology* (2023). DOI: [10.1038/s41565-023-01497-x](https://doi.org/10.1038/s41565-023-01497-x).
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