A new native oxide high-k gate dielectric for fabricating 2-D electronics

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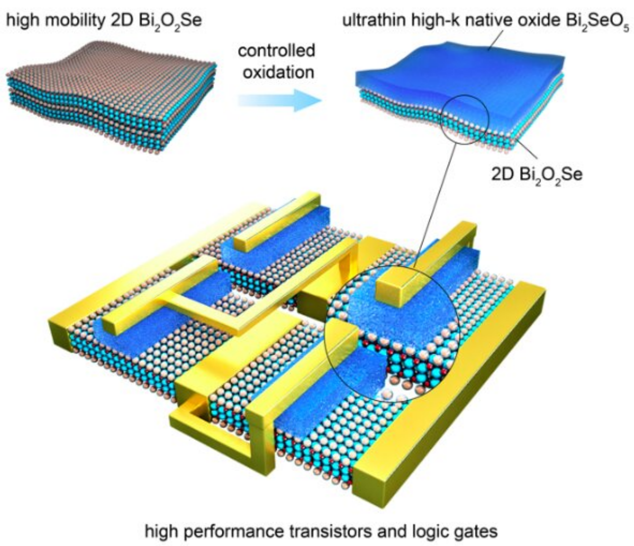


Credit: Li et al.

So far, silicon has been the primary material for the fabrication of integrated circuits (ICs) and other electronic components. Recently, however, researchers have been trying to identify new high-mobility semiconductors that could replace silicon in electronics applications, as it appears to be approaching its limit in terms of the computational efficiency and speeds it can produce.

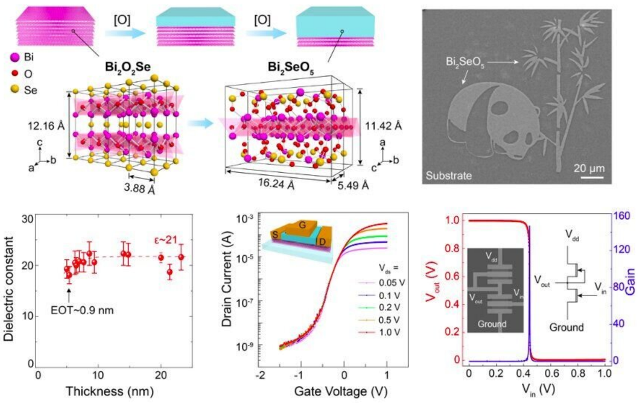
Past studies have explored the potential of two distinct types of materials, namely bulk materials (e.g. silicon-germanium) and low-dimensional nanomaterials (e.g., 1-D carbon nanotubes, 2-D transition metal dichalcogenides). While some of these materials have proved to be promising alternatives to silicon, they typically suffer from the absence of a high-quality native oxide as a dielectric counterpart, which can significantly limit their compatibility with other electronic components.

Researchers at Peking University have recently identified a new native oxide high-*k* gate dielectric that could be used to solve the compatibility problems of semiconductors that have the potential to replace silicon in the fabrication of electronics. This new dielectric, presented in a paper published in *Nature Electronics*, was accidentally uncovered while they were working on a different research project.

Back in 2016, the researchers were completing a study exploring the qualities of 2-D Bi_2O_2Se. Jinxiong Wu, one of the students conducting the experiments who is now a professor at Nankai University, was trying to clean the surface of Bi_2O_2Se using air plasma, when he realized that the material's nanoplates had gradually become almost transparent.

"At such low plasma power, it is highly unlikely that the samples could be blown away," Hailin Peng, the researcher who supervised the study, told TechXplore. "I thus realized that a chemical reaction must have taken place and the product of this reaction had a much wider bandgap than Bi_2O_2Se. As soon as we finished the first project of 2-D Bi_2O_2Se, I asked another student of mine, Teng Tu, to investigate the chemical reaction after thermal oxidation of 2-D Bi_2O_2Se. She discovered that the final product was Bi_2SeO_5 and through much hard work was able to confirm that Bi_2SeO_5 can form a uniform and atomically sharp interface with underlying Bi_2O_2Se."

Initially, Peng and his colleagues thought that they had merely discovered an intriguing new chemical reaction. When another researcher, Tianran Li, joined the project and started conducting a vast amount of device fabrications and electrical measurements, however, they realized that Bi_2SeO_5 could be an excellent gate dielectric, as it exhibited an extraordinarily high dielectric constant and low leakage current. This realization led to new research aimed at fabricating the first-ever native oxide gate dielectric that resembles thermal SiO_2.



Credit: Li et al.

"Frankly speaking, fabricating a native oxide gate dielectric similar to thermal SiO_2 is not as easy as it may seem," Peng said. "It took us almost two years to optimize the whole procedure, but we were very excited to find that Bi_2SeO_5 has a better performance than ALD HfO_2 or thermal SiO_2 in many aspects."

In their study, Peng and his colleagues used native Bi_2SeO_5 as the top gate of a 2-D Bi_2O_2Se channel to create high-performance field-effect transistors and inverter circuits. These circuits exhibit considerable gains in voltage compared to conventional circuits. Moreover, the newly identified material's high dielectric constant reduced the equivalent oxide thickness down to 0.9 nm, retaining a gate leakage that is below that of thermal SiO_2.

"I believe that our findings can inspire researchers in different ways," Peng said. "For material scientists, this work shows another way to fabricate high-quality 2-D heterojunctions besides van der Waals integration. In fact, to transform surface into a different material seems a more scalable and convenient approach to construct heterojunctions than van der Waals integration. Our work also proved that the quality of such in-situ heterojunctions can be very high."

The new native oxide high-*k* gate dielectric identified by Peng and his research group could prove very valuable for the fabrication of electronics. In fact, the integration of a high mobility 2-D material and its high-k native oxide gate dielectric could open new opportunities for exploring the potential of 2-D materials in next-generation integrated circuits.

"I have been studying two-dimensional materials for more than 15 years, sticking to one principle—to do something useful," Peng said. "For instance, our group synthesized ultra-flat single crystal graphene wafer on copper and designed special equipment for batch synthesis and transfer of such graphene wafers, which I believe is crucial for advanced electronic industry. We also conducted extensive research focusing on 2-D Bi_2O_2Se, as this semiconductor embodies atomic thickness, high mobility, air stability as well as high-k native oxide, which makes it most suitable for next-generation electronic industry among all the existing 2-D semiconductors."

The findings gathered by the researchers suggest that the newly identified Bi_2O_2Se/Bi_2SeO_5 system they uncovered could be a desirable substitute for silicon in a number of electronic components. Moreover, other 2-D materials containing Se or Te may have similar matching high-quality native oxides, which could be identified in future studies. Peng and his colleagues will now be examining the potential of their Bi_2O_2Se/Bi_2SeO_5 system further and conducting addition studies related to 2-D electronics.

"We plan to exploit the Bi_2O_2Se/Bi_2SeO_5 system in all kinds of electronic devices, such as memristors, floating gate memory devices and tunneling devices," Peng said. "Eventually, we hope to construct a library of devices that are based on Bi_2O_2Se/Bi_2SeO_5 system and combine these devices together as an SOC. At some point, we may introduce other novel materials in this library, but we will always stick to 2-D electronics."

More information: A native oxide high-k gate dielectric for two-dimensional electronics. *Nature Electronics* (2020). DOI: 10.1038/s41928-020-0444-6.

High electron mobility and quantum oscillations in non-encapsulated ultrathin semiconducting Bi_2O_2Se. *Nature Nanotechnology* (2017). DOI: 10.1038/nnano.2017.43