Terraced Graphene for Ultrasensitive Magnetic Field Sensors

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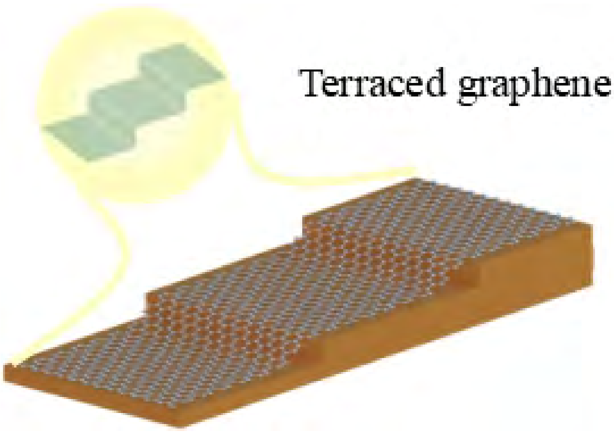
Physicists at the National University of Singapore (NUS) have developed a sensitive two-dimensional (2-D) magnetic field sensor, which could potentially be used for the detection and direct imaging of nanoscale magnetic domains and for data storage applications [1].

Magnetoresistance (MR), the change in the electrical resistance of a material due to the influence of an external magnetic field, has been widely used in magnetic sensors, magnetic memories, and hard disk drives. However, in traditional three-dimensional (3D) material-based magnetic sensors that use giant MR (GMR) or tunneling MR (TMR) spin-valves, the detectable signal of the magnetic field decays exponentially with the thickness of its sensing layer. This limits the spatial resolution and sensitivity of the sensors. Therefore, a 2D-based sensor could potentially improve the detection of minuscule magnetic fields, as the decay is limited to a thickness of only one atomic layer.

Graphene is an atom-thick thin material with high mobility and high current carrying capabilities. By adding a graphene layer on top of an artificial terraced substrate, the research team led by Prof. Ariando from the Department of Physics, NUS, has developed a 2D magnetic sensor with an electrical resistance that can increase by 50-fold of its original value at room temperature under the influence of the magnetic field. This is 10 times higher than values reported on previous single-layer graphene devices at the same conditions.

The detection of nanoscale magnetic domains is a fundamental challenge. As magnetic domains become smaller (nanoscale), the dimensions of the sensor are reduced accordingly to maintain the high spatial resolution and signal-to-noise ratio. However, for traditional 3D material-based sensors, the reduction in size leads to thermal magnetic noise and spin-torque instability. The discovery



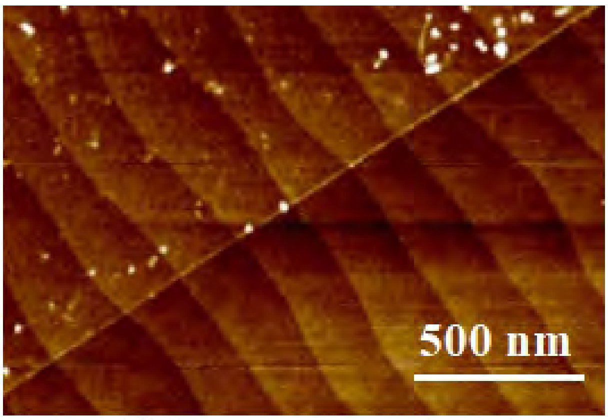


Fig. 1: (Left) the concept of the terraced single-layer graphene formation. This is similar to the terraced paddy fields used widely in Asia for agriculture. (Right) Atomic force microscopy image of the terraced morphology for graphene on strontium.

reported here paves the way for the development of 2D magnetic field sensors that can operate at room temperature for the detection of nanoscale magnetic domains. This can improve the performance of scanning probe magnetometry, biosensing, and magnetic storage applications.

Mr Junxiong HU, a PhD student in the research team, said, "The core part of the 2D magnetic sensor is the terraced graphene formed by stacking graphene on an atomically terraced substrate. The process is similar to placing carpet on a staircase."

Due to its flexibility, the graphene will also replicate the staircase morphology. During this process, topographic corrugations and charge puddles are induced in the terraced graphene. In the presence of a magnetic field, the current in the terraced graphene does not travel in a straight line but it is strongly distorted by the discontinuities at the boundary of the puddles, causing a significant change of its resistance.

This technology has the potential for developing the next generation of highly sensitive sensors for the detection of nanoscale magnetic domains. The single-layer graphene films used for the sensor can be manufactured by batch production for scalability.

The research team has filed a patent for the invention. Following this proof-of-concept study, the researchers plan to optimize the terraced geometry further and adapt it for large-scale production techniques. This would allow them to scale up their experimental outcomes for the manufacture of industry-size wafers for commercial use. For more information, please refer to [2].

References

[1] Hu JX; Gou J; Yang M; Omar GJ; Tan JY; Zeng SW; Liu YP; Han K; Lim Z; Huang Z; Wee ATS; Ariando A*, "Room-Temperature Colossal Magnetoresistance in Terraced Single-Layer Graphene" ADVANCED MATERIALS Article Number: 2002201 DOI: 10.1002/adma.202002201.

[2] https://www.science.nus.edu.sg/blog/2020/09/28/terraced-graphene-for-ultrasensitive-magnetic-field-sensor/