Transport properties of pristine few-layer black phosphorus by van der Waals passivation in an inert atmosphere

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The rapid expansion of digital electronics, personal computers, internet, mobile devices, and information technology in the past four decades has influenced humanity’s everyday life in such a profound way which is only comparable to the industrial revolution of the 19th century. To a large extent the fast expansion and development of consumer electronics was enabled by the ability to make ever smaller, faster, and cheaper Silicon transistors in dense integrated circuits. This is captured by Moore’s law, which is the observation that the number of transistors on a chip doubles approximately every two years. Over a period of about 50 years this trend has resulted in an almost million-fold increase in transistor density and thousand-fold decrease in transistor length. As the miniaturization of transistors continues, the length of a transistor is projected to soon reach sizes comparable or smaller than the diameter of a large molecule. Continuing progress beyond this point will require new paradigms which are outside the scope of present-day Silicon technology.

In the Center for Advanced 2D Materials at NUS novel two-dimensional materials that are as thin as a single atom and yet possess semiconducting properties which are far superior to those of Silicon are being actively synthesized and studied as candidates for use in future electronics. Notable examples are graphene and phosphorene, which consist of a single-layer sheet of perfectly arranged and tightly bound carbon or phosphorus atoms. And while graphene behaves more like a metallic conductor, phosphorene possesses excellent semiconducting properties which can be utilized in next-generation transistors. However, a major challenge in the early stages of phosphorene research was the natural tendency of the phosphorus atoms to react with the surrounding air, which had a detrimental effect on the surface and electronic properties of this ultrathin material.
In our recent work published in Nature Communications we demonstrated a passivation method that allowed us to protect the air-sensitive phosphorene prior to any exposure to ambient air. Utilizing the excellent chemical stability and impermeability of graphene and other two-dimensional materials, we fabricated a “shield” around phosphorene in an inert gas environment, before taking the device in air. We were then able to observe how exposure to air affects the surface and electronic properties of the material and, for the first time, study the pristine properties of protected phosphorene. The “shielding” utilizing graphene in an inert gas environment could prove to be an important step towards making phosphorene more manageable, and could enable studies on the pristine properties of other air-sensitive atomically-thin materials.

(a-b) AFM scans of ultrathin phosphorene partly covered with graphene. The images are acquired respectively 10 min and 24 hours after exposure to air. The white dashed lines outline the passivating graphene crystal. (c) An atomic scale schematic of a monolayer hBN “shield” on top of phosphorene.

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