Flexible Black Phosphorus Transistors: Materials, Devices, and Radio Circuits

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Two dimensional atomic sheets, such as graphene and transition metal dichalcogenides (TMDs), have been widely studied as electronic materials for flexible nanoelectronics applications due to the high flexibility enabled by their natural 2D layered crystal structure. However, with the growing need for both high speed and low power consumption in realistic applications, TMDs with relatively low mobility and graphene with zero band gap are facing critical challenges to satisfy practical requirements. Recently, few-layer phosphorene, a new candidate in the portfolio of 2D crystals, has demonstrated high room temperature mobility and high on/off ratio, which is very attractive for advanced flexible nanoelectronics.

In this work, we present the first black phosphorus flexible field effect transistors (BP-FETs), fundamental circuits and a radio receiver. For flexible BP-FETs based on exfoliated phosphorene films with thickness between 5nm to 15nm, clear ambipolar characteristics and negligible hysteresis were achieved (Fig. 1), attributed to a dielectric capping layer, which significantly enhanced long-term air stability. Outstanding device performance were achieved at room temperature; hole mobility and current on/off ratio are 300 cm^2/Vs and 10^5, respectively. With significantly enhanced ambipolar characteristics, electron mobility of 100 cm^2/Vs was observed. In this work, high performance electronic circuit blocks, including digital inverters, frequency doublers, inverting and non-inverting amplifiers were realized for the first time on plastics. Furthermore, we demonstrate a phosphorene flexible radio receiver which effectively demodulates amplitude modulated audio signals. In conclusion, our results indicate that few layer black phosphorus is the most promising 2D material for future high speed and low power flexible electronics beyond the low mobility of TMDs and zero bandgap of graphene.

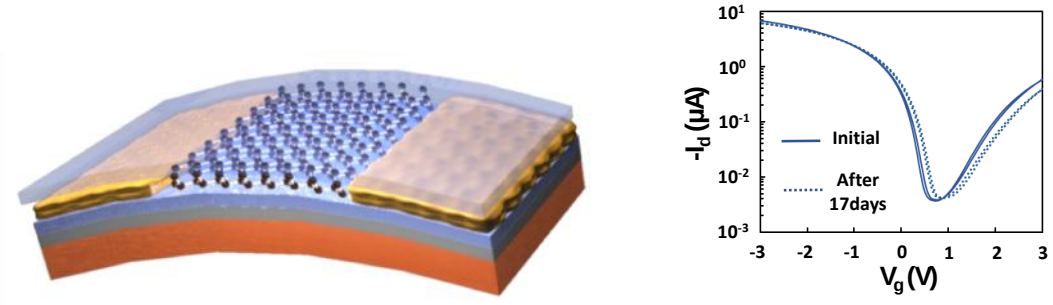

Figure 1. (left) Illustration of flexible phosphorene transistor on plastic, and (right) air-stable electrical characteristics.