Highlights

RESEARCH AREA 2 - **Functional and Complex Materials for Innovative Electronics and Sensing** - 2022

“Memory effects in black phosphorus field effect transistors”

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Black phosphorus (BP) is a layered material in which, similarly to graphite, individual atomic layers are held together by van der Waals interactions. In the single-layer limit, BP is also known as phosphorene and has a numerically predicted direct band gap of ∼2 eV at the Γ point of the first Brillouin zone. With increasing number of layers, the interlayer interactions reduce the bandgap to a minimum of 0.3 eV for bulk BP moving the direct gap to the *Z* point. The presence of a finite bandgap makes BP suitable for the realization of field-effect transistors (FETs), and the thickness-dependent direct bandgap may lead to applications in optoelectronics, especially in the infrared region. A remarkable application of BP has been in the field of memory devices. Common non-volatile FET-based memories use a charge-trapping layer to accumulate and retain the electric charge induced by a gate pulse. Fig. 1(a) shows the crystal structure of BP where the layered structure is composed of sheets with the phosphorus atoms arranged in a puckered honeycomb lattice. Ultrathin BP flakes were exfoliated from bulk BP single crystals using a standard mechanical exfoliation method by adhesive tape. The flakes were transferred onto degenerately doped p-type silicon substrates, covered by 90 nm thick SiO_2, on which they were located through optical microscopy. A standard photolithography process followed by electron beam evaporation was used to deposit electrodes, as shown in Fig. 1(b).

The standard electrical characterization shows a large hysteresis width, which can be exploited for memory applications. The hysteresis width has been investigated as a function of the voltage sweep duration and during recovery after irradiating the device with a super-continuous white laser source, revealing that the slow intrinsic trap states are the main responsible for the hysteretic behaviour (Fig. 2). It has also been demonstrated that it is possible to realize BP-based non-volatile memory devices without adding a dedicated charge-trapping layer to accumulate and retain the electric charge. Finally, encapsulating BP with a PMMA protective layer has been used as a simple way to preserve the electrical properties of the memory over a month. These results may pave the way for the realization of simple-to-make memory-type devices based on BP or other 2D materials with intrinsic defects.

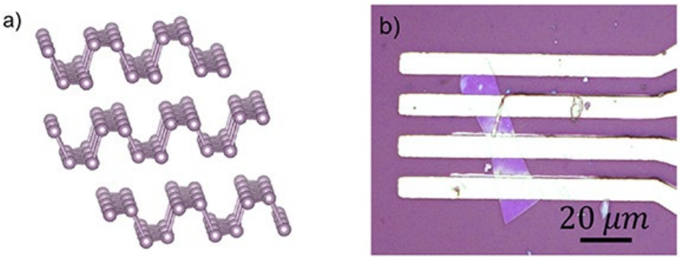

Fig. 1: Figure 1. (a) Crystal structure of few-layer BP. (b) Optical image of the device showing a BP flake covered by four Cr/Au contacts.

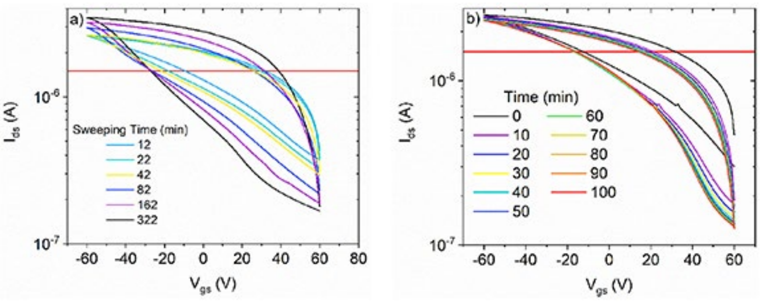

Fig. 2: (a) Transfer characteristics recorded at different sweeping times. (b) Transfer characteristics measured under supercontinuous white laser illumination (black line) and in the dark every 10 min after the laser was switched off.