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Black Phosphorus Electronic and Optoelectronic Devices

Since the discovery of graphene, two-dimensional layered materials (2DLM) have sparked an extraordinary level of interests due to their unique properties for electronic and optoelectronic applications. Materials such as transition metal dichalcogenides (TMDC),[1] hexagonal boron nitride (h-BN),[2] and black phosphorus (BP)[3] are among the 2DLMs that may have an impact in high speed digital logic circuits and broadband optical detection application from ultraviolet to infrared wavelengths. In this talk, we report the demonstration of complementary inverter circuit fabricated using all-BP material on highly flexible substrate. The conduction type and carrier concentration within a homogeneous BP nanosheet are modulated by a combination of donor doping and metal contact engineering, which offer both electron and hole dominated conducting channels with nearly symmetric pinch-off and current saturation. The flexible inverter circuit shows a clear digital voltage inversion operation along with a larger-than-unity DC voltage gain, while exhibits AC dynamic signal switching at a record high frequency up to 100 kHz, and remarkable electrical stability upon mechanical bending with a radii as small as 4 mm. Additionally, we realize a high sensitivity BP phototransistor that operates at short-wavelength infrared (SWIR) of 2 μm. By exploiting the electrostatic gating effect, a peak responsivity of 8.5 A/W and an ultralow noise equivalent power (NEP) of less than 1 pW/Hz$^{1/2}$ are achieved under nanowatt-level illumination with a small operating source-drain bias of –1 V. The high sensitivity coupled with low NEP makes BP a promising material for numerous weak signal detection applications in the SWIR such as bio-molecular sensing and thermal imaging.

References

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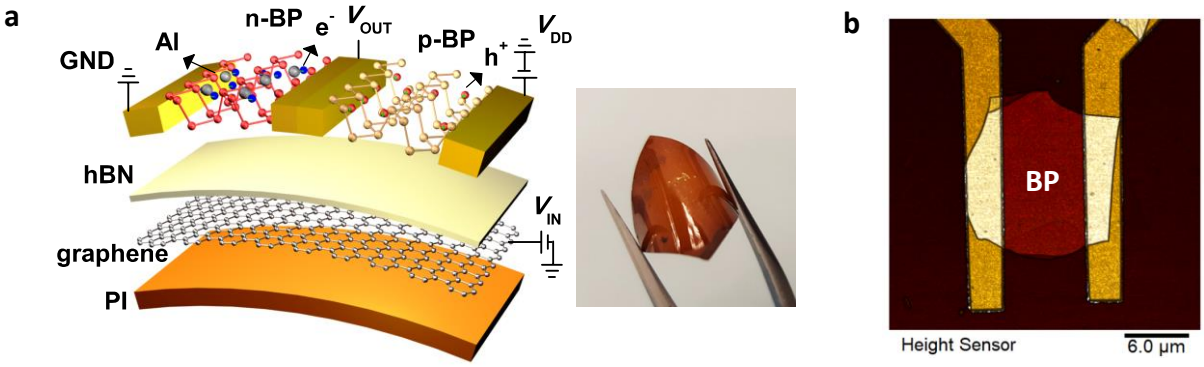

Figure 1. (a) Flexible complementary inverter circuits based on p- and n-type BP field-effect transistors. (b) Infrared BP phototransistor with tunable responsivity and low noise-equivalent-power.

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