Black Phosphorus/GaAs Heterojunctions for Infrared Detection

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We report our recent results on the development of ultra-thin black Phosphorus (bP)/GaAs junction photodiodes for infrared (IR) detection. The devices comprise an epitaxially grown n-type GaAs nanomembrane and a p-type bP flake exfoliated from commercially available bulk crystals. bP is a promising material for the realization of visible-to-mid-IR detectors as its direct bandgap can be tuned from 0.3 eV to 2 eV by varying its thickness at the nanoscale [1]. The GaAs nanomembrane is multifunctional in that it serves as the n-side of the IR junction photodiode, and it is expected to shield the device from radio-frequency (RF) waves as it has been heavily doped. The fabricated devices have a strong potential to implement RF-waves hardened electronic sensing of IR radiation, a capability of tremendous interest for military and commercial applications. An additional value of the GaAs/bP ultra-thin photodiodes is that they can conform to non-planar surfaces such as aircraft windows and domes of IR cameras, and they can be readily integrated into soldiers' uniforms.

We have established a process to integrate large-area bP flakes onto 220 nm-thick GaAs nanomembranes and used conventional top-down photolithography to fabricate bP-GaAs p-n diodes with areas up to 1.27 x 10^{-4} cm^2. Measured dark-current-voltage characteristics showed a turn-on voltage of 1.4 V with a maximum forward current density of ~ 90 A/cm^2 at 2 V and a dark current density of ~ 2 A/cm^2 at -2 V. We correlate the materials and devices parameters extracted from the current-voltage characteristics with electronic band-structure diagrams and the structure of surfaces and interfaces probed by electron microscopy and x-ray photoelectron spectroscopy. In this talk, we will show the geometry of the bP/GaAs photodiode and the physical-chemical structure of surfaces and interfaces at the nanoscale determine the dominant transport mechanisms and the performance parameters of the device.

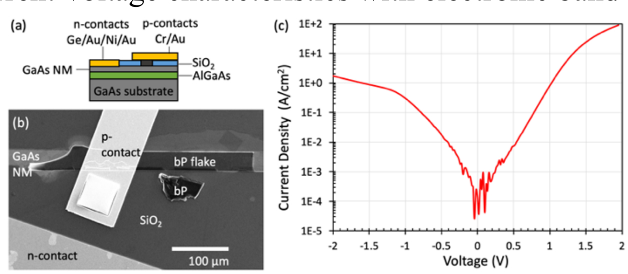

Figure 1. (a) A cross-sectional schematic and (b) SEM image of the diode with its (c) current density – voltage characteristics.

[1] X. Chen, X. Lu, B. Deng, O. Sinai, Y. Shao, C. Li, S. Yuan, V. Tran, K. Wantanabe, T. Taniguchi, D. Naveh, L. Yang, and F. Xia, Nat. Commun. **8**, 1 (2017)

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Supplementary Pages (Optional)

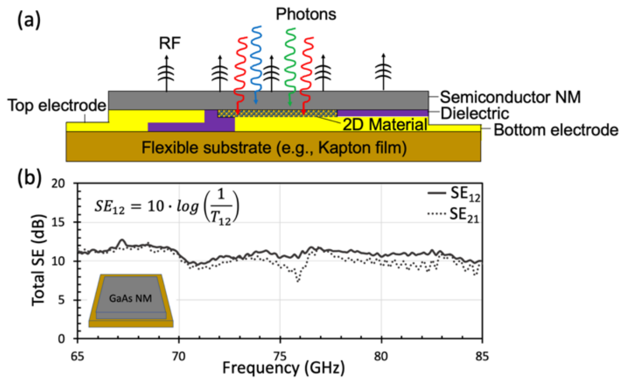

Figure 1. (a) Cross-sectional view schematic of the proposed photodetector with integrated RF shield and (b) shielding effectiveness (SE) of the heavily doped GaAs nanomembrane (NM).

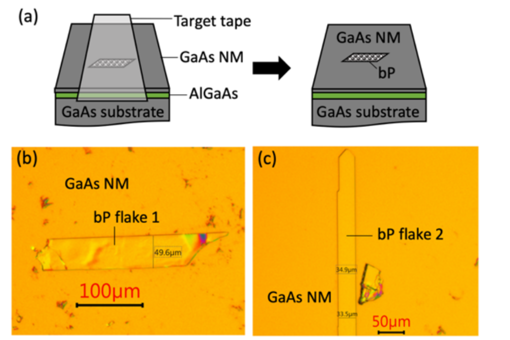

Figure 2. (a) Schematic of the transfer process and optical images of (b) bP flake 1 right after transfer, and (c) transferred bP flake 2 after cleaning protocol to remove adhesive residues.

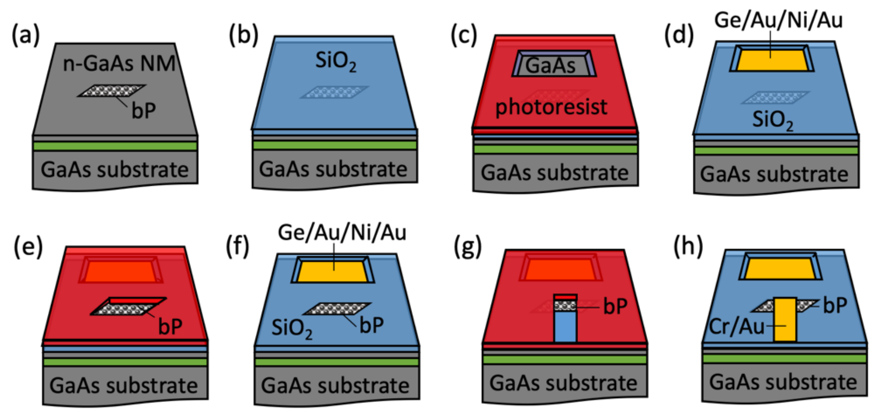

Figure 3. Schematic illustration of the process to fabricate the bP/GaAs p-n diode. (a) Transfer of bP flake to the GaAs surface, (b) deposition of SiO_2, (c) pattern definition for metal contacts. (d) metal deposition to GaAs. (e) Pattern definition and SiO_2 etch to expose bP flake. (f) anneal of n-GaAs contacts. (g) Patterning to deposit the metal contacts for bP. (h) After metal deposition.

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