Surface Passivation in Black Phosphorous/GaAs Ultra-Thin Heterojunctions

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We have previously demonstrated a black phosphorous (bP)/GaAs ultra-thin heterojunction diode with potential application as a radio-frequency (RF)-hard photodetector [1]. In this device, an inherently p-type bP flake obtained by mechanical exfoliation from a naturally occurring bulk crystal is interfaced with a heavily doped n-type GaAs semiconductor nanomembrane (NM). The GaAs NM serves as the cathode of the diode and acts as a shield against electromagnetic interference for the device [2]. The bP, i.e., the anode of the diode, allows for potentially tuning the spectral range of the detector between 0.6 and 4 µm, depending on its thickness [3]. The measured current-voltage characteristics of the bP/GaAs p-n junctions showed a dark current of ~ 6.5 x 10^{-4} A at an applied bias of -2 V upon device fabrication, a value that would severely limit the signal-to-noise ratio and the sensitivity of the photodiode. Here we present our recent efforts directed to evaluating self-passivation of bP as a strategy to minimize the dark current in our fabricated devices. Preliminary results for a diode exposed to air through a porous dielectric for 206 days showed a decrease in the dark current, triggering further investigation of the surface structure-leakage current relationship in the bP/GaAs devices. Specifically, we conducted a systematic study to quantify charge transport through the surface and the perimeter of the diodes via characterization of variable area devices. For this purpose, we established processes to exfoliate large-area bP flakes of uniform thickness, followed by patterning of the flakes by photolithography and inductively coupled plasma etching. The surface resistance extracted from the current-voltage characteristics of the variable-area devices was correlated with the physical and chemical structure of surfaces, sidewalls, and interfaces, as probed by electron microscopy, energy-dispersive X-ray spectroscopy, and X-ray photoelectron spectroscopy.

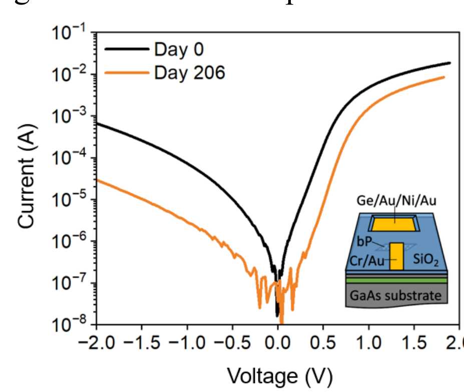

Figure 1. Current-voltage characteristics of a bP/GaAs diode encapsulated with SiO_2 upon fabrication and after 206 days from fabrication.

[1] E. J. Renteria et al., Proc. SPIE PC13119, Spintronics XVII, PC131191R (2024).
[2] E. J. Renteria et al. Adv. Mater. Technol. **9**, 19 (2024).
[3] X. Chen et al., Nat. Commun. **8**, 1 (2017).