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Graphene-Oxide-Semiconductor Junctions for Photodetection

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Introduction

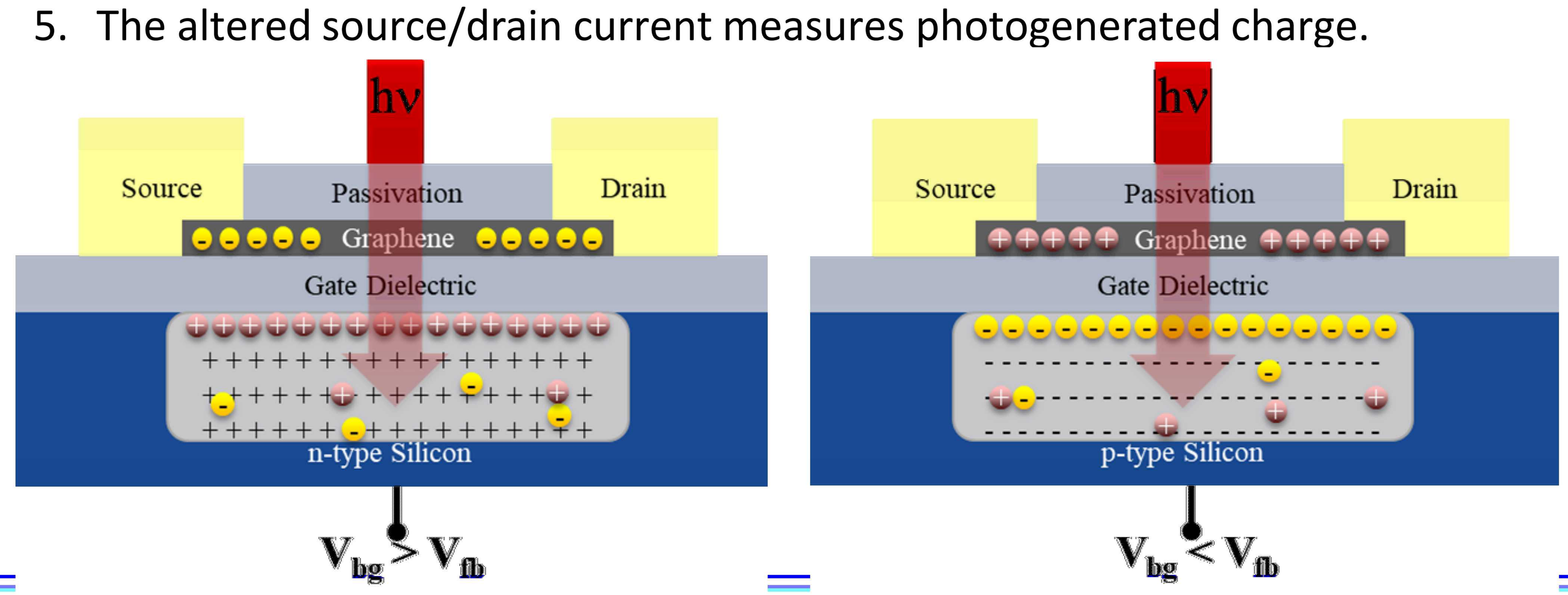
Premise: Due to its low carrier concentration and high mobility, graphene is an ideal charge sensing material for detecting photogenerated charge created in a nearby semiconductor using the graphene-oxide-semiconductor (GOS) junction.

Hypothesis: The number of interface defects between the semiconductor and dielectric play an important role in the amount of dark charge generation, thus affecting the ultimate sensitivity of the detector.

Goal: Characterize the effects of semiconductor/oxide interface defect density on the deeply depleted graphene-oxide-semiconductor (D^2GOS) junction detector and how it affects responsivity and depletion well lifetime.

Operating Principle

1. The GOS junction is biased into deep depletion
2. Incident light creates electron-hole pairs in the silicon.
3. Charge collects at the Si/oxide interface inducing the opposite charge in the graphene producing a **photo-gain proportional to graphene mobility**.
4. Subsequent changes in graphene resistivity alter the source/drain current.
5. The altered source/drain current measures photogenerated charge.



Experiment

Four different devices with varying defect densities were fabricated to study effects between device performance and interface defect density.

Sample Identifier	Semiconductor	Semiconductor/Dielectric Interface	Dielectric	Graphene Doping
HID p-D^2GOS	n-type (111) Si >5,000 Ωcm	Highly Defected Reactive Ion Surface Etch	HfO_2 (50 nm)	n-type
MID p-D^2GOS	n-type (111) Si >5,000 Ωcm	Mild Defect Hydrogen Surface Passivation	HfO_2 (50 nm)	n-type
LID p-D^2GOS	n-type (100) Si 100 Ωcm	Low Defect Hydrogen & SiO_2 Surface Passivation	SiO_2 (15 nm)/ HfO_2 (50 nm)	p-type
LID n-D^2GOS	p-type (100) Si 30-60 Ωcm	Low Defect SiO_2 Surface Passivation	SiO_2 (15 nm)/ HfO_2 (50 nm)	p-type

Device Characterization

Figure 1: Graphene transconductance with varying incident optical powers is a diagnostic tool for detector characterization.

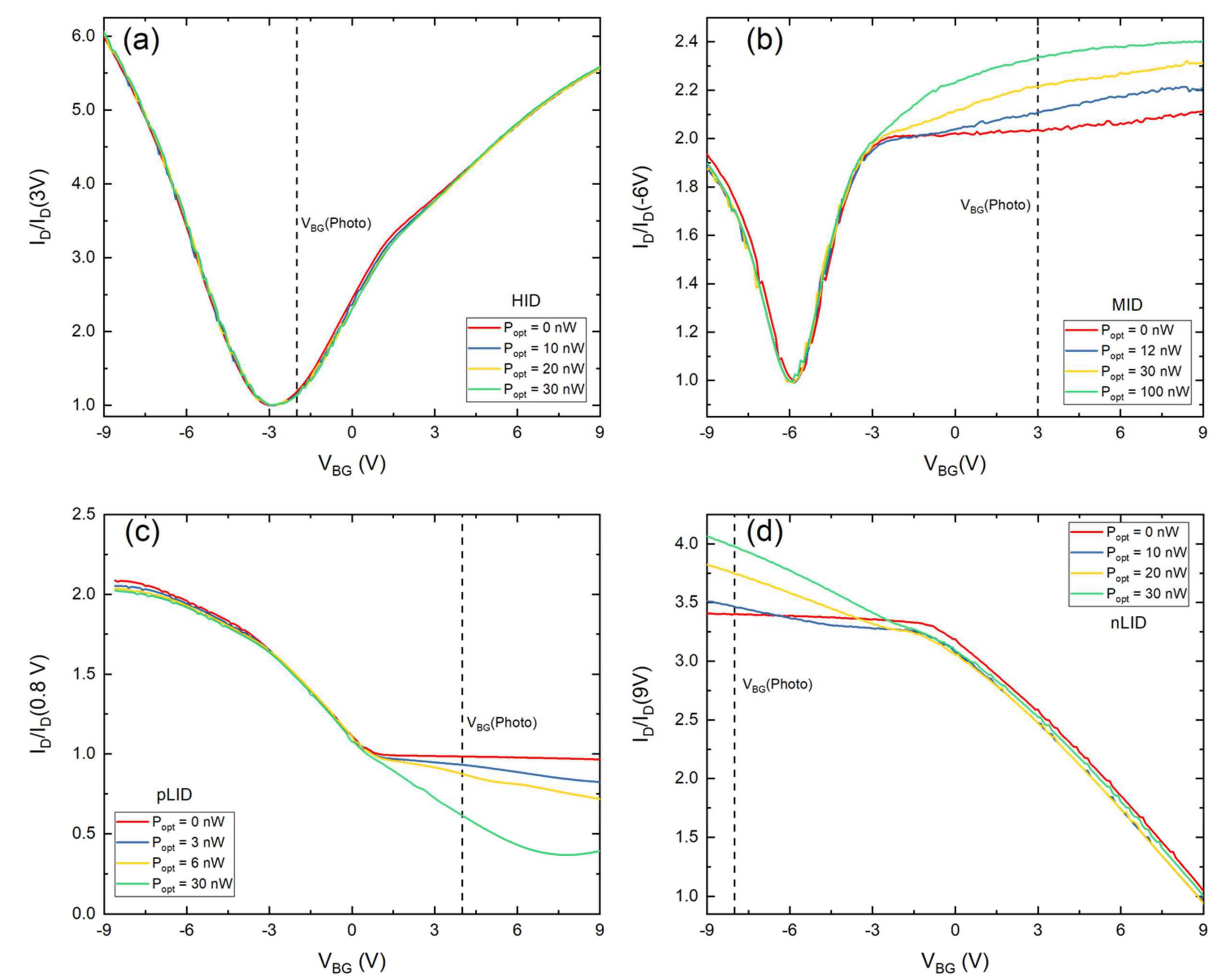


Figure 2: Well lifetime and Responsivity of the D^2GOS junction.

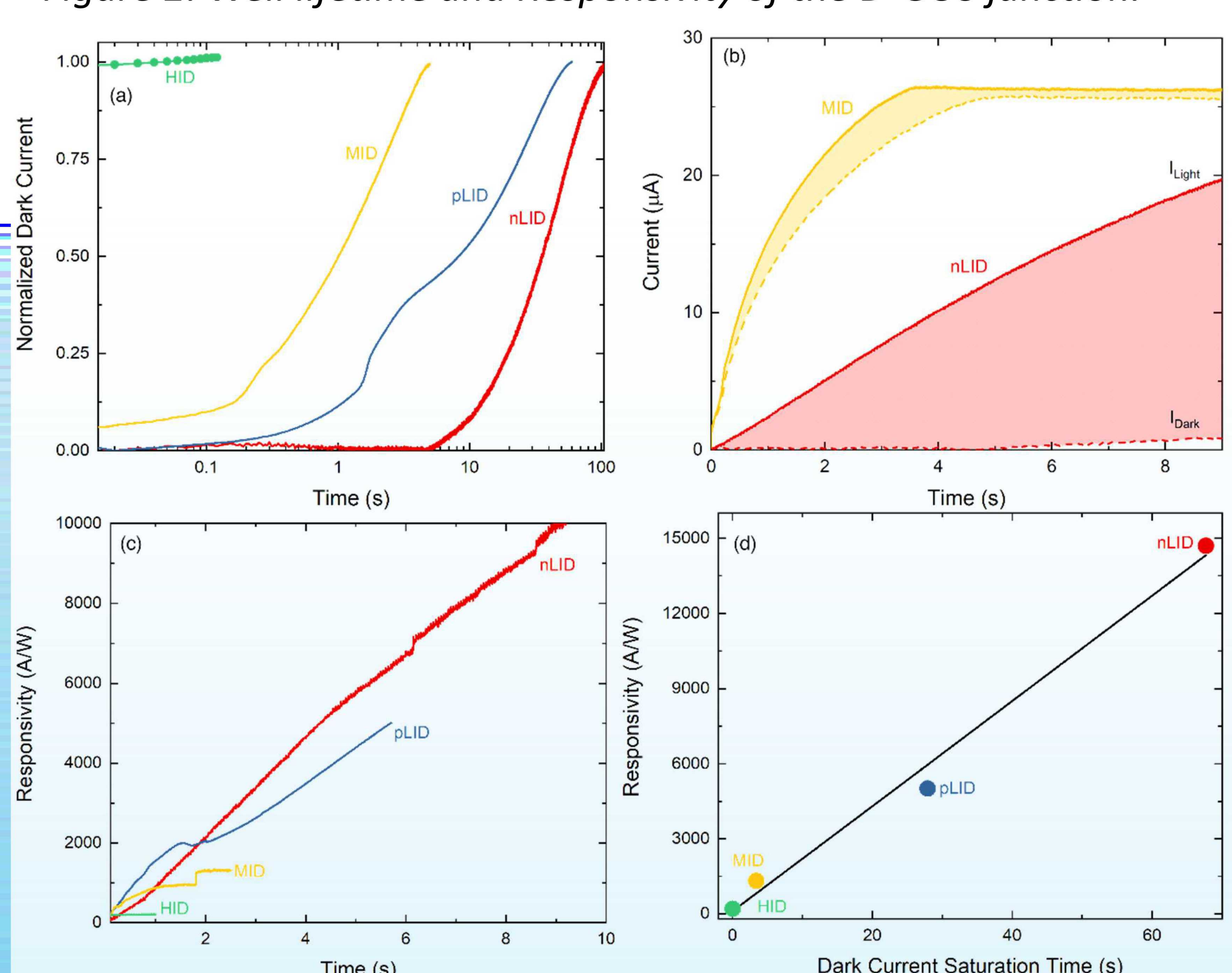
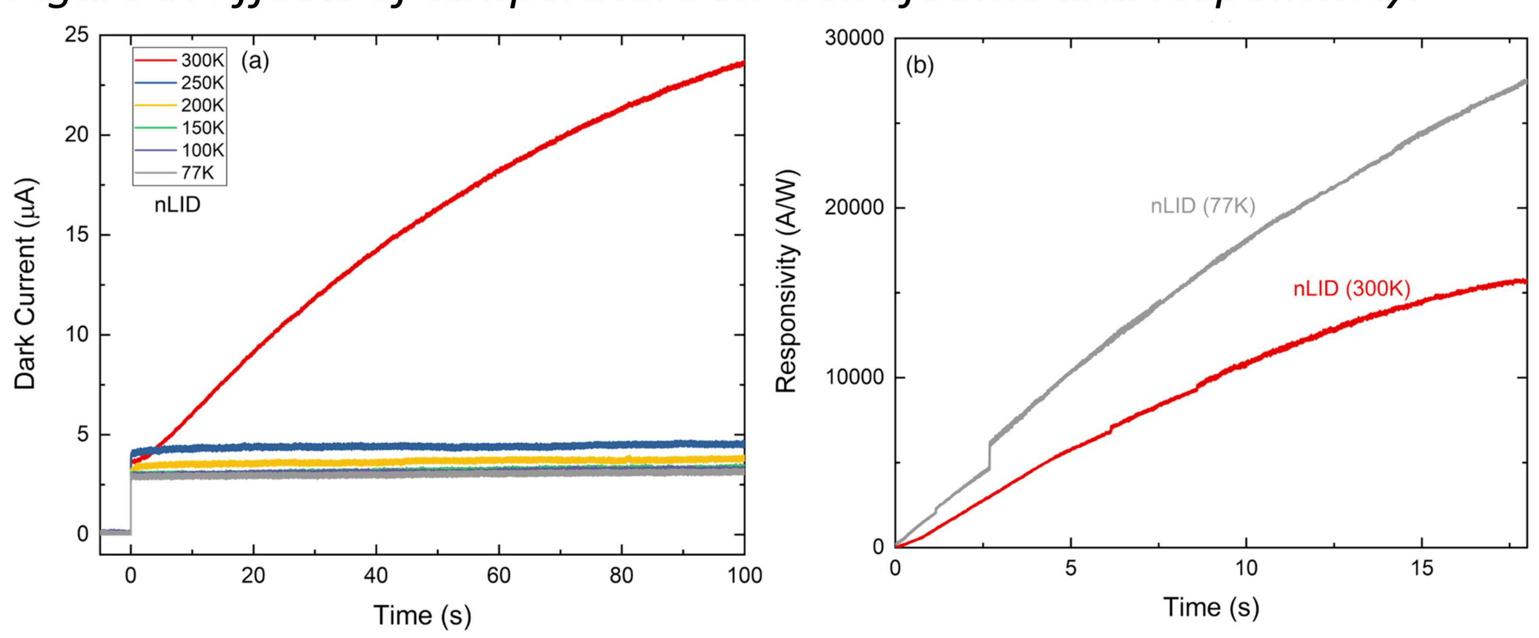


Figure 3: Effects of temperature on well lifetime and responsivity.



Results

- HID transconductance **(Fig 1(a))** is not affected by photogenerated charge due to immediate well-filling by thermally generated dark charge due to the interface defects.
- MID, nLID, pLID transconductance **(Fig 1(b-d))** shows sensitivity to light from reduced interface defect density (less dark charge geration).
- Source drain current (I_D) changes with optical power but only when the substrate is biased into depletion.
- Decreasing interface defect density increases the well lifetime **(Fig 2(a))**, due to the reduction of dark charge generation.
- There are several orders of magnitude improvement is responsivity for nLID in comparison to HID **(Fig 2 (c,d))**.
- Dark current shows negligible changes at varying temperatures for 77K-250K **(Fig 3(a))**.
- The responsivity increases at lower temperatures due to the lack of thermal charge excitation **(Fig 3(b))**.

Conclusion

- The defect density at the Si/oxide interface impacts the well lifetime and responsivity of the D^2GOS junction detector.
- **Responsivities in optimized devices were found to increase by orders of magnitude up to nearly 30,000 A/W.**
- **Well filling lifetimes were increased from 1 ms to 2 minutes, by reducing interface defect density.**

Next steps

- Demonstrate detection employing other semiconductor absorbing substrates to expand from the mid-IR to Gamma.
- Test concept using other 2D materials such as MoS_2, $MoSe_2$, WS_2, etc., to demonstrate higher sensitivity.

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Howell, Stephen W., et al. "Graphene-insulator-semiconductor junction for hybrid photodetection modalities." *Scientific reports* 7.1 (2017): 14651.
Ruiz, Isaac, et al. "Interface Defect Engineering for Improved Graphene-Oxide-Semiconductor Junction Photodetectors." *ACS Applied Nano materials* (2019): Submitted.