Graphene Black Phosphorus Hybrid Photodetector

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Introduction

The principle of photodetector is sensing of light signal and converting into electrical signal. Graphene is a conductive material that has high mobility and flexibility which is commonly applied in a lot of optoelectronic devices, like photodetector. However, the shortcomings with graphene as a photodetector are its zero bandgap characteristic and low light absorption 2.3%.

In view of the deficiency, black phosphorus can fetch up the defect of graphene because of its high light absorption. In the photodetector with photoconductor mode, the responsivity is proportional to carrier mobility and light absorption rate. Therefore, integrating graphene with black phosphorous may consequently increase the responsivity of the photodetector.

Device Structure and Material Characteristics

Graphene is positioned upon SiO_2 and heavily doped silicon substrate. Black phosphorus is located on top of graphene layer. It is a metallic characteristic interface that demonstrates the Schottky junction [1]. Band bending appears and a Schottky barrier can be used for controlling the current flow. Source and drain are the electrodes of the whole device which is for measuring the current flow through graphene.

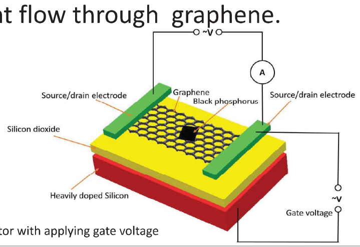

Figure 1: Device structure of photodetector with applying gate voltage

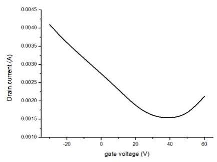

Figure 2: Transfer curve of GFET

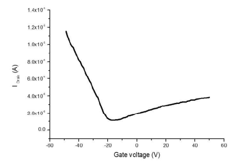

Figure 3: Transfer curve of BPFET

For Fig.2, before V_{Dirac} point, holes dominate the conductivity of graphene and the conductivity increases as the gate voltage decreases.

For Fig.3, the current ON state is shown before 0V of the gate voltage indicating this black phosphorus is in p-type conductivity. Also, the slope of ON and OFF status of the current is the on/off ratio of the FET.

Device Properties

Photoresponsivity

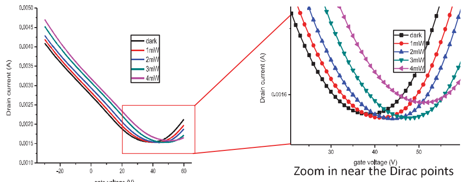

Figure 4: Transfer curve of photodetector

Fig.4 demonstrates when the device is illuminated by 1550nm laser with the higher power, the Dirac points shift to a higher voltage. Black phosphorus absorbs light and injects photo-induced carriers into graphene. In fact, variation of graphene Fermi level may modulate its conductivity. Eventually, the number of majority carriers, holes in graphene can be increased, thus the conductivity will also be enhanced.

Photocurrent and Responsivity

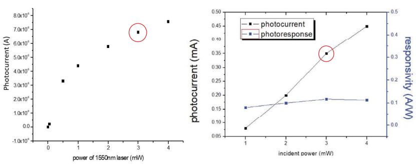

Figure 5: Comparison of photocurrent between BPFET and photodetector

For Fig.5, the photocurrent of photodetector is about 50 times higher than that of pure BPFET device.

As the mobility of graphene $2.3\times10^3 cm^2/(V\cdot s)$ is much higher than BP $80 cm^2/(V\cdot s)$, which will induce a higher photoresponse.

Response time

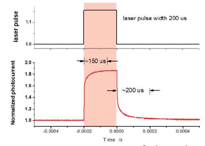

Figure 6: Response time of photodetector

- The rising time is about 150us with input laser pulse width 200us. It refers to the time for injecting holes into graphene from BP for achieving the maximum photocurrent. On the other hand, the fall time is about 200us.

Polarization

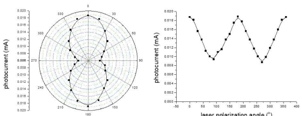

Figure 7: Polarization photoresponse of photodetector

- The polar coordinate graph shows a dumbbell shape from 0° to 360°. The polarization coefficient can be figured out by the formula: $P = \frac{I_x - I_y}{(I_x+I_y)/2} = 0.6$

Discussion

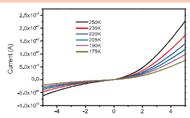

Figure 8: Temperature-dependent I-V behavior of graphene-BP Schottky junction

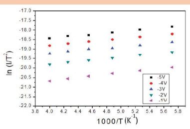

Figure 9: Richardson plot (ln(I/T2) vs. 1000/T) of different reverse bias

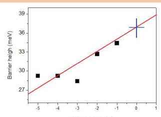

Figure 10: Barrier height at various reverse bias of Schottky junction

When thermionic emission is applied to excite the carriers, current will be conducted through the barrier of a Schottky contact, which is $I = A * T^2 \exp\left(\frac{-q\Phi_b}{kT}\right)\left(\exp\left(\frac{qV}{\eta kT}\right) - 1\right)$. The barrier height can be calculated by $\ln\frac{I}{T^2} = \ln A + \Phi_b * \left(\frac{-q}{kT}\right)$ [2]. By plotting the graph, it displays that the barriers height is about 37meV at zero bias.

Conclusion

Due to the cooperation between graphene and black phosphorus, the performance of the photodetector is indeed improved compare with GFET and BPFET, such as the responsivity and induced photocurrent.

References

[1] A. Di Bartolomeo, "Graphene Schottky diodes: An experimental review of the rectifying graphene/semiconductor heterojunction", sciencedirect, 2017.

[2] G. Ru, R. Van Meirhaeghe, S. Forment, Y. Jiang, X. Qu, S. Zhu and B. Li. (2004). *Voltage dependence of effective barrier height reduction in inhomogeneous Schottky diodes.*