Ultrasensitive NIR Photodetectors Based on Graphene-MoTe_2-Graphene Vertical vdWs Heterostructure

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Background and Motivation

- Ultrathin body
- Strong light-matter interaction
- Flexiblility
- vdwS assembly
- Large band gaps

transition-metal dichalcogenides (TMDs)

- Telecommunication
- NIR photodetector
- Remote sensing
- Biological imaging
We choose MoTe$_2$, since its bandgap is about 1.0 eV in its bulk form.

### Photoconductors
- High responsivity
- Low speed
- External power supply

### Photodiodes
- Low responsivity
- High speed
- Without external power
Grpahene-MoTe$_2$-Graphene Heterostructure

Uniformly large photoresponse area and short transmit distance

- CVD graphene
- Exfoliated MoTe$_2$
- Microscale triangular knife
- PMMA layer
- 1064 nm NIR laser illumination
- Obvious photovoltaic behavior

$V_{oc}$: 82 mV
$I_{sc}$: 1.5 µA

65 µW, 2 µm

The *I*_ds-*V*_ds* curves show asymmetric transport behaviors.

- Back-to-back Schottky barriers with different Schottky barrier heights.
- Ambient water vapor and oxygen p-doping of the top graphene.
- The *I*_sc and *V*_oc increase with the back-gate.
Photocurrent Generation

At $V_g=0$, the Schottky barrier height at $G_T$/MoTe$_2$ is higher than that at $G_B$/MoTe$_2$.

Due to the screening effect from the bottom graphene and MoTe$_2$, the Schottky barrier height at $G_T$/MoTe$_2$ is less sensitive to the back gate.
NIR Photoresponse Performance

- Back-gate voltage
- Laser power

When the power < 5 μW
- Responsivity ~ 110 mA W⁻¹
- EQE ~ 12.6%
Temporal Photoresponse

- Rise and fall times: 24 µs, 46 µs
- Considering the intrinsic response time of the mechanical chopping process (~10 µs), the rise and fall times are even shorter.
Comparison

An overall high performance

<table>
<thead>
<tr>
<th>Materials</th>
<th>$V_{ds}$ (V)</th>
<th>Responsivity (mA W$^{-1}$)</th>
<th>Response time (ms)</th>
<th>Wavelength</th>
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</thead>
<tbody>
<tr>
<td>MoTe$_2$</td>
<td>0</td>
<td>110</td>
<td>0.024</td>
<td>1064 nm</td>
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<td>b-P</td>
<td>0.2</td>
<td>&lt;5</td>
<td>1</td>
<td>400 - 997 nm</td>
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<td>b-P/MoS$_2$</td>
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<td>0.015</td>
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<tr>
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<td>40-50</td>
<td>633</td>
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<tr>
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<td>$4 \times 10^7$</td>
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<tr>
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<td>0.06</td>
<td>543</td>
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</table>
Photoresponse Properties in Visible Range

@ 473 nm, \( R \sim 205 \text{ mA W}^{-1} \) (EQE \( \sim 53.8\% \))

@ 633 nm, \( R \sim 183 \text{ mA W}^{-1} \) (EQE \( \sim 35.8\% \))
Conclusion

- Graphene-MoTe$_2$-Graphene vertical vdWs heterostructure, which has uniformly large photoresponse area and short transmit distance between the source and drain.
- Self powered with high responsivity (110 mA W$^{-1}$), high speed (24 $\mu$s) in the NIR range.
- Photo response can be tuned by the back-gate voltage.
Acknowledgement

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The work function of MoTe$_2$ was reported to be 4.1–4.3 eV.