GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO

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Graphene-PbS Quantum Dot Based Highly Sensitive Infrared Photodetector

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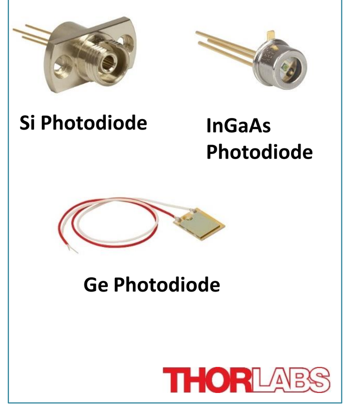
INFRARED (IR) PHOTODETECTORS

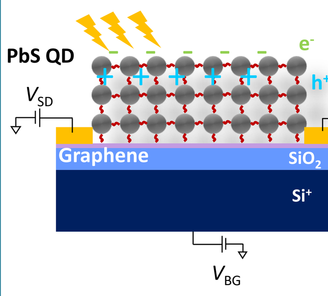
Markets for room temperature IR photodetectors

- Thermal management of electronic products
- Night vision
- Thermal drone for building inspection
- Environmental monitoring
- Food analyzer etc.

Few commercially available products



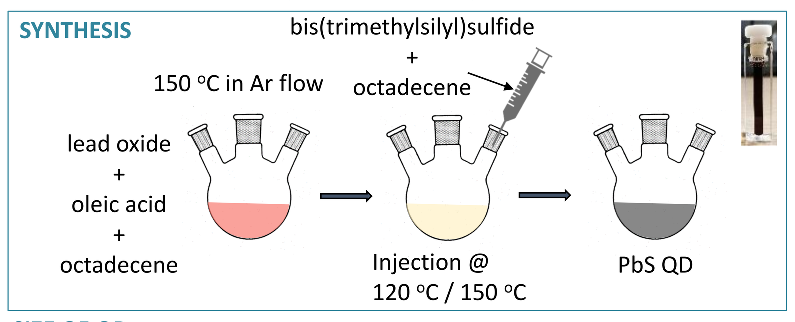
Alternative, cost effective, high resolution IR photodetector of graphene/PbS QD hybrid

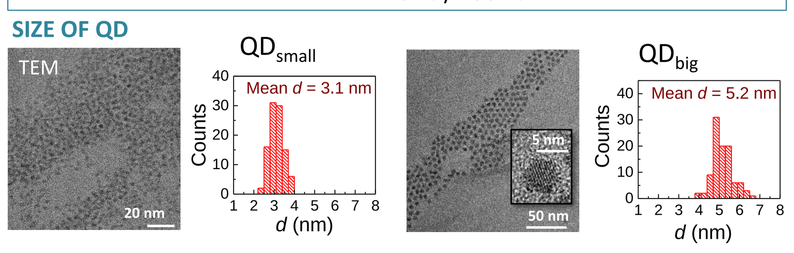


- Photogenerated e⁻s get trapped inside QD layers for time $\tau_{lifetime}$ and h⁺s get transferred to graphene circulating multiple times for $\tau_{lifetime}$, resulting in photoconductive gain

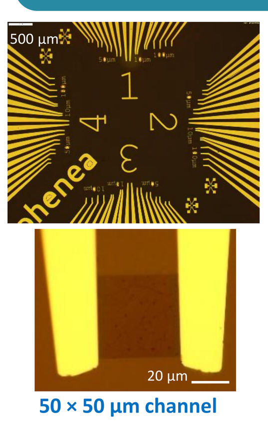
GRAPHENE/PBS QD HYBRID

PbS QD

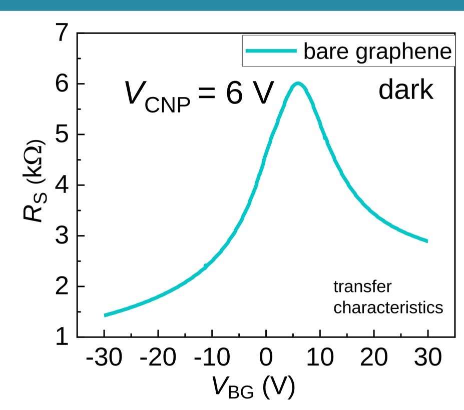




CVD grown single layer graphene FET on SiO_2/Si (low p-doped, 1 – 10 Ωcm resistivity)



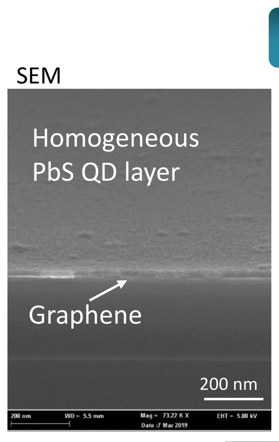
* Graphene FET purchased from Graphenea

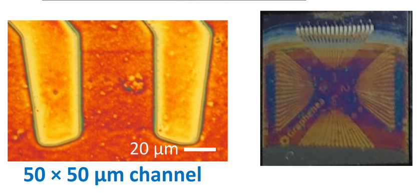


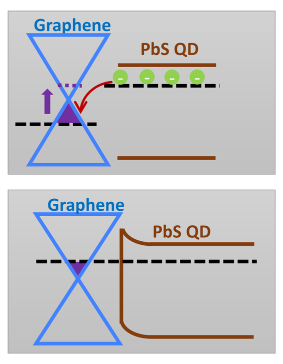
- Mobility ≈ $500 - 1000\ \mathrm{cm^2/Vs}$

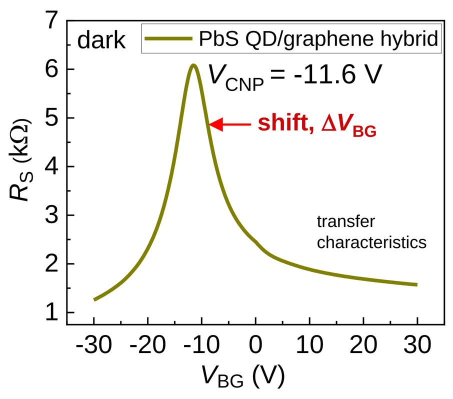
Hybrid

- Layer-by-layer controlled dip coating of PbS QD on graphene to obtain homogeneous crack-free light absorbing layer
- Ligand exchange from oleic acid to 1,3 benzene dithiol
- Surface passivation via tetrabutylammonium iodide



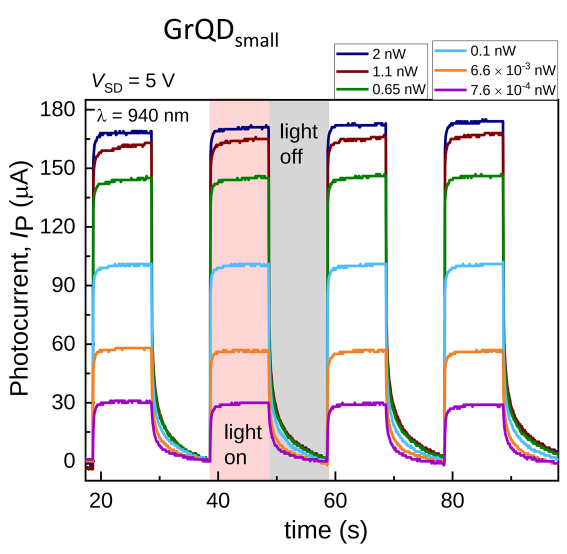


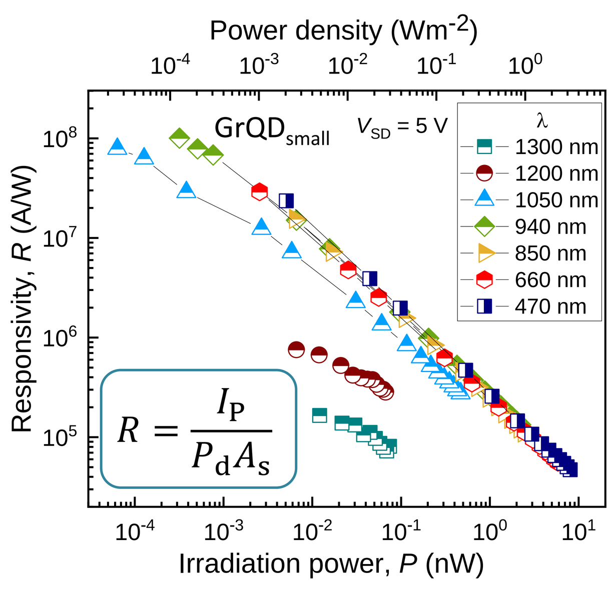




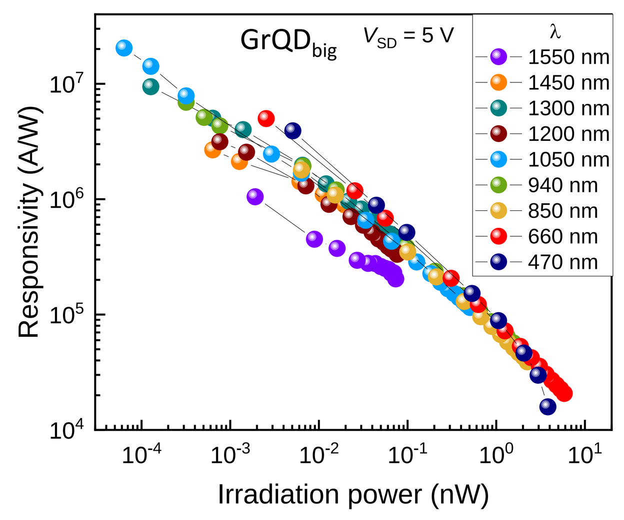
- Band bending at the interface
- Charge neutrality point (CNP) shifts to negative back gate voltage
- Similar mobility

PHOTORESPONSE

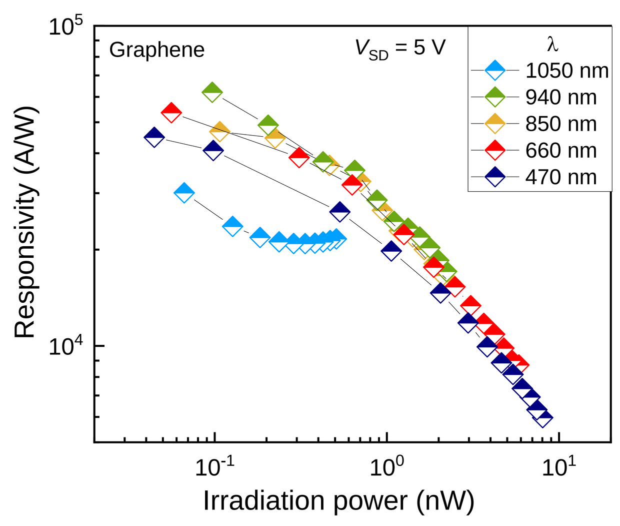




- Maximum responsivity, $R = 10^8$ A/W
- Detection capability of low light upto power 0.1 pW
- Photoconductive gain $= 8 \times 10^8$
- External quantum efficiency = 16 %
- Slow detector, high response time ~55 ms



- Maximum responsivity = 2×10^7 A/W
- Lower responsivity due to lower filling factor of bigger QDs

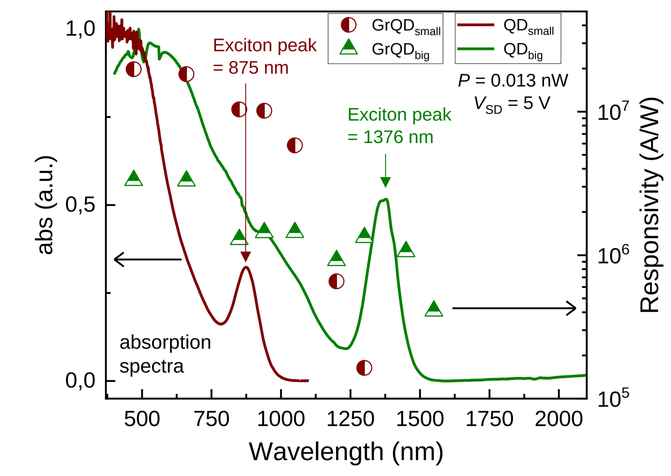


- Maximum responsivity = 6×10^4 A/W
- In low-doped Si substrate, accumulation of photogenerated e⁻s with longer lifetime at Si/SiO_2 interface results in additional gating effect leading to higher responsivity
- Sensitive until 1050 nm as Si substrate acts as primary light absorbing material

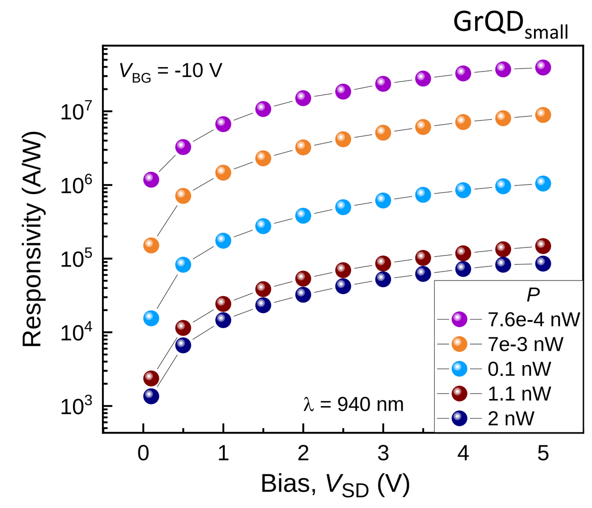
TUNABILITY OF PHOTORESPONSE

QD size dependence

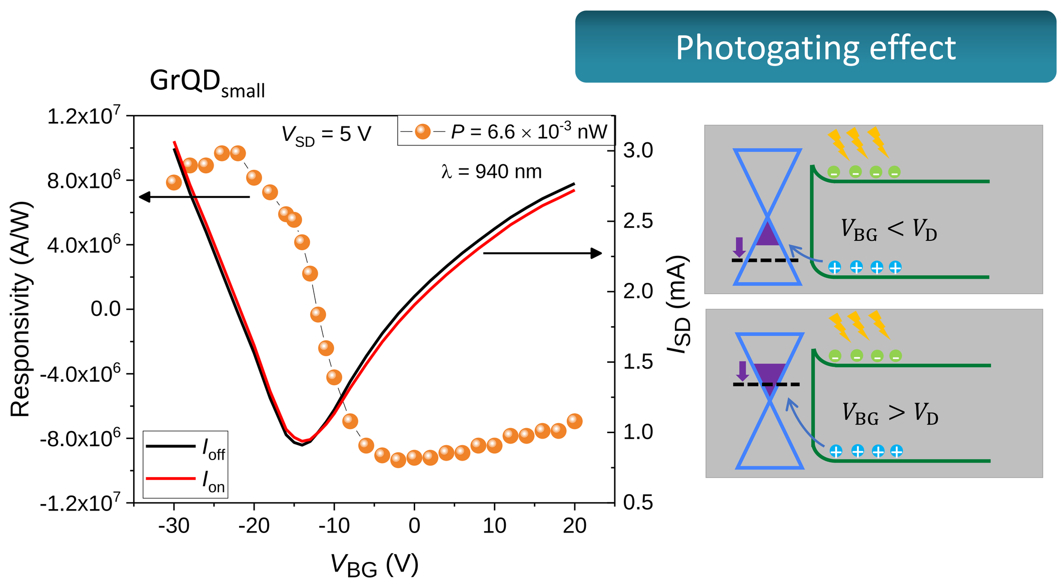
- Tunability of photodetection range of wavelength with the size of PbS QD



Bias dependence

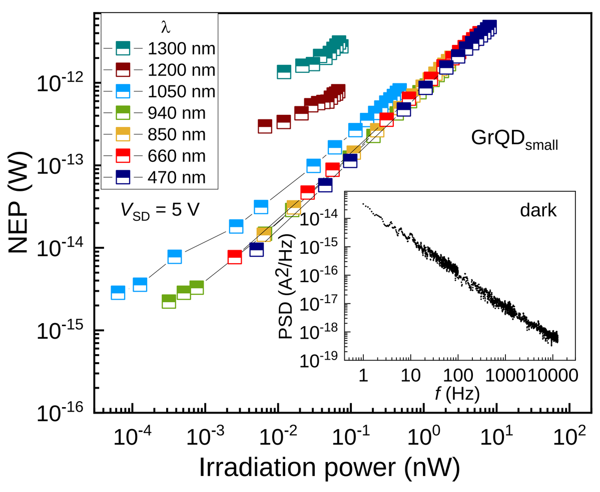


Photogating effect

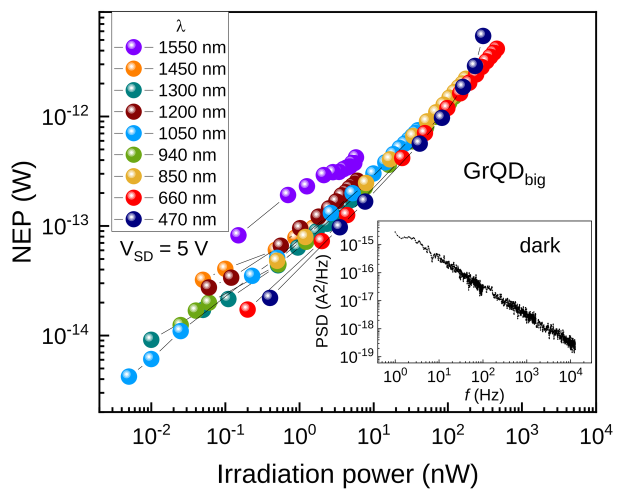


- Graphene is hole doped. Hole transfers from QD to graphene. I_{SD} ↑ ⇒ Positive photoresponse
- Graphene is electron doped. Hole transfers from QD to graphene. I_{SD} ↓ ⇒ Negative photoresponse

NOISE EQUIVALENT POWER (NEP)

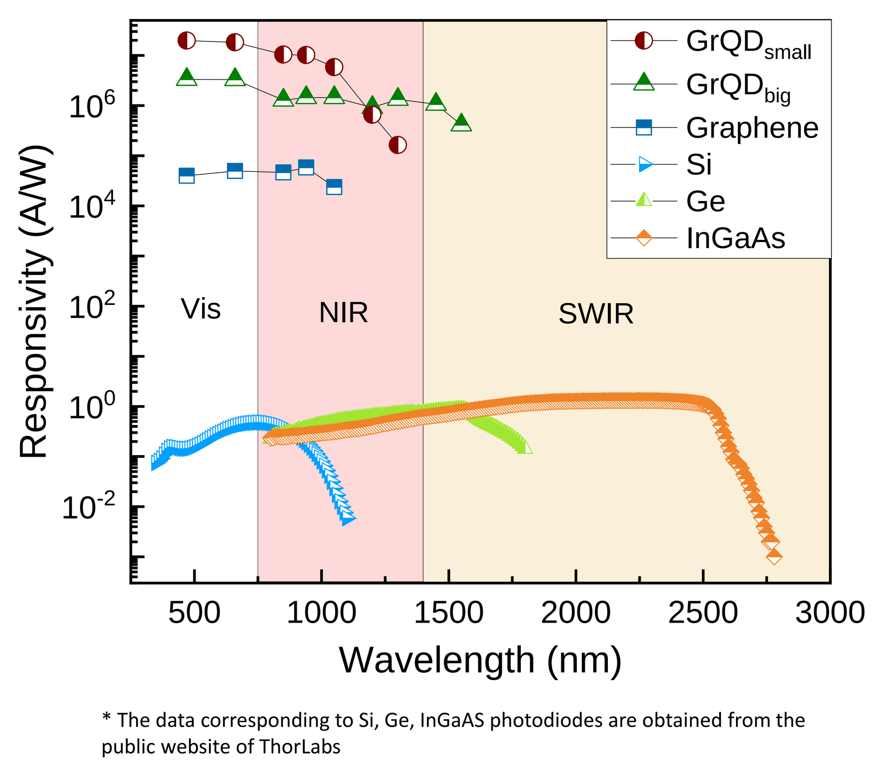


- NEP $= 2 \times 10^{-15}$ W for integrated noise power spectral density (PSD), $5 \times 10^{-14}\ \mathrm{A^2/Hz}$

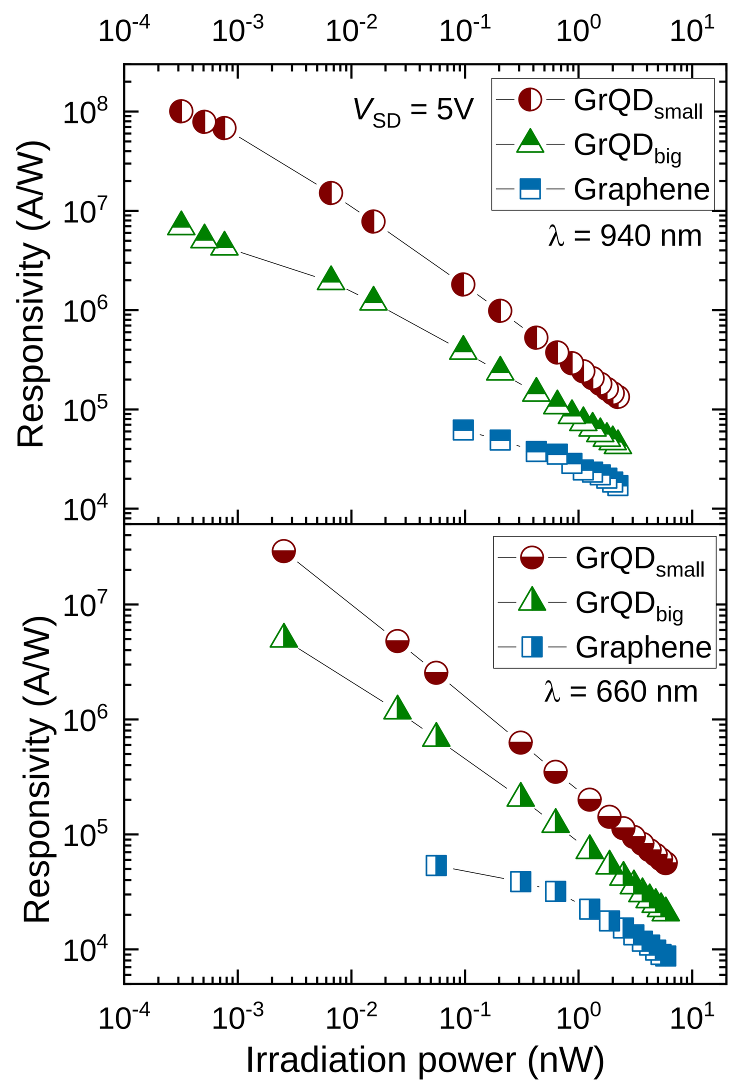


- NEP $= 4 \times 10^{-15}$ W for integrated noise PSD, $7 \times 10^{-15}\ \mathrm{A^2/Hz}$

COMPARISON OF DIFFERENT DETECTORS



* The data corresponding to Si, Ge, InGaAs photodiodes are obtained from the public website of ThorLabs



CONCLUSIONS:

- Graphene/PbS QD hybrid photodetectors operate in the visible-NIR-SWIR range whereas the graphene device is photosensitive only until 1050 nm due to the its absorbing material, Silicon.
- Maximum responsivity of graphene/PbS QD hybrid is more than 7 orders of magnitude higher than commercially available IR detectors.
- Graphene photodetector cannot detect light of power below 0.1 nW (0.06 nW) for 940 nm (660 nm) wavelength, whereas the graphene/PbS QD hybrid exhibit high responsivity below 1 pW.
- Modification of the ligand exchange and surface passivation chemistry in QD layers can possibly improve the response time further.

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