Supporting information for

A Dual-Band Graphene/Silicon Nanowires Array Heterojunctions Photodetector Induced by Leaky Mode Resonances

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Solution of leaky modes:

A single semiconductor nanowire is a cylindrical dielectric waveguide with optical losses due to material absorption at frequencies above the band edge. In free space, leaky mode resonant-caused absorption due to field confinement can exist in cylindrical waveguides and in high-refractive-index nanowires.[1] These leaky mode resonances (LMRs) are defined by Maxwell's equations.[2]

$$\left(\frac{1}{{k_c}^2-k^2}\right)^2\left(\frac{k_z m}{k_0 R}\right)^2=\left(\frac{\varepsilon_c J_m'(k_c R)}{k_c J_m(k_c R)}-\frac{1 H_m'(kR)}{k H_m(kR)}\right)\times\left(\frac{1 J_m'(k_c R)}{k_c J_m(k_c R)}-\frac{1 H_m'(kR)}{k H_m(kR)}\right) \quad (1)$$

Where k_0 is the free space wavevector, k_c and k are the transverse components of the wavevector inside and outside the cylinder, k_z is the wavevector along the cylinder axis. *Jm* and *Hm* are the *m*-order Bessel function and Hankel function of the first kind, respectively. ε_c and R are the complex permittivity and the radius of the cylinder. LMRs are labelled with the azimuthal mode number *m* and the radial mode number *n*, which arise from the oscillatory behavior of the Bessel functions and their polarization, respectively.[3]

Their polarization can be TM (transverse magnetic, HZ = 0), TE (transverse electric, EZ = 0), HE (magnetoelectric, TM-like), or EH (electromagnetic, TE-like). m is an integer. When m = 0, there are only TM_{0n} and TE_{0n} can be used as solutions to set the first and second terms of the right-hand side of Eq. (1) equal to zero. When m > 0 or the electromagnetic wave is parallel to the nanowire axis, only the HE_{1n} LMRs cause the absorption enhancement due to symmetry matching requirements.[4]

Discussion of the Si NWs of 140 nm diameter with the Si substrate:

The mode containing the Si NWs (2 μm) of 140 nm diameter on the Si substrate (10 μm) was simulated by COMSOL. Clearly, in Fig. S2, it can be seen that the absorption curve of the Si NWs is similar to that of the absorption curve in the original manuscript (Fig. 1c); both have dual-peak absorption at 430 nm and 660 nm. It should be noted that the total absorption of Si NWs and substrate appears as a broad-spectrum effect.

Nevertheless, in the actual device, the depth of the Si/graphene's depletion region can be calculated to be 0.8993 μm, which is much shorter than the length of Si NWs (10 μm). It means that the electrodes do not collect the photogenerated carriers generated from the substrate because of the limited range of the depletion region, so the absorption of the Si substrate does not contribute to the dual-band photoresponse. Therefore, the dual-band phenomenon is only related to Si NWs; in other words, it is reasonable to simulate only the Si NWs in the manuscript. Overall, It is unnecessary to consider the effect of the Si substrate on the dual-band response.

Discussion of graphene of the photodetector:

In this work, choosing graphene as the electrode is the best result for achieving a DBPD in that the graphene is actually a typical transparent electrode in this device: On one hand, the transmittance of MLG is 93.9883% and 95.3839% at 430 nm and 660 nm by measurements, the majority of the incident light will penetrate the graphene layer and be absorbed by the underlying SiNWs array, which is beneficial for good optoelectronic performance. In other words, the selection of any other metal electrodes will lead to substantial reductions in light absorption due to strong reflection. On the other hand, the metallic behaviour will help to form an effective Schottky junction with the Si; in addition, the relatively low sheet resistance of MLG (about 300 ohm/sq) is very useful for the efficient separation of electron-hole pairs during the photodetection process.

In light of the above, we choose graphene as the electrode material during the device fabrication process.

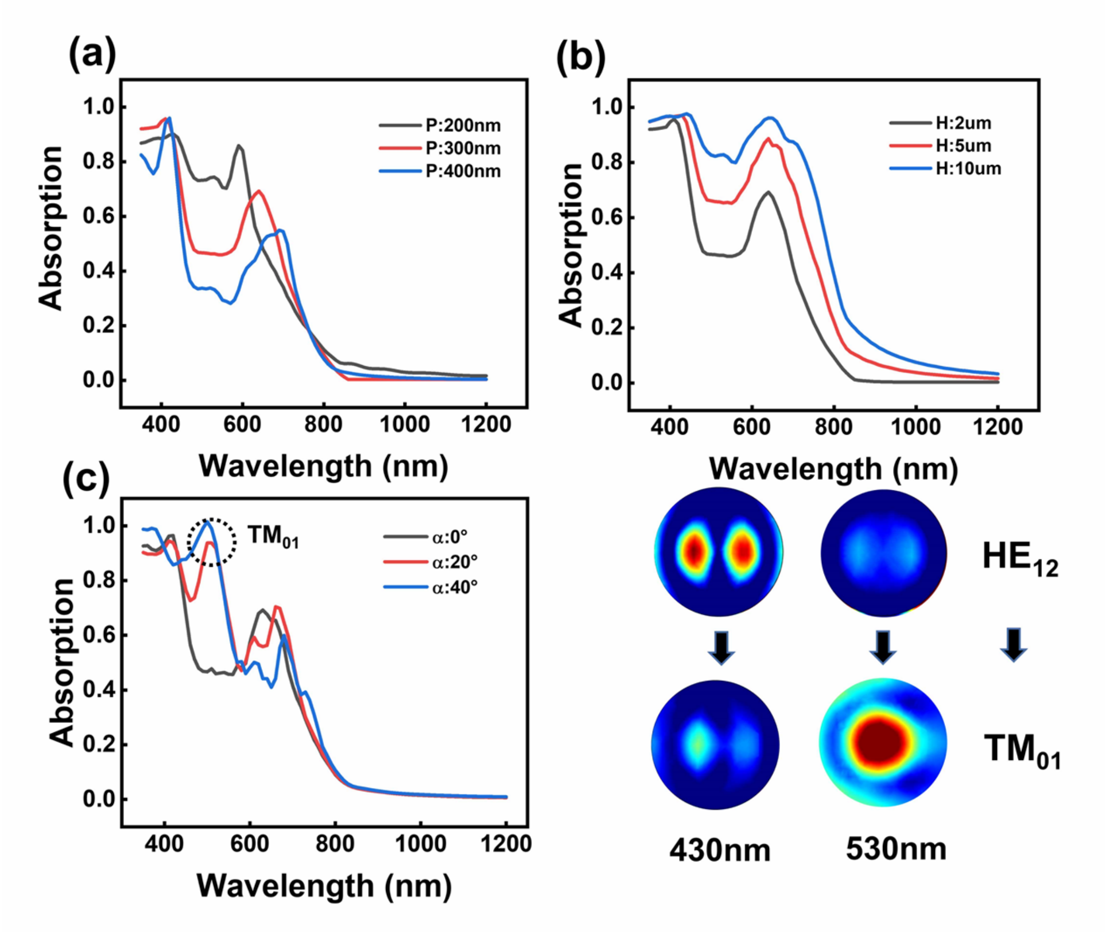

Figure S1. The effect of the (a) period, (b) height and (c) incident angle on the absorption spectrum. All of three simulation parameters of the Si NWs array are D = 140 nm.

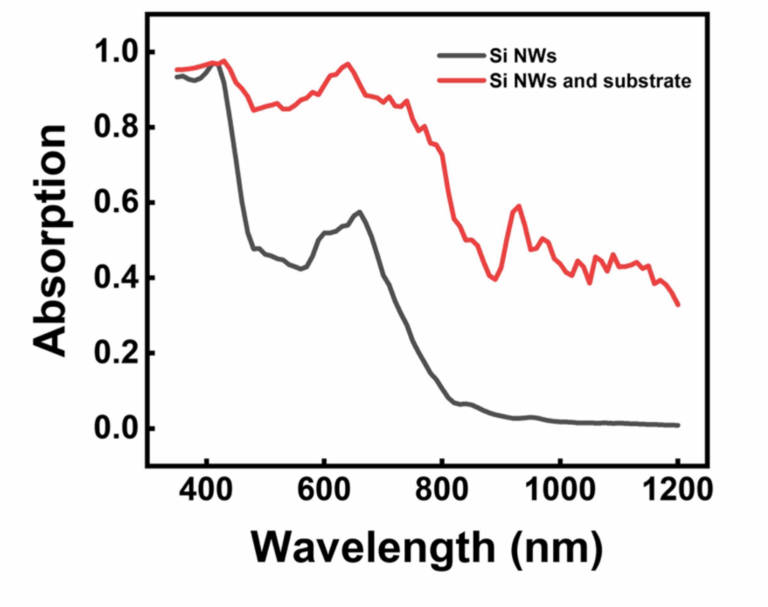

Figure S2. The simulated absorption spectrum of 140 nm Si NWs on the Si substrate.

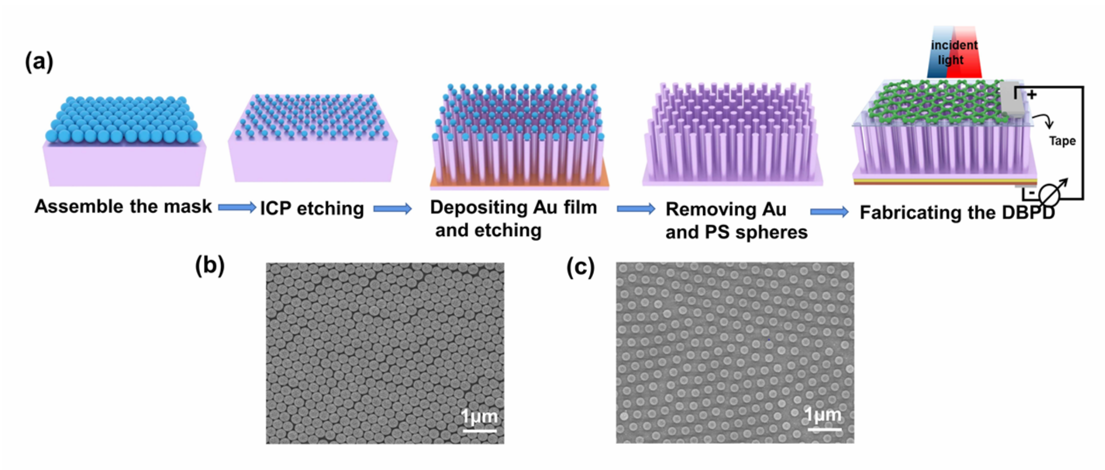

Figure S3. (a) Flowchart for fabricating Gr/Si NWs array heterojunctions DBPD. (b) SEM image of PS spheres. (c) SEM image of PS spheres after ICP etching.

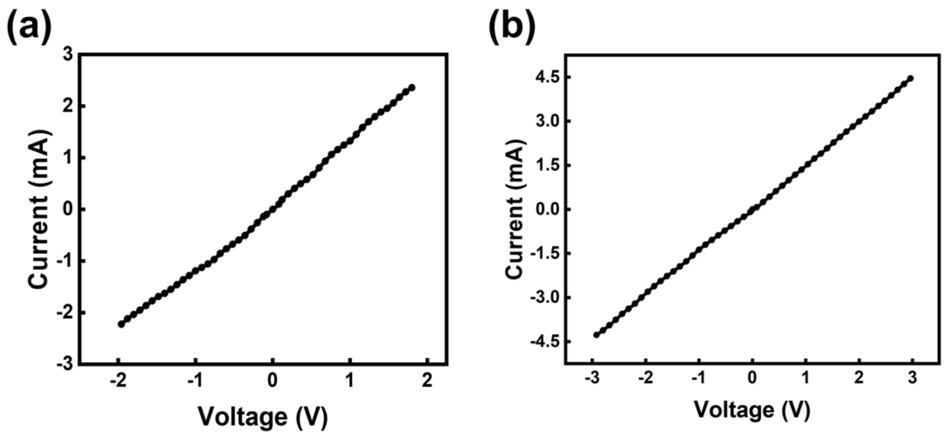

Figure S4. (a) *I-V* curve of the In-Ga/n-Si/In-Ga contact. (b) *I-V* curve of the Ag/Graphene/Ag contact.

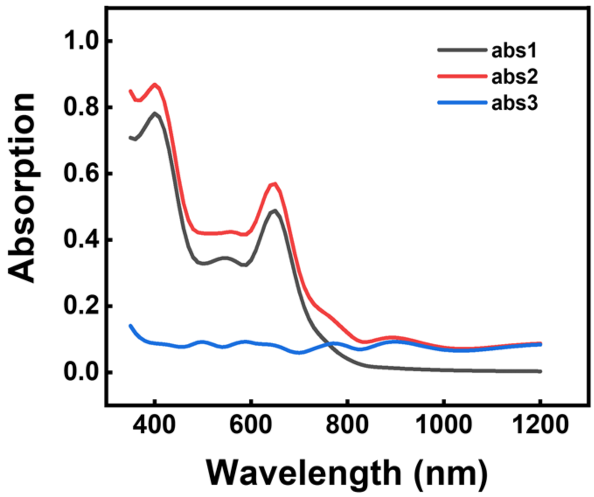

Figure S5. The simulated absorption spectrum of 140 nm Si NWs covered with MLG. “abs1, abs2 and abs3” are the Simulated absorption spectrum of Si NWs, MLG, and both of them, respectively.

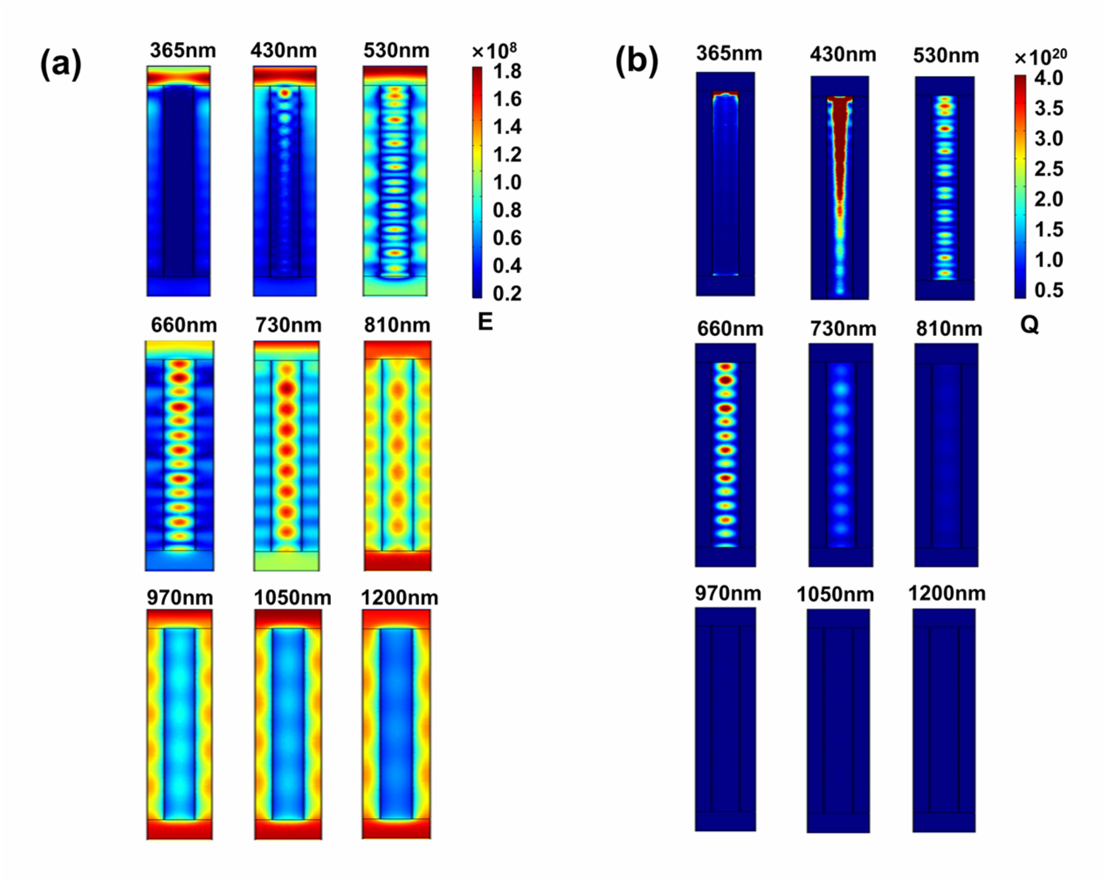

Figure S6. (a) Electric field distribution and (b) the total power loss density of the Si NWs array in the y-z planes excited by illumination with wavelengths of 365, 430, 530, 660, 730, 810, 970, 1050 and 1200 nm, respectively.

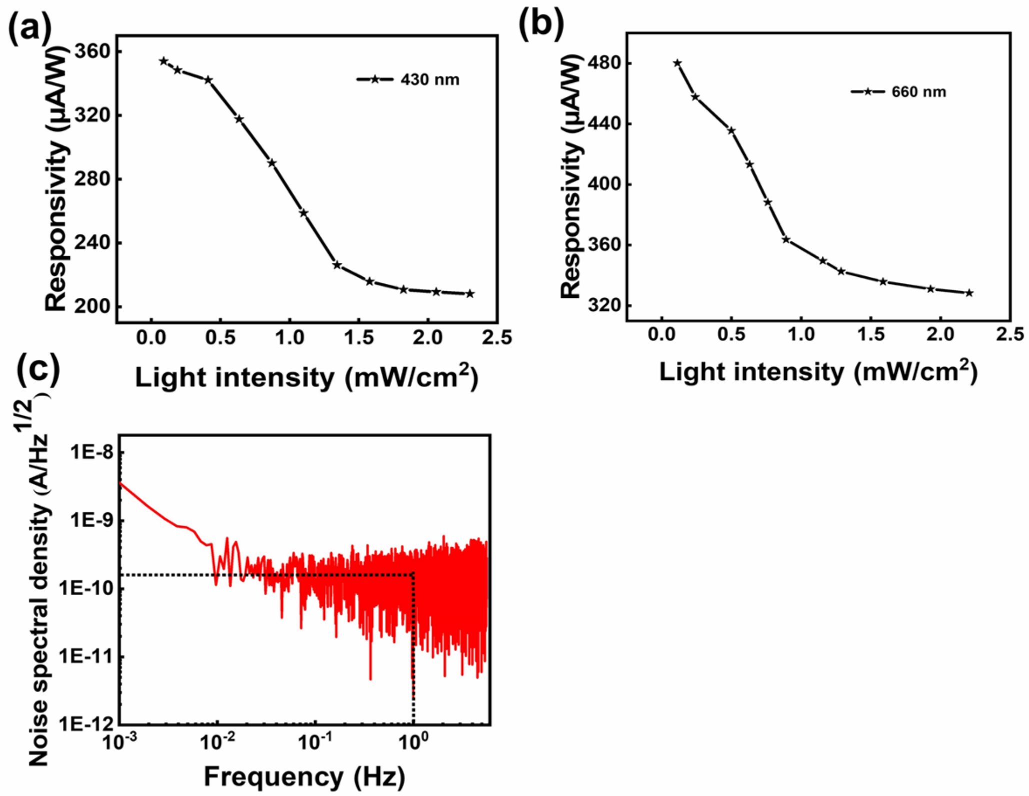

Figure S7. (a) Responsivity (R) of the DBPD of 430nm at 0v. (b) Responsivity (R) of the DBPD of 660nm at 0v. (c) Noise equivalent power (NEP) of DBPD.

REFERENCES

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