Electronic Supplementary Information (ESI)

Photogating-Enhanced Photodetection in Substrate-Assisted Borophene-Graphene Hybrids

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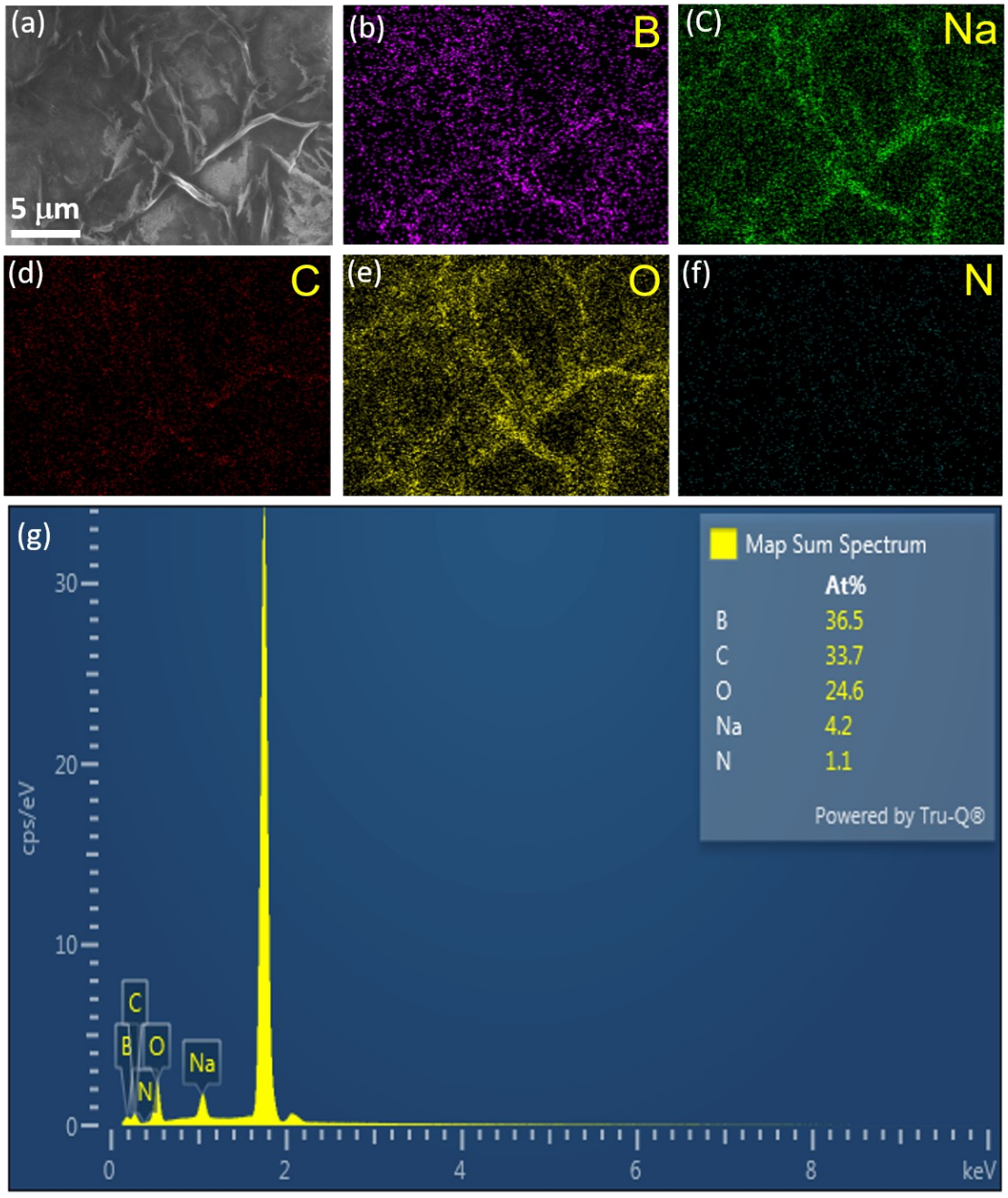

Figure S1. (a) SEM image of borophene dispersed on a silicon substrate. (b–e) SEM-EDS mapping images showing the distribution of (b) boron (B), (c) sodium (Na), (d) carbon (C), (e) oxygen (O), and (f) nitrogen (N) atoms corresponding to the region in (a). (g) SEM-EDS spectrum of borophene, confirming its elemental composition.

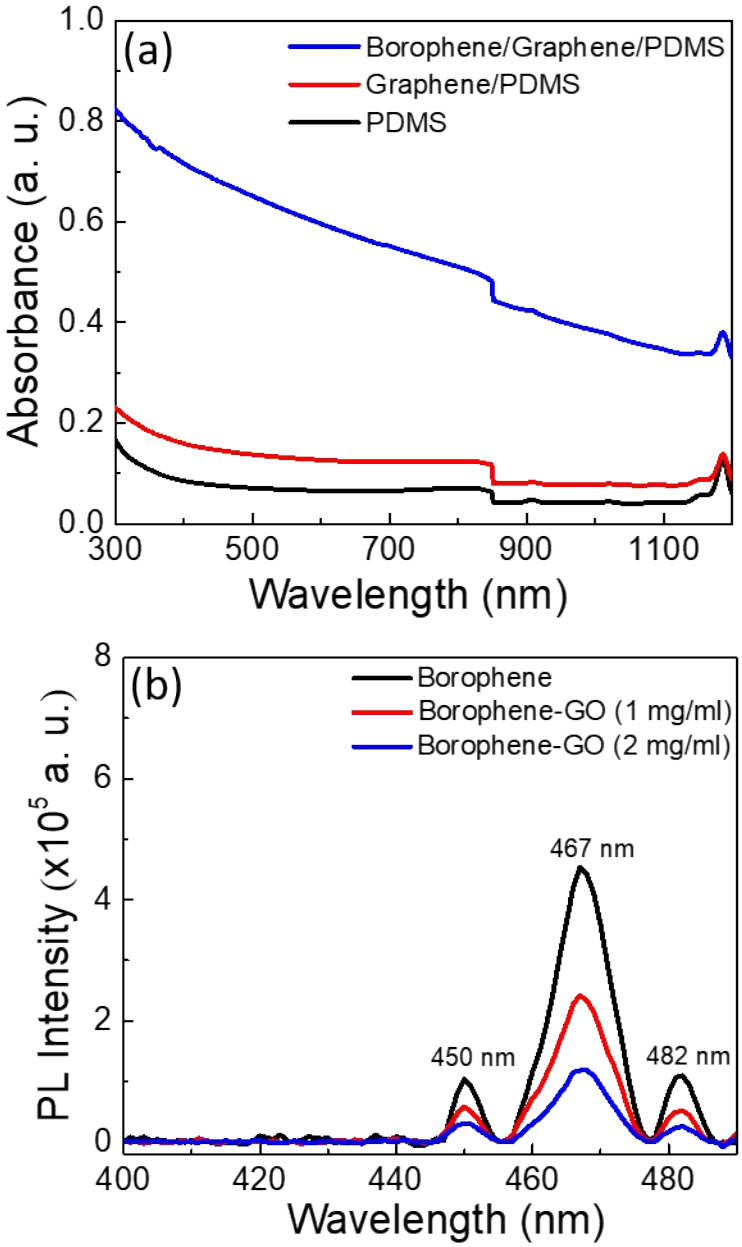

Figure S2. (a) UV-Vis absorption spectra of bare PDMS, Graphene/PDMS, and Borophene/Graphene/PDMS substrates. The shift at ~850 nm is a machine artefact. (b) Background subtracted Photoluminescence (PL) spectra of borophene (4 mg/mL) and borophene–graphene oxide (GO) hybrids with GO concentrations of 1 mg/mL and 2 mg/mL, all dispersed in ethanol. Three distinct emission peaks are observed at 450, 467, and 482 nm. All measurements were performed using an excitation wavelength of 255 nm.

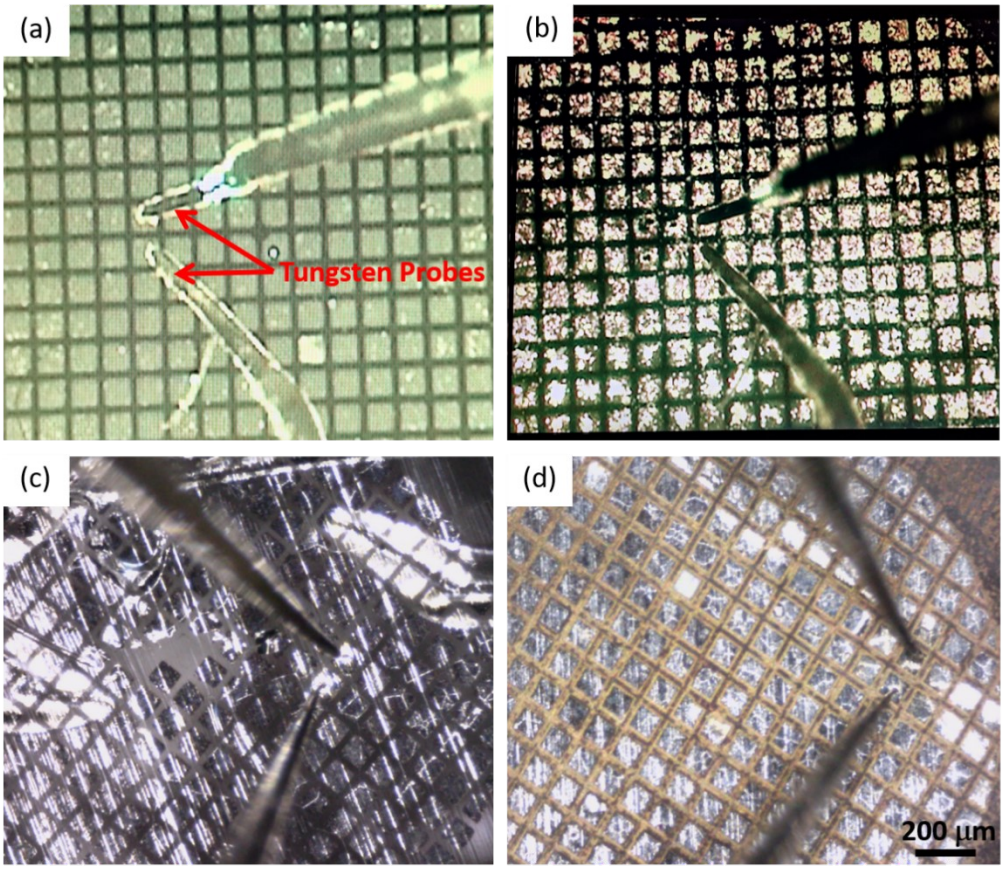

Figure S3. Optical image of (a) Graphene/SiO_2/Si, (b) Borophene/Graphene/SiO_2/Si, (c) Graphene/PDMS, and (d) Borophene/Graphene/PDMS PD devices. Tungsten probes are landed on the square shaped silver contacts shown in each panel. The dark contrast area between the bright silver squares is the device area. A 200 µm scale bar is depicted in panel (d).

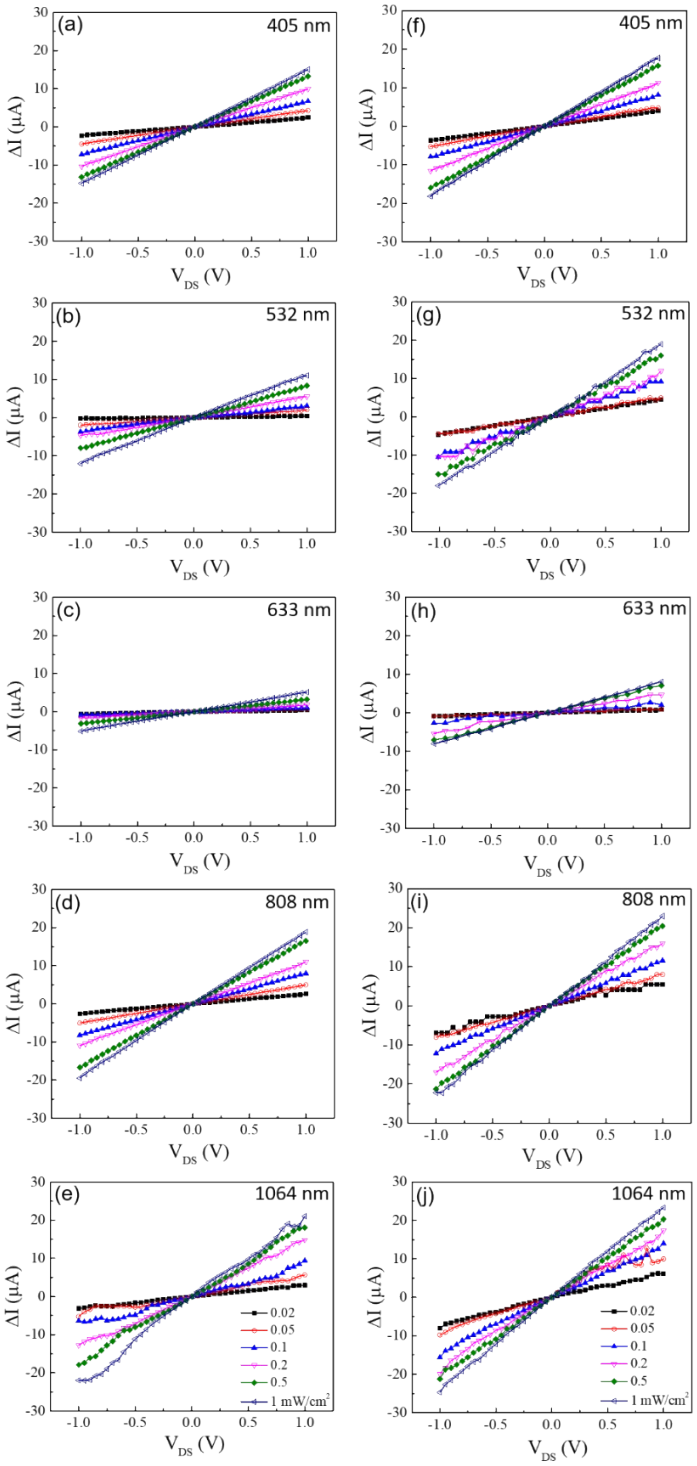

Figure S4. Power-dependent I-V characteristics of (a-e) Graphene/SiO_2/Si, and (f-j) Borophene/Graphene/SiO_2/Si under 405, 532, 633, 808, and 1064 nm laser illuminations. The power densities are colour coded in panel (e), and (j). All measurements are performed under room temperature.

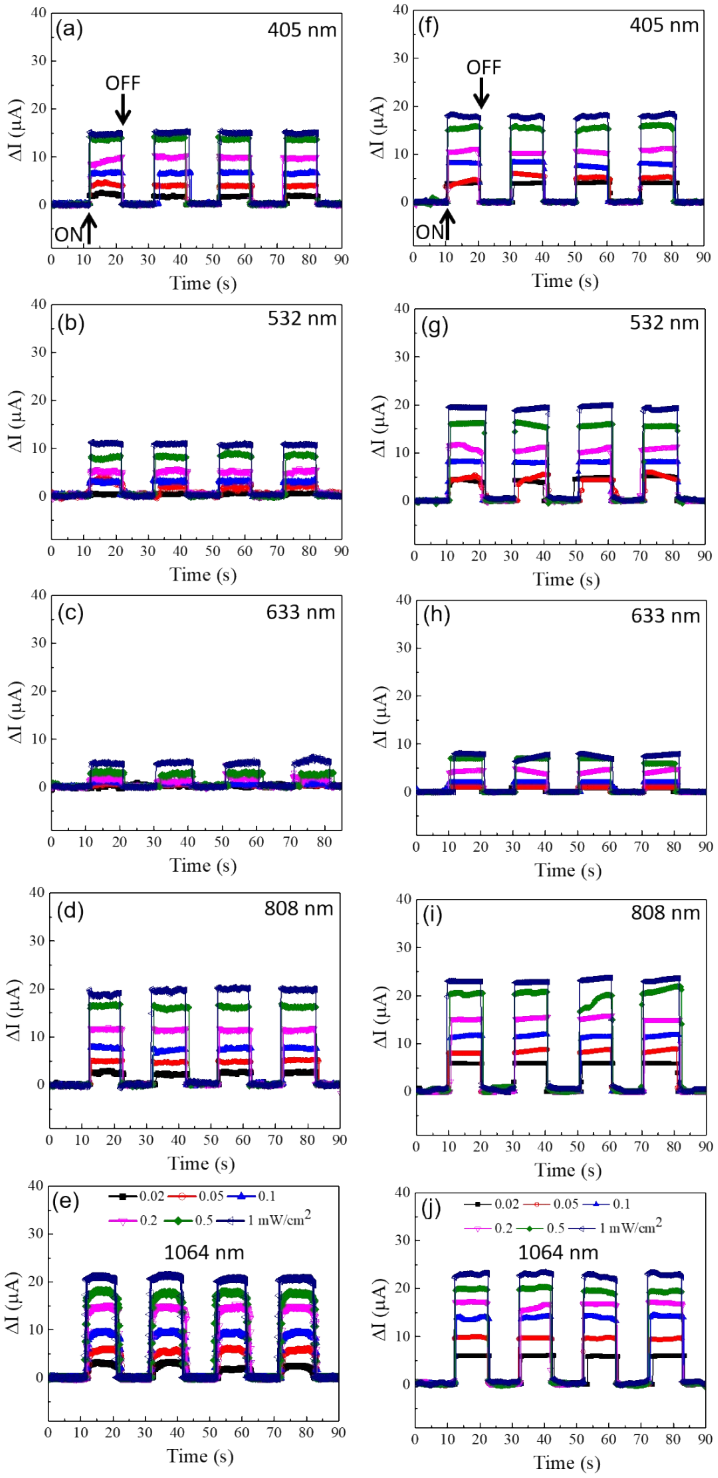

Figure S5. Power-dependent dynamic photoresponse of (a-e) Graphene/SiO_2/Si, and (f-j) Borophene/Graphene/SiO_2/Si under 405, 532, 633, 808, and 1064 nm laser illuminations. The power densities are mentioned in panel (e), and (j). All measurements are performed under room temperature and 1 V bias. The arrows in panel (a) and (f) show the times at which the illumination was turned ON and OFF.

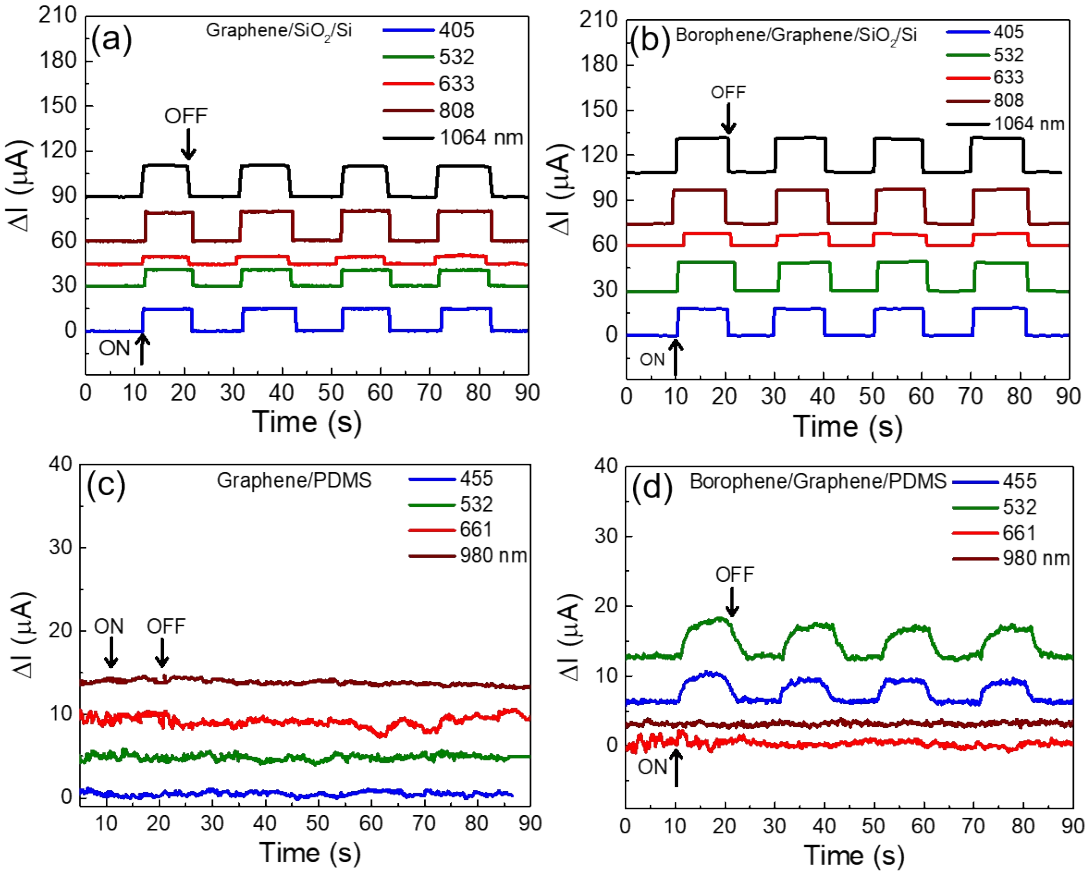

Figure S6. Multicycle dynamic photoresponse of (a) Graphene/SiO_2/Si, (b) Borophene/Graphene/SiO_2/Si, (c) Graphene/PDMS, and (d) Borophene/Graphene/PDMS PDs under 405 - 1064 nm laser illumination. All measurements are performed at 1 V bias and 1mW/cm^2 power density. The arrows show the times at which the illumination was turned ON and OFF.

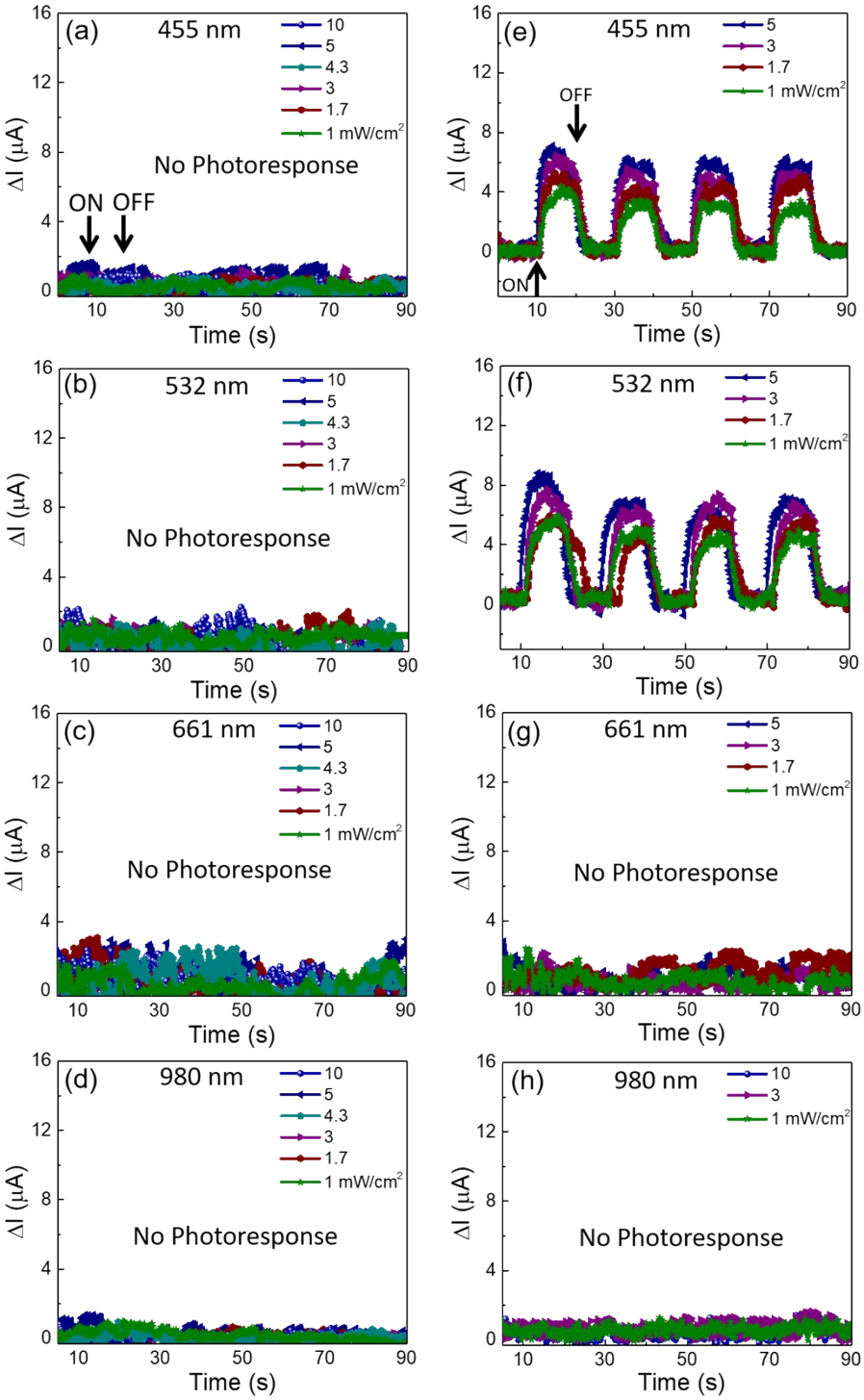

Figure S7. Power-dependent dynamic photoresponse of (a-d) Graphene/PDMS, and (e-h) Borophene/Graphene/PDMS under 405, 532, 633, 661, 808, 980 and 1064 nm laser illuminations. The power densities are mentioned in each panel. All measurements are performed in room temperature and 1 V bias. The arrows in panel (a) and (e) show the times at which the illumination was turned ON and OFF.

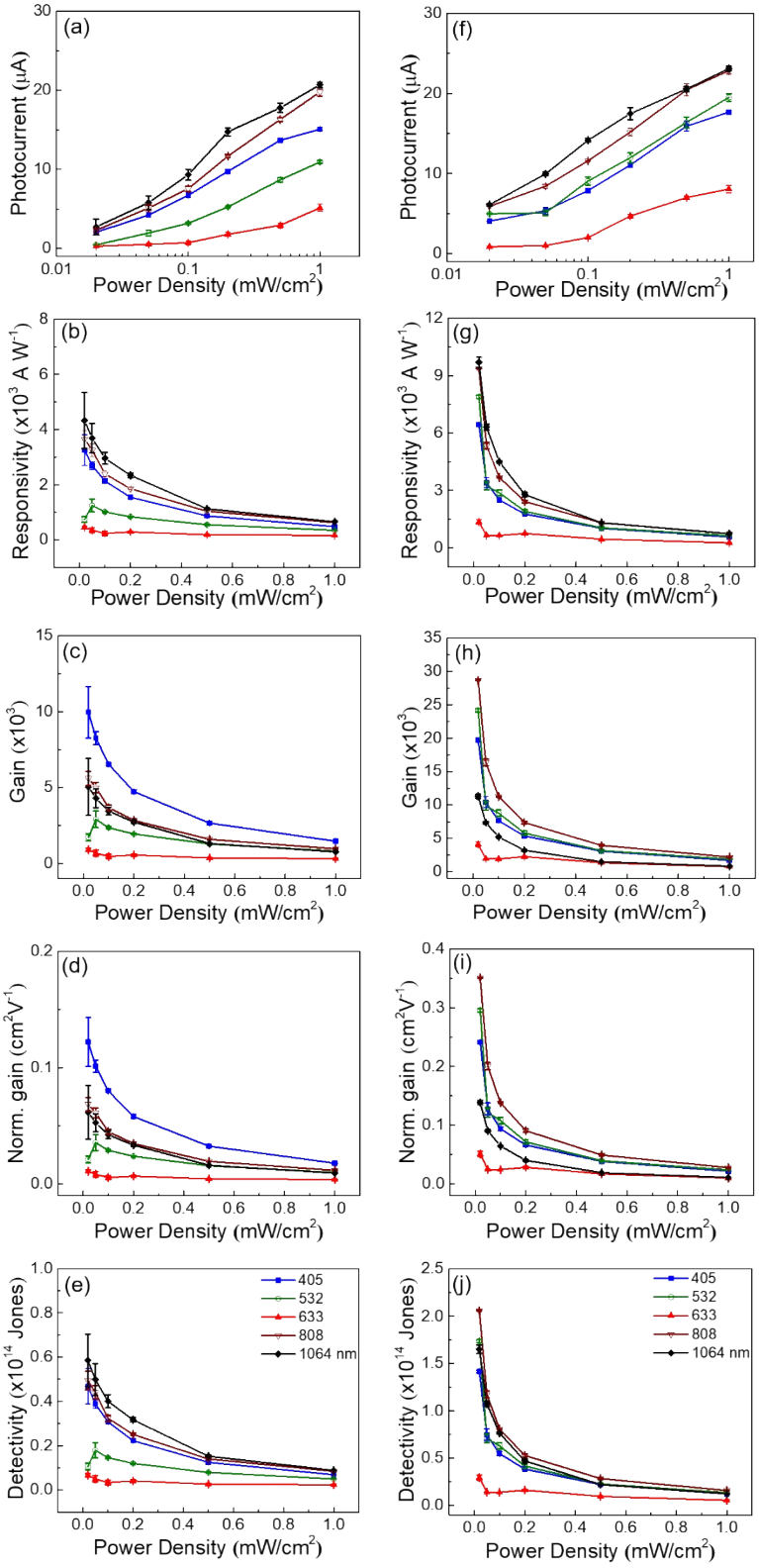

Figure S8. Power dependent (a) Photocurrent, (b) Responsivity, (c) Gain, (d) Normalized gain, and (e) Detectivity (D*) for the Graphene/SiO_2/Si PD. Power dependent (f) Photocurrent, (g) Responsivity, (h) Gain, (i) Normalized gain,

and (j) Detectivity (D*) for the Borophene/Graphene/SiO_2/Si PD device. All the measurements were done under 405-1064 nm laser illumination (colour coded), and 1 V bias voltage. The error bar indicates the scatter in the data over 4 cycles of measurement shown in Figure S5.

Standard formulas for calculating photodetector device parameters

Responsivity (R): $R = \frac{I_{ph}}{P}$

I_{ph}: Photocurrent (I_{light} -I_{dark}); P: Power of illumination [P = (Light power/ laser spot area) X A_D)]

Gain (Γ) and Normalized Gain (Γ_n):

$$\Gamma = \frac{E\,I_p}{e\eta P}, \text{ and } \Gamma_n = \frac{E\,I_p\,l^2}{e\eta P V}$$

E: Photon energy; *I_{ph}: Photocurrent; P: Power of illumination; l: Device channel length = 35 μm*

η: Quantum efficiency (η = 1); e: Electronic charge;V: Bias voltage

Specific Detectivity (D*): $D^* = \frac{R\sqrt{A_D}}{\sqrt{2eI_d}}$

R: Responsivity; A_D: Active device area = 3150 μm^2 ;e: Electronic charge; I_d: Dark current

To estimate D*, we employed the widely used shot-noise-limited formula: $D^* = \frac{R\sqrt{A_D}}{\sqrt{2eI_d}}$. This approach may overestimate the D* as the dominant noise contribution arises from shot noise associated with the I_d, a common approximation in cases where full noise spectral data are unavailable[1]. However, an accurate evaluation often require direct measurement of the total noise

current (i_{noise}) across a defined bandwidth (Δf)[2-4] using D* = $\frac{R\sqrt{A_D} \times \sqrt{\Delta f}}{i_{noise}}$, providing a more realistic assessment of device performance. We have used the shot-noise limited formula in all cases for device to device comparison (Figure 6d).

Photodetector devices	**Laser (nm)**	τ_{rise} **(ms)**	τ_{fall} **(ms)**
Graphene/SiO_2/Si	405	122	127
	532	123	129
	633	130	132
	808	132	135
	1064	99	102
Borophene/Graphene/SiO_2/Si	405	115	104
	532	111	119
	633	125	127
	808	109	116
	1064	91	93

Table S1: Response time (τ_{rise}, and τ_{fall}) of Graphene/SiO_2/Si, and Borophene/Graphene/SiO_2/Si PDs.

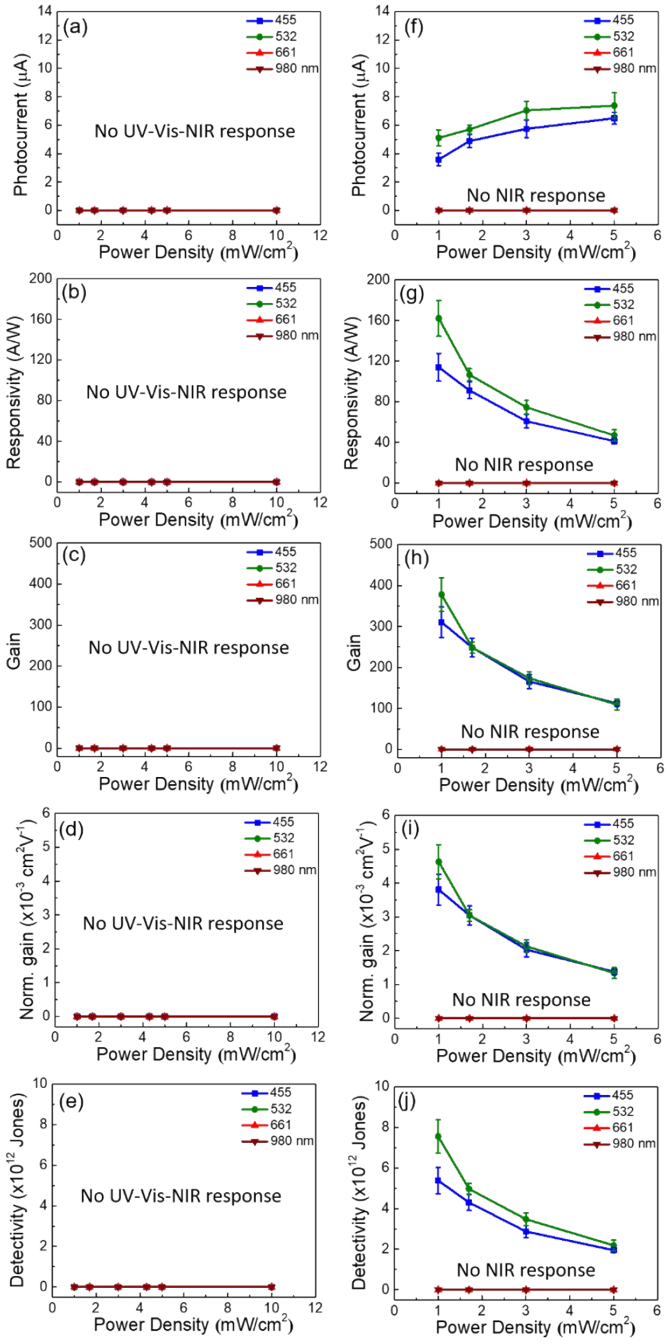

Figure S9. Power dependent (a) Photocurrent, (b) Responsivity, (c) Gain, (d) Normalized gain, and (e) Detectivity (D*) for the Graphene/PDMS PD. Power dependent (f) Photocurrent, (g) Responsivity, (h) Gain, (i) Normalized gain, and (j) Detectivity (D*) for the Borophene/Graphene/PDMS PD. All the measurements were done under 455-980 nm laser illumination (colour coded), and 1 V bias voltage. The error bar indicates the scatter in the data over 4 cycles of measurement shown in Figure S7.

References for ESI only

1. Z. Wu, G. Tai, R. Liu, C. Hou, W. Shao, X. Liang and Z. Wu, *ACS Applied Materials & Interfaces*, 2021, **13**, 31808-31815.
2. J. Fu, C. Nie, F. Sun, G. Li, H. Shi and X. Wei, *Science Advances*, **10**, eadk8199.
3. J. Fu, C. Nie, F. Sun, G. Li and X. Wei, *Advanced Devices & Instrumentation*, **4**, 0031.
4. J. Fu, Z. Guo, C. Nie, F. Sun, G. Li, S. Feng and X. Wei, *The Innovation*, 2024, **5**.