Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

A fully printed ultrafast Si/WS_2 quantum dot photodetector with very high responsivity over the UV to near-infrared region

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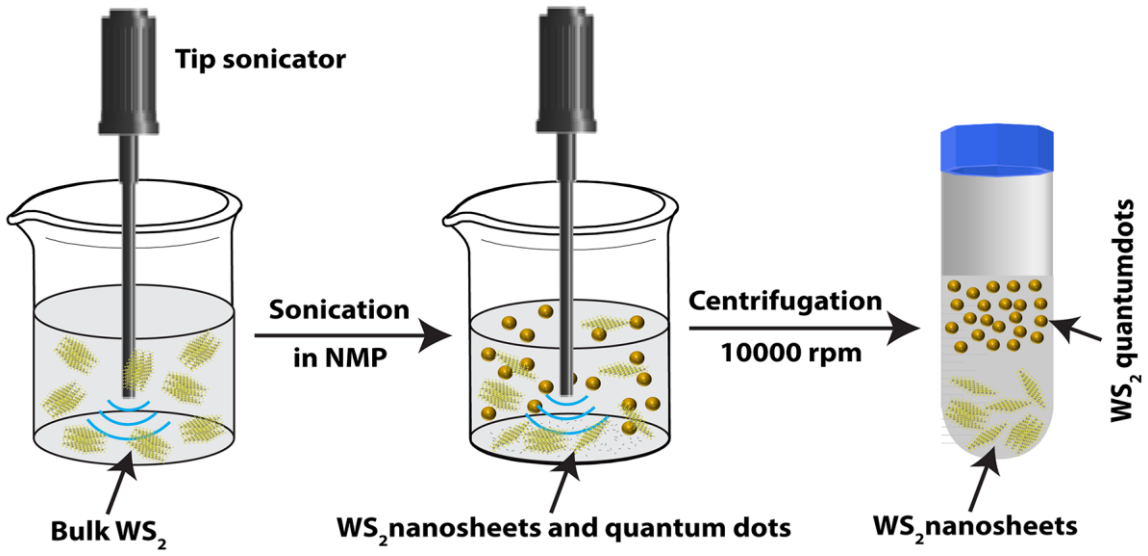

Figure S1. Schematic diagram showing the preparation of WS_2 quantum dots.

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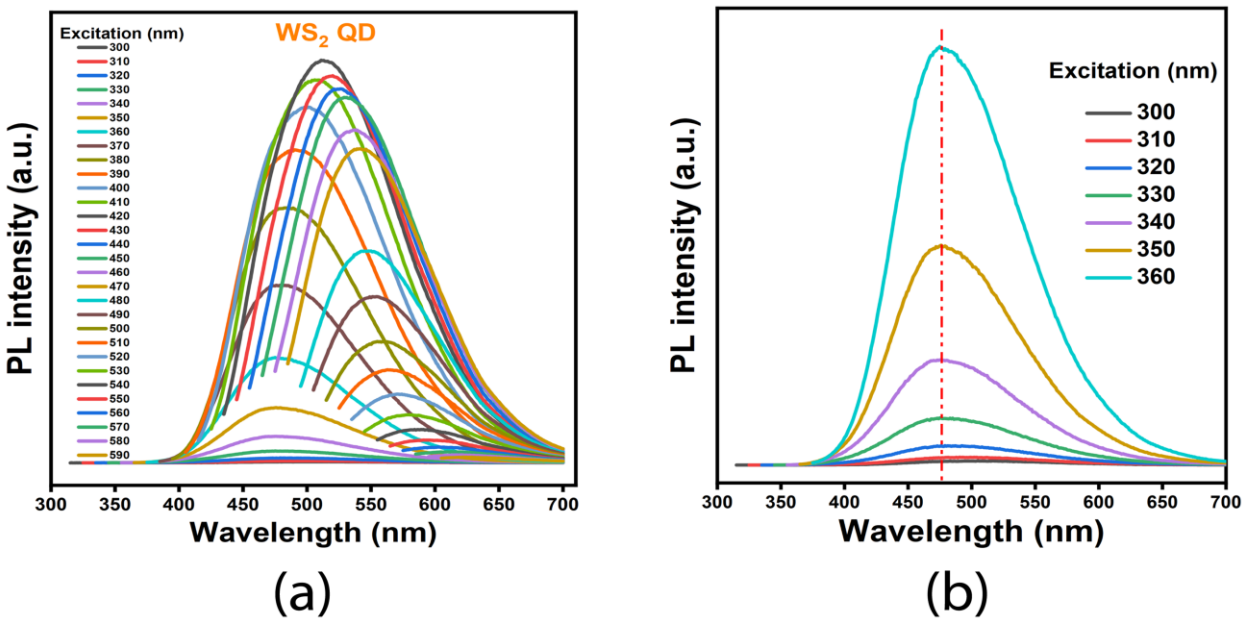

Figure S2: (a) PL spectra of WS_2 QDs at different excitation wavelengths. (b) Excitation dependent PL spectra for selective low wavelegths showing no spectral shift.

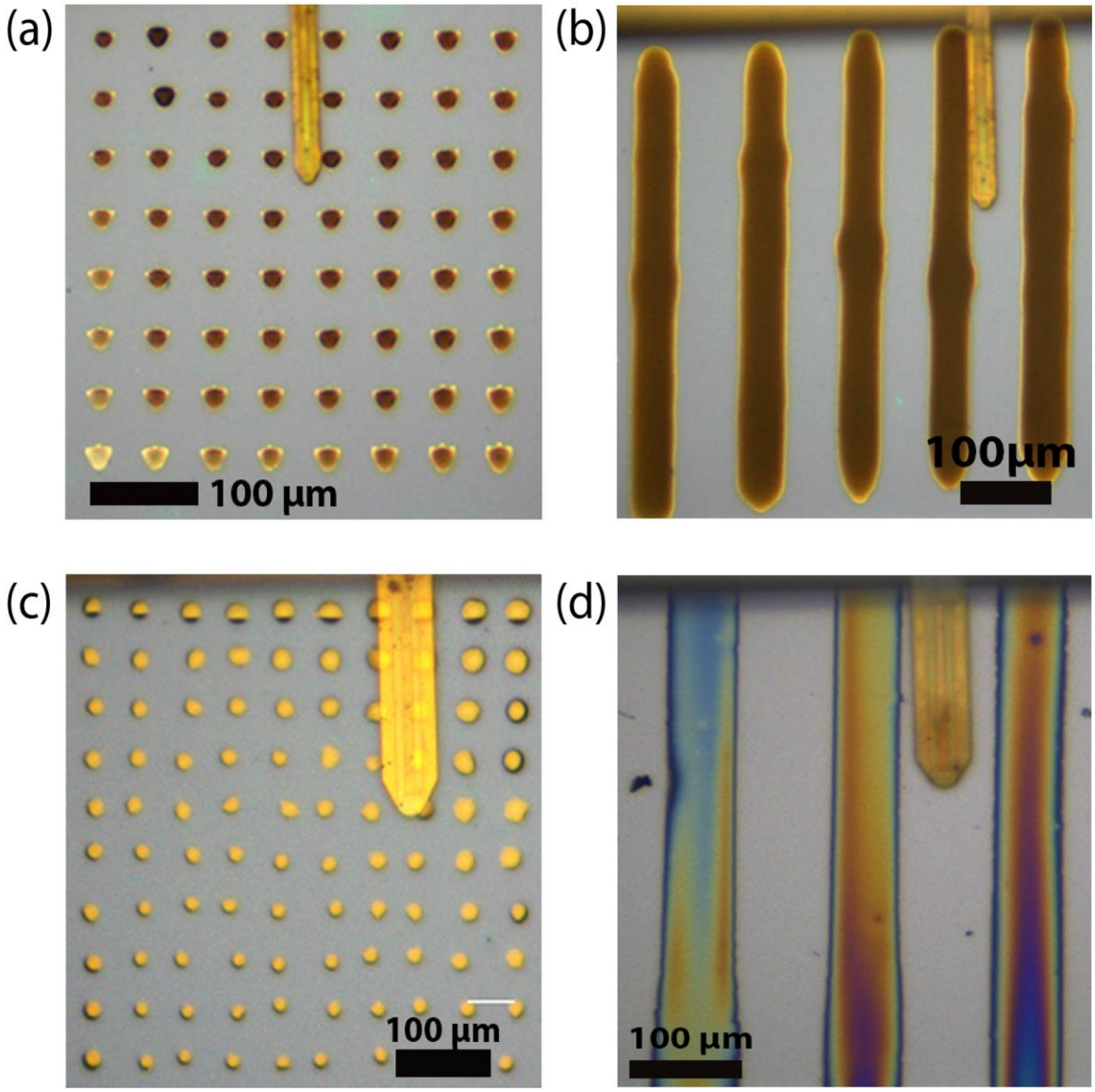

Figure S3. Microscopic image of printed test patterns. (a, b) Printed patterns of Ag NP ink. (c, d) Printed patterns of WS_2 QD ink.

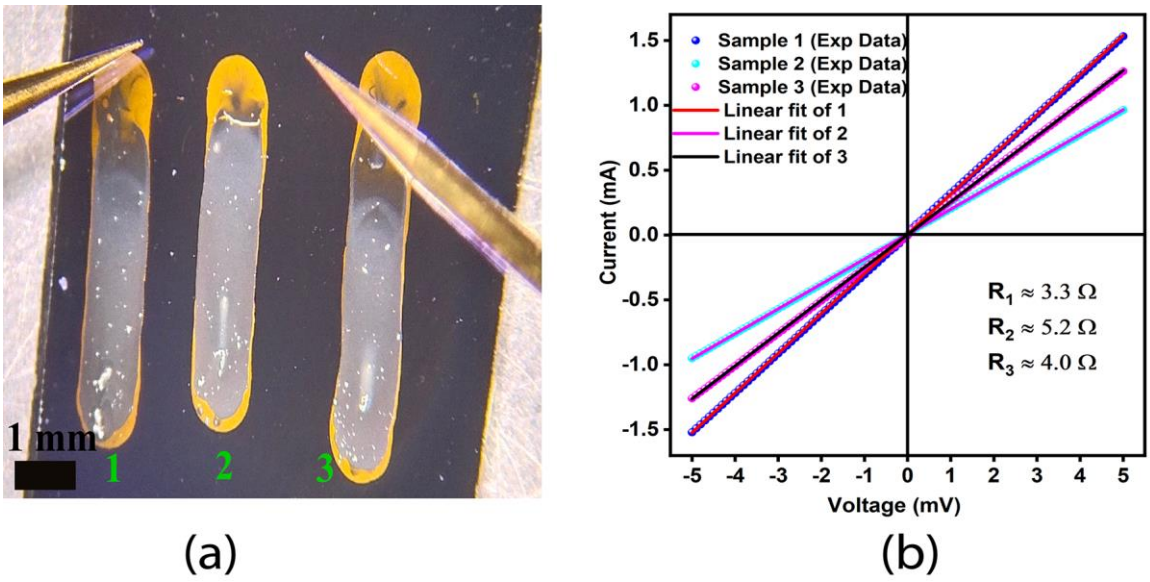

Figure S4. (a) Microscopic image of printed silver lines. (b) I-V characteristics of different samples.

Table S1. Summary of the resistivity data of the printed silver lines.

Sample number	Resistance (Ω)	Length (mm)	Width (μm)	Thickness (nm)	Resistivity (Ω-m)
1	3.3	5.95	972	923	4.98×10^{-7}
2	5.2	5.71	1002	857	7.82×10^{-7}
3	4.0	6.51	970	1066	6.35×10^{-7}

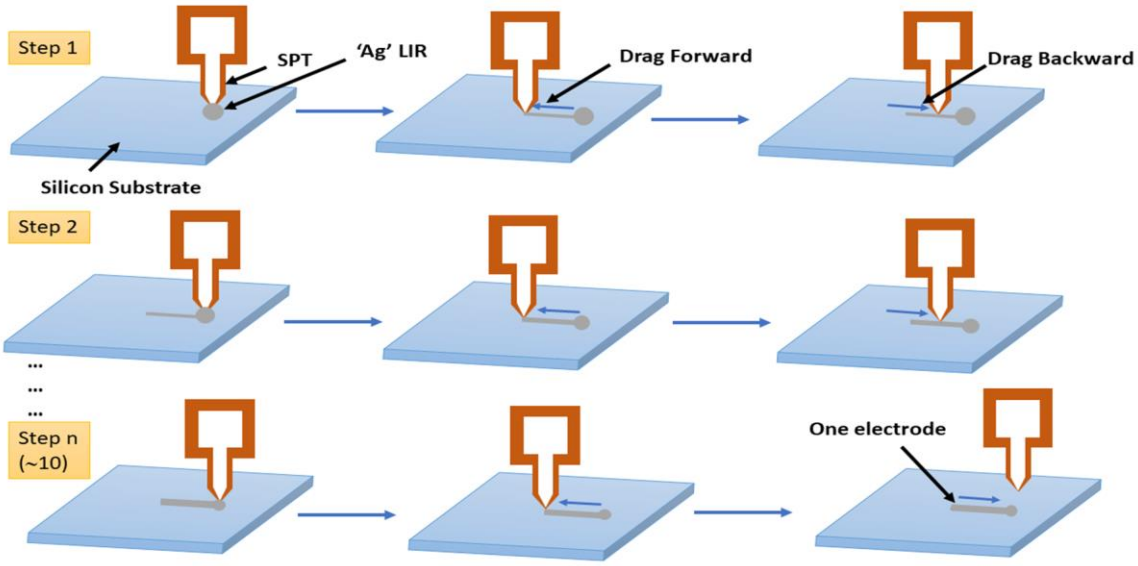

Figure S5. Schematic diagram of the device printing process. Step 2 onwards processes are repetitions of step 1.

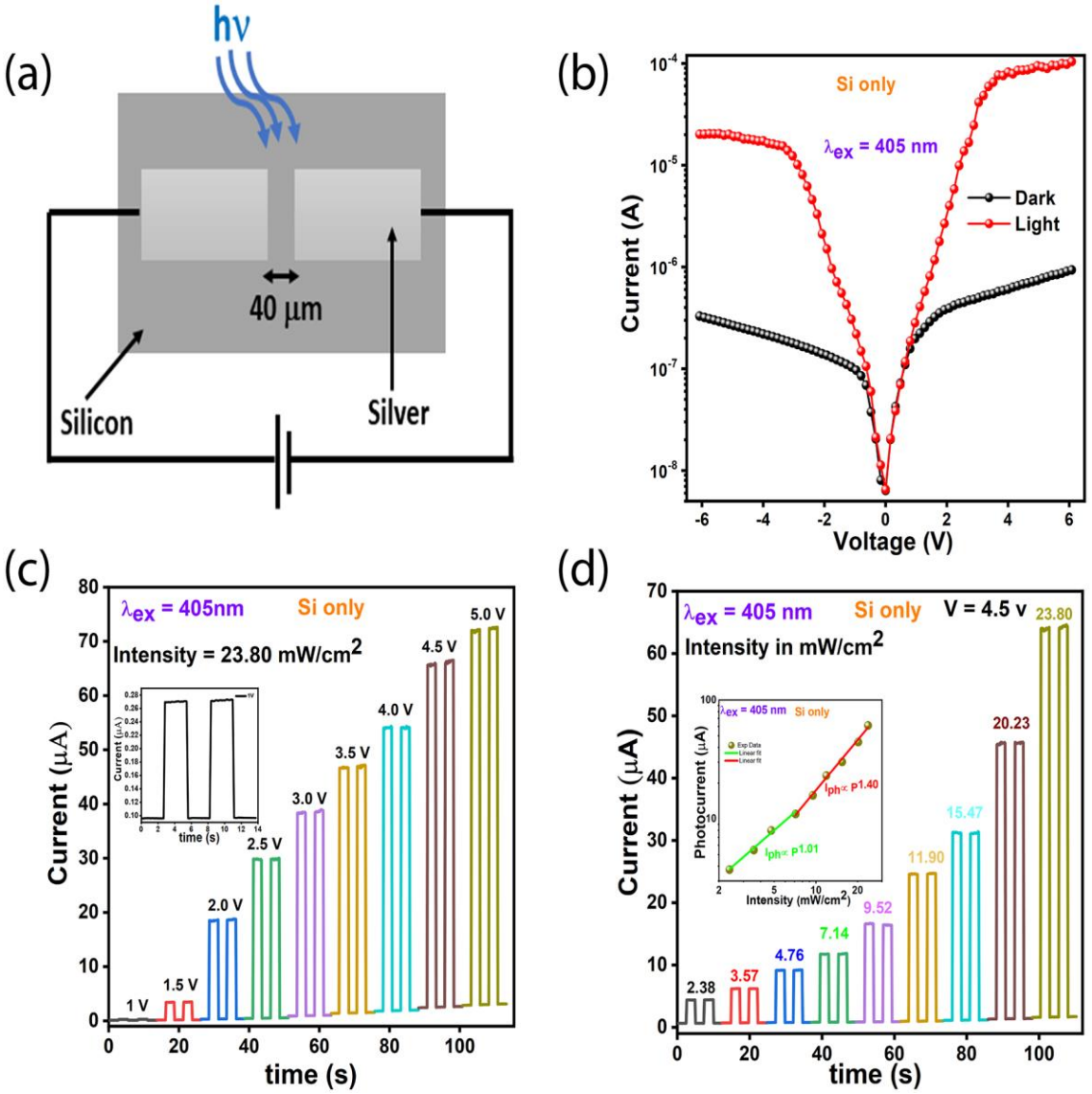

Figure S6. (a) Schematic of the bare Si PD with printed Ag electrodes. (b) I-V characteristics of the PD at dark and under 405 nm laser illumination. (c) Voltage-dependent I-t response of the Si PD. (d) Illumination power dependent I-t of the device. The inset shows a light intensity dependent photocurrent showing non-linear response of the device.

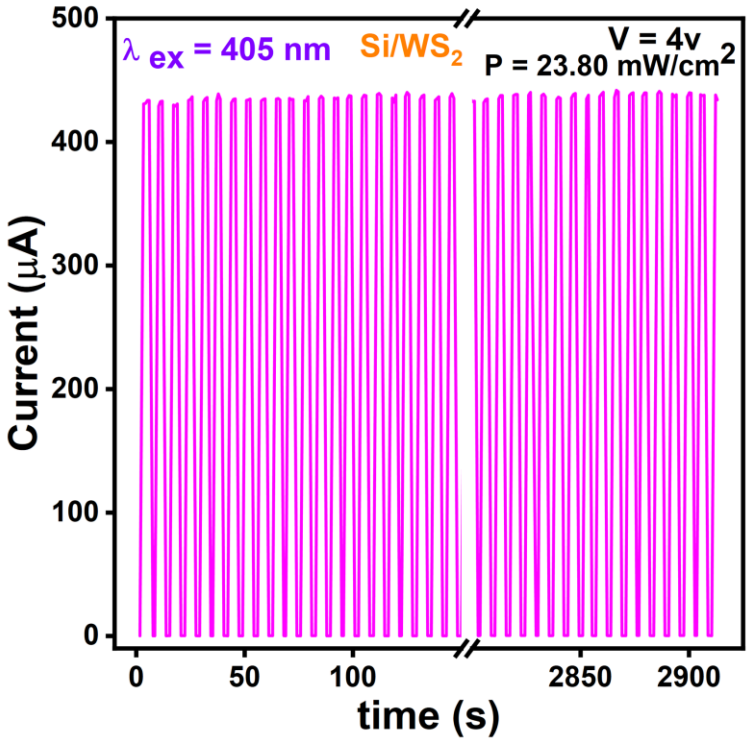

Figure S7. Stability of the printed Si/WS_2 photodetector under prolonged light (405 nm) illumination.

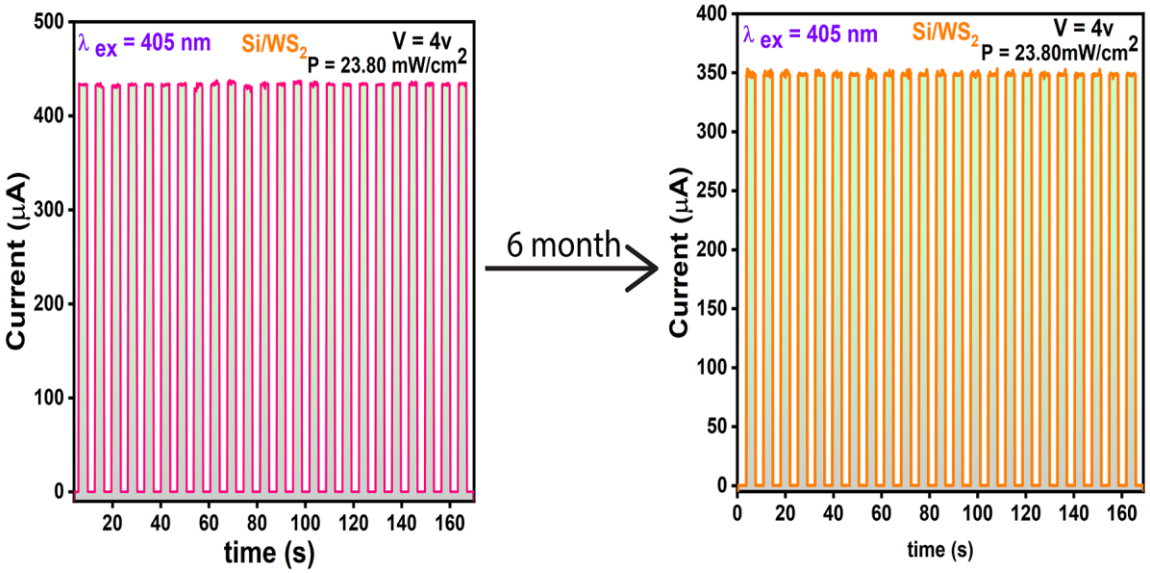

Figure S8. Storage stability of the printed Si/WS_2 photodetector after six months.

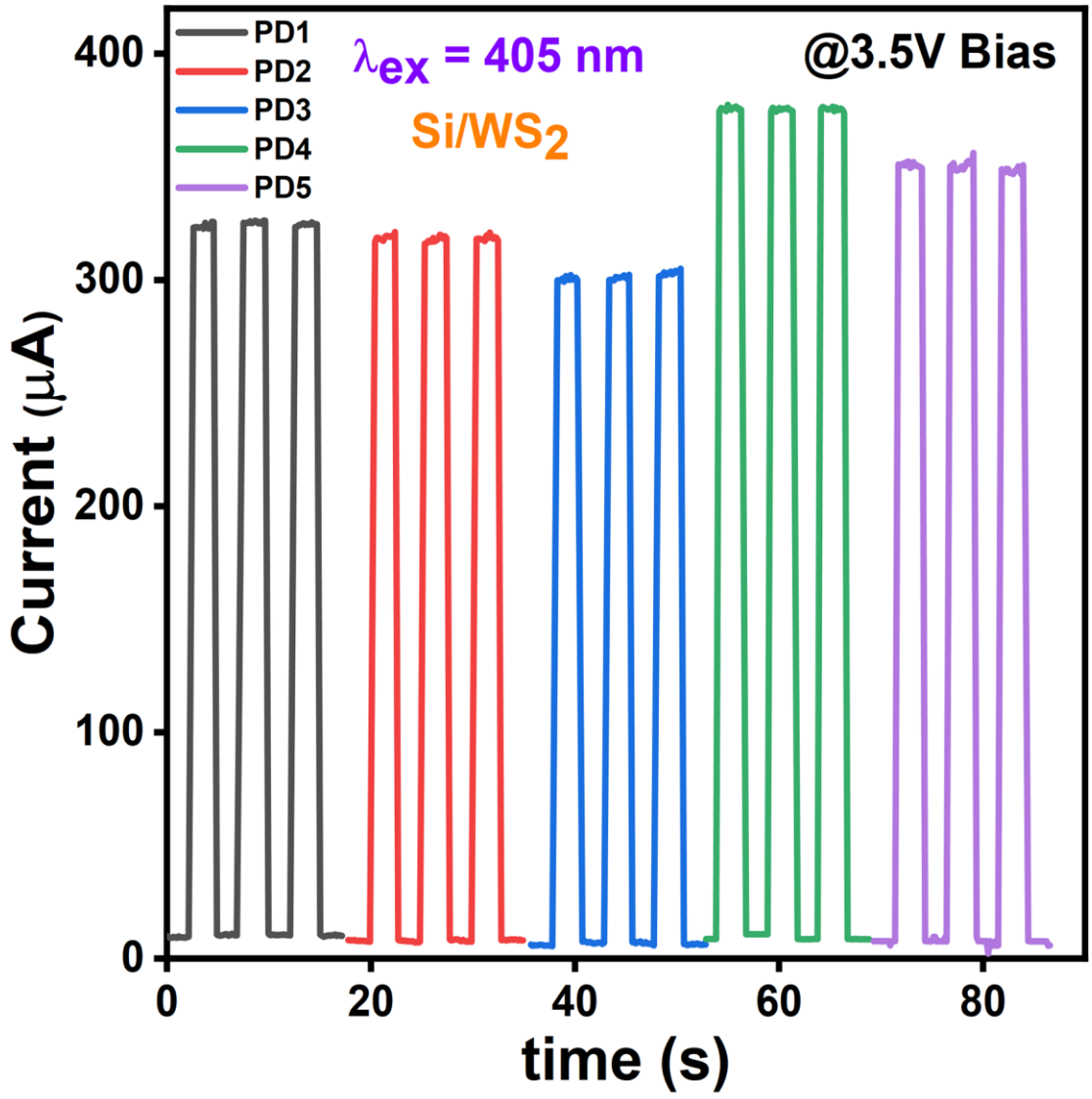

Figure S9. Reproducibility of the device fabrication and performance of the PDs. I-t data for five different printed Si/WS_2 PDs show nearly identical results.

Table S2. Comparison of the Si/WS_2 photodetector performance fabricated by different techniques.

Synthesis / Fabrication method	**I_{on} / I_{off}**	**Responsivity (A/W)**	**Specific Detectivity (Jones)**	**Response Time**	**Ref.**
Sputtering/ silver paste coat	10^2	5.70		670 / 998 (μs)	[48]
Li-ion intercalation (dip coat) / Thermal evaporation	10^3	1.11	5×10^{11}	42 / 72 (ms)	[49]
Thermal decomposition/ photolithography	10^6	0.22	1.5×10^{12}	16 / 29 (μs)	[50]
Sputtering / Au electrode	1.2×10^3	5.2	4.8×10^{12}	14, <1 (ms)	[51]
Sputtering/thermal evaporation (Drop-cast)	227	186.6	5.4×10^{12}	55.1/139.8 (μs)	[24]
Liquid phase exfoliation / Fully printed	5.2×10^3	126	9.24×10^{12}	7.8 / 9.5 (μs)	*This work*

Table S3. Comparison of TMD-based printed photodetector performance.

Materials	Printing Technique	Responsivity (A/W)	Specific Detectivity (Jones)	Response time	Ref.
MoS_2, graphene electrode	Inkjet printing	0.30	3.6×10^{10}	-	[36]
MoS_2, graphene electrode	Inkjet printing	0.05	3.18×10^{9}	~ 150 (μs)	[37]
MoS_2, graphene electrode	Aerosol Jet printing	10^{3}	1.8×10^{7}	~ 2, <1 (ms)	[38]
MoS_2, Ti/ Au electrode	Electrohydrodynamic-Jet Printing / Lithography	3.78	-	-	[39]
WS_2 / graphene electrode	Inkjet/screen printing	0.61×10^{-3}	-	-	[40]
Si /WS_2, Silver electrode	Microcantilever-based printing	126	9.24×10^{12}	7.8 / 9.5 (μs)	This work

REFERENCES

(48) Lan, C.; Li, C.; Wang, S.; He, T.; Jiao, T.; Wei, D.; Jing, W.; Li, L.; Liu, Y. Zener Tunneling and Photoresponse of a WS2/Si van Der Waals Heterojunction. *ACS Appl. Mater. Interfaces* **2016**, *8* (28), 18375–18382. https://doi.org/10.1021/acsami.6b05109.

(49) K. Chowdhury, R.; Maiti, R.; Ghorai, A.; Midya, A.; K. Ray, S. Novel Silicon Compatible P-WS 2 2D/3D Heterojunction Devices Exhibiting Broadband Photoresponse and Superior Detectivity. *Nanoscale* **2016**, *8* (27), 13429–13436. https://doi.org/10.1039/C6NR01642A.

(50) Wu, E.; Wu, D.; Jia, C.; Wang, Y.; Yuan, H.; Zeng, L.; Xu, T.; Shi, Z.; Tian, Y.; Li, X. In Situ Fabrication of 2D WS2/Si Type-II Heterojunction for Self-Powered Broadband Photodetector with Response up to Mid-Infrared. *ACS Photonics* **2019**, *6* (2), 565–572. https://doi.org/10.1021/acsphotonics.8b01675.

(51) Pal, S.; Mukherjee, S.; Jangir, R.; Nand, M.; Jana, D.; Mandal, S. K.; Bhunia, S.; Mukherjee, C.; Jha, S. N.; Ray, S. K. WS2 Nanosheet/Si p–n Heterojunction Diodes for UV–Visible Broadband Photodetection. *ACS Appl. Nano Mater.* **2021**, *4* (3), 3241–3251. https://doi.org/10.1021/acsanm.1c00421.