Supporting Information

Solution-Processed Vertical Field-Effect Transistor with Separated Charge Generation and Charge Transport Layers for High-Performance Near-Infrared Photodetection

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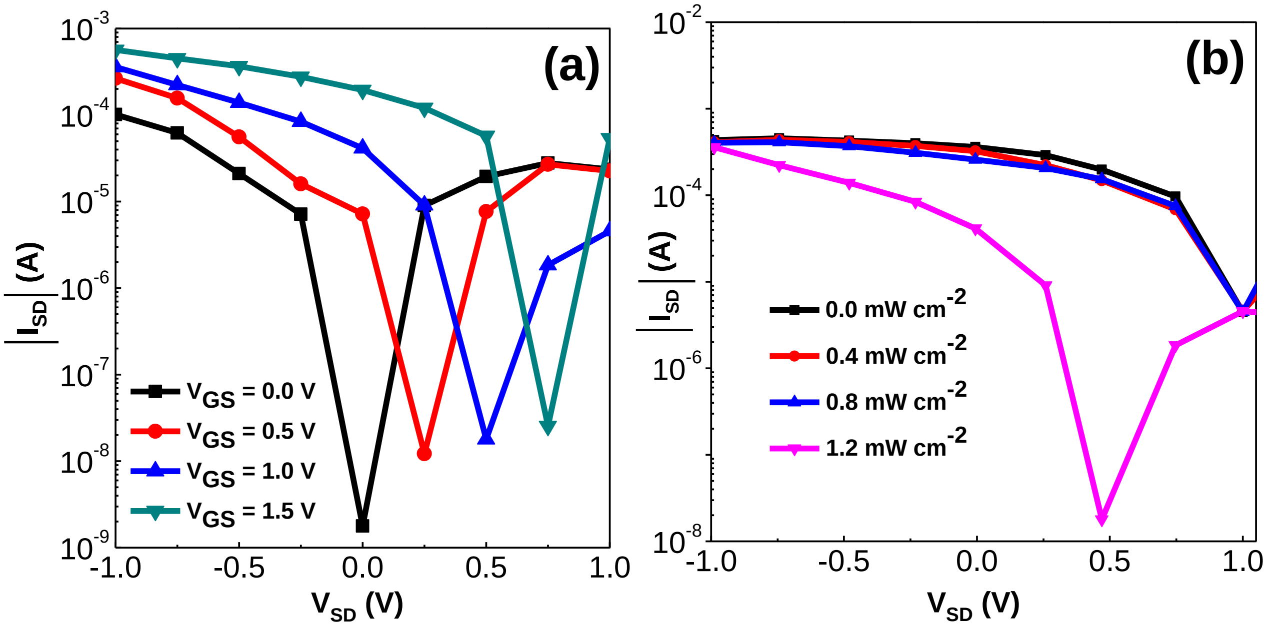
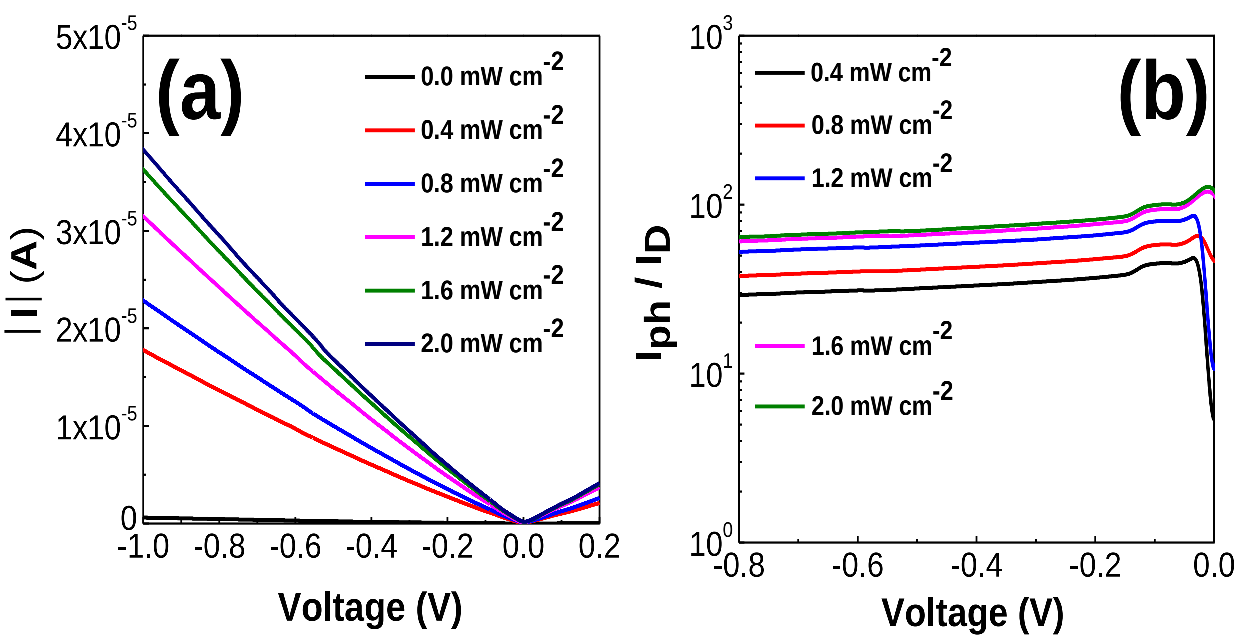


Figure S1 (a) Output characteristics (I_{SD}-V_{SD}) of the as-designed VFEPT device in the dark condition at different V_{GS} voltages. (b) Output characteristics of the device at a fixed V_{GS} of 1 V in the dark and under light irradiance of 1064 nm laser.



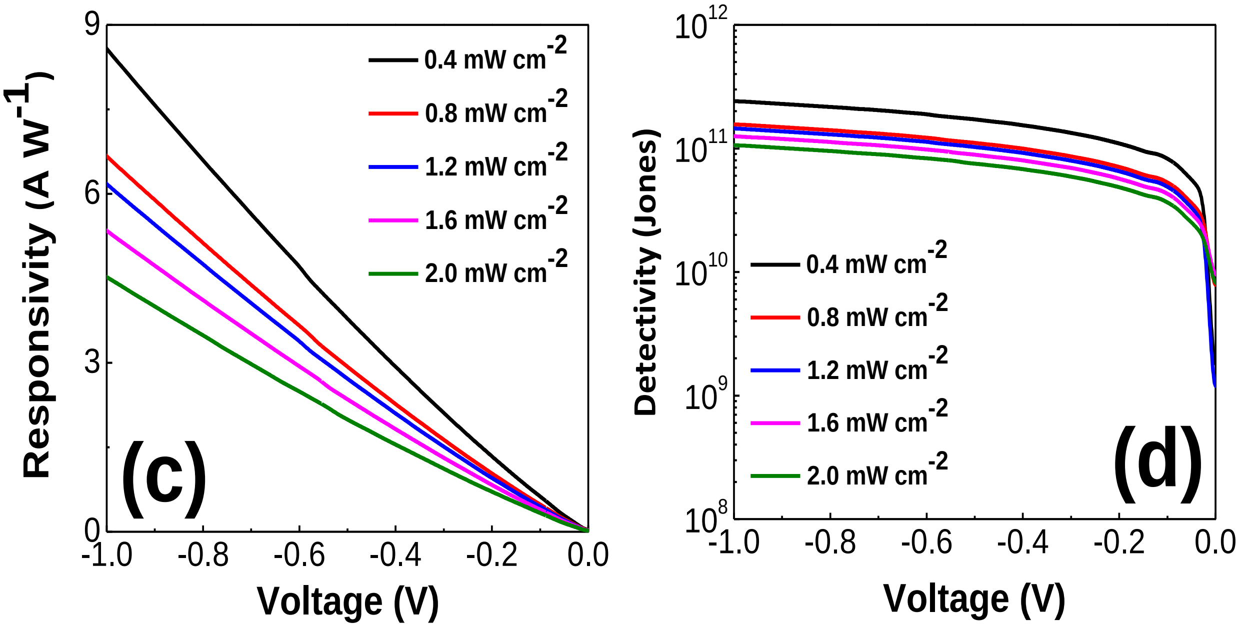
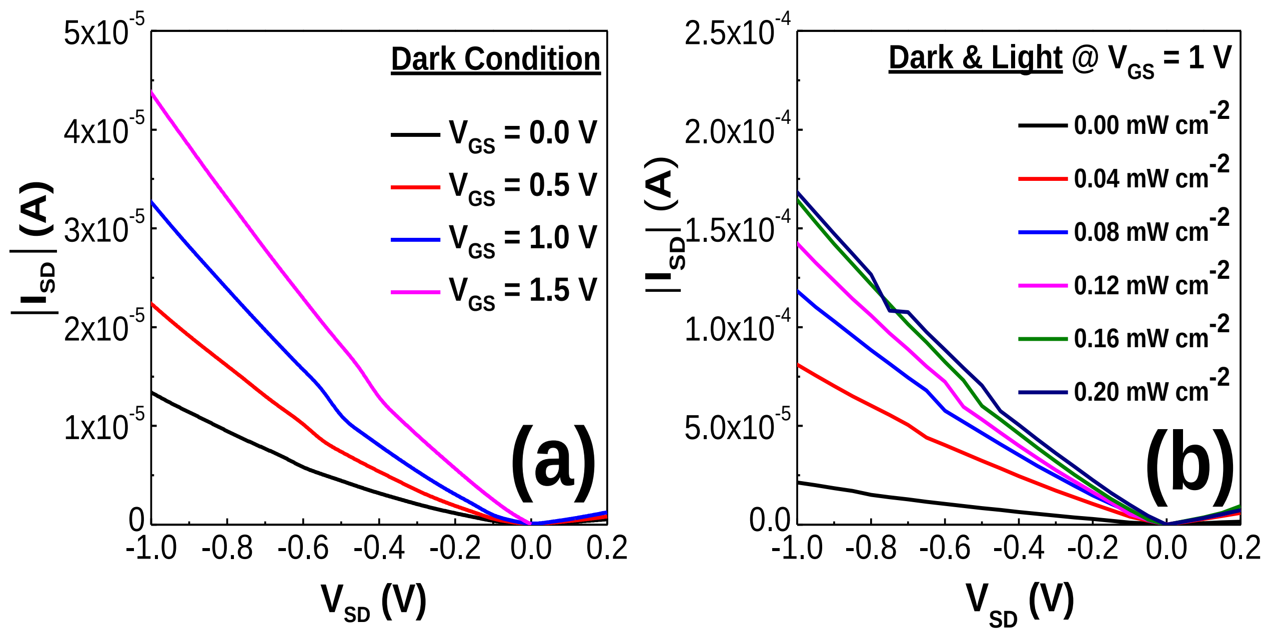


Figure S2 (a) Output characteristics of the two-terminal device (ITO/PbSe/PCBM/AgNWs) in the dark and under light irradiance of 1064 nm laser, (b) photo-to-dark current ratio, (c) the responsivity and (d) the detectivity of the two-terminal device.



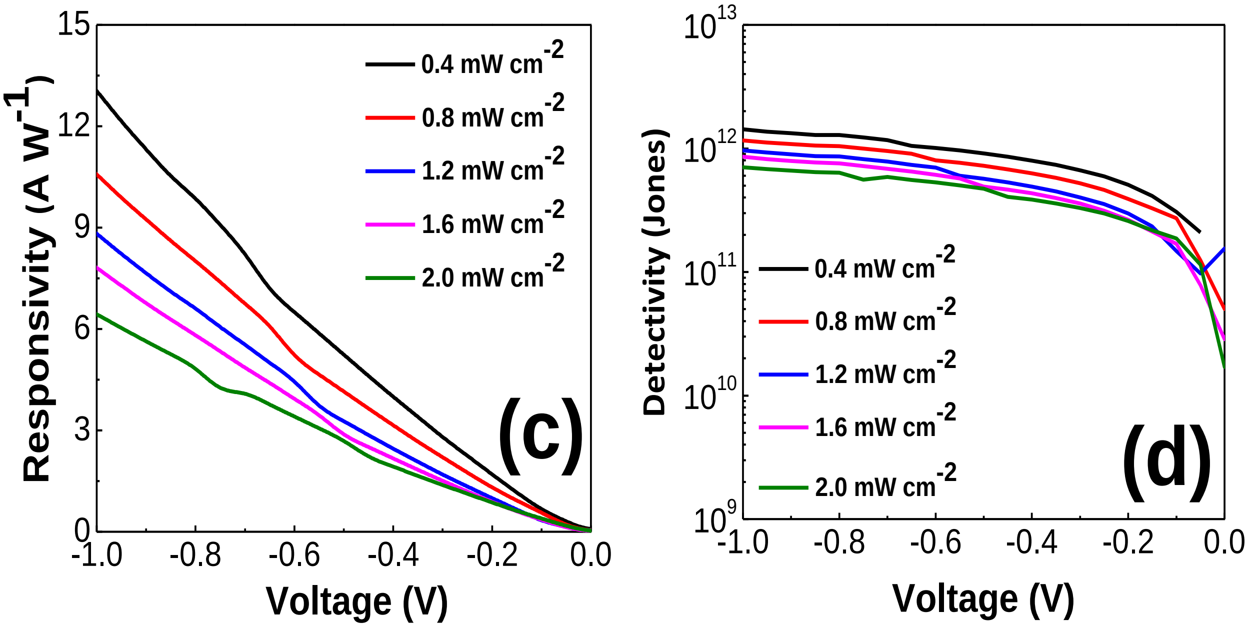


Figure S3 (a) Output characteristics (I_{SD}-V_{SD}) of the conventional VFEPT device (ITO/Ionic gel dielectric/AgNWs/PbSe QDs/AgNWs) in the dark condition at different V_{GS} voltages. (b) Output characteristics of the device at a fixed V_{GS} of 1 V in the dark and under light irradiance of 1064 nm laser. (c) The responsivity and (b) the detectivity of the conventional device as a function of V_{SD} at a fixed V_{GS} of 1 V.

Table S1 Comparison of performance of the as-designed VFEPT device with the reference devices (Figures S2 and S3) under ~1 µm wavelength irradiation.

Device structure	Photo-to-dark current ratio	Responsivity (A W^{-1}) @ V_{bias}	Detectivity (Jones)
Two-terminal device	~ 10^2	9 @ V_{bias} = -1 V	2.4 × 10^{11} @ V = 1 V
Conventional VFEPT	~ 10^3	13.5 @ V_{sd} = -1 V & V_{gs} = 1 V	1.1 × 10^{12} @ V_{sd} = -1 V & V_{gs} = 1 V
As-designed VFEPT	~ 10^4	28 @ V_{sd} = -0.75 & V_{gs} = 1 V	1.3 × 10^{13} @ V_{sd} = 0.5 V & V_{gs} = 1 V

Table S2 Performance of PbX-based photodetectors under ~1 μm wavelength irradiation.

Device structure / Materials	**Responsivity ($A\ W^{-1}$) @ V_{bias}**	**Detectivity (Jones)**	**References**
Photoconductor / PbS QDs:PCBM	6.9 @ 15 V 1060 nm	3.3×10^{11}	1
Photoconductor / PbS QDs:PCBM	0.32 @ 15 V 1200 nm	2.5×10^{10}	2
Photoconductor / PbS QDs:C60 crystal	0.7 @ 15 V 1200 nm	2.5×10^{10}	3
Photodiode / PbS_xSe_{1-x}	25.8 @ -1.5 V 980 nm	1.3×10^{13}	4
Photodiode / ZnO:PbS QDs:TAPC	NA, 10 V 1200 nm	7×10^{13}	5
Phototransistor / PbSe QDs:P3HT	500 @ V_{sd} = -40 V & V_{gs} = -40 V 980 nm	5.02×10^{12}	6
Phototransistor / PbSe QDs:PVK	2.93 @ V_{sd} = 5 V & V_{gs} = -20 V 980 nm	1.24×10^{13}	7
Phototransistor / PbSe QDs:MoS_2	6×10^5 @ V_{sd} = ~10 V & V_{gs} = -100 V 400-1500 nm	NA	8
Phototransistor / PbSe QDs:P3HT	2×10^4 @ V_{sd} = -100 V & V_{gs} = -100 V 895 nm	NA	9
Phototransistor / PbSe QDs:WeS_2	7×10^5 @ V_{sd} = 1 V & V_{gs} = -60 V 970 nm	7×10^{13}	10

Phototransistor / PbSe QDs	28 @ V_{sd} = -0.75 & V_{gs} = 1 V 1064 nm	1.3 × 10^{13} @ V_{sd} = 0.5 V & V_{gs} = 1 V	This Work

References

(1) Osedach, T. P.; Zhao, N.; Geyer, S. M.; Chang, L. Y.; Wanger, D. D.; Arango, A. C.; Bawendi, M. C.; Bulovic, V., Interfacial recombination for fast operation of a planar organic/QD infrared photodetector. *Adv Mater* **2010,** *22* (46), 5250-5254.

(2) Szendrei, K.; Cordella, F.; Kovalenko, M. V.; Böberl, M.; Hesser, G.; Yarema, M.; Jarzab, D.; Mikhnenko, O. V.; Gocalinska, A.; Saba, M.; Quochi, F.; Mura, A.; Bongiovanni, G.; Blom, P. W. M.; Heiss, W.; Loi, M. A., Solution-Processable Near-IR Photodetectors Based on Electron Transfer from PbS Nanocrystals to Fullerene Derivatives. *Adv Mater* **2009,** *21* (6), 683-687.

(3) Saran, R.; Nordin, M. N.; Curry, R. J., Facile Fabrication of PbS Nanocrystal:C60Fullerite Broadband Photodetectors with High Detectivity. *Adv Funct Mater* **2013,** *23* (33), 4149-4155.

(4) Sulaman, M.; Yang, S.; Song, T.; Wang, H.; Wang, Y.; He, B.; Dong, M.; Tang, Y.; Song, Y.; Zou, B., High performance solution-processed infrared photodiode based on ternary PbSxSe1−x colloidal quantum dots. *Rsc Adv* **2016,** *6* (90), 87730-87737.

(5) Lee, J. W.; Kim, D. Y.; So, F., Unraveling the Gain Mechanism in High Performance Solution-Processed PbS Infrared PIN Photodiodes. *Adv Funct Mater* **2015,** *25* (8), 1233-1238.

(6) Wang, H.; Li, Z.; Fu, C.; Yang, D.; Zhang, L.; Yang, S.; Zou, B., Solution-Processed PbSe Colloidal Quantum Dot-Based Near-Infrared Photodetector. *IEEE Photonics Technology Letters* **2015,** *27* (6), 612-615.

(7) Sulaman, M.; Yang, S.; Bukhtiar, A.; Fu, C.; Song, T.; Wang, H.; Wang, Y.; Bo, H.; Tang, Y.; Zou, B., High performance solution-processed infrared photodetector based on PbSe quantum dots doped with low carrier mobility polymer poly(N-vinylcarbazole). *Rsc Adv* **2016,** *6* (50), 44514-44521.

(8) Kufer, D.; Nikitskiy, I.; Lasanta, T.; Navickaite, G.; Koppens, F. H.; Konstantatos, G., Hybrid 2D-0D MoS2 -PbS quantum dot photodetectors. *Adv Mater* **2015,** *27* (1), 176-180.

(9) Sun, Z.; Li, J.; Yan, F., Highly sensitive organic near-infrared phototransistors based on poly(3-hexylthiophene) and PbS quantum dots. *Journal of Materials Chemistry* **2012,** *22* (40), 21673.

(10) Hu, C.; Dong, D.; Yang, X.; Qiao, K.; Yang, D.; Deng, H.; Yuan, S.; Khan, J.; Lan, Y.; Song, H.; Tang, J., Synergistic Effect of Hybrid PbS Quantum Dots/2D-WSe2Toward High Performance and Broadband Phototransistors. *Adv Funct Mater* **2017,** *27* (2), 1603605.