Support Information

Step-like 10 nm Channel for High-performance PbS Colloidal Quantum Dots Near-infrared Photodetector

Xuanguang Su[1], Jianfu Han[1], Yiwei Liu[1], Kai Huang[1,2*], Juexian Cao[1*]

[1]Hunan Institute of Advanced Sensing and Information Technology, Xiangtan University, Hunan, 411105, P. R. China

[2]School of Physics and Optoelectronics, Xiangtan University, Hunan, 411105, P. R. China

1. PL characterization of quantum dots

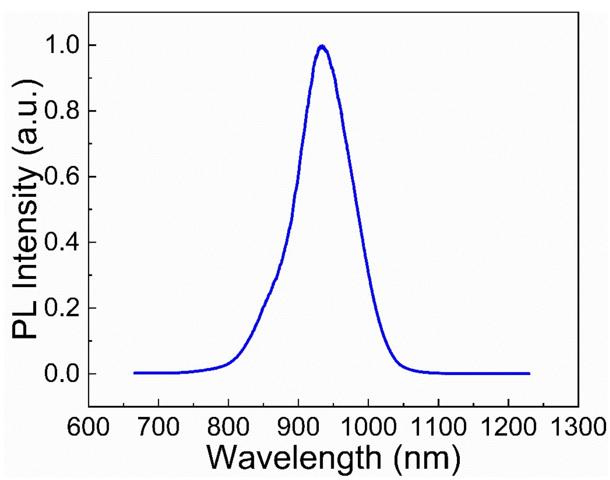


Figure S1. PL characterization of PbS CQDs.

* Corresponding author. E-mail address: huangk@xtu.edu.cn, jxcao@xtu.edu.cn.

2. Additional characterization of devices and quantum dots

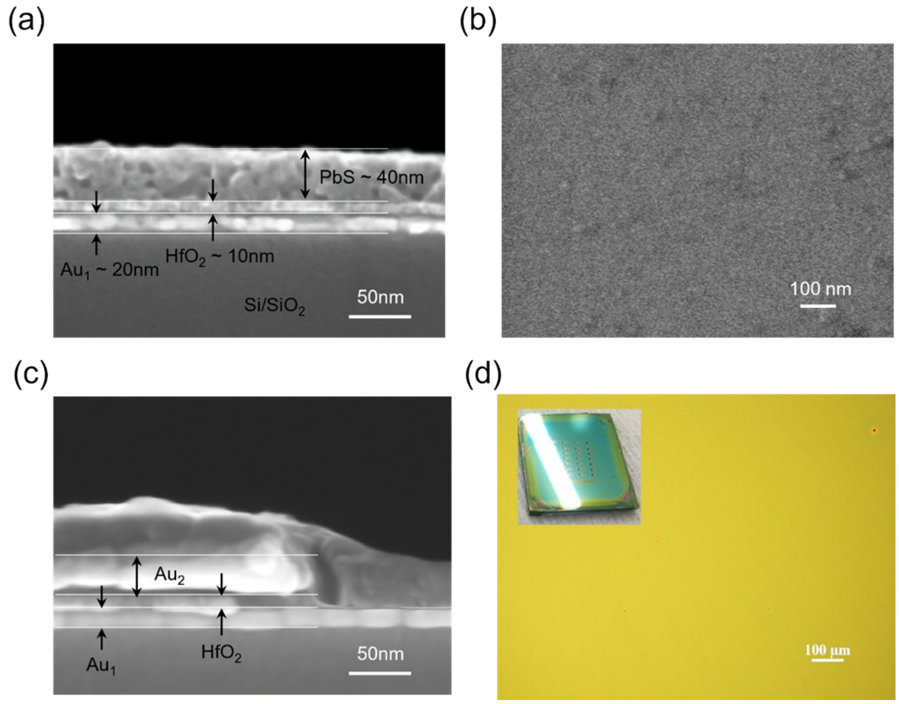
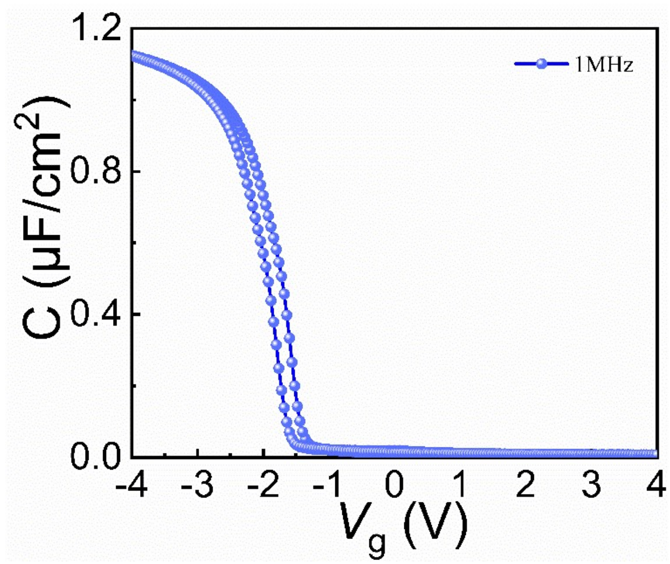


Figure S2. (a) Cross-section SEM image of $SiO_2/Au_1/HfO_2/PbS$. (b) SEM image of PbS CQDs surface. (c) The ultra-short stepped channel of the device in cross-sectional SEM view. (d) Optical image of the PbS CQDs spin-coated on the Si/SiO_2 substrate after solution phase ligand exchange. Inset: optical microscope image of a photodetector array coated with PbS CQD film.

3. Characterization of HfO_2 dielectric constant in devices

Regarding capacitor fabrication, a pure silicon wafer is used as a companion piece in the growth process of HfO_2 for the convenience of testing. And the dielectric constant can be calculated as $\varepsilon = \frac{C \times d}{\varepsilon_0 \times S}$, where *C* is the measured capacitance, *d* is the thickness of the sample (10 nm), ε_0 is the relative permittivity, *S* is the contact area. The dielectric constant



of the device is about ~18.2 F/m.

Figure S3. In addition, we have presented in the article the current levels of the Au/HfO_2/Au structure measured under various voltages for leakage current evaluation in Figure 4a. The results indicate that the HfO_2 exhibits good insulation performance, as the device remains almost non-conductive even under bias of 4 V.

4. Characterization of FET mobility of devices

In the devices presented in this article, the gain can be calculated as $\tau_{lifetime}/\tau_{transit}$, where $\tau_{lifetime}$ is carrier lifetime and $\tau_{transit}$ is the transit time related to the channel length, carrier mobility and applied voltage. The ultra-short channel reduces electron transit time, enabling photo-generated carriers to traverse the channel multiple times prior to recombination under an electric field. This leads to a significant enhancement of photoconductivity gain. And it can be calculated as

$$\tau_{transit} = \frac{L^2}{\mu \times V_{ds}} \tag{1}$$

where L is the channel length (10 nm here) and μ is the carrier mobility, and V_{ds} is the applied voltage. The ultra-short channel of the device described in this paper facilitates rapid carrier transit, resulting in a high photoconductance gain.

For the carrier mobility of the PbS quantum in this work, we tested it by means of FET devices. The FET mobility is determined using the slopes of the FET transfer characteristics (red lines in Figure), calculated as :

$$\mu = \frac{dI_{ds}}{dV_g}\frac{1}{V_{ds}}\frac{1}{C}\frac{L}{W} \tag{2}$$

where I_{ds} is the drain-source current, V_g is the gate potential, V_{ds} is the drain-source bias, C is the capacitance of the 300 nm SiO_2 gate dielectric, L is the channel length, and W is the channel width[1]. As can be seen from the figure, the hole mobility and electron mobility of quantum dots are both low, 0.0045 cm^2/Vs and 0.046 cm^2/Vs respectively, which is highly similar to the results of Tang group's research[2].

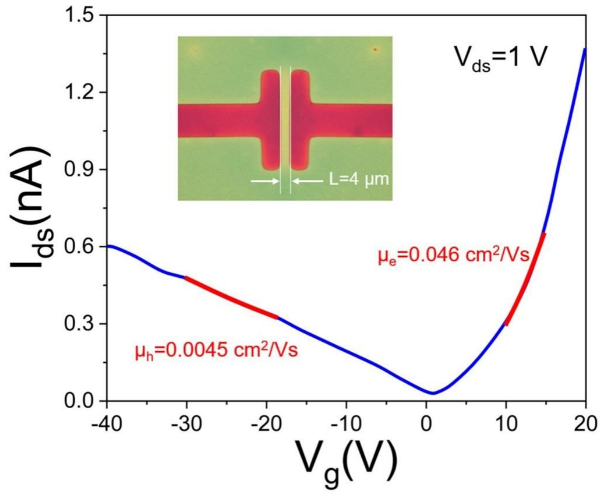


Figure S4. The transfer characteristic curve of PbS CQD film.

5. Characterization of device at other frequencies and stability

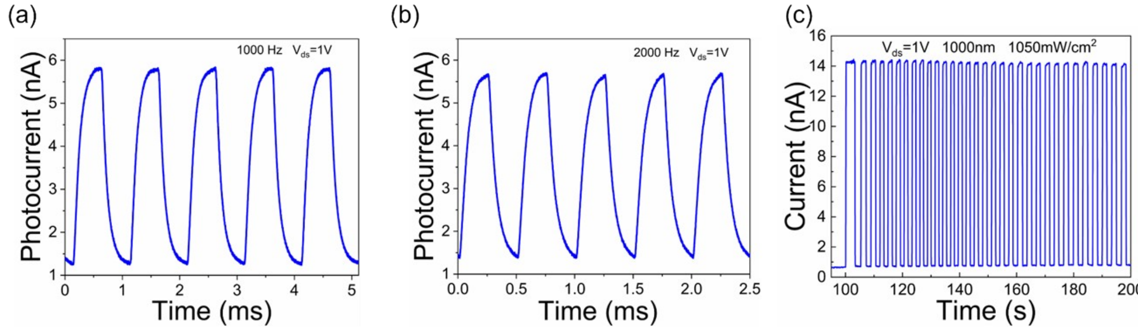


Figure S5. Photoresponse characteristics of the device to pulsed light irradiation at frequencies of (a) 1000 Hz, (b) 2000 Hz at V_{ds} = 1 V and 1000 nm illumination with power density of 1050mW/cm^2. (c) Periodic response stability of photodetectors.

References

[1] M. Chen, X. Lan, X. Tang, Y. Wang, M. H. Hudson, D. V. Talapin, P. Guyot-Sionnest, *ACS Photonics* **2019**, 6, 2358.
[2] J. Liu, P. Liu, D. Chen, T. Shi, X. Qu, L. Chen, T. Wu, J. Ke, K. Xiong, M. Li, H. Song, W. Wei, J. Cao, J. Zhang, L. Gao, J. Tang, *Nature Electronics* **2022**, 5, 443.