Electronic Supporting Information

High-performance vertical field-effect transistors based on all-inorganic perovskite microplatelets

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1. Experimental details

1.1 Synthesis of $CsPbBr_3$, MoS_2 and Graphene:

All the reagents were purchased from Aladdin without further purification. $CsPbBr_3$ microplatelets were synthesized in a single-zone tube furnace with a 1-inch quartz tube. The substrate was placed inside the downstream of the quartz tube. To prepare the precursors, the $PbBr_2$ powder and CsBr powder with a molar ratio of 1:1 are mixed in a ceramic boat placed in the center of the furnace. The whole system was kept at the pressure of 10 Pa with a continuous 35 sccm flow of high purity Ar (99.99%). The furnace temperature was raised up to 575 °C at a ramping rate of 25 °C/min. After the temperature was held for 15 min, the furnace was then naturally cooled to room temperature.

To synthesize MoS_2, the CVD method was performed in a two-temperature-zone tube furnace with a 2-inch quartz tube. The substrates were placed inside the downstream of the quartz tube. MoO_3 powder (30 mg) was placed in a ceramic boat and inserted the heating zone near the substrate, and pure Sulfur powder (1 g) was placed in another ceramic boat at the upper stream side maintained at 130 °C. Afterward, a mixed gas of Ar and H_2 (volume ratio of Ar and H_2 was 95:5) was passing through the tube at a low pressure of 50 Pa. The reaction temperature was increased from room temperature to 785 °C and then held for 15 minutes.

As for graphene, a single-zone tube furnace with a 2-inch quartz tube was used. The copper foil was first placed in a dilute hydrochloric acid solution and was then sonicated for 15 minutes with an ultrasonic cleaner to remove the surface oxide layer. Afterward, it was placed in the center of the furnace. A mixed gas of CH_4 and H_2 (volume ratio of CH_4 and H_2 was 2:1) was passing through the tube and the whole system was kept at the pressure of 100 Pa. The reaction temperature was increased from room temperature to 800 °C and then held for 1 h.

1.2 Fabrication of $CsPbBr_3$ VFETs

Firstly, the graphene was transferred from Cu foils to Si/SiO_2 substrates by a well-developed wet transfer method[1]. The $CsPbBr_3$ microplatelets were grown on the graphene substrate by CVD above-mentioned. Then utilizing a height difference between the $CsPbBr_3$ single-crystal and the substrate, 100 nm Au electrons were prepared by direct vacuum evaporation to achieve the vertical structure of the transistors.

1.3 Fabrication of Inverters

Firstly, the graphene, MoS_2 and graphene were transferred to SiO_2/Si substrates by a dry transfer method[1], respectively. Then $CsPbBr_3$ single-crystals were prepared with the graphene/MoS_2/graphene/SiO_2/Si substrate by van der Waals epitaxy in the single-zone tube furnace. Afterward, the Au (100 nm) electrodes were evaporated to obtain the inverters.

1.4 Characteristics of $CsPbBr_3$ Microplatelets

Optical images were captured by Olympus BX51. SEM and AFM images were taken by FEI Quanta 250FEG and a Bruker Multimode 8 AFM system, respectively. The optical spectra were characterized by PL spectroscopy (HORIBA, HRi 320, 442 nm laser wavelength), and UV−VIS (Shimadzu, UV3600). XRD patterns were recorded using a Bruker D8 multipurpose system.

1.5 Device Measurement

The electrical properties of the samples were measured by a Keysight B1500A Semiconductor Device Analyzer at room temperature under ambient conditions.

2. Supplemental Figures

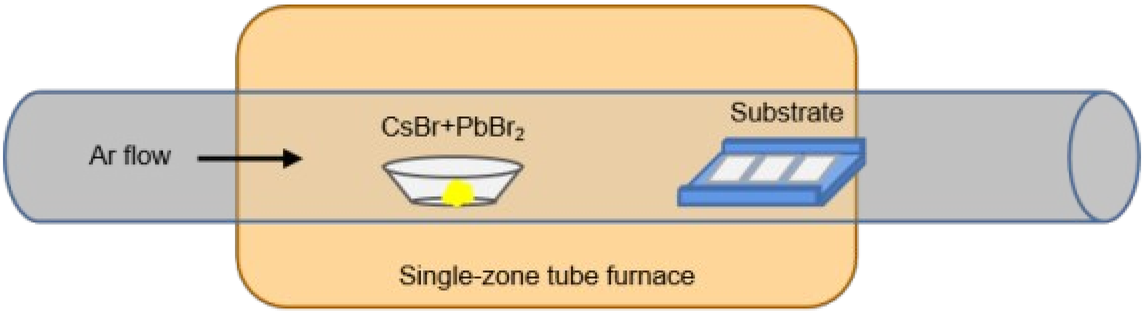

Figure S1. Schematic diagram of preparation of $CsPbBr_3$ microplatelets.

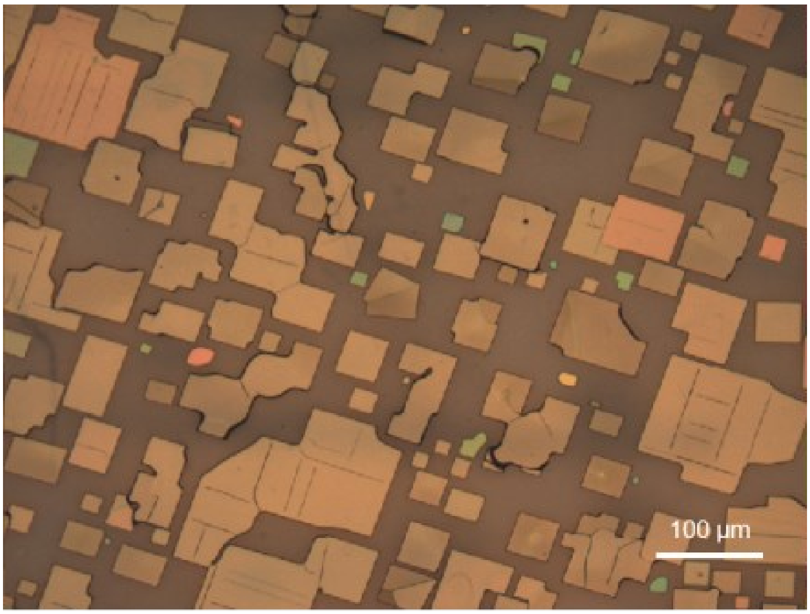

Figure S2. OM image of the $CsPbBr_3$ microplatelets grown by CVD.

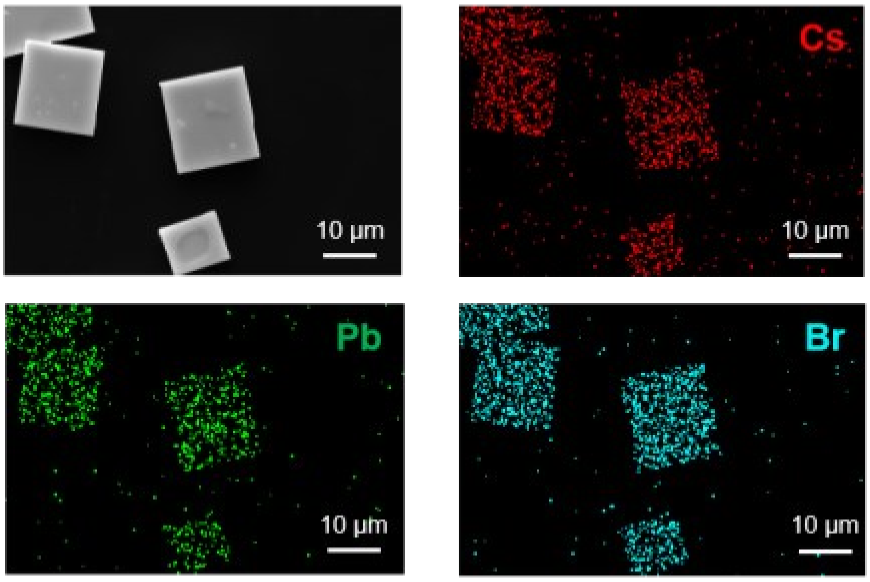

Figure S3. SEM-EDS mapping of $CsPbBr_3$ single-crystals.

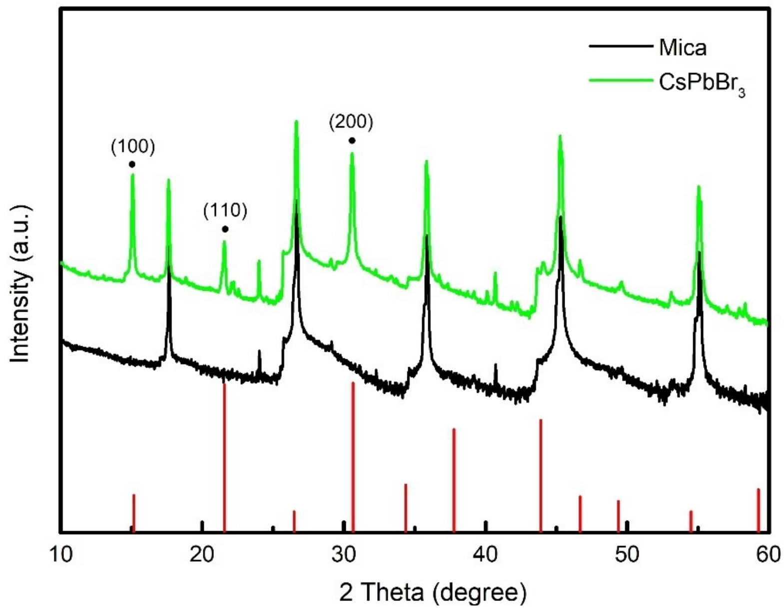

Figure S4. XRD spectra of $CsPbBr_3$ microplatelets (green line) on the Mica and Mica(black line). Red line represents the PDF standard card of $CsPbBr_3$ cubic phase.

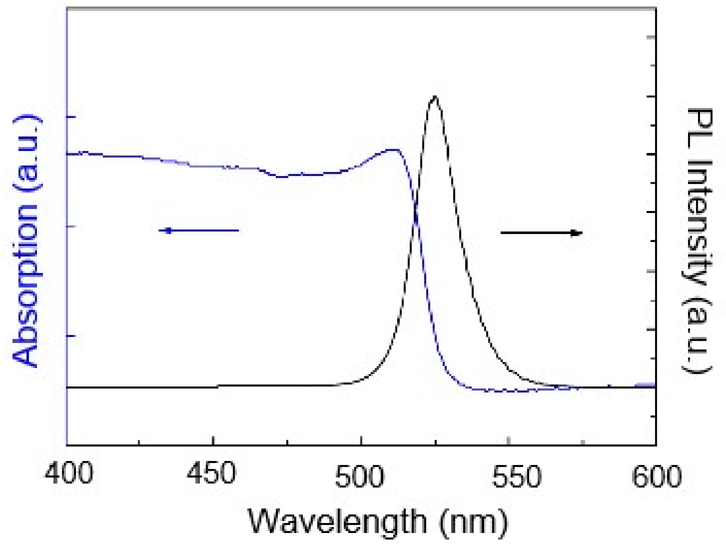

Figure S5. Absorption and photoluminescence spectra of the $CsPbBr_3$ single-crystal.

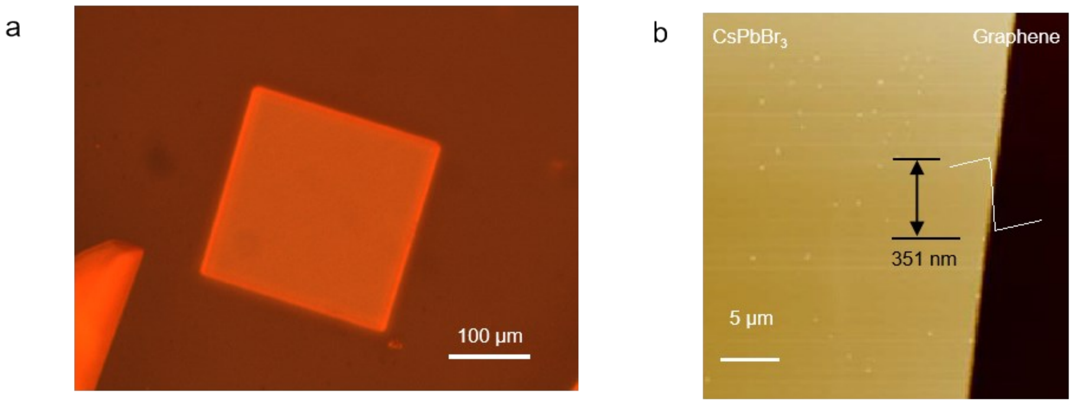

Figure S6. (a) OM image of the $CsPbBr_3$ microplatelet after evaporation. The lateral size of the single-crystal is above 200 μm. (b) AFM image of the $CsPbBr_3$ microplatelet. The thickness of the $CsPbBr_3$ microplatelet is about 351 nm.

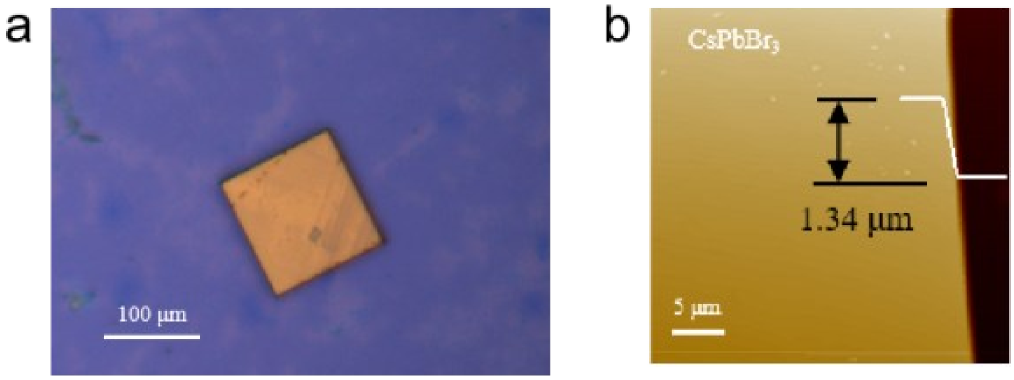

Figure S7. a) OM image of the $CsPbBr_3$ microplatelet on Graphene substrate. b) AFM image of the $CsPbBr_3$ microplatelet. The thickness of the $CsPbBr_3$ microplatelet is about 1.34 µm.

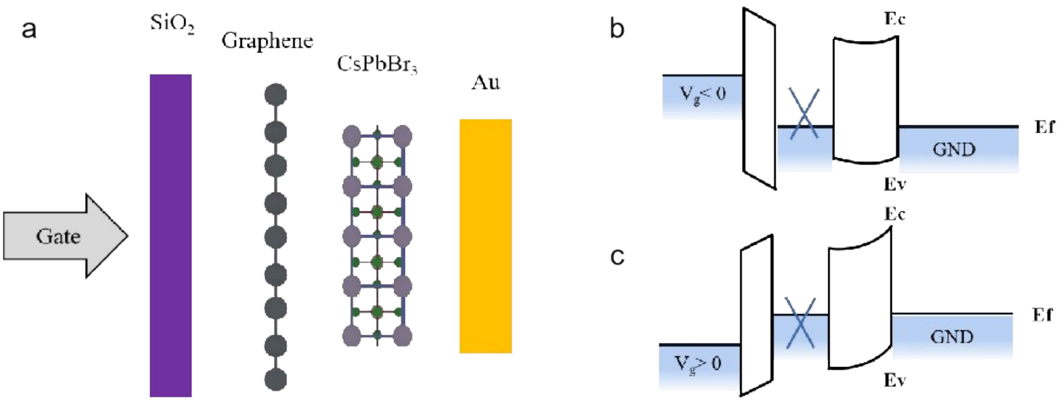

Figure S8. (a) Schematic structure of the $CsPbBr_3$-based VFET. Gate electric field is applied from silicon back gate. (b) The band structure under negative gate voltage (b, $V_g < 0$) and positive gate voltage (c, $V_g > 0$) at zero source-drain bias with the top Au electrode connected to ground.

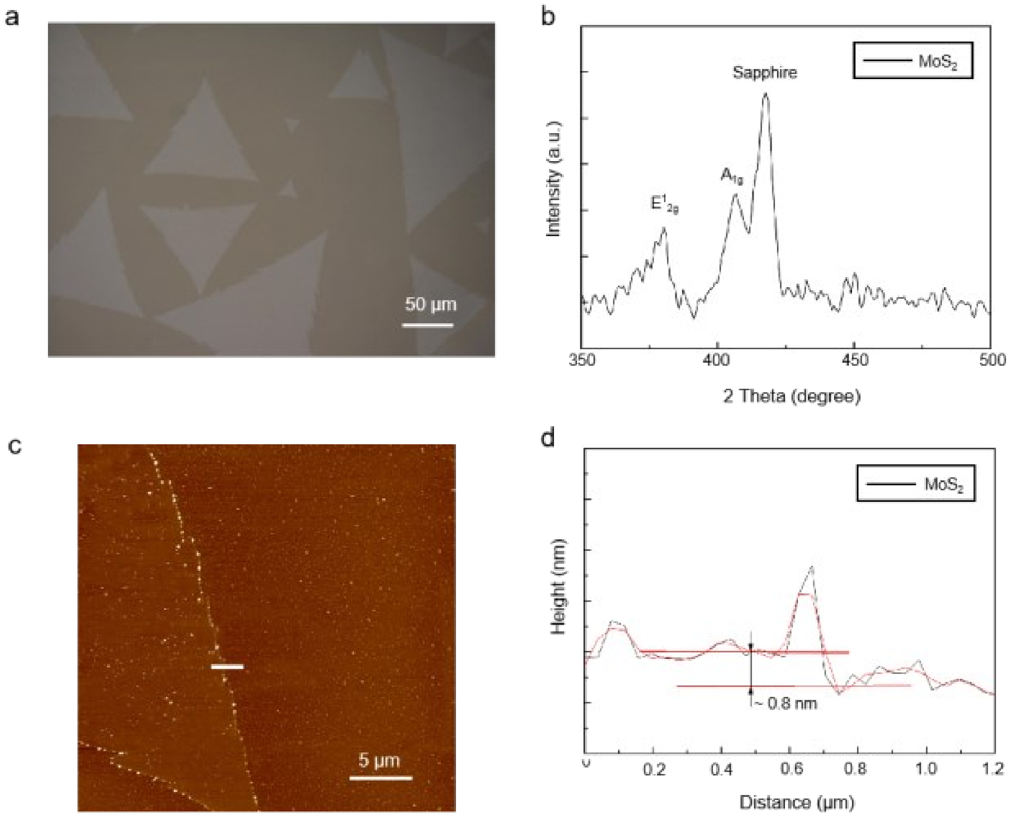

Figure S9. (a) OM image of the MoS_2 simples prepared by CVD. (b) Raman spectrum of the MoS_2 shown in (a). (c) AFM image of the MoS_2 simple. (d) AFM height profile of the MoS_2 simple shown in (c).

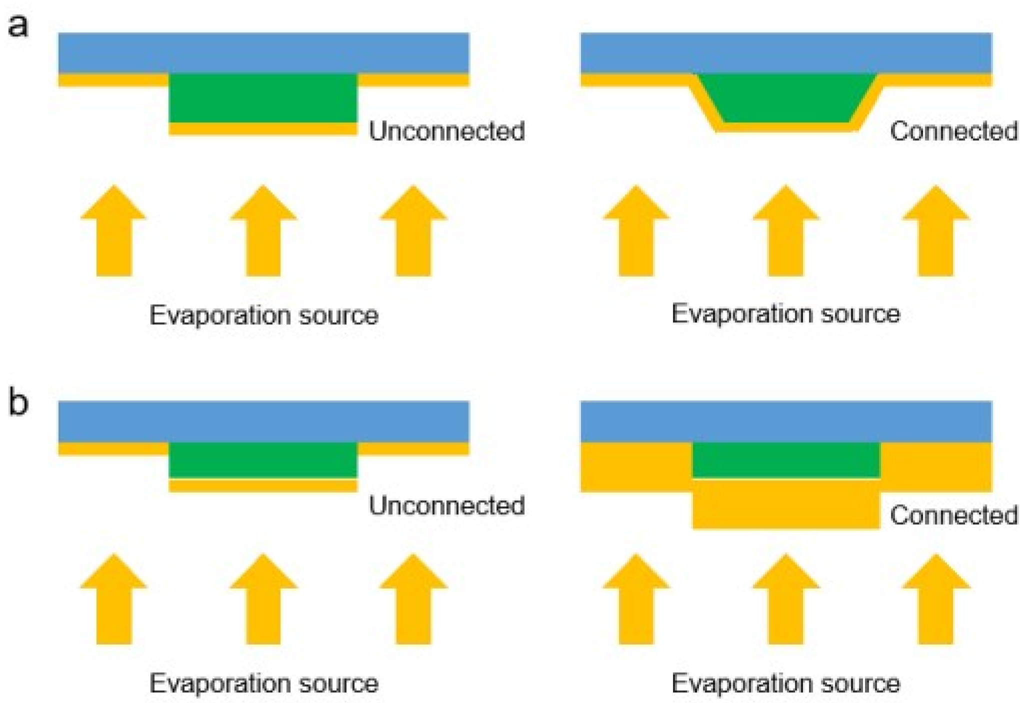

Figure S10. Schematic diagram of the metal deposition process. (a) The schematic diagram of vapor deposition when the quality of the $CsPbBr_3$ single-crystal is poor, (b) when the deposited metal is too thick.

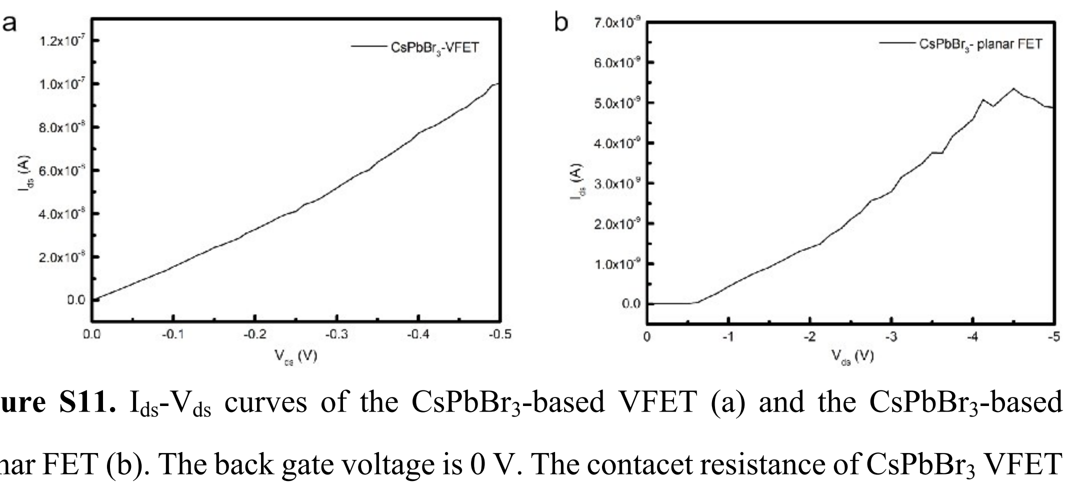

Figure S11. I_{ds}-V_{ds} curves of the $CsPbBr_3$-based VFET (a) and the $CsPbBr_3$-based planar FET (b). The back gate voltage is 0 V. The contacet resistance of $CsPbBr_3$ VFET and planar FET is about 1.2×10^{17} and 4×10^{17} Ω/m^2.

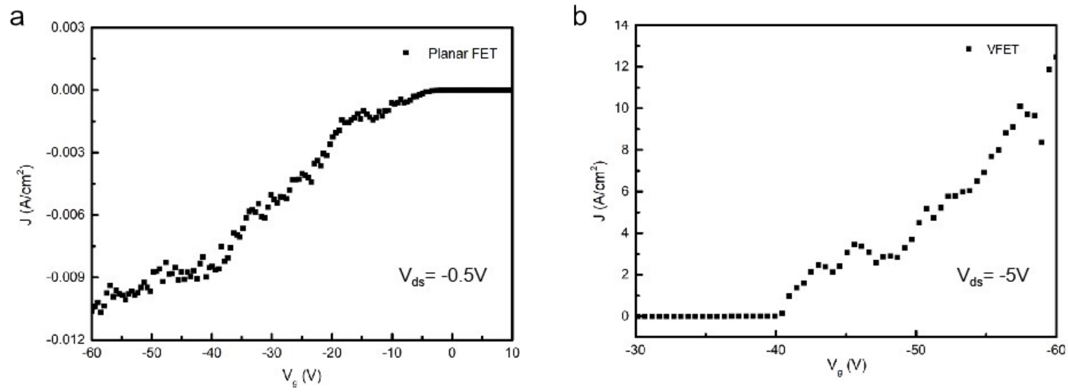

Figure S12. Current density - Gate voltage (J-V_g) transfer curves of the $CsPbBr_3$-based VFET (a) and the $CsPbBr_3$-based planar FET (b).

Table S1. Key parameters comparing different channel materials based VFET.

Materials	Thickness (nm)	on/off ratio	Current density	Reference
n-IGZO/p-Ge	10-20	10^6	1.72 uA/um^2	Ref.2
IGZO	<100	10^5	6 uA/um^2	Ref.3
P3HT	<200	>10^3	3.4 A/cm^2	Ref.4
p-Si	~ 1	10^2	20 A/cm^2	Ref.5
bis(l,2,5-thiadiazolo)-p-quinobis(l,3-dithiole) (BTQBT)	100	10^5	1 A/cm^2	Ref.6
InAs	~45	11	45000 A/cm^2	Ref.7
$CsPbBr_3$ NCs	160	-	0.25 A/cm^2	Ref.8
MoS_2	36	10^3	5000 A/cm^2	Ref.9
$CsPbBr_3$ microplatelts	350	10^6	12.3 A/cm^2	Our work

Table S2. Key parameters comparing planar FET and VFET.

Type	Channel length	on/off ratio	Current density
Planar FET	20 µm	5000	0.01 A/cm^2
VFET	350 nm	10^6	12.3 A/cm^2

Reference

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