

SUPPORTING INFORMATION

Photovoltaic Effect in Individual Asymmetrically Contacted Lead Sulfide Nanosheets

Sedat Dogan, Thomas Bielewicz, Vera Lebedeva, Christian Klinke*

Institute of Physical Chemistry, University of Hamburg,

Grindelallee 117, 20146 Hamburg, Germany

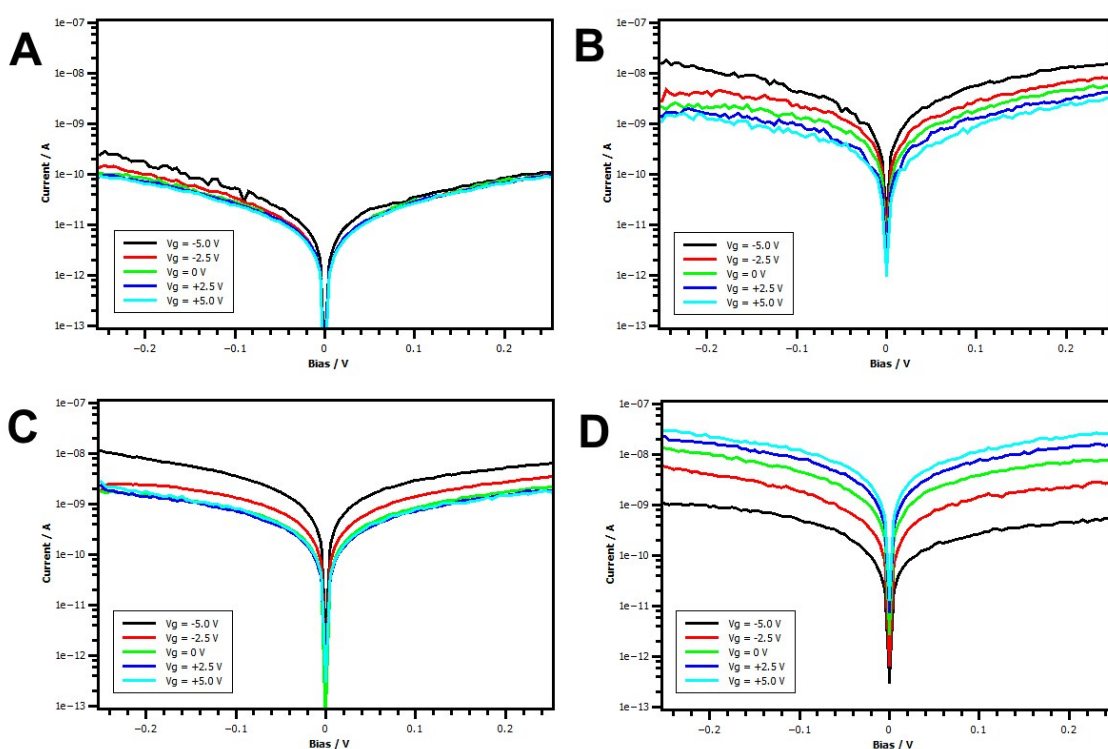


Figure S1: Output characteristics (log scale) of PbS nanosheets contacted with (A) titanium, (B) gold, (C) palladium, and (D) platinum.

Transport

The carrier mobility of the PbS nanosheets displayed in the following tables were obtained from the linear regime of the Transfer characteristics using the following formula:

$$\mu = \frac{dI_{DS}}{dV_g} \cdot \frac{L^2}{V_{DS}C} = \frac{dI_{DS}}{dV_g} \cdot \frac{L^2}{V_{DS}\epsilon_o\epsilon_r LW/d} = \frac{dI_{DS}}{dV_g} \cdot \frac{d}{V_{DS}\epsilon_o\epsilon_r} \cdot \frac{L}{W}$$

and to determine the conductivity we used following formula:

$$\sigma = \frac{I L}{V h W}_{DS DS}$$

Data of the symmetrically contacted 5.4 nm nanosheets (transistors)

Devices contacted with titanium	Type	On/Off ratio	Mobility [cm ² /Vs]	Conductivity [S/m]
1	p	1.23	0.072	0.01165
2	p	2.35	0.085	0.000945
3	p	1.60	0.046	0.00169
4	p	3.99	0.29	0.00765
5	p	12.37	1.3	0.0082
6	p	1.23	1.05	0.07433
7	p	1.23	0.00047	0.0000163
8	p	3.92	0.158	0.0029
9	p	1.37	0.00083	0.00015
Average		3.26	0.33	0.01196

Devices contacted with gold	Type	On/Off ratio	Mobility [cm ² /Vs]	Conductivity [S/m]
1	p	12.05	22.46	0.102
2	p	14.06	23.55	0.17
3	p	16.87	19.56	0.101
4	p	6.51	3.79	0.056
5	p	10.39	3.60	0.05
6	p	12.05	2.89	0.01
7	p	24.68	15.43	0.062
8	p	16.34	2.28	0.033
9	p	10.39	4.89	0.030
10	p	23.35	2.09	-
11	p	12.63	4.68	0.034
12	p	9.73	0.57	0.083

13	p	7.59	7.93	0.079
14	p	9.93	3.15	-
Average		13.33	8.35	0.07

Devices contacted with palladium	Type	On/Off ratio	Mobility [cm ² /Vs]	Conductivity [S/m]
1	p	13.73	31.80	0.10
2	p	9.51	4.43	0.15
3	p	12.70	13.38	0.10
4	p	11.62	3.83	0.06
5	p	13.50	3.80	0.03
6	p	12.59	1.99	0.05
7	p	5.43	8.98	0.10
8	p	2.26	0.07	0.0035
9	p	3.74	3.15	0.04
10	p	25.08	10.22	0.07
11	p	24.88	2.60	0.03
12	p	5.19	3.56	0.04
13	p	2.64	19.41	0.13
14	p	3.48	4.36	0.07
15	p	4.25	8.14	0.06
16	p	13.17	6.65	0.05
17	p	2.53	4.84	0.05
Average		9.78	7.72	0.07

Devices contacted with platinum	Type	On/Off ratio	Mobility [cm ² /Vs]	Conductivity [S/m]
1	p	2.01	0.10	0.01
2	n	3.41	0.08	0.02

3	n	42.15	2.74	0.40
4	n	6.68	11.93	0.05
5	n	22.70	20.56	0.70
6	p	3.04	0.006	0.0002
7	n	14.99	0.35	0.02
8	n	4.28	2.49	0.58
9	n	14.99	0.35	0.01
10	n	4.28	3.286	0.46
11	n	14.99	0.344	0.02
12	n	104.90	3.286	0.13
13	p	18.60	0.276	0.02
14	p	330.31	17.50	0.13
15	p	2.78	1.91	0.04
16	p	1.22	0.15	0.0005
17	p	1.54	0.27	0.0041
18	p	3.06	0.66	0.0068
19	p	1.65	0.18	0.0019
20	n	2.01	0.35	0.0023
21	n	2.18	0.34	0.0025
22	p	1.38	0.127	0.0042
23	n	1.39	0.15	0.006
24	n	3.13	0.3	0.0016
25	n	7.11	0.011	0.003
26	n	18.47	0.034	0.0058
27	n	18.28	0.0078	0.023
Average		25.29	2.57	0.099

Data of the asymmetrically contacted 5.4 nm nanosheets

Devices contacted with palladium and titanium	I_{sc} [A]	V_{oc} [V]	FF [%]	Power efficiency [%]	External quantum efficiency [%]
1	1.71E-10	0.022	30.4	0.024	7.58
2	1.22E-10	0.0065	9.64	0.0061	20.36
3	1.13E-10	0.006	22.49	0.0070	10.76
4	4.52E-11	0.0045	21.03	0.0015	3.38
5	1.13E-10	0.0025	12.69	0.0018	12.19
6	7.46E-11	0.007	23.83	0.0058	7.27
7	7.59E-11	0.0042	23.55	0.0023	4.91
8	9.69E-11	0.02	31.09	0.014	4.86
9	1.24E-10	0.038	28.45	0.055	10.62
10	2.27E-10	0.021	25.62	0.035	13.70
11	4.04E-10	0.075	2.3	0.006	7.39
12	1.39E-10	0.012	35.42	0.021	10.43
13	1.75E-10	0.014	23.53	0.022	13.92
14	5.74E-11	0.022	30.32	0.03	9.40
15	4.38E-10	0.06	28.43	0.307	37.22
Average	1.34E-10	0.021	23.26	0.04	11.60

Devices contacted with platinum and titanium	I_{sc} [A]	V_{oc} [V]	FF [%]	Power efficiency [%]	External quantum efficiency [%]
1	8.44E-11	0.05	32.3	0.17	22
2	9.84E-11	0.059	32.5	0.15	16.37
3	8.79E-11	0.1075	44.5	0.27	11.75
4	7.13E-11	0.026	27.8	0.02	6.53
5	1.53E-10	0.085	39.6	0.23	13.83

6	5.75E-11	0.064	38.4	0.10	7.96
7	1.50E-10	0.077	39.4	0.25	16.94
8	3.47E-11	0.037	30.1	0.06	11.54
9	8.50E-11	0.088	26.05	0.12	10.41
10	2.51E-11	0.034	27.66	0.10	21.03
11	3.45E-11	0.031	6.52	0.01	6.32
12	2.72E-11	0.041	29.17	0.18	30.67
13	2.70E-10	0.06	34.77	0.23	22.44
14	1.78E-10	0.038	5.66	0.01	11.51
15	1.16E-10	0.0445	30.45	0.05	8.01
16	1.45E-10	0.078	36.44	0.31	22.67
17	3.45E-11	0.072	39.31	0.07	5.41
18	2.92E-10	0.0525	31.58	0.21	25.84
19	2.02E-10	0.0815	31.32	0.94	75.70
20	2.28E-10	0.0585	30.67	0.33	37.77
21	1.62E-10	0.081	37.16	0.39	26.78
22	1.16E-10	0.0445	30.45	0.05	7.57
23	2.45E-11	0.094	41.21	0.26	14.08
24	1.34E-10	0.071	34.98	0.45	37.12
25	1.53E-10	0.076	35.91	0.35	26.46
26	1.34E-10	0.071	9.99	0.08	23.20
27	7.35E-11	0.101	42.95	0.25	11.97
28	2.76E-10	0.066	32.49	0.19	18.08
29	3.22E-10	0.085	41.44	0.70	41.26
30	2.53E-10	0.07	30.87	0.34	32.35
31	2.24E-10	0.062	35.90	0.19	17.99
32	1.94E-10	0.09	41.85	0.41	22.36
Average	1.53E-10	0.0655	32.18	0.23	20.75

Data of the asymmetrically contacted 2.4 nm nanosheets

Devices contacted with palladium and titanium	I_{sc} [A]	V_{oc} [V]	FF [%]	Power efficiency [%]	External quantum efficiency [%]
1	7.71E-12	0.132	35.41	0.05	2.01
2	4.25E-12	0.21	30.50	0.22	7.07
3	3.41E-12	0.164	31.31	0.11	4.56
4	4.89E-12	0.122	32.52	0.01	0.45
5	5.05E-12	0.176	30.79	0.12	4.57
6	5.53E-12	0.174	26.95	0.17	7.66
7	4.33E-12	0.166	28.07	0.11	4.87
8	1.36E-10	0.202	5.68	0.25	45.11
9	4.30E-11	0.188	30.28	0.15	5.27
10	1.22E-12	0.14	30.58	0.002	0.1
11	9.24E-12	0.12	31.84	0.03	1.69
12	2.72E-10	0.041	29.17	0.18	30.67
13	2.70E-10	0.06	34.77	0.23	22.44
14	1.78E-10	0.038	5.66	0.01	11.51
15	1.16E-10	0.0445	30.45	0.05	8.01
16	1.45E-10	0.078	36.44	0.31	22.67
17	3.45E-11	0.072	39.31	0.07	5.41
18	2.92E-10	0.0525	31.58	0.21	25.84
19	8.60E-12	0.154	32.31	0.08	3.22
20	4.95E-11	0.154	28.1	0.17	8.19
21	5.85E-11	0.146	29.85	0.20	9.65
22	4.35E-11	0.174	30.81	0.07	2.84
23	4.02E-11	0.182	27.41	0.56	23.04
24	5.25E-11	0.166	23.42	0.27	14.54
25	6.30E-11	0.168	32.56	0.29	10.91
26	1.27E-11	0.172	29.13	0.05	2.20

27	2.39E-11	0.144	25.63	0.07	3.90
28	2.39E-11	0.118	26.02	0.02	1.57
29	2.78E-11	0.186	28.88	0.09	3.57
Average	7.37E-11	0.136	28.81	0.14	10.12

Devices contacted with platinum and titanium	I _{sc} [A]	V _{oc} [V]	FF [%]	Power efficiency [%]	External quantum efficiency [%]
1	3.95E-11	0.16	28.81	0.22	10.29
2	1.29E-11	0.21	28.95	0.06	2.15
3	8.82E-12	0.16	39.73	0.04	1.18
4	1.78E-11	0.13	26.04	0.03	1.63
5	5.50E-12	0.14	23.41	0.01	0.50
6	1.76E-11	0.18	24.19	0.05	2.43
7	2.64E-11	0.22	27.98	0.09	2.97
8	7.88E-12	0.25	30.73	0.10	2.62
9	6.01E-11	0.21	33.21	0.25	7.36
10	5.45E-12	0.18	35.02	0.01	0.46
11	1.66E-12	0.19	40.55	0.01	0.3
12	1.59E-11	0.26	26.65	0.17	5.29
Average	1.83E-11	0.19	30.44	0.09	3.10

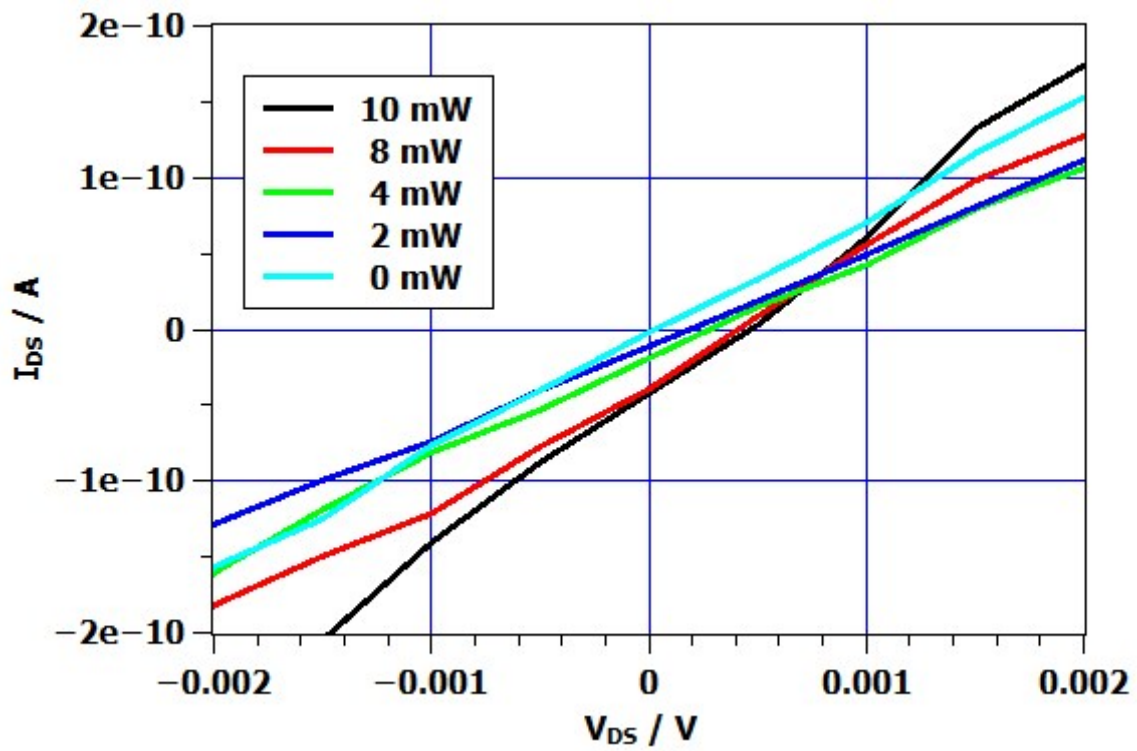


Figure S2: *I-V* characteristics performed in the dark and under illumination for various intensities for 11.4 nm thick PbS nanosheet contacted with palladium and titanium ($V_g = 0$ V).