

Supporting Information for: Symmetric transport in sub-5-nm monolayer Sn₂S₂-based homogeneous CMOS devices

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(Dated: 15 January 2026)

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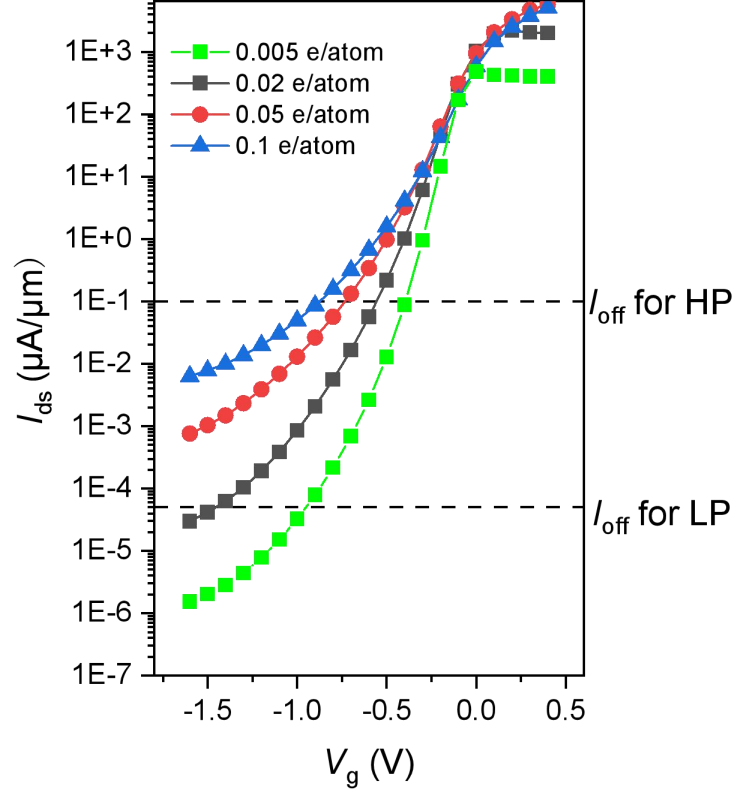


FIG. S1: Source/drain doping concentration test for n-type Sn_2S_2 -a MOSFETs with $L_g = 5$ nm.

TABLE S1: The doping concentration test for ML Sn_2S_2 MOSFETs.

	L_g (nm)	Type	Doping(e/atom)	Doping(e/cm ²)	$I_{\text{on}}(\mu\text{A}/\mu\text{m})$	SS(mV/dec)	$I_{\text{off}}(\mu\text{A}/\mu\text{m})$	$I_{\text{on}}/I_{\text{off}}$
Sn_2S_2	5	n	0.005	1.8×10^{13}	412	84	0.1	4120
			0.02	7.2×10^{13}	1653	111	0.1	16530
			0.05	1.8×10^{14}	302	143	0.1	3020
			0.1	3.6×10^{14}	30	182	0.1	300

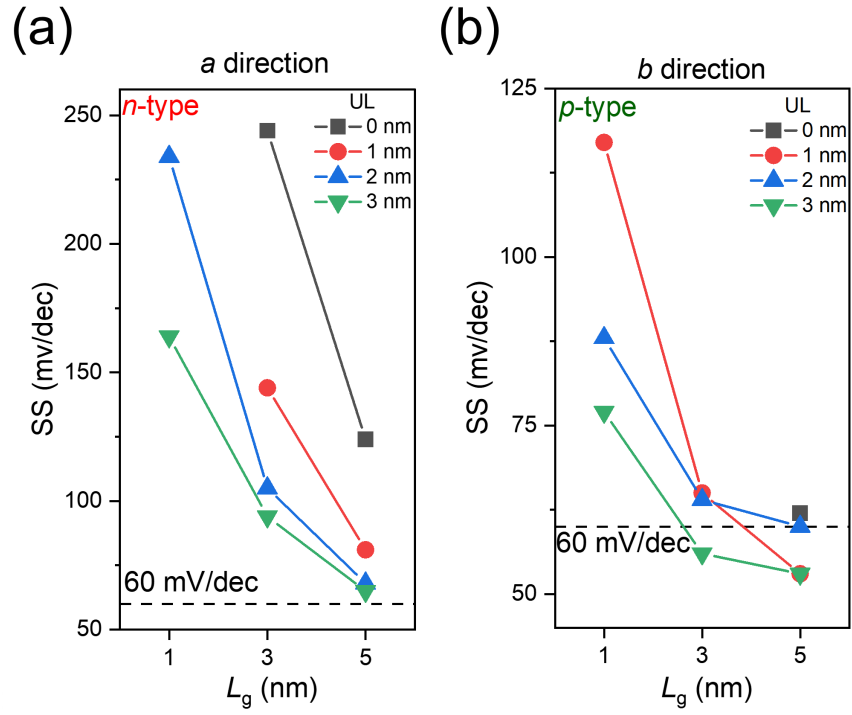


FIG. S2: SS varying with L_g for (a) *n*-type Sn_2S_2 -a and (b) *p*-type Sn_2S_2 -b MOSFETs, respectively.

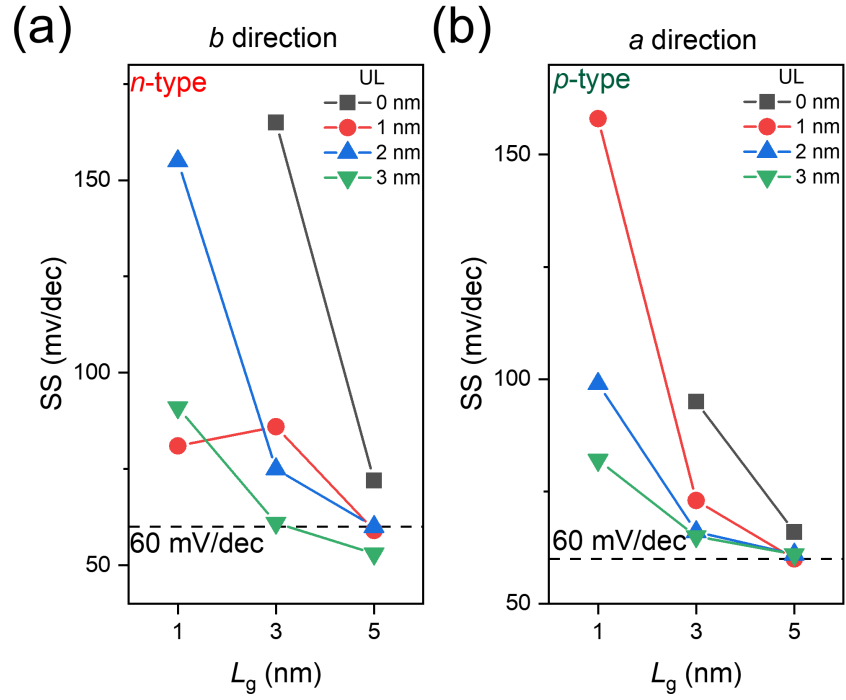


FIG. S3: SS varying with L_g for (a) *n*-type Sn_2S_2 -b and (b) *p*-type Sn_2S_2 -a MOSFETs, respectively.

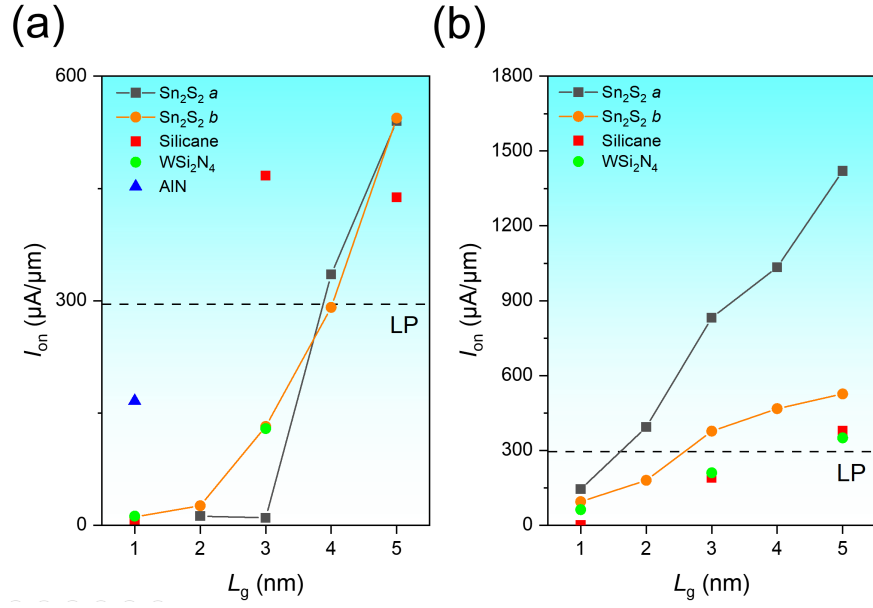


FIG. S4: I_{on} versus L_g for ML Sn_2S_2 MOSFETs compared with a series of ML MOSFETs for LP applications. (a) n -type and (b) p -type.

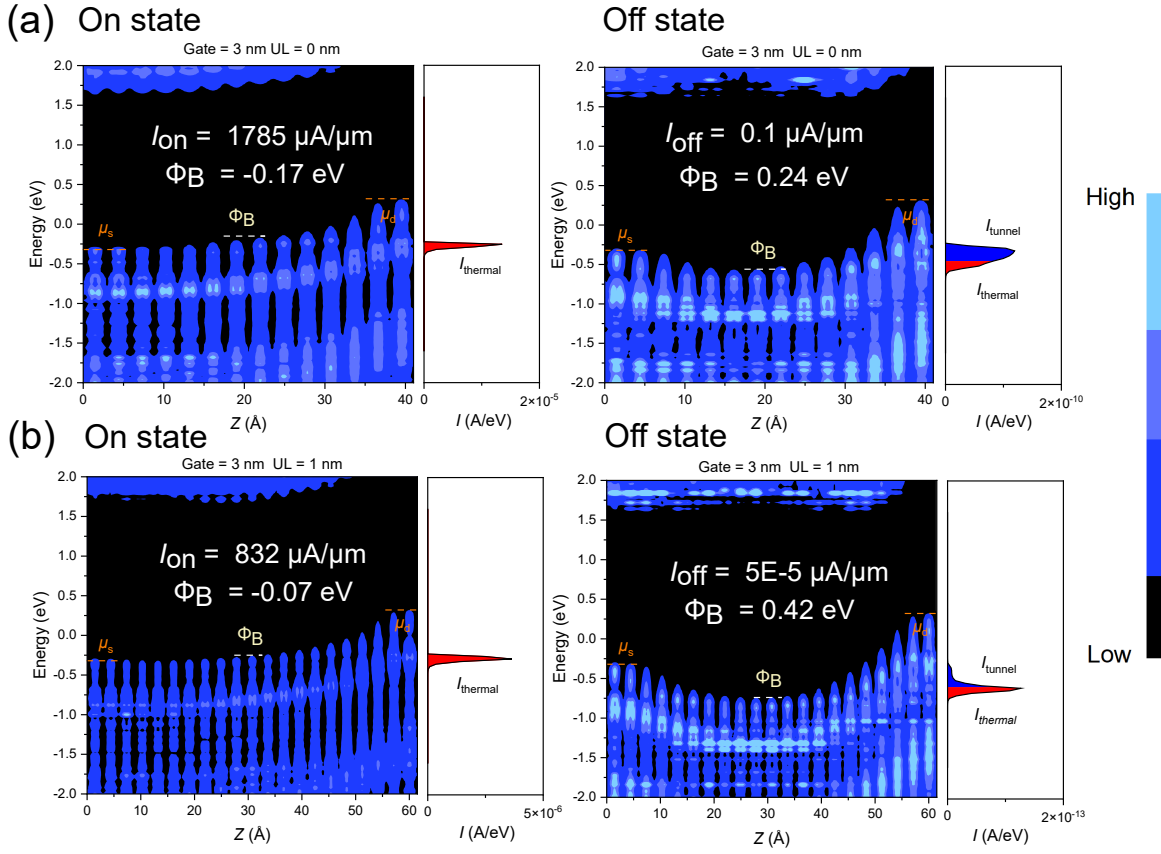


FIG. S5: Local device density of states for p-type ML Sn_2S_2 -a MOSFETs (a) in HP applications with $L_g = 3$ nm and $UL = 0$, and (b) in LP applications with $L_g = 3$ nm and $UL = 1$ nm, respectively.

TABLE S2: The FOMs of n - and p -type ML Sn_2S_2 - a MOSFETs with various L_g and ULs against the ITRS LP requirement for the year 2028.

	L_g	Type	UL (nm)	I_{on} ($\mu\text{A}/\mu\text{m}$)	SS (mV/dec)	I_{off} ($\mu\text{A}/\mu\text{m}$)	$I_{\text{on}}/I_{\text{off}}$	τ (ps)	PDP (fJ/ μm)	C_t (fF/ μm)	
Sn ₂ S ₂	5	n	0	0.005	111	5×10^{-5}	1.00×10^2	21713	0.069	0.170	
			1	0.937	81	5×10^{-5}	1.87×10^4	70.66	0.042	0.103	
			2	361	68	5×10^{-5}	7.22×10^6	0.190	0.044	0.107	
			3	540	65	5×10^{-5}	1.08×10^7	0.138	0.048	0.117	
		p	0	1420	66	5×10^{-5}	2.84×10^7	0.068	0.062	0.151	
			1	1216	60	5×10^{-5}	2.43×10^7	0.144	0.112	0.273	
			2	757	61	5×10^{-5}	1.51×10^7	0.131	0.063	0.155	
			3	429	61	5×10^{-5}	8.58×10^6	0.165	0.045	0.111	
		4	n	0	-	-	-	-	-	-	-
				1	-	-	-	-	-	-	-
				2	302	67	5×10^{-5}	6.04×10^6	0.118	0.023	0.056
				3	335	63	5×10^{-5}	6.70×10^6	0.091	0.019	0.048
			p	0	978	71	5×10^{-5}	1.96×10^7	0.106	0.066	0.162
				1	1034	64	5×10^{-5}	2.07×10^7	0.061	0.041	0.099
				2	708	62	5×10^{-5}	1.42×10^7	0.052	0.023	0.057
				3	437	63	5×10^{-5}	8.74×10^6	0.070	0.020	0.048
	3	n	0	-	-	-	-	-	-	-	
			1	-	-	-	-	-	-	-	
			2	0.01	105	5×10^{-5}	2.00×10^2	4035	0.026	0.063	
			3	9.8	94	5×10^{-5}	1.96×10^5	3.677	0.023	0.056	
			p	0	45	95	5×10^{-5}	9.00×10^5	2.604	0.075	0.183
				1	832	73	5×10^{-5}	1.66×10^7	0.137	0.073	0.178
				2	510	66	5×10^{-5}	1.02×10^7	0.132	0.043	0.105
				3	297	65	5×10^{-5}	5.94×10^6	0.178	0.034	0.083
		2	n	0	-	-	-	-	-	-	-
				1	-	-	-	-	-	-	-
				2	-	-	-	-	-	-	-
				3	12	81	5×10^{-5}	2.40×10^5	2.261	0.017	0.042
			p	-	-	-	-	-	-	-	-
				1	142	90	5×10^{-5}	2.84×10^6	0.404	0.037	0.089
				2	393	74	5×10^{-5}	7.86×10^6	0.089	0.022	0.054
				3	263	73	5×10^{-5}	5.26×10^6	0.106	0.018	0.044
	1	n	0	-	-	-	-	-	-	-	
			1	-	-	-	-	-	-	-	
			2	-	-	-	-	-	-	-	
			3	-	-	-	-	-	-	-	
		p	0	-	-	-	-	-	-	-	
			1	0.3	158	5×10^{-5}	6.00×10^3	157.9	0.030	0.074	
			2	40	99	5×10^{-5}	8.00×10^5	0.702	0.018	0.044	
			1	144	82	5×10^{-5}	2.88×10^6	0.213	0.020	0.048	
ITRS LP				295		5×10^{-5}	5.90×10^6	1.493	0.280	0.690	

TABLE S3: The FOMs of n - and p -type ML Sn_2S_2 - b MOSFETs with various L_g and ULs against the ITRS HP requirement for the year 2028.

	L_g	Type	UL (nm)	I_{on} ($\mu\text{A}/\mu\text{m}$)	SS (mV/dec)	I_{off} ($\mu\text{A}/\mu\text{m}$)	$I_{\text{on}}/I_{\text{off}}$	τ (ps)	PDP (fJ/ μm)	C_t (fF/ μm)	
Sn ₂ S ₂ <i>b</i>	5	<i>n</i>	0	1914	72	0.1	19140	0.151	0.187	0.457	
			1	1493	59	0.1	14930	0.128	0.122	0.298	
			2	725	60	0.1	7250	0.176	0.082	0.199	
			3	417	53	0.1	4170	0.197	0.053	0.128	
		<i>p</i>	0	529	62	0.1	5290	0.296	0.100	0.244	
			1	551	53	0.1	5510	0.162	0.057	0.139	
			2	469	60	0.1	4690	0.112	0.034	0.082	
			3	344	53	0.1	3440	0.098	0.022	0.053	
		4	<i>n</i>	0	671	143	0.1	6710	0.137	0.059	0.144
				1	1737	73	0.1	17370	0.025	0.028	0.069
				2	823	63	0.1	8230	0.028	0.015	0.036
				3	490	60	0.1	4900	0.037	0.012	0.029
		<i>p</i>	0	548	65	0.1	5480	0.183	0.064	0.157	
			1	556	57	0.1	5560	0.080	0.029	0.069	
			2	481	56	0.1	4810	0.050	0.015	0.038	
			3	343	60	0.1	3430	0.057	0.012	0.031	
	3	<i>n</i>	0	15	165	0.1	150	6.256	0.060	0.147	
			1	1189	86	0.1	11890	0.096	0.073	0.178	
			2	754	75	0.1	7450	0.110	0.053	0.129	
			3	350	61	0.1	3500	0.150	0.033	0.082	
		<i>p</i>	0	545	82	0.1	5450	0.241	0.084	0.206	
			1	554	65	0.1	5540	0.122	0.043	0.106	
			2	469	64	0.1	4690	0.093	0.028	0.068	
			3	340	56	0.1	3400	0.084	0.018	0.045	
		2	<i>n</i>	-	-	-	-	-	-	-	-
				1	68	117	0.1	680	0.562	0.024	0.059
				2	576	115	0.1	5760	0.038	0.014	0.034
				3	376	86	0.1	3760	0.044	0.011	0.026
			<i>p</i>	0	510	103	0.1	5100	0.160	0.052	0.128
				1	531	77	0.1	5310	0.080	0.027	0.067
				2	483	68	0.1	4830	0.047	0.015	0.036
				3	337	65	0.1	3370	0.052	0.011	0.028
	1	<i>n</i>	0	-	-	-	-	-	-	-	
			1	1.37	81	0.1	13.7	23.58	0.021	0.050	
			2	239	155	0.1	2390	0.084	0.013	0.031	
			3	274	91	0.1	2740	0.077	0.014	0.033	
		<i>p</i>	0	-	-	-	-	-	-	-	
			1	452	117	0.1	4520	0.097	0.028	0.068	
			2	410	88	0.1	4100	0.048	0.013	0.031	
			3	268	77	0.1	2680	0.065	0.011	0.027	
ITRS HP				900		0.1	9000	0.423	0.240	0.600	

TABLE S4: The FOMs of n - and p -type ML Sn_2S_2 - b MOSFETs with various L_g and ULs against the ITRS LP requirement for the year 2028.

	L_g	Type	UL (nm)	I_{on} ($\mu\text{A}/\mu\text{m}$)	SS (mV/dec)	I_{off} ($\mu\text{A}/\mu\text{m}$)	$I_{\text{on}}/I_{\text{off}}$	τ (ps)	PDP (fJ/ μm)	C_t (fF/ μm)		
Sn_2S_2 b	5	n	0	4.8	72	5×10^{-5}	9.60×10^4	20.19	0.062	0.151		
			1	544	59	5×10^{-5}	1.09×10^7	0.183	0.064	0.155		
			2	304	60	5×10^{-5}	6.08×10^6	0.200	0.039	0.095		
			3	202	53	5×10^{-5}	4.04×10^6	0.199	0.026	0.063		
		p	0	526	62	5×10^{-5}	1.05×10^7	0.307	0.103	0.253		
			1	437	53	5×10^{-5}	8.74×10^6	0.177	0.050	0.121		
			2	285	60	5×10^{-5}	5.70×10^6	0.164	0.030	0.073		
			3	161	53	5×10^{-5}	3.22×10^6	0.170	0.017	0.043		
	4	n	0	-	-	-	-	-	-	-		
			1	28	73	5×10^{-5}	5.60×10^2	1.436	0.026	0.063		
			2	291	63	5×10^{-5}	5.82×10^6	0.076	0.014	0.034		
			3	168	60	5×10^{-5}	3.36×10^6	0.104	0.011	0.027		
		p	0	467	65	5×10^{-5}	9.34×10^6	0.184	0.055	0.134		
			1	439	57	5×10^{-5}	8.78×10^6	0.092	0.026	0.063		
			2	275	56	5×10^{-5}	5.50×10^6	0.080	0.014	0.034		
			3	152	60	5×10^{-5}	3.04×10^6	0.116	0.011	0.028		
	3	n	0	-	-	-	-	-	-	-		
			1	0.01	86	5×10^{-5}	2.00×10^2	4032	0.026	0.063		
			2	132	75	5×10^{-5}	2.64×10^6	0.312	0.026	0.064		
			3	127	61	5×10^{-5}	2.54×10^6	0.222	0.018	0.044		
		p	0	-	-	-	-	-	-	-		
			1	377	65	5×10^{-5}	7.54×10^6	0.171	0.041	0.100		
			2	271	64	5×10^{-5}	5.42×10^6	0.124	0.022	0.053		
			3	154	56	5×10^{-5}	3.08×10^6	0.162	0.016	0.039		
	2	n	0	-	-	-	-	-	-	-		
			1	-	-	-	-	-	-	-	-	
			2	-	-	-	-	-	-	-	-	
			3	26	86	5×10^{-5}	5.20×10^5	0.614	0.010	0.025		
		p	-	-	-	-	-	-	-	-	-	
			1	172	77	5×10^{-5}	3.44×10^6	0.222	0.024	0.059		
			2	180	68	5×10^{-5}	3.60×10^6	0.119	0.014	0.034		
			3	131	65	5×10^{-5}	2.63×10^6	0.124	0.010	0.025		
	1	n	0	-	-	-	-	-	-	-	-	
			1	-	-	-	-	-	-	-	-	-
			2	-	-	-	-	-	-	-	-	-
			3	11	91	5×10^{-5}	2.20×10^5	1.284	0.009	0.022		
		p	0	-	-	-	-	-	-	-	-	-
			1	-	-	-	-	-	-	-	-	-
			2	85	88	5×10^{-5}	1.70×10^6	0.211	0.011	0.028		
			3	94	77	5×10^{-5}	1.88×10^6	0.171	0.010	0.025		
ITRS LP			295		5×10^{-5}	5.90×10^6	1.493	0.280	0.690			

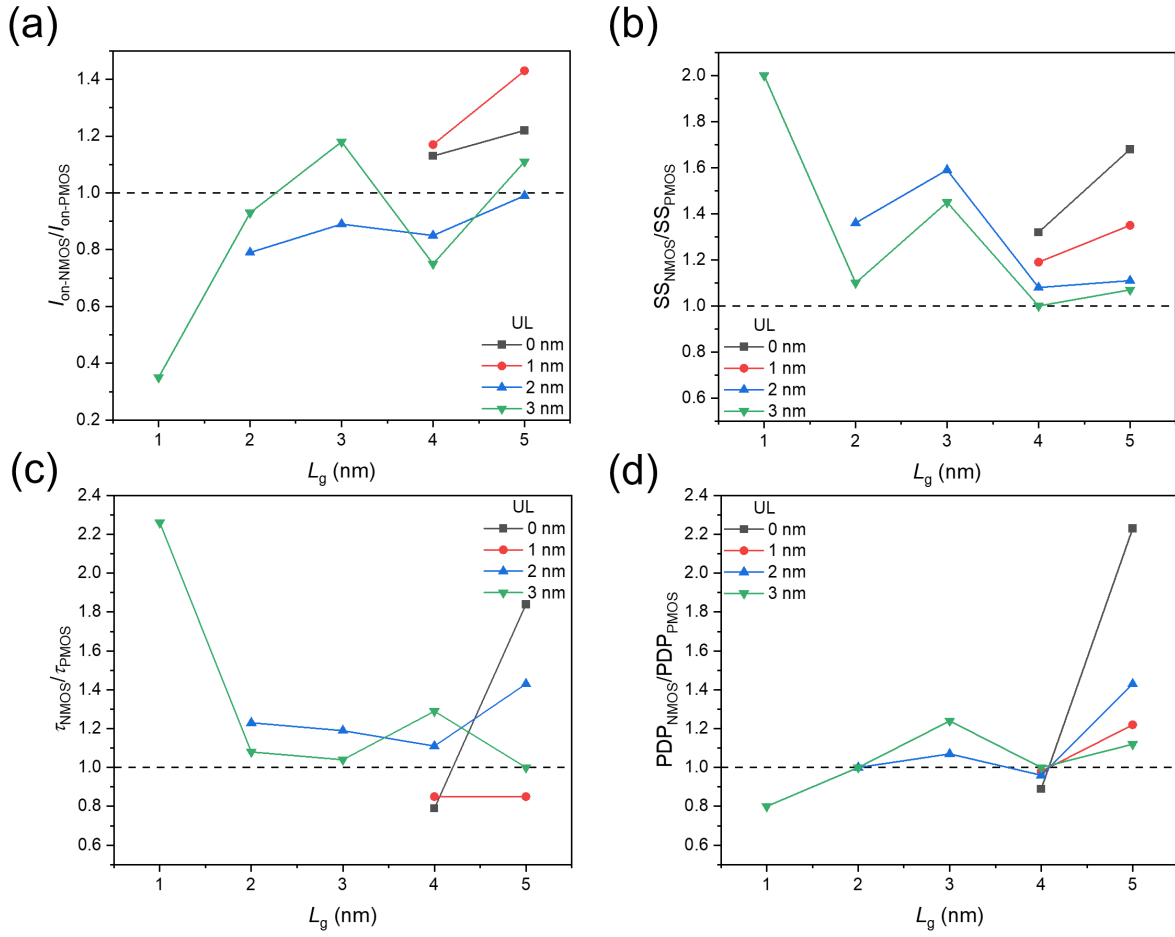


FIG. S6: The ratios of NMOS to PMOS for (a) I_{on} , (b) SS, (c) τ , and (d) PDP for the monolayer Sn_2S_2 MOSFETs.

TABLE S5: The FOMs of n - and p -type monolayer Sn_2S_2 -a MOSFETs with various L_g and ULs against IRDS HP requirements for the year 2037 (2022 version: $L_g = 12$ nm; 2024 version: $L_g = 10$ nm).

	Gate (nm)	Type	UL (nm)	I_{on} ($\mu\text{A}/\mu\text{m}$)	SS (mV/dec)	I_{off} ($\mu\text{A}/\mu\text{m}$)	I_{on}/I_{off}	τ (ps)	PDP (fJ/ μm)	C_t (fF/ μm)
Sn_2S_2	5	n	0	253	111	0.01	25300	0.337	0.055	0.133
			1	1821	81	0.01	182100	0.034	0.040	0.098
			2	1312	68	0.01	131200	0.033	0.028	0.069
			3	926	65	0.01	92600	0.040	0.024	0.058
		p	0	1387	66	0.01	138700	0.080	0.071	0.174
			1	1565	60	0.01	156500	0.045	0.045	0.111
			2	1362	61	0.01	136200	0.033	0.028	0.069
			3	763	61	0.01	76300	0.049	0.024	0.058
2022	5			753	70	0.01	75300	0.88	0.4	0.37
2024	5			827	70	0.01	82700	0.64	0.33	0.31

TABLE S6: The FOMs of n - and p -type monolayer Sn_2S_2 - a MOSFETs with various L_g and ULs against IRDS LP requirements for the year 2037 (2022 version: $L_g = 12$ nm; 2024 version: $L_g = 10$ nm).

	Gate (nm)	Type	UL (nm)	I_{on} ($\mu\text{A}/\mu\text{m}$)	SS (mV/dec)	I_{off} ($\mu\text{A}/\mu\text{m}$)	$I_{\text{on}}/I_{\text{off}}$	τ (ps)	PDP (fJ/ μm)	C_t (fF/ μm)
Sn_2S_2	5	n	0	0.029	111	1×10^{-4}	2.90×10^2	3281	0.061	0.149
			1	11	81	1×10^{-4}	1.10×10^5	11.14	0.078	0.191
			2	550	68	1×10^{-4}	5.50×10^6	0.076	0.027	0.065
			3	618	65	1×10^{-4}	6.18×10^6	0.058	0.023	0.056
		p	0	1302	66	1×10^{-4}	1.30×10^7	0.074	0.061	0.149
			1	1383	60	1×10^{-4}	1.38×10^7	0.049	0.043	0.105
			2	855	61	1×10^{-4}	8.55×10^6	0.050	0.027	0.066
			3	451	61	1×10^{-4}	4.51×10^6	0.079	0.023	0.056
				547	70	1×10^{-4}	5.47×10^6	1.218	0.4	0.37
				614	70	1×10^{-4}	6.14×10^6	0.86	0.33	0.31

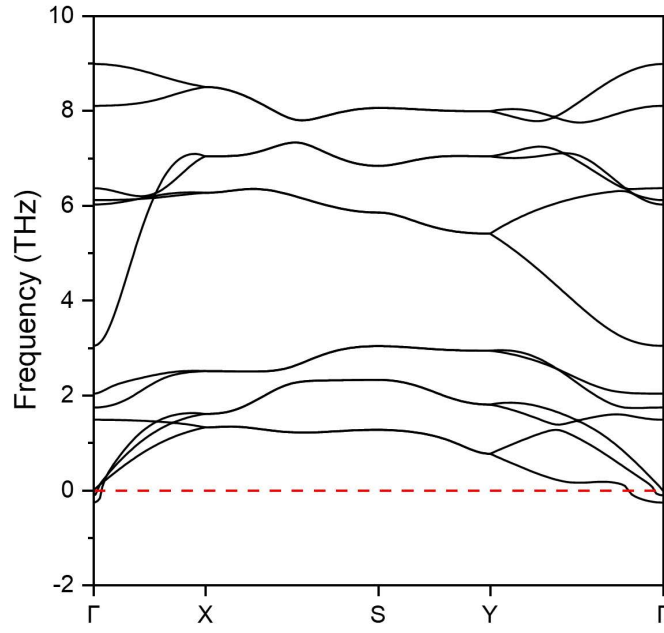


FIG. S7: Phonon spectrum of monolayer Sn_2S_2 , which demonstrates the stability of the structure.

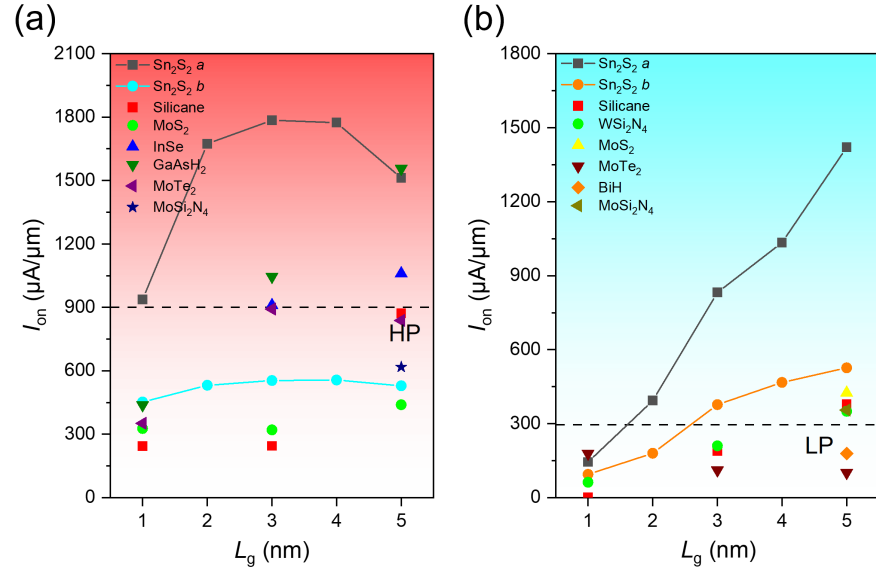


FIG. S8: The optimal I_{on} versus L_g of monolayer p -type Sn_2S_2 MOSFETs compared with a series of monolayer MOSFETs for (a) HP applications and (b) LP applications.