

High-frequency, low-energy organic event-based sensors for closed-loop neurostimulation

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Supplementary Information

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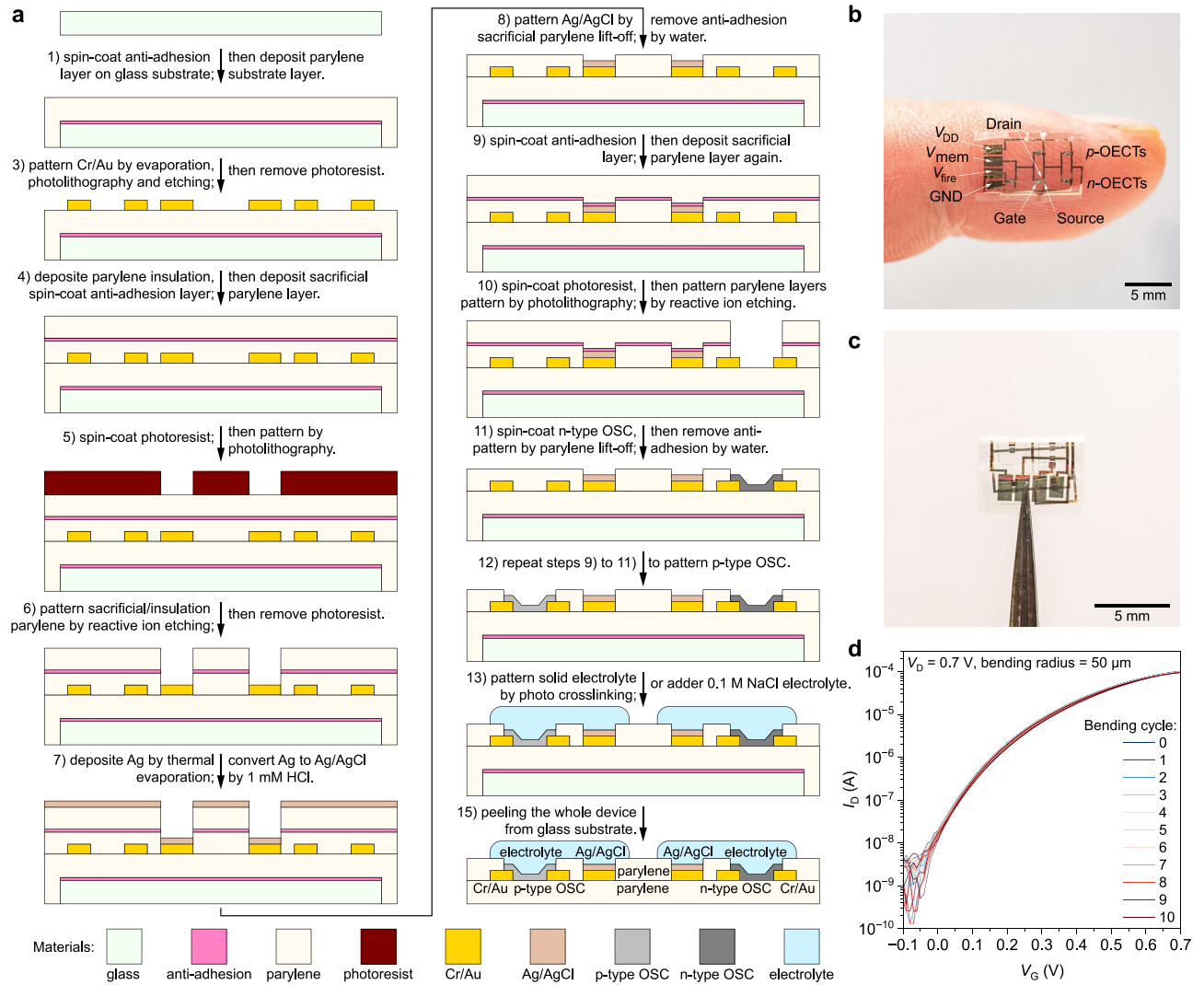
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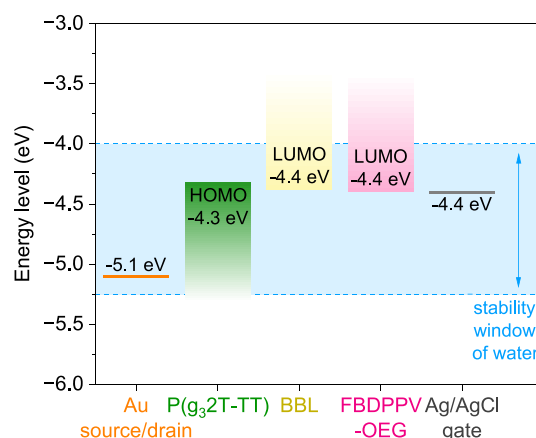
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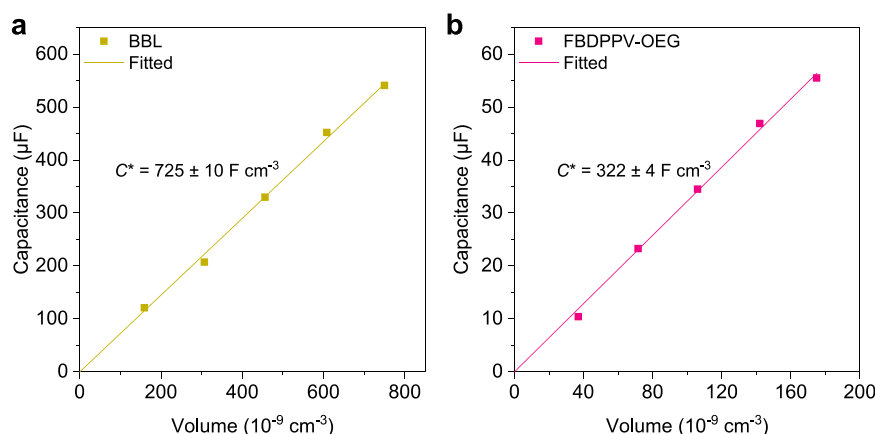
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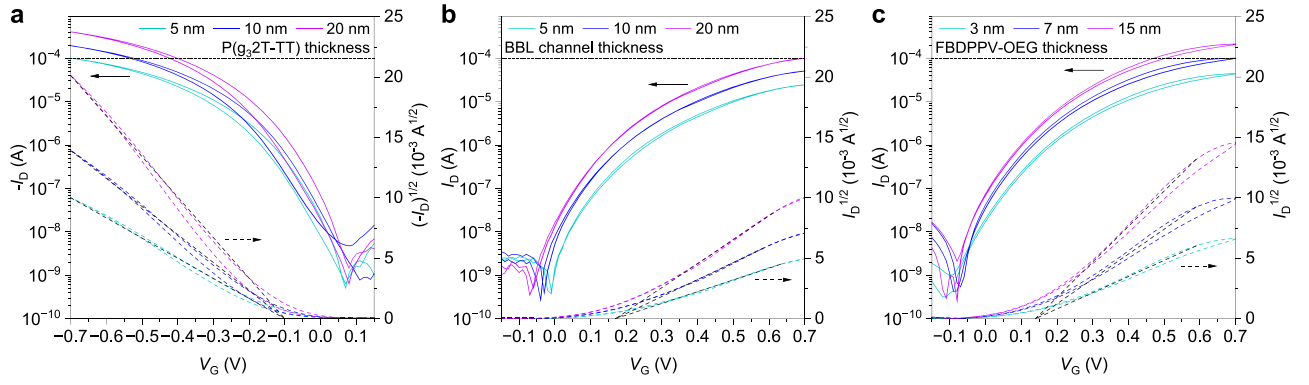
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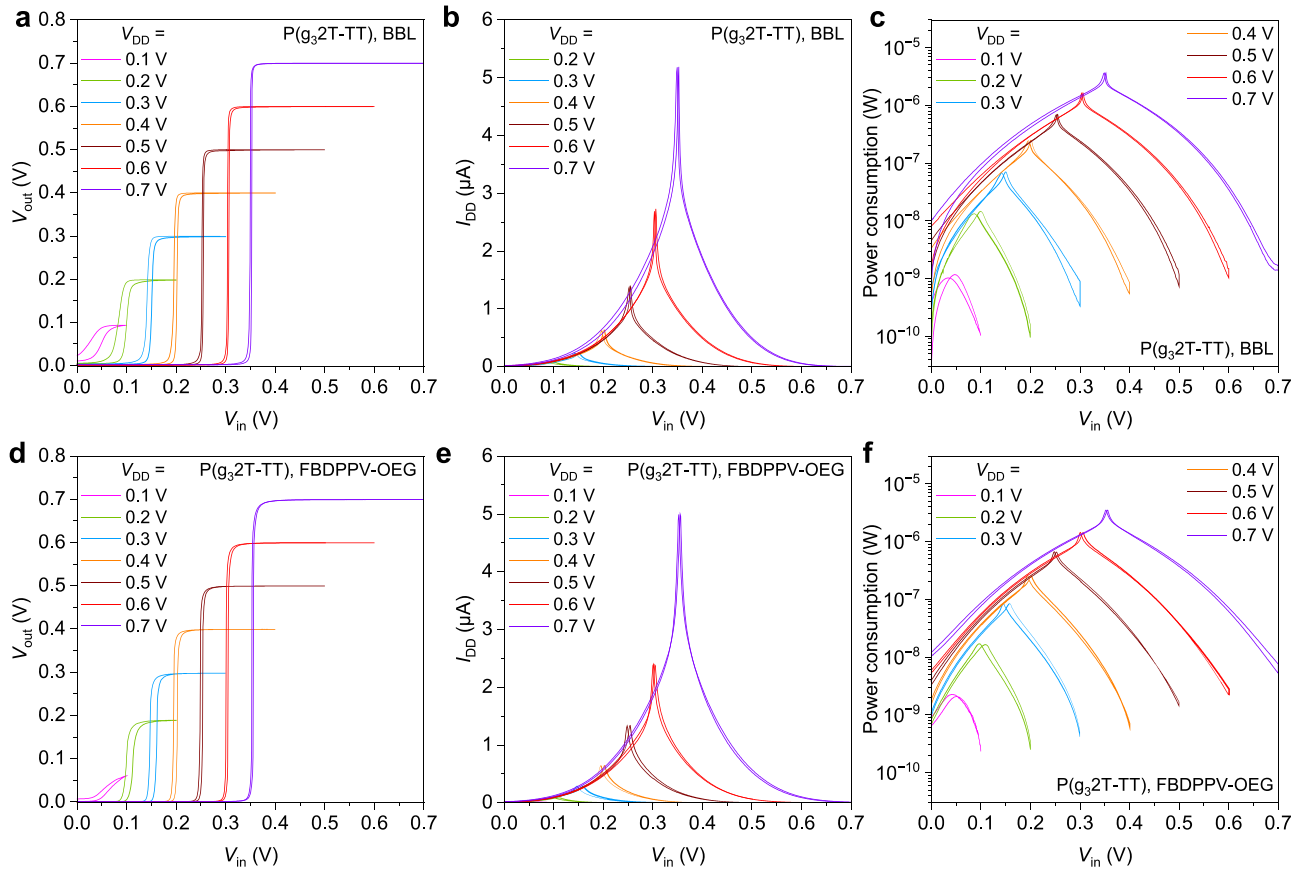
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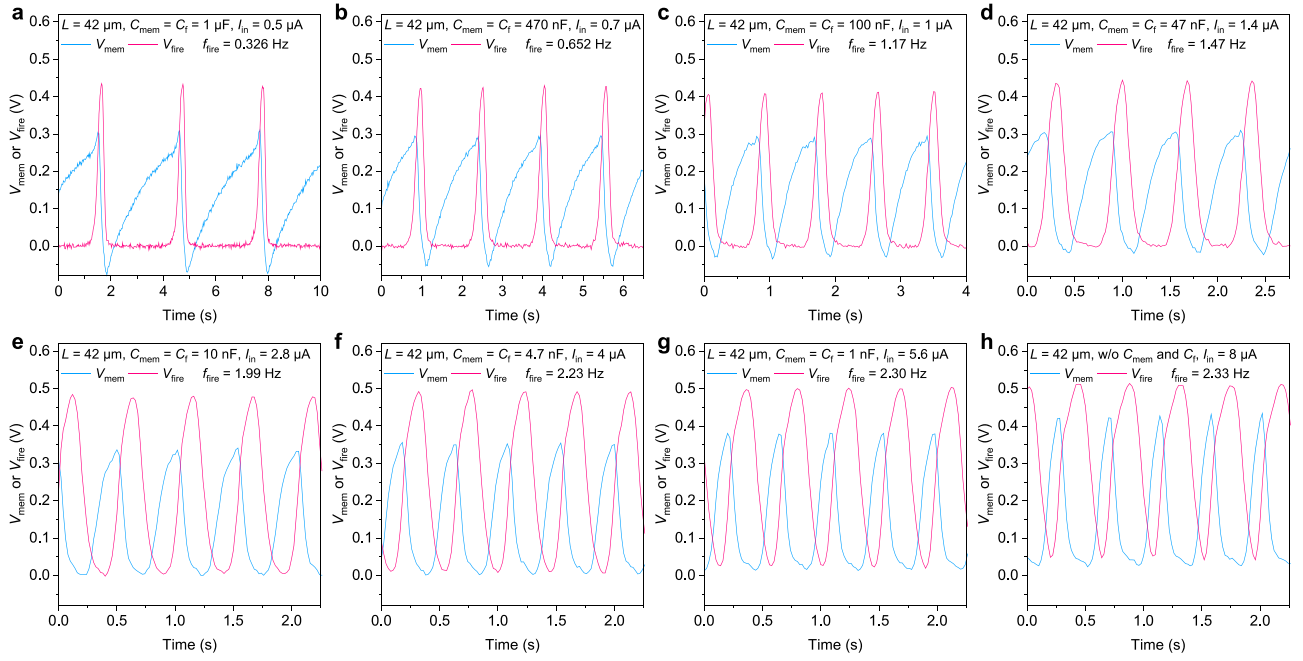
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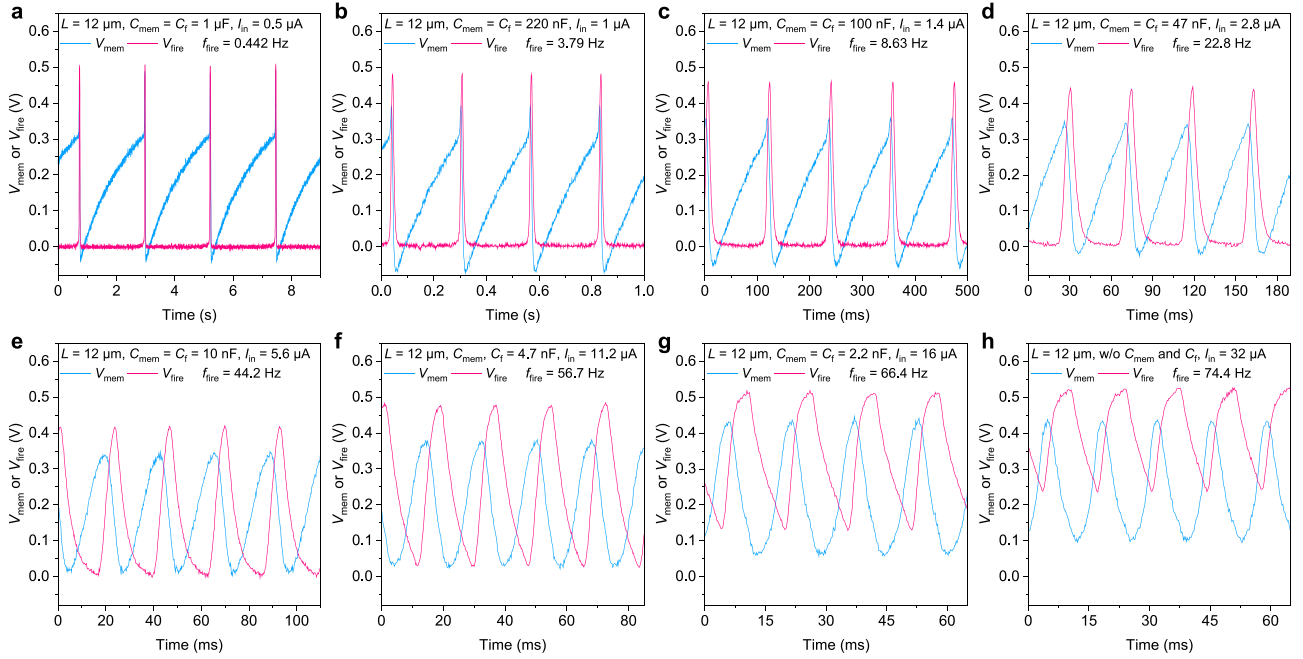
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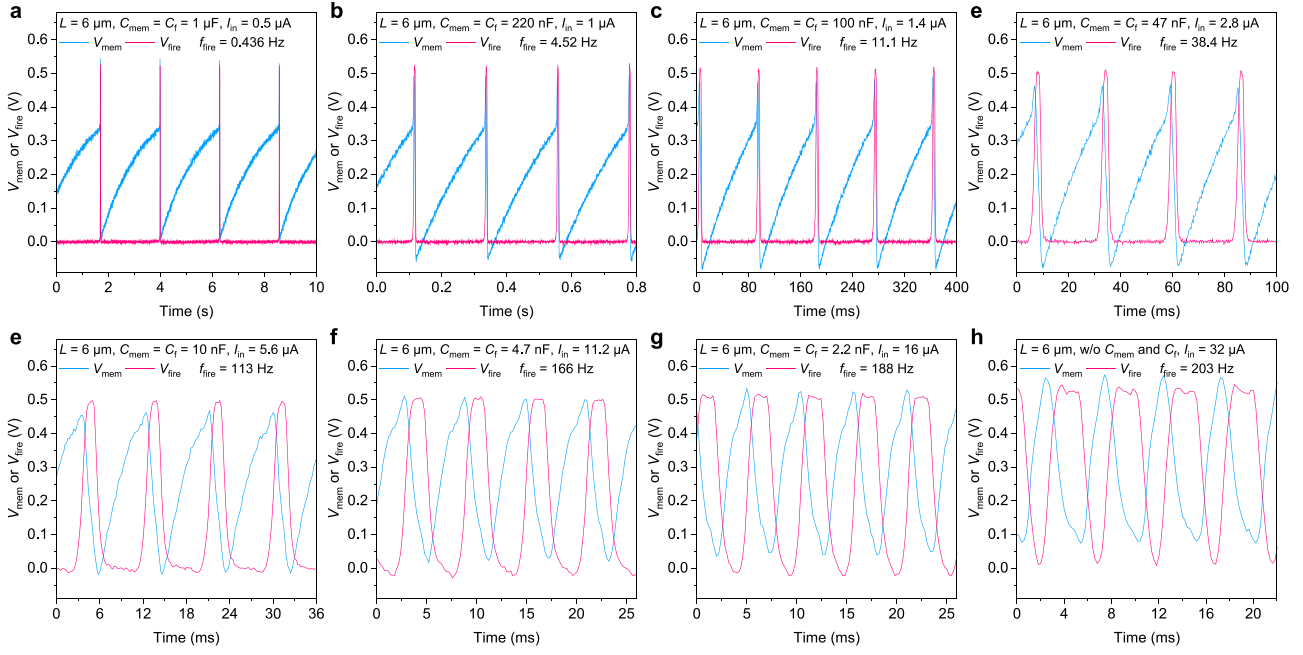
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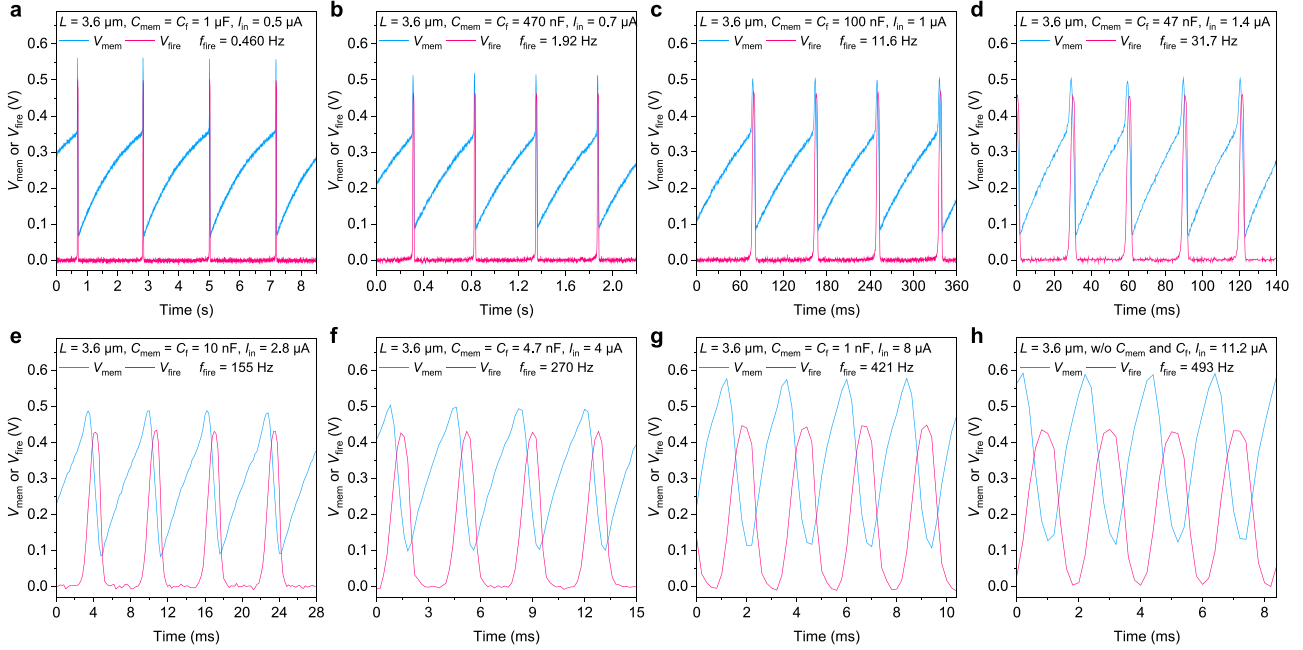
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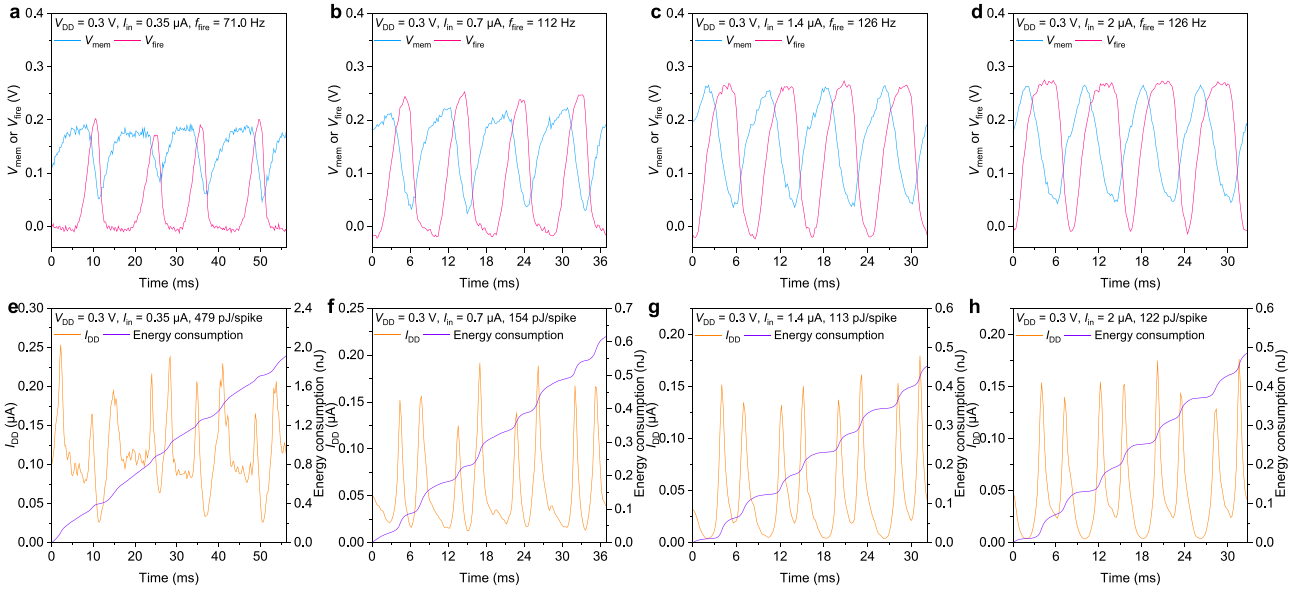
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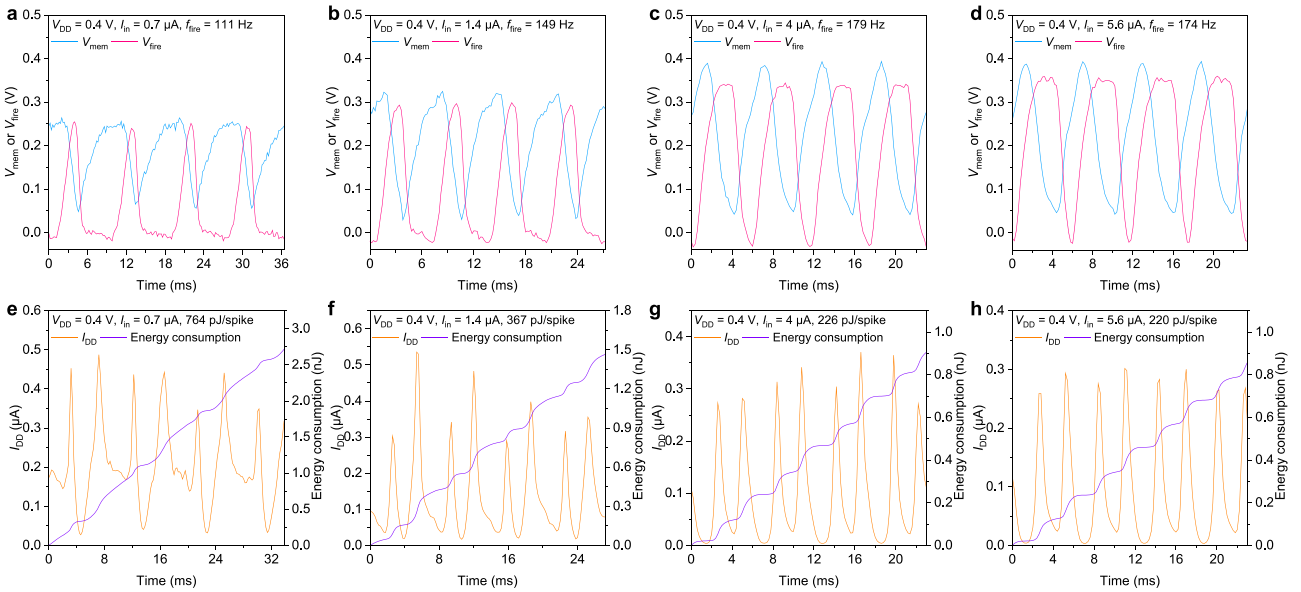
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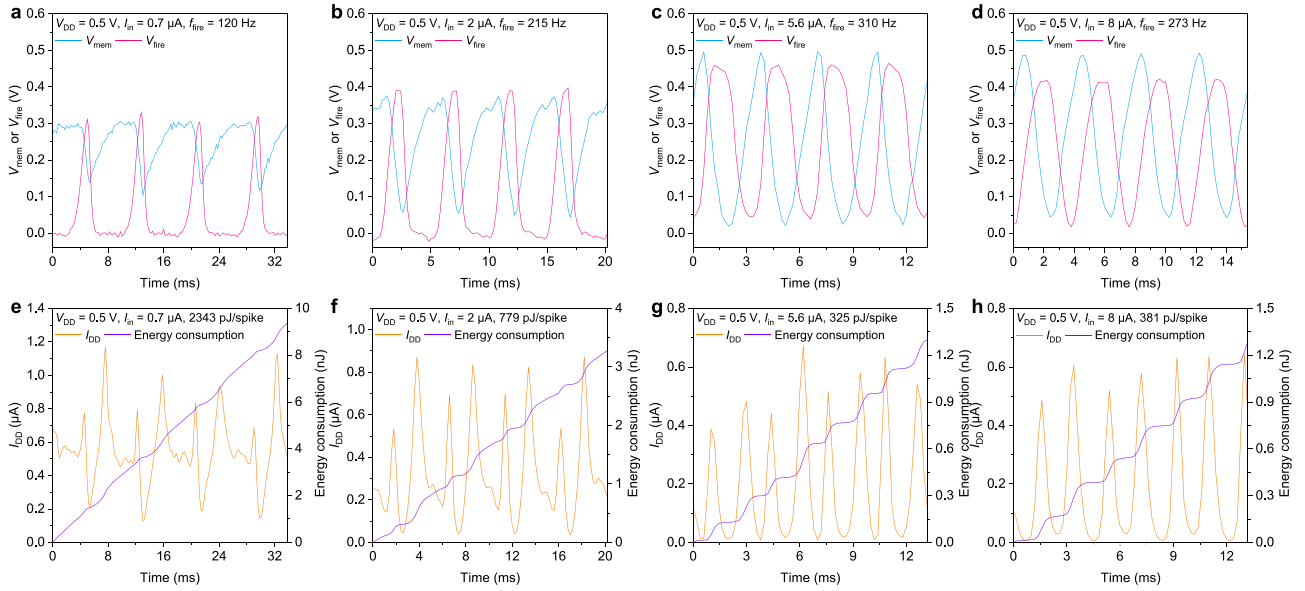
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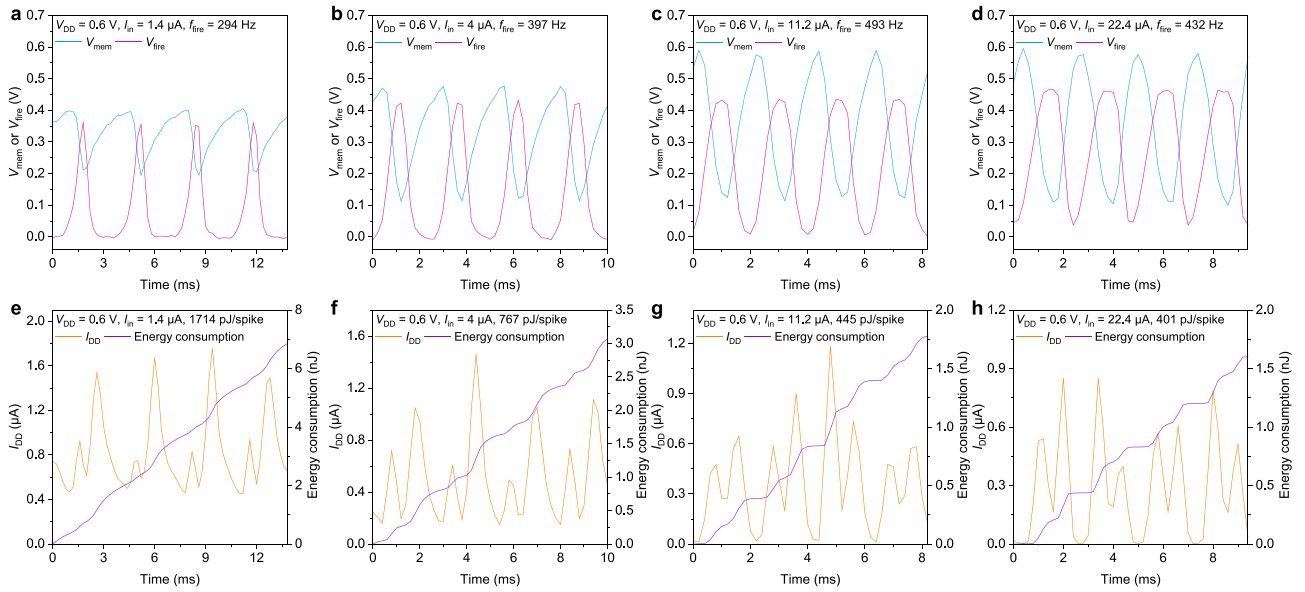
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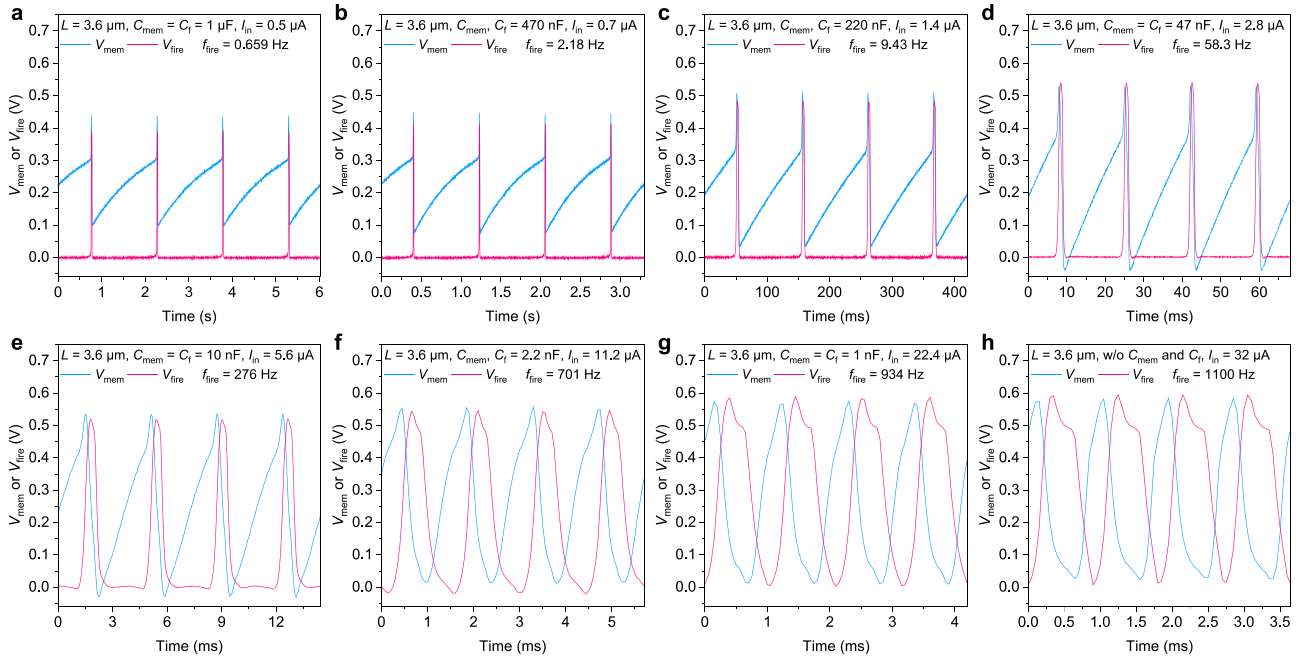
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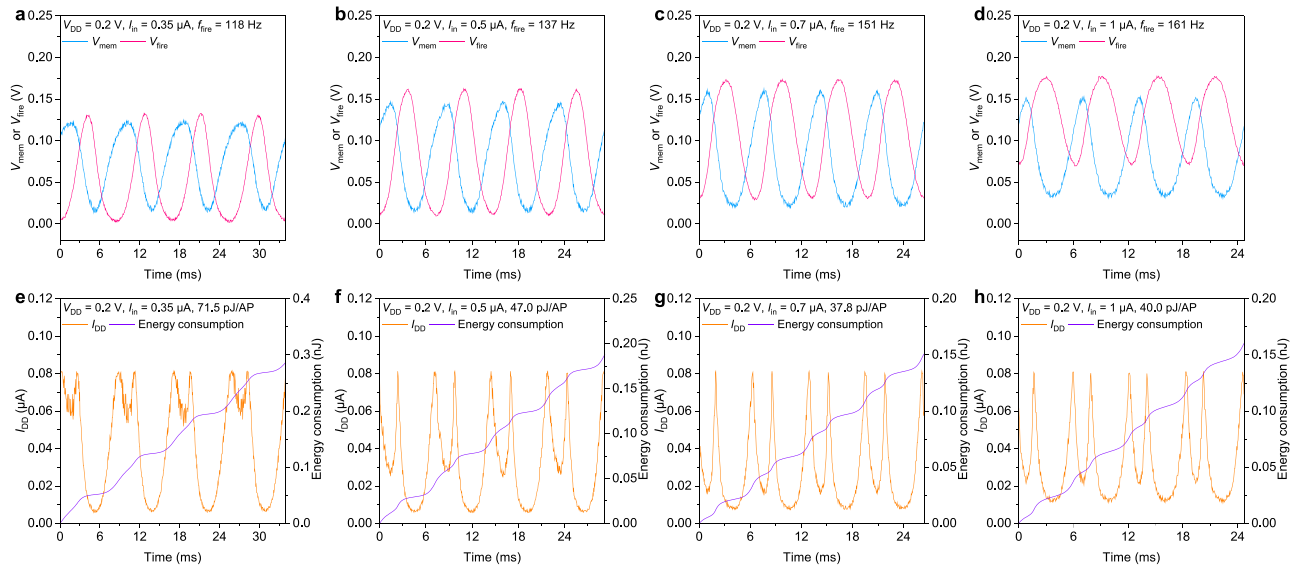
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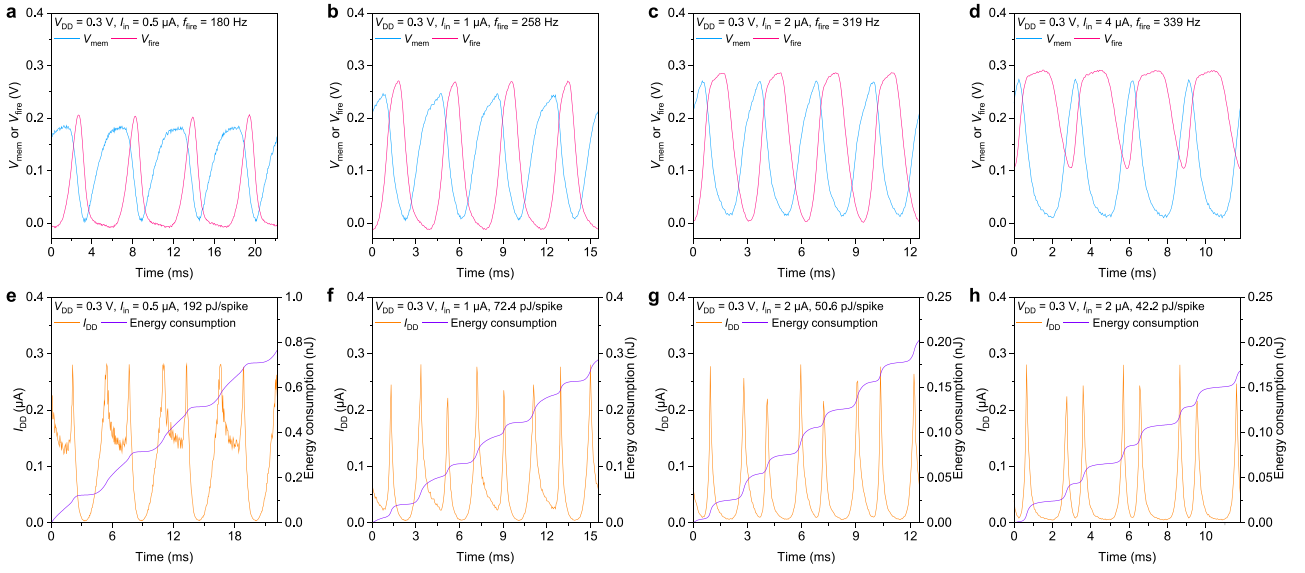
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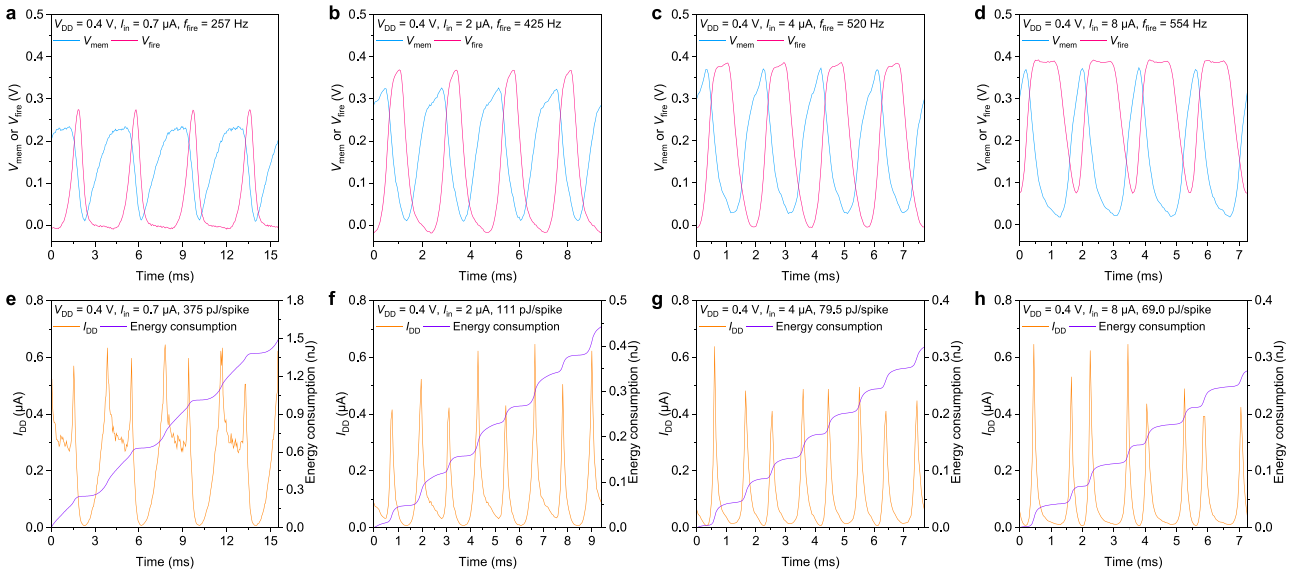
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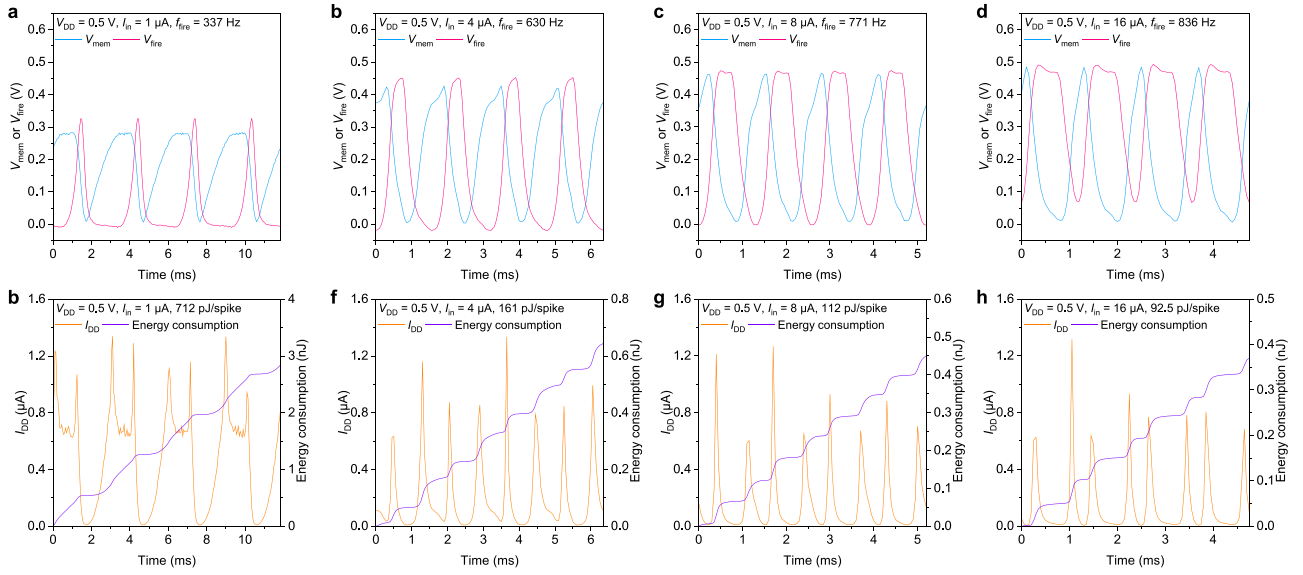
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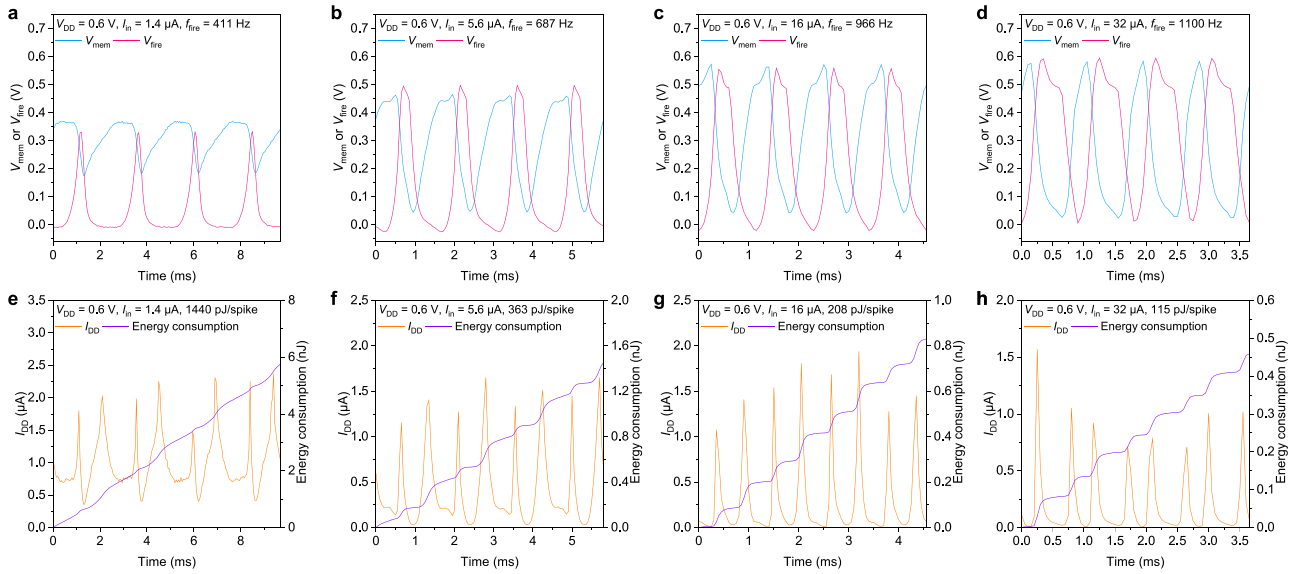
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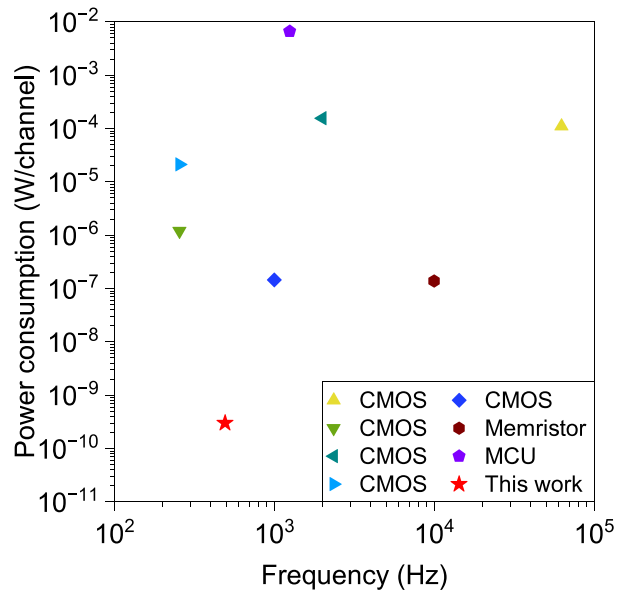
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Supplementary Fig. 19 | OECN energy consumption. a-d, Spiking behavior of OECNs based on P(g32T-TT)/FBDPPV-OEG ($L = 3.6 \mu\text{m}$, without C_{mem} and C_f , $V_{\text{DD}} = 0.6 \text{ V}$) under various input currents and corresponding energy consumption (e-f).



Supplementary Fig. 20 | Power consumption of neural signal processors. Comparison of OECN power consumption with other closed-loop neural signal processors, including CMOS SoCs, MCUs, and memristor-based systems. Detailed data and references are provided in Supplementary Table 3.

Supplementary Tables 1-3

Supplementary Table 1. Survey of n-type OECT materials. Summary of high-performance n-type channel materials used in planar n-type accumulation-mode OECTs.

Materials	V_{th} [V]	$g_{m,norm}$ [S cm ⁻¹]	μC^* [F cm ⁻¹ V ⁻¹ s ⁻¹]	τ_{ON} [ms]	Year	Refs.
p(gNDI-gT2)	0.28	0.1085	NA	5	2016	[1]
P-50	0.36	0.067	NA	NA	2018	[2]
P-75	0.29	0.141	NA	NA	2018	[2]
P-90	0.26	0.21	NA	NA	2018	[2]
P-100	0.25	0.204	NA	NA	2018	[2]
C60-TEG	0.55	0.0146	7	80	2019	[3]
P90, PFBT	0.29	0.0111	0.0008	NA	2019	[4]
P90, MBT	0.27	0.0059	0.0023	NA	2019	[4]
p(NDI-T2-L2)	0.22	0.0084	0.046	40	2020	[5]
P-90	0.25	0.0113	NA	NA	2020	[6]
P-90:TBAF(10%)	0.25	0.0299	NA	NA	2020	[6]
P-90:TBAF(40%)	0.22	0.0905	NA	24	2020	[6]
P-90:TBAF(80%)	0.25	0.0833	NA	NA	2020	[6]
f-BTI2TEG-T	0.68	0.26	2.13	332	2021	[7]
f-BTI2TEG-FT	0.53	4.42	14.71	272	2021	[7]
BBL	0.19	0.815	1.99	5.2	2021	[8]
P90	0.24	0.009	0.0343	41	2021	[8]
PgNaN	0.37	0.212	0.662	127	2021	[9]
PgNgN	0.21	0.007	0.037	NA	2021	[9]
p(gNDI-gT2)	0.26	0.13	0.06	NA	2021	[10]
p(C3-gNDI-gT2)	0.25	0.34	0.13	NA	2021	[10]
p(C6-gNDI-gT2)	0.37	0.37	0.16	NA	2021	[10]
p(C4-T2-OMe)	0.46	0.10	0.07	NA	2021	[11]
p(C4-T2-C0-EG)	0.32	0.31	0.22	24.6	2021	[11]
p(C4-T2-C2-EG)	0.30	0.02	0.01	6.2	2021	[11]
p(C4-T2-C4-EG)	0.33	0.01	0.006	12.5	2021	[11]
p(C2-T2)	0.27	0.40	0.2	6.3	2021	[11]
p(C4-T2)	0.24	0.63	0.3	7.5	2021	[11]
p(C6-T2)	0.30	2.28	1.29	9.6	2021	[11]
p(C8-T2)	0.37	0.15	0.13	12.7	2021	[11]
2DPP-OD-TEG	0.89	0.73	7	500	2021	[12]
f-BTI2g-TVT	0.9	0.27	1.50	68	2022	[13]
f-BTI2g-TVTCN	0.68	12.8	41.3	52	2022	[13]
P(gTDPP2FT)	0.64	0.52	54.8	1.75	2022	[14]
AIG-BT	0.55	0.029	0.12	NA	2022	[15]
p(C-T)	0.43	0.80	6.7	NA	2022	[16]
p(N-T)	0.25	0.72	4.3	NA	2022	[16]
p(C-2T)	0.44	0.14	1.0	NA	2022	[16]
PBBTL:BBL	0.26	0.43	1.36	1.72	2022	[17]
BBL	0.15	11.1	25.9	0.38	2022	[18]
gNDI-EDBT	0.52	0.3	0.02	377.6	2022	[19]
gNDI-BT	0.30	1.9	0.09	102.3	2022	[19]
gNDI-FBT	0.19	3.6	0.12	45.5	2022	[19]
p(C-V)	0.17	1.81	14.89	1.201	2023	[20]

p(C2F-V)	0.02	25.67	107.56	0.336	2023	[20]
P75	0.28	0.03	0.01	161.6	2023	[21]
P75-TBAClO4	0.29	0.39	0.24	7.4	2023	[21]
P75-TBAPF6	0.29	0.21	0.11	7.5	2023	[21]
P75-LiClO4	0.30	0.22	0.09	6.0	2023	[21]
gNDI-V	0.3	0.42	2.31	NA	2023	[22]
gNDI-T	0.2	0.11	0.42	NA	2023	[22]
CNg4T2-CNT2	0.75	6.75	27.01	102	2023	[23]
lgTNR	0.35	0.97	4.2	308	2023	[24]
bgTNR	0.29	7.10	31.6	489	2023	[24]
t-gdiPDI	-0.07	0.055	0.21	123	2023	[25]
d-gdiPDI	0.11	0.101	0.33	87	2023	[25]
3gDNR	0.27	2.16	9.4	439	2023	[26]
4gDNR	0.25	1.17	4.7	207	2023	[26]
TDPP-CN-G7	0.16	NA	0.68	NA	2023	[27]
TDPP-RD-G7	0.34	NA	5.43	10.5	2023	[27]
f-BTI2g-TVT	0.97	1.60	6.96	NA	2024	[28]
f-BTI2g-TVTF	0.75	22.6	90.2	NA	2024	[28]
f-BTI2g-TVTC1	0.79	3.97	18.9	NA	2024	[28]
f-BTI2g-SVSCN	0.70	48.3	150.9	7.3	2024	[29]
f-BseI2g-SVSCN	0.68	71.4	191.2	5.1	2024	[29]
p(N-T)	0.25	0.72	4.3	NA	2024	[30]
p(N-T):PS 10K 1:6	0.27	1.6	13.4	NA	2024	[30]
p(N-T):PMM 10K 1:6	0.25	0.7	5.3	NA	2024	[30]
p(N-T):PS 1K 1:6	0.25	0.6	4.9	NA	2024	[30]
Cl ₂ -BAL	0.26	1.63	6.20	2.4	2024	[31]
Cl ₄ -BAL	0.32	0.21	0.83	3.1	2024	[31]
o-CNgTVT-2FT	0.79	17.4	88.2	2.86	2025	[32]
FBDPPV-OEG	0.4	22	40	0.1	2025	This work

Supplementary Table 2. Survey of p-type OEET materials. Summary of high-performance p-type channel materials used in planar p-type accumulation-mode OEETs.

Materials	V_{th} [V]	$g_{m,norm}$ [S cm ⁻¹]	μC^* [F cm ⁻¹ V ⁻¹ s ⁻¹]	τ_{ON} [ms]	Year	Refs.
PTHS	-0.4	5.67	NA	0.4	2014	[33]
P(g2T-TT)	-0.1	135	227	0.42	2016	[34]
g2T-T	-0.2	NA	167	1.4	2017	[35–37]
Crys-P	NA	4100	490	NA	2018	[38]
ProDOT(OE)-DMP	-0.45	NA	6.99	NA	2018	[39]
P3MEEMT	-0.42	NA	96.7	NA	2019	[40]
PIBET-AO	-0.44	1.3	NA	654	2019	[41]
PIBET-O	-0.44	1.0	NA	714	2019	[41]
PIBET-BO	-0.62	0.8	NA	862	2019	[41]
PIBET-A	-0.86	0.5	NA	29000	2019	[41]
PIBT-BO	-0.80	1.4	NA	3500	2019	[41]
PTHS-TMA+co-P3HT	-0.15	70.49	1.7	0.4	2019	[42]
P(g2T2-g4T2)	0.02	NA	522	NA	2020	[43]
p(gPyDPP-MeOT2)	-0.35	19.5	1.8	0.77	2020	[44]
g-0%	-0.39	0.00125	0.001	3.2	2020	[45]
g-50%	-0.27	0.87	0.87	2.9	2020	[45]

g-75%	-0.21	129.09	78	2.3	2020	[45]
g-100%	-0.08	341.82	163	0.13	2020	[45]
2g	-0.08	23.64	16	0.14	2020	[45]
P(lgDPP-MeOT2)	-0.17	7.04	174	0.578	2021	[46]
P(bgDPP-MeOT2)	-0.33	5.33	195	0.516	2021	[46]
TDPP-gTVT	-0.36	47.8	205.2	7.3	2021	[47]
TDPP-gTBTT	-0.42	3.65	21.5	8.7	2021	[47]
PProDOT-DPP LiPF ₆	+0.10	NA	310	260	2021	[48]
Pg ₃ BTTT	-0.24	194	502	NA	2021	[49]
P(gDPP-T2)	-0.52	NA	342	NA	2021	[50]
PTDPP-DT	-0.93	19	149	NA	2021	[51]
PDPP[T] ₂ (TEG)-EDOT	-0.38	0.53	14	11	2021	[52]
PDPP[T] ₂ (TEG) ₃ -MEET	-0.36	0.51	45	6	2021	[52]
PBBT-H	-0.36	1.11	2.52	0.738	2022	[53]
PBBT-Me	-0.52	40.6	92.3	3.19	2022	[53]
P(gTDPPT)	-0.62	1.18	45.9	0.46	2022	[14]
PBBTL	-0.41	0.58	4.82	2.89	2022	[17]
P3APPT	-0.27	NA	41.3	9000	2022	[54]
P(g ₃ 2T-TT)	-0.06	130	556	NA	2022	[55]
P3gCPDT-2gT2	-0.24	38.3	92.0	22.8	2022	[56]
P3gCPDT-1gT2	-0.21	168.3	288.6	36.7	2022	[56]
P3gCPDT-MeOT2	-0.09	344.0	448.6	49.3	2022	[56]
g2T2-gBT2	-0.17	16.3	40	93	2023	[57]
g2T2-gBT4	-0.10	154.9	359	50	2023	[57]
g2T2-gBT6	-0.10	92.4	203	37	2023	[57]
g4T2-T2	-0.21	38.75	133.62	971	2023	[23]
g4T2-CNT2	-0.74	0.77	4.84	471	2023	[23]
CNg4T2-T2	-0.83	0.89	12.73	981	2023	[23]
Aligned PBTTT- ⁸ O	-0.32	2580	10660	820	2025	[58]
Pristine PBTTT- ⁸ O	-0.32	430	960	1670	2025	[58]
gFBT-g2T	-0.33	298	826	19	2025	[59]

Supplementary Table 3. Power consumption data of OECNs and other neural signal processors. Comparison of OECN power consumption with other closed-loop neural signal processors, including CMOS SoCs, MCUs, and memristor-based systems.

Neural signal processor	Frequency [Hz]	Channel	Power consumption [W/channel]	Refs.
CMOS SoC	62500	8	1.1×10^{-4}	[60]
CMOS SoC	256	8	1.2×10^{-6}	[61]
CMOS SoC	2000	16	1.6×10^{-4}	[62]
CMOS SoC	256	32	2.1×10^{-5}	[63]
CMOS SoC	1000	8	1.5×10^{-7}	[64]
Memristor	10000	1	1.4×10^{-7}	[65]
MCU	1250	1	6.6×10^{-3}	[66]
OECN	493	1	3.0×10^{-10}	This work

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