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Emulating Ebbinghaus forgetting behavior in a neuromorphic device based on 1D supramolecular nanofibres

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SUPPLEMENTARY FIGURES

Table S1. Comparison of two-terminal optoelectronic synaptic devices reported in the literature

Material	Material dimension	Electrode terminals	Response time (ms)	Energy	Electrical/ Optical (E/ O)	STP/ LTP	Forgetting behavior	Synaptic functionalities	Ref
Au/C8-BTBT/SiO_2/Si	2 D	Three	50	13.6 pJ	O	✓	✓	PPF/learning and forgetting	1
Si/SiO_2/IDTBT-PCBM/Au	3 D	Three	60		E+O	✓	✓	EPSC/IPSC, PPF/PPD	2
Au/pentacene/poly methyl methacrylate (PMMA)/2DP/SiO_2/ Si	2 D	Three	50	0.29 pJ	O	✓	✓	PPF /learning- relearning/pixel array/Classical conditioning	3
Carotene: Organic semiconductor	Bulk	Three	1000	3.4 aJ	E+O	✓		EPSC/PPF/ learning relearning/pixel array	4
Hydrogel/ PEDOT: PSS	Bulk	Three	5		E	LTP		IPSC/PPF/PPD /LTD/Pixel array using additional circuit	5
Au/PVDT 10-N2200 mix/silver nanowire/SiO_2/Si	Bulk	Three	1000(O) 50 (E)		E+O	✓		EPSC/IPSC PPF/PPD	6
Au/IDTBT/SiO_2/Si	2D	Three	30	0.416 pJ	E	LTP	✓	PPF/ PPD/LTD/programming ANN	7
Au/WCN/chlorophyll – a-PDPPDT/ SiO_2/Si	3 D	Three	500		E+O	✕		EPSC/IPSC/PPF/PPD/ morse code/image recognition	8
Au/P_3HT/Glass	2D	Two	100		O	✓		EPSC/learning relearning/ PPF/ Pixel array/SDDP/SNDP	9
Ag/PEDOT: PSS/Ta	Bulk	Two	20		E	✓	✓	STDP/SRDP/ learning relearning	10
Au/ Gold NPs/ Pentacene/SiO_2/Si	Bulk	Three			E	✓			11
PEDOT/PTHF OCET	Bulk	Three	50		E	✓		PPD	12
P_3HT/PEO	1 D	Three	111.2/50	1.23 fJ	E	✓	✓	EPSC/IPSC/LTD	13
Ion gel/P_3HT	Bulk	Three	15		E	STP		PPF/self-tuning/spike logic operation/spatiotemporal dendritic integration and modulation	14
Supramolecular nanofibre	1 D	Two	100	1.06 pJ	O	✓		PPF/learning relearning/pixel array	Present work

for emulating different synaptic functions

Note S1

The power consumption of the device is calculated using the equation: $E = V \times I \times t$

Where V is the reading voltage, I is the peak current, and t is the pulse duration.

Substituting the values for $V = 1.2\ V$, $I = 11.3\ nA$, and $t = 0.1\ s$, the power consumption of the device per unit pulse of 0.1 s is found to be $E = 1.2 \times 11.3 \times 0.1 = 1.35\ nJ$ per pulse.

The power consumption of $1.35\ nJ$ per pulse is for the whole device with several nanofibres spread across the Ti electrodes. However, each nanofibre across the Ti electrodes acts as a synaptic junction.

On average, there are 15 nanofibres spread across the electrodes in a single IDT pattern. There are 85 IDT patterns, and therefore, the whole device consists of $85 \times 15 = 1275$ nanofibres.

Therefore, the power consumption per synaptic junction is given by;

$1.35\ nJ/1275 = 1.06\ pJ$.

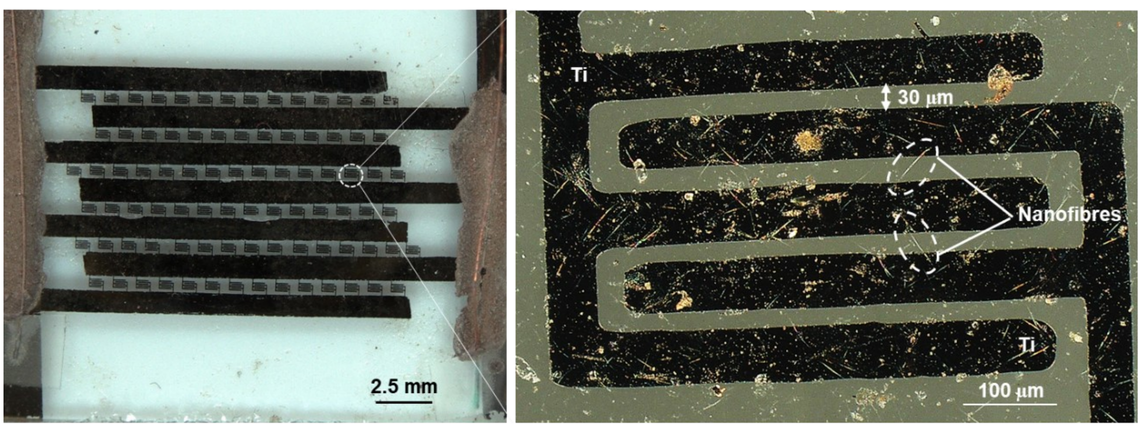

Fig. S1 Optical microscopy image of the complete device is shown on the left. The magnified image of a single unit of interdigitated (IDT) pattern is shown on the right with the nanofibres spread across the Ti electrodes.

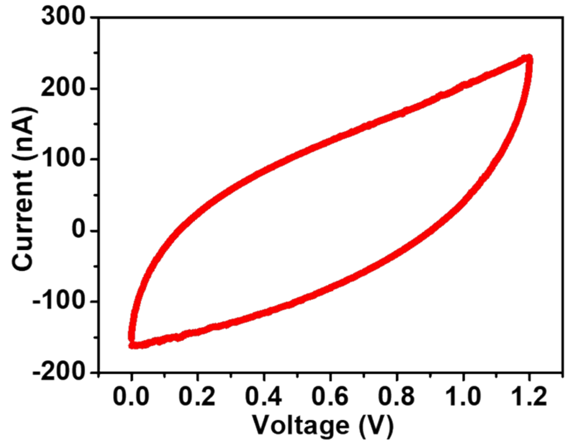

Fig. S2 IV sweep of the device (in dark) from 0 to 1.2 V, showing a capacitive behavior of the device. This aspect has been studied earlier[15].

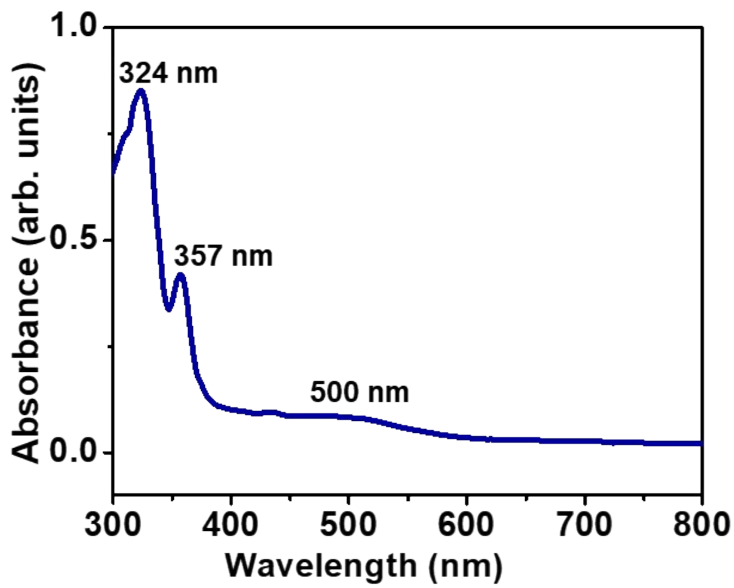

Fig. S3 UV-visible absorption spectrum of the supramolecular nanofibre thin film.

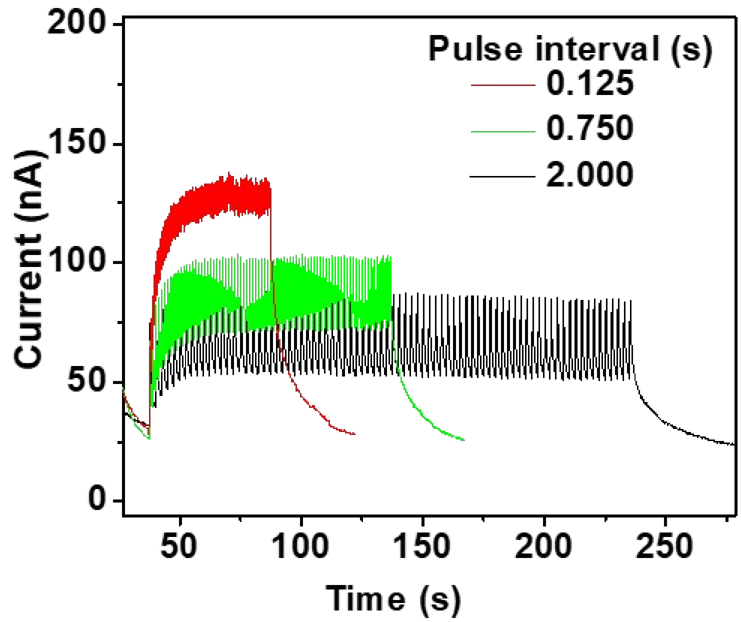

Fig. S4 Current response of the device for 80 UV light pulses with varying pulse intervals.

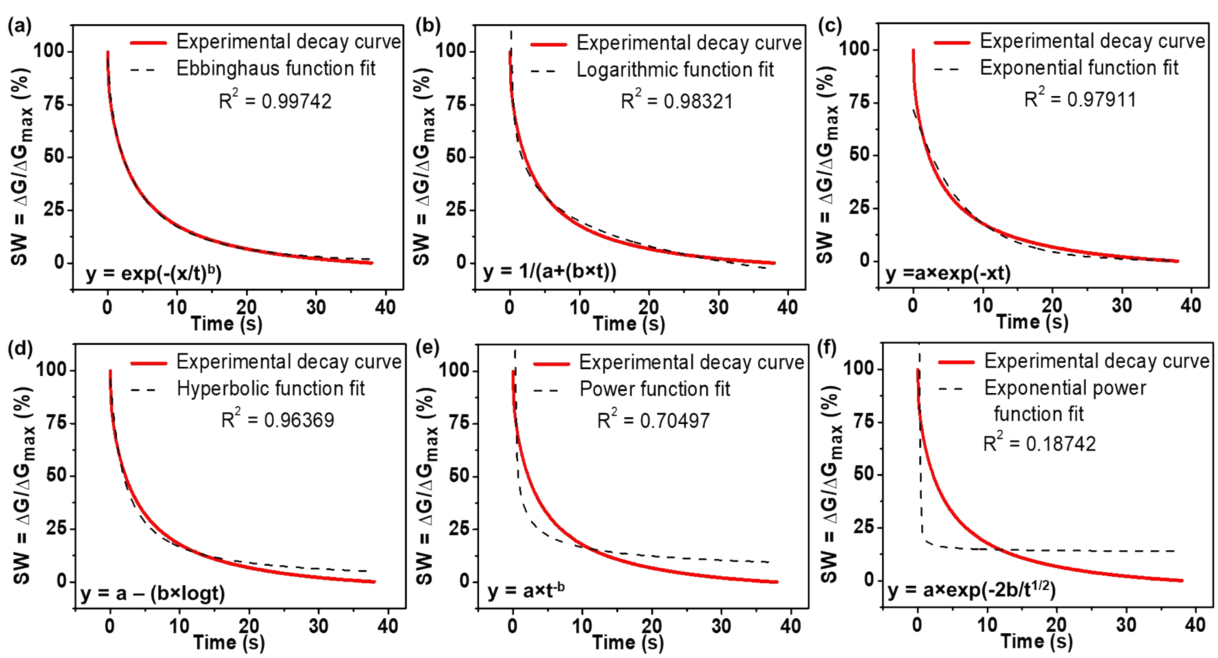

Fig. S5 The decay curve after application of 80 pulses with 0.125 s pulse interval fitted with the (a) Ebbinghaus (b) logarithmic (c) exponential (d) hyperbolic (e) power (f) exponential power functions with Ebbinghaus function being the best fit.

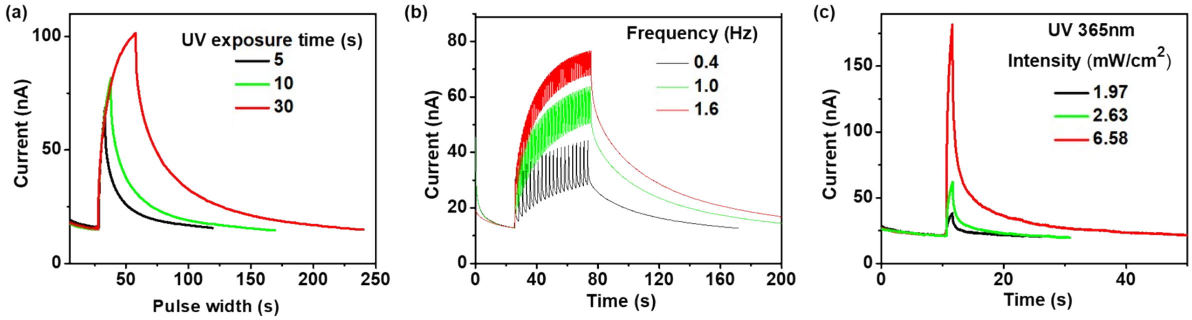

Fig. S6 Current response of the device for different UV exposure (a) times. (b) frequencies. (c) intensities.

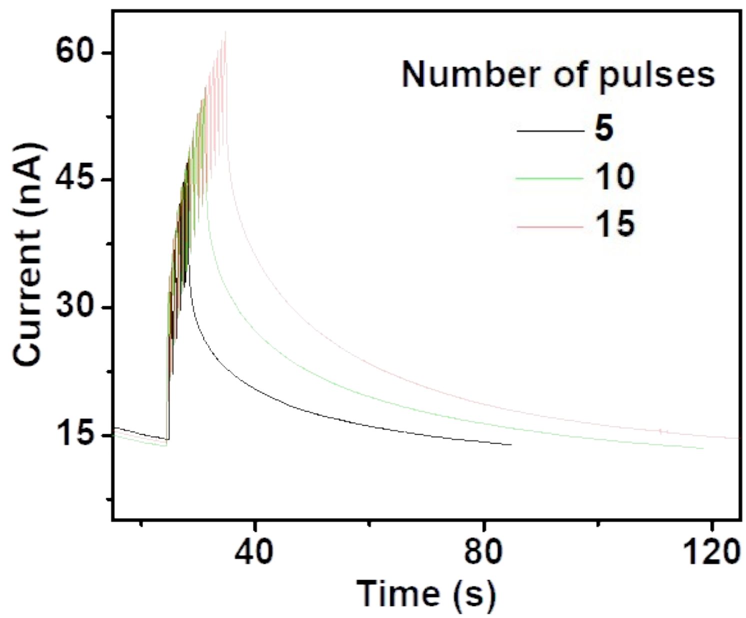

Fig. S7 Current response of the device for varying numbers of pulses.

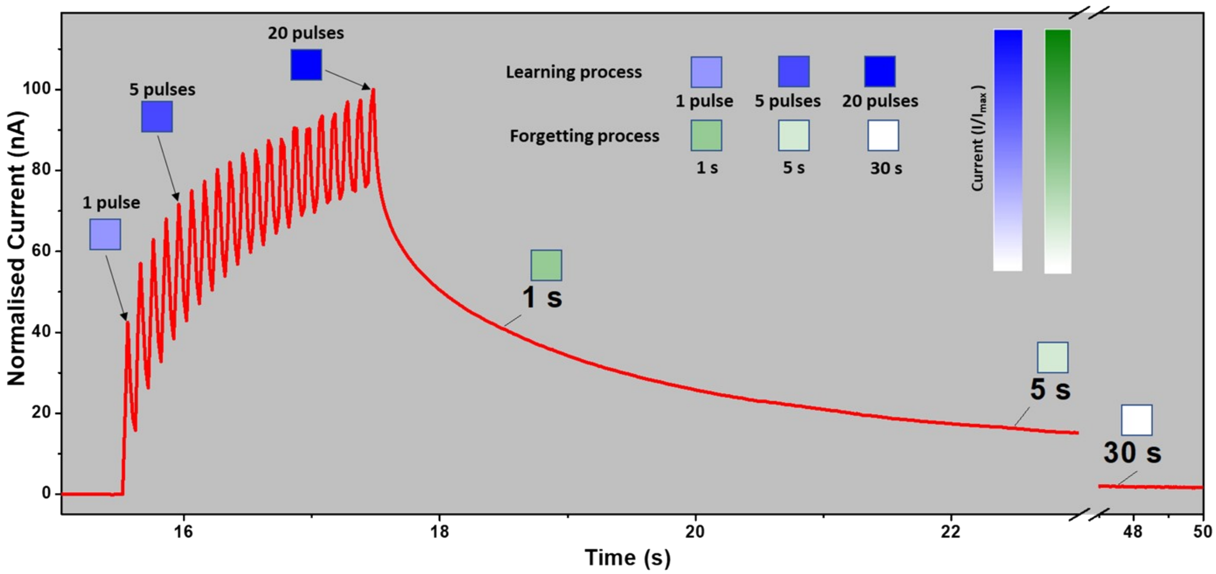

Fig. S8 Current response and decay behavior of a single pixel from a 3x3 pixel array for the application of 20 UV light pulses.

References:

1 C. Yang, J. Qian, S. Jiang, H. Wang, Q. Wang, Q. Wan, P. K. L. Chan, Y. Shi and Y. Li, *Adv. Opt. Mater.*, 2020, **8**, 2000153.

2 S. Lan, J. Zhong, J. Chen, W. He, L. He, R. Yu, G. Chen and H. Chen, *J. Mater. Chem. C*, 2021, **9**, 3412.

3. J. Zhang, Q. Shi, R. Wang, X. Zhang and L. Li, *InfoMat*, 2021, **3**, 904.

4 B. Yang, Y. Wang, Z. Hua, J. Zhang, L. Li, D. Hao, P. Guo, L. Xiong and J. Huang, *Chem. Commun.*, 2021, **57**, 8300.

5 S. Han, S. Yu, S. Hu, H. J. Chen, J. Wu and C. Liu, *J. Mater. Chem. C*, 2021, **9**, 11801.

6 C. Gao, H. Yang, E. Li, Y. Yan, L. He, H. Chen, Z. Lin and T. Guo, *ACS Photonics*, 2021, **8**, 3094.

7 Q. Yang, H. Yang, D. Lv, R. Yu, E. Li, L. He, Q. Chen, H. Chen and T. Guo, *ACS Appl. Mater. Interfaces*, 2021, **13**, 8672.

8 J. Zhang, D. Liu, Q. Shi, B. Yang, P. Guo, L. Fang, S. Dai, L. Xiong and J. Huang, *npj Flex. Electron.*, 2022, **6**, 30.

9 P. Zhao, R. Ji, J. Lao, W. Xu, C. Jiang, C. Luo, H. Lin, H. Peng and C. G. Duan, *Org. Electron.*, 2022, **100**, 106390.

10. S. Li, F. Zeng, C. Chen, H. Liu, G. Tang, S. Gao, C. Song, Y. Lin, F. Pan and D. Guo, *J. Mater. Chem. C*, 2013, **1**, 5292.

11 F. Alibart, S. Pieutin, D. Guérin, C. Novembre, S. Lenfant, K. Lmimouni, C. Gamrat and D. Vuillaume, *Adv. Funct. Mater.*, 2010, **20**, 330.

12 P. Gkoupidenis, N. Schaefer, X. Strakosas, J. A. Fairfield and G. G. Malliaras, *Appl. Phys. Lett.,* 2010, **20**, 330.

13 W. Xu, S. Y. Min, H. Hwang and T. W. Lee, *Sci. Adv.*, 2016, **2**, e1501326.

14 C. Qian, J. Sun, L. Kong, G. Gou, J. Yang, J. He, Y. Gao and Q. Wan, *ACS Appl. Mater. Interfaces*, 2016, **8**, 26169.

15 S. Kundu, U. Mogera, S. J. George and G. U. Kulkarni, *Nano Energy*, 2019, **61**, 259.