Supplementary information

Second order Synaptic Plasticity with multistate memory in flexible MoO_3-Aloe vera composite Devices for low energy Neuromorphic applications

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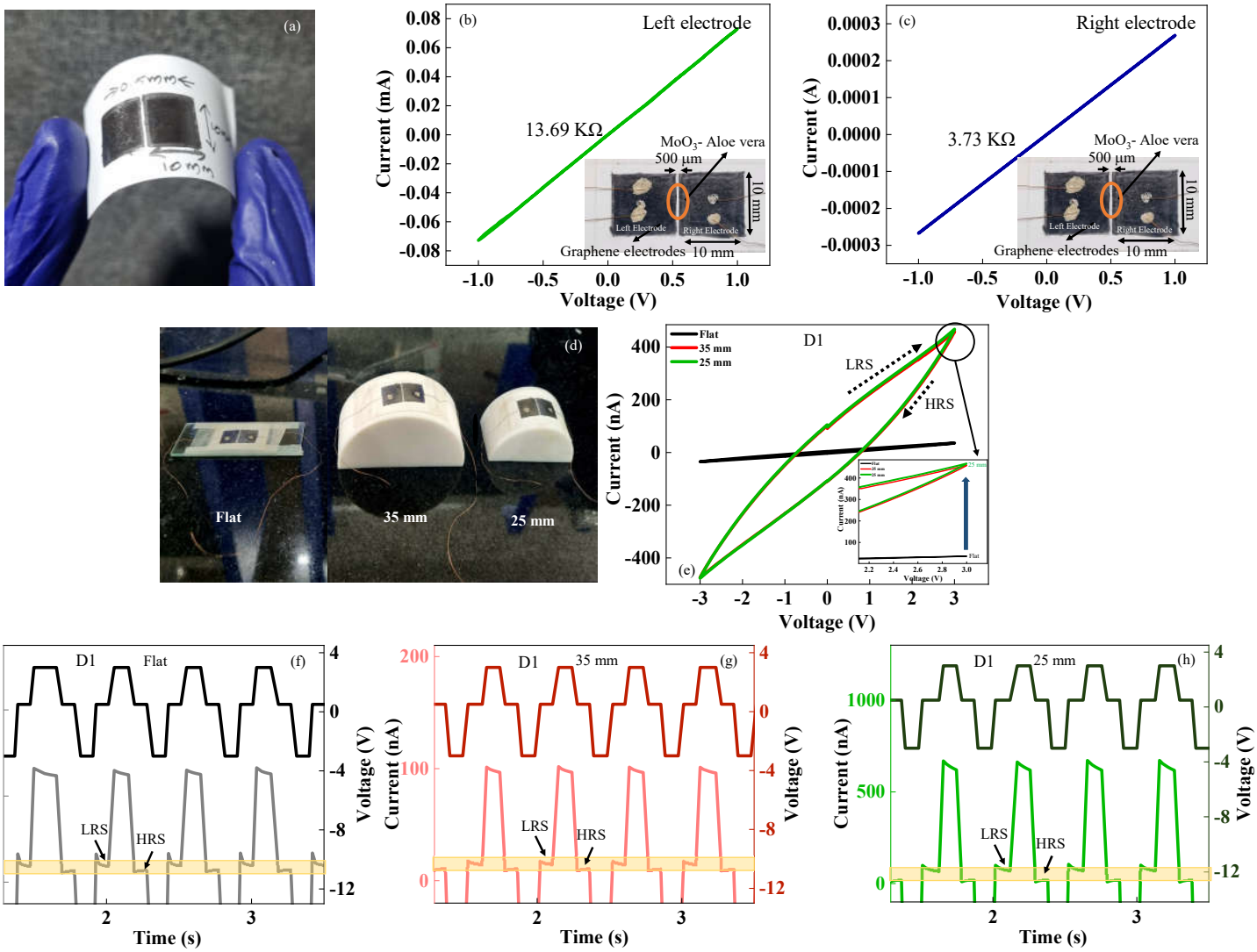


Figure S1. (a) Schematic representation of flexible multilayer graphene electrodes developed using pencil-on-paper (b) and (c) Electrode resistance of Left Electrode and Right Electrode. Insets display the fabricated device with connections to check the individual electrode resistance. (d) Fabricated device placed on a flat surface, strained to a radius of 35 mm (0.3% strain) and the device Strained to a radius of 25 mm (0.42% strain) (d) Comparison of Current-Voltage characteristics for device in flat surface with 0% strain and under strain of 0.3% and 0.42% respectively. (f-h) Read-write-Erase (RWE) measurements performed with a write voltage of +3 V and 0.5 V as the read pulse at 100 ms pulse width. (f) Flat surface (g) Strained device to a radius of 35 mm (0.3% strain) (h) Strained device to a radius of 25 mm (0.42% strain)

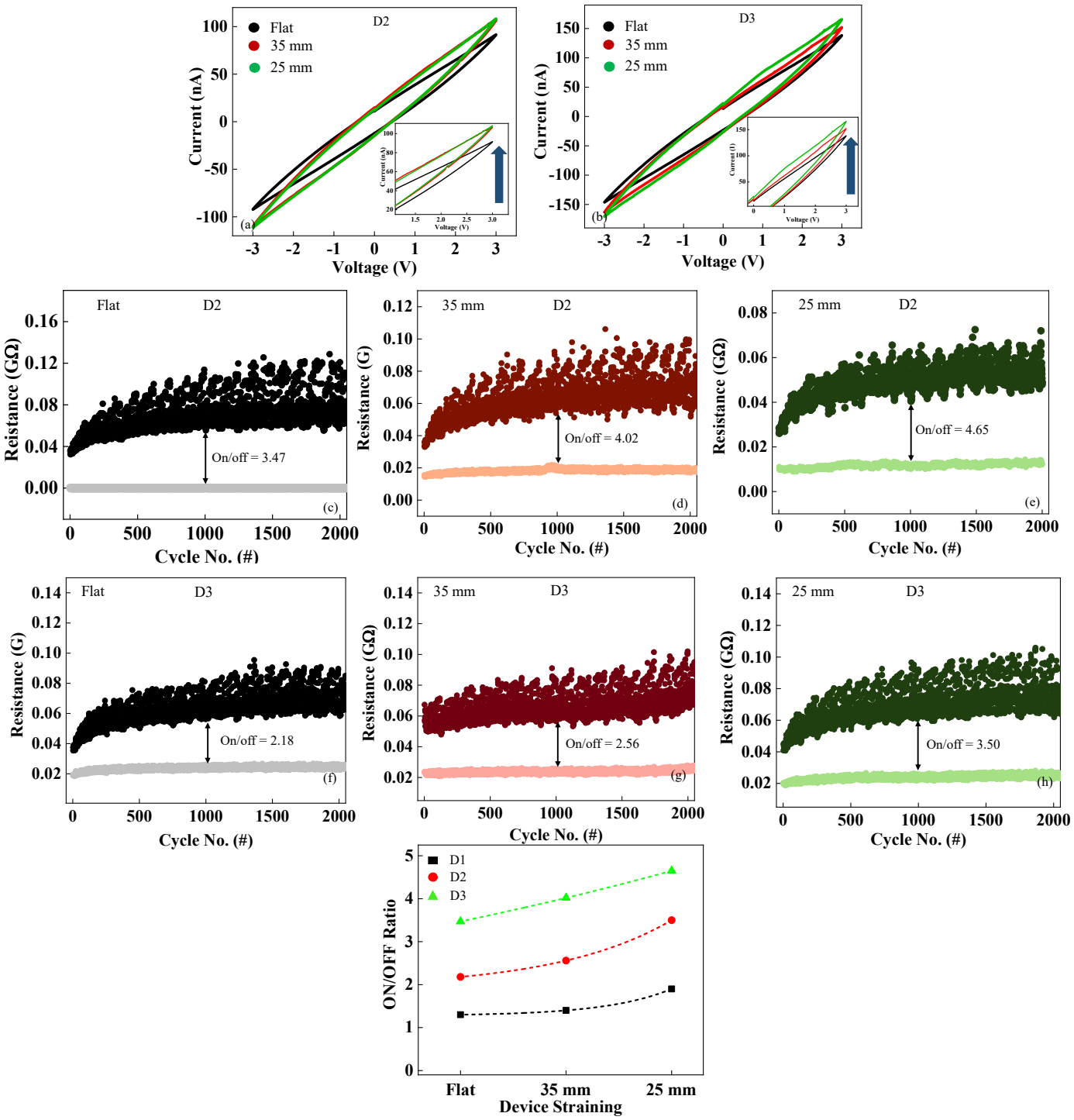


Fig. S2 (a) Comparison of Current-Voltage characteristics for device D2 in flat surface with 0% strain and under strain of 0.3% and 0.42% respectively. (b) Comparison of Current-Voltage characteristics for device D3 in flat surface with 0 \% strain and under strain of 0.3 \% and 0.42% respectively. (c-d) Read-write-Erase (RWE) measurements performed for device D2 with a write voltage of +3 V and 0.5 V as the read pulse at 100 ms pulse width. (c) Flat surface (d) Strained device to a radius of 35 mm (0.3% strain) (e) Strained device to a radius of 25 mm (0.42% strain) (f-h) Read-write-Erase (RWE) measurements performed for device D2 with a write voltage of +3 V and 0.5 V as the read pulse at 100 ms pulse width. (f) Flat surface (g) Strained device to a radius of 35 mm (0.3% strain) (h) Strained device to a radius of 25 mm (0.42% strain) (i) ON/OFF ratio vs device straining (no strain to 0.42% strain) for devices D1, D2 and D3. (i) on/off ratio vs device straining for devices D1, D2, D3 respectively.

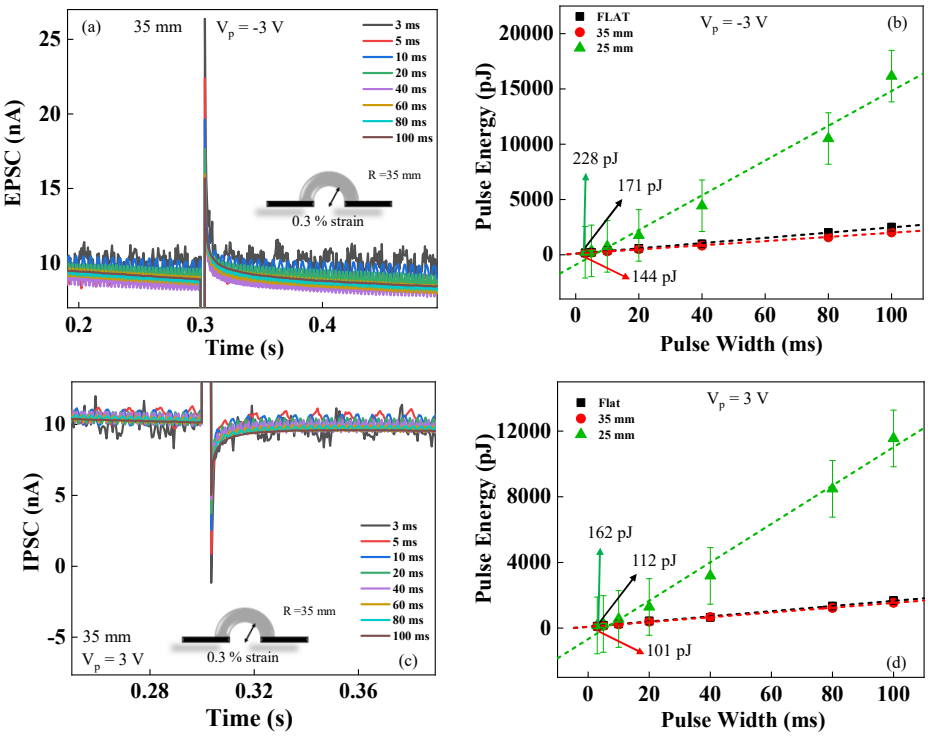


Figure S3. Inhibitory and Excitatory post synaptic current. (a) Electrical pulse (EPSC) applied to device undergoing 0.3% strain with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms. (b) Comparison of pulse energy calculated for EPSC with -3 V pulse by varying pulse width (P_w) for the device in a flat surface, and undergoing strain at 0.3% and 0.42% respectively.(c) Electrical pulse (IPSC) applied to device undergoing 0.3% strain with an amplitude of +3 V with pulse width varying from 3 ms to 100 ms. (d) Comparison of pulse energy calculated for IPSC with -3 V pulse by varying pulse width (P_w) for the device in a flat surface and undergoing strain at 0.3% and 0.42% respectively.

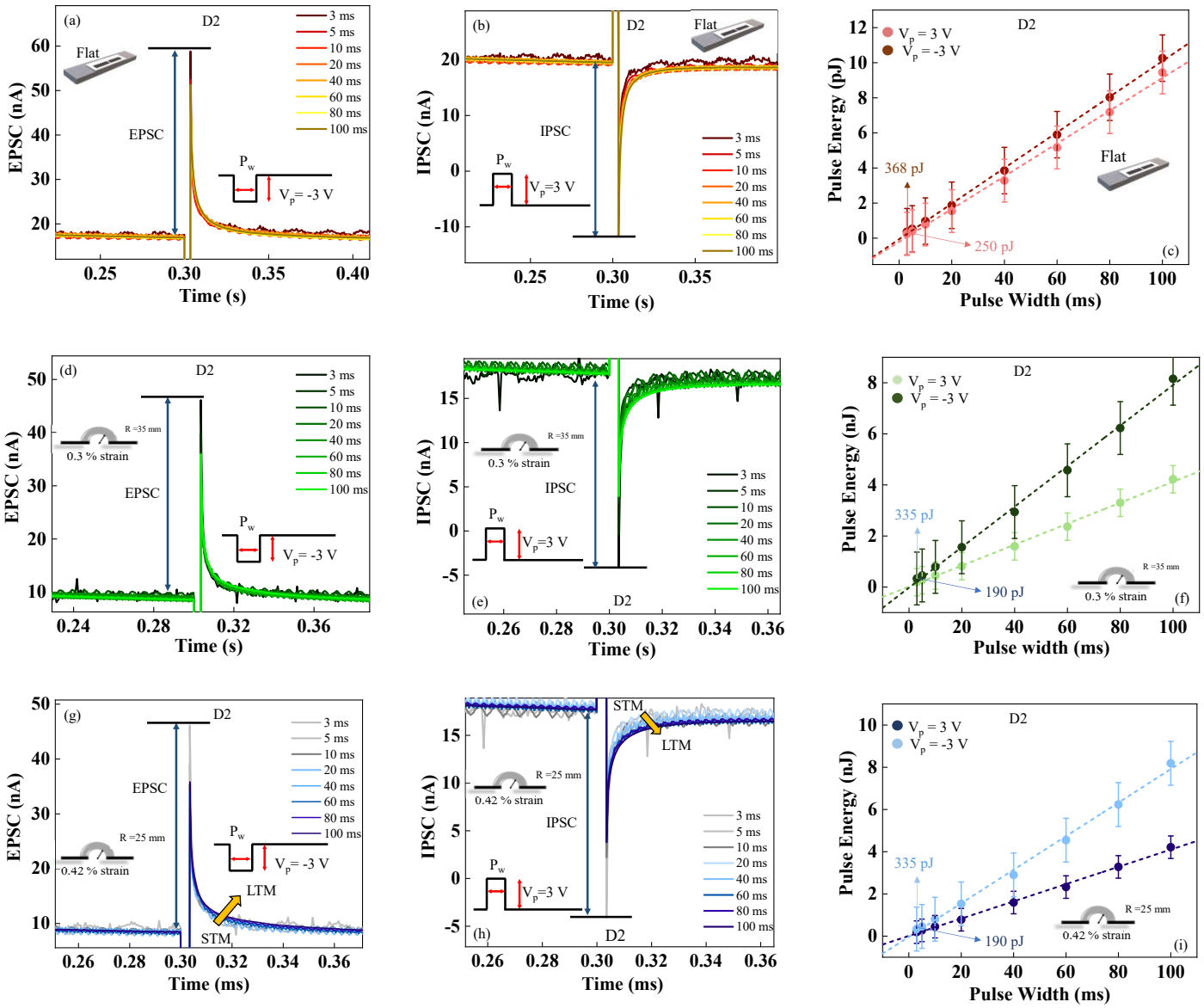


Figure S4. Inhibitory and Excitatory post synaptic current measured for Device 2 (D2). (a) Electrical pulse (EPSC) applied to device in a flat surface with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms. (b) Electrical pulse (IPSC) applied to device in a flat surface with an amplitude of +3 V with pulse width varying from 3 ms to 100 ms. (c) Comparison of pulse energy calculated for ±3 V pulse by varying pulse width (P_w) for the device in a flat surface. (d) Electrical pulse (EPSC) applied to device undergoing 0.3% strain with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms.(e) Electrical pulse (IPSC) applied to device undergoing 0.3% strain with an amplitude of +3 V with pulse width varying from 3 ms to 100 ms. (f) Comparison of pulse energy calculated for ± 3 V pulse by varying pulse width (P_w) for the device undergoing strain at 0.3%. (g) Electrical pulse (EPSC) applied to device undergoing 0.42% strain with an amplitude of +3 V with pulse width varying from -3 ms to 100 ms. (h) Electrical pulse (IPSC) applied to device undergoing 0.42% strain with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms. (i) Comparison of pulse energy calculated for ± 3 V pulse by varying pulse width (P_w) for the device undergoing strain at 0.42 %.

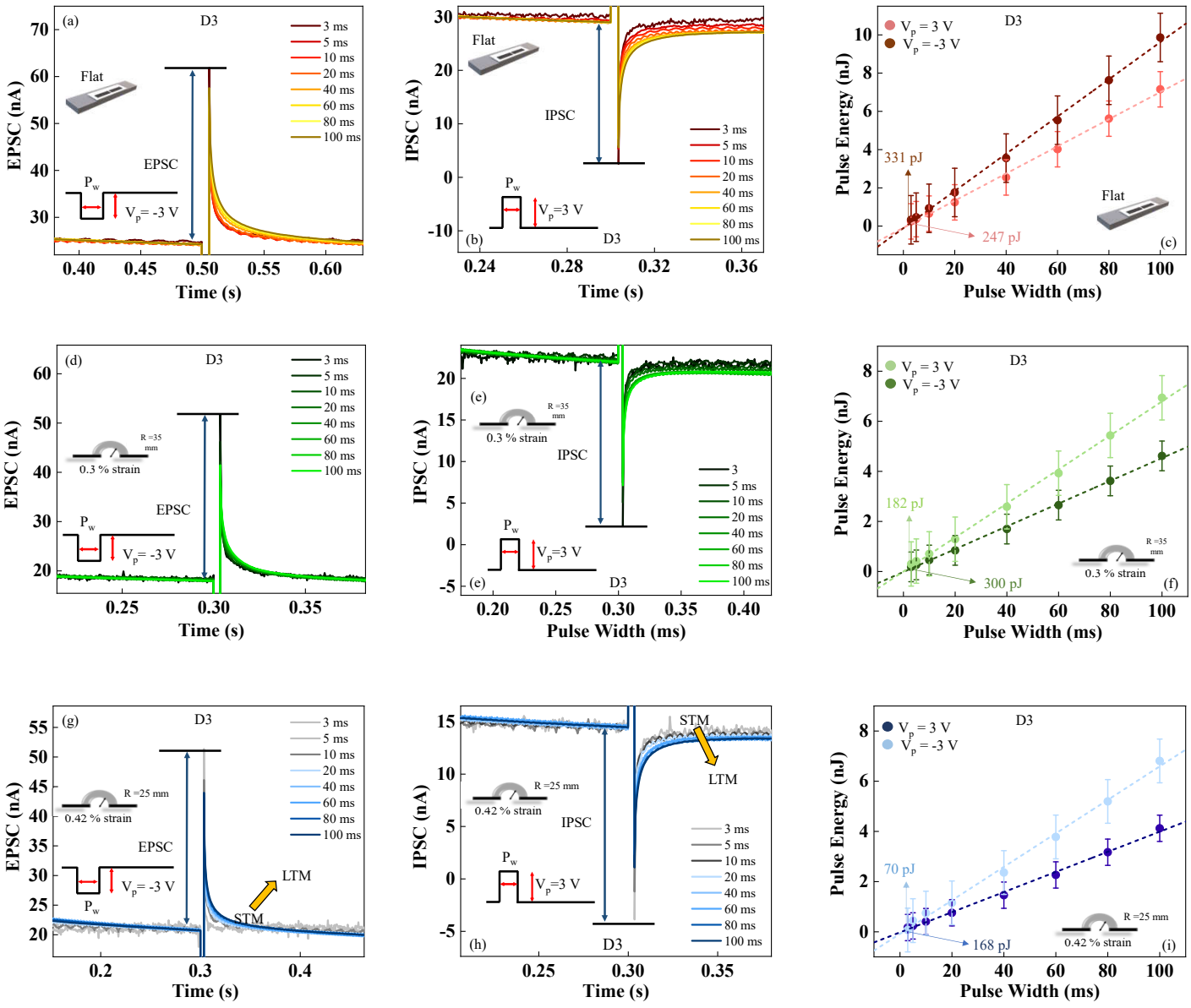
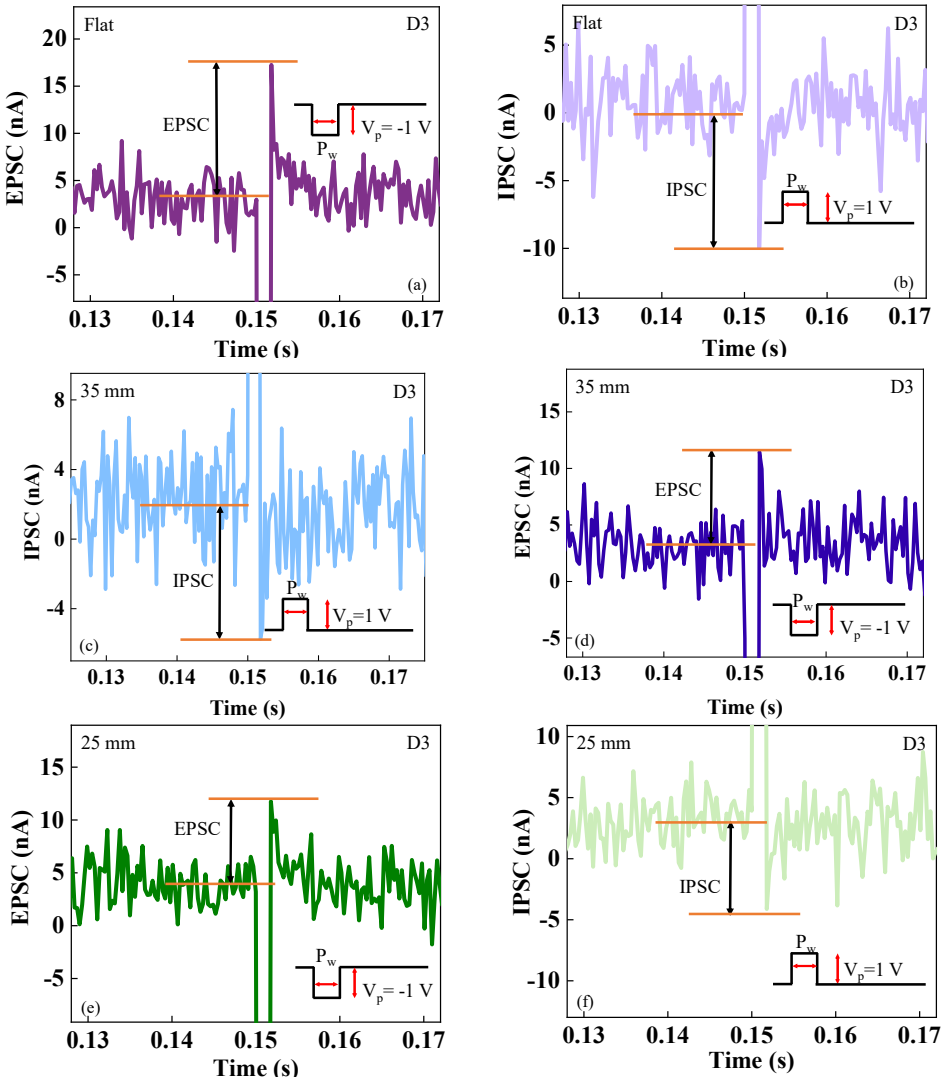


Figure S5. Inhibitory and Excitatory post synaptic current measured for Device 3 (D3). (a) Electrical pulse (EPSC) applied to device in a flat surface with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms. (b) Electrical pulse (IPSC) applied to device in a flat surface with an amplitude of +3 V with pulse width varying from 3 ms to 100 ms. (c) Comparison of pulse energy calculated for ± 3 V pulse by varying pulse width (P_w) for the device in a flat surface. (d) Electrical pulse (EPSC) applied to device undergoing 0.3% strain with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms.(e) Electrical pulse (IPSC) applied to device undergoing 0.3 \% strain with an amplitude of +3 V with pulse width varying from 3 ms to 100 ms. (f) Comparison of pulse energy calculated for ± 3 V pulse by varying pulse width (P_w) for the device undergoing strain at 0.3%. (g) Electrical pulse (EPSC) applied to device undergoing 0.42% strain with an amplitude of +3 V with pulse width varying from -3 ms to 100 ms. (h) Electrical pulse (IPSC) applied to device undergoing 0.42% strain with an amplitude of -3 V with pulse width varying from 3 ms to 100 ms. (i) Comparison of pulse energy calculated for ± 3 V pulse by varying pulse width (P_w) for the device undergoing strain at 0.42%.



Strain	D2 V = 1 V (pJ)	D2 V = -1 V (pJ)	D3 V = 1 V (pJ)	D3 V = -1 V (pJ)
FLAT (0 %)	10	20.6	15	5
35 mm (0.3 %)	8	11.3	11.8	13.3
25 mm (0.42 %)	18.6	21.8	12.7	12.7

Figure S6. Inhibitory and Excitatory post synaptic current measured for Device 3 (D3) at a pulse amplitude of 1 V and read voltage of 0.1 V. The pulse width is 1.5 ms. (a) EPSC measured for device in Flat surface with an amplitude of -1 V (b) IPSC measured for device in Flat surface with an amplitude of 1 V (c) EPSC measured for device undergoing 0.3% strain with an amplitude of -1 V (d) IPSC measured for device undergoing 0.3 \% strain with an amplitude of 1 V (e) EPSC measured for device undergoing 0.42% strain with an amplitude of -1 V (f) IPSC measured for device undergoing 0.42% strain with an amplitude of 1 V (g) Table with the energy consumption computed for devices D2 and D3 under strained and unstrained conditions.

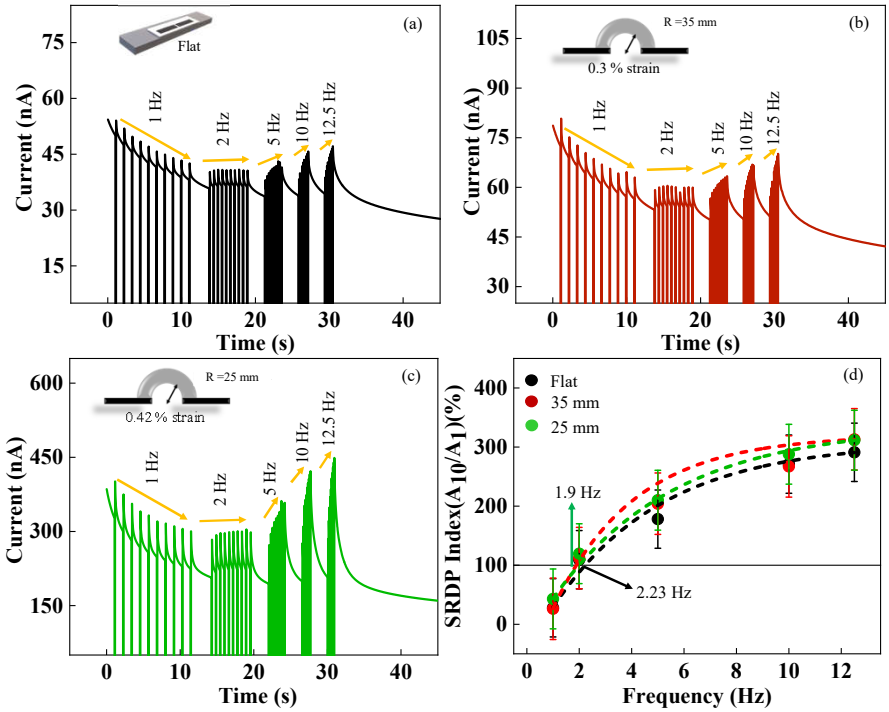


Figure S7. Spike rate dependant plasticity in MLG/MoO_3-Aloevera/MLG device. (a)-(c) Frequency dependant EPSC measurement for -3 V with 10 pulses (a) Device in flat surface (0% strain) (b) Device under 0.3% strain. (c) Device under 0.42% strain (d) Comparison ratio of PSC for 10^{th} pulse to 1^{st} pulse A_{10}/A_1 for the device under no strain and under strain of 0.3% and 0.42% respectively.