Bio-inspired Artificial synapse for neuromorphic computing based on NiO nanoparticle thin film

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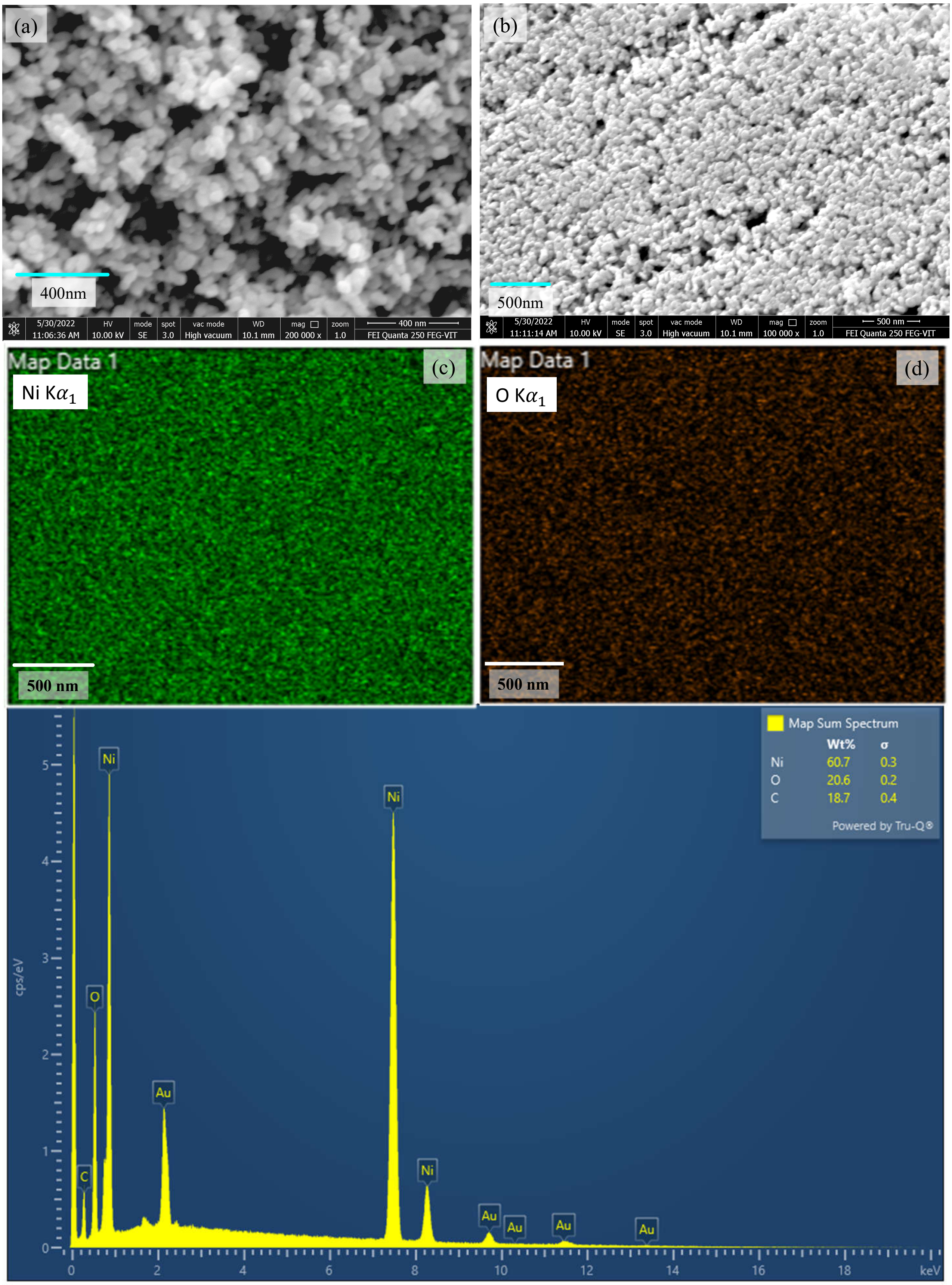
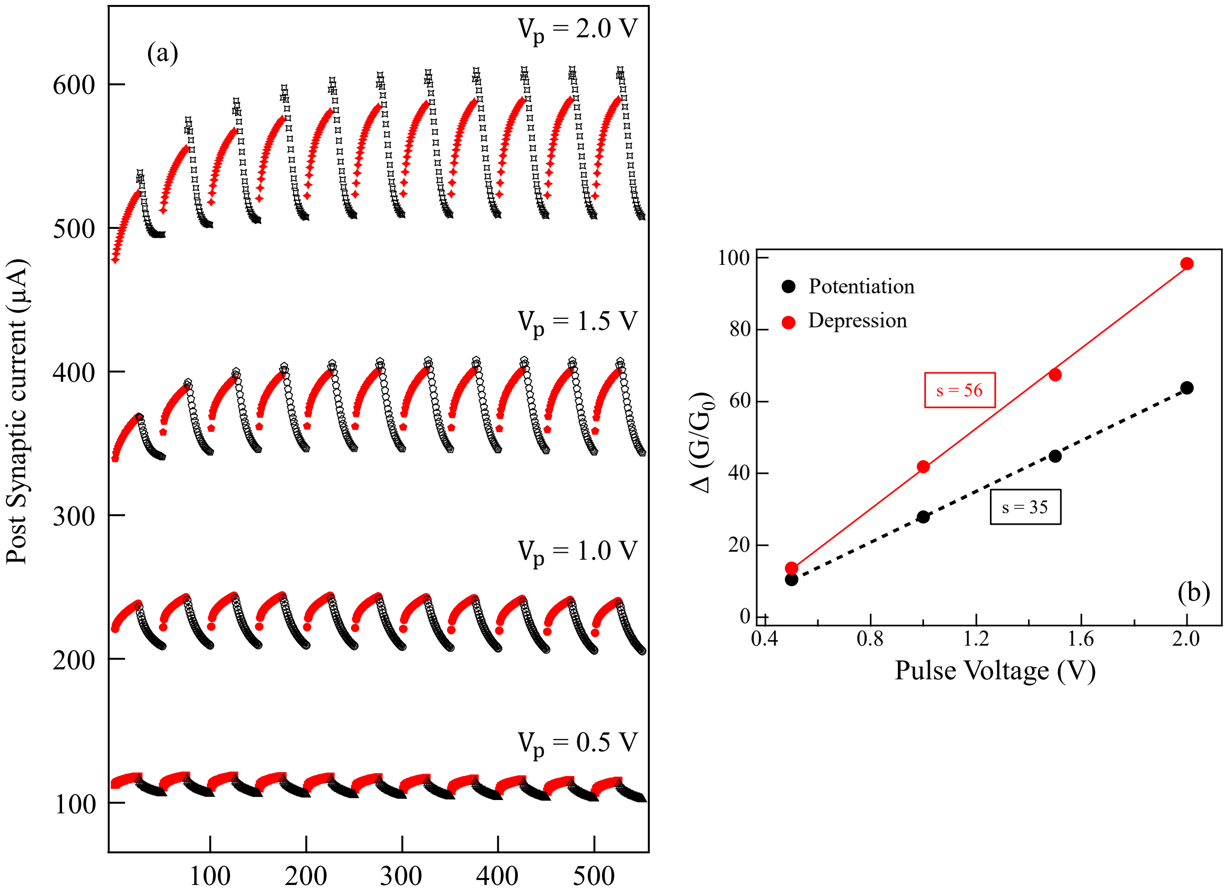


Figure S1 : The Scanning electron Microscopy images of the NiO nanoparticle thin film. (a) and (b) show large area image Depicting uniform distribution of NiO nanoparticles. (c) ED Spectroscopy image for Ni in an area of 3.1 um x 2.4 um and (d) The ED spectroscopy image in the same area depicting the presence of oxygen. (e) Overall E D Spectra shows strong peaks of Ni and O. The average size of the nanoparticle is found to be ~ 45nm.

2θ	FWHM	Crystalline Size D (nm)	Average size (nm)
36.903	0.344	24.345	**23.452**
42.949	0.344	24.816	
62.545	0.394	23.590	
75.071	0.394	25.427	
79.111	0.54	19.081	

Table S2 : Analysis of the XRD peaks (shown in Figure(1)). For the calculation of the crystallite size, all the peaks are considered individually and we used Scherrer formula to calculate the average crystallite size.



(c) Pulse voltage	Potentiation (t_p)			Depression (t_d)		
	$t_{short,p}$	$t_{long,p}$	$\frac{t_{long,p}}{t_{short,p}}$	$t_{short,d}$	$t_{long,d}$	$\frac{t_{long,d}}{t_{short,d}}$
0.5	0.96	16.38	17.1	1.4542	17.493	12.03
1.0	0.85	18.96	22.31	6.5196	18.021	2.76
1.5	0.88	19.25	21.88	10.796	10.899	1.0086
2.0	2.96	23.11	7.81	6.5	6.3	0.97

Figure S3 : The combined potentiation and depression curves with various values of pulse voltages used. For each pulse voltage, series of 11 cycles are repeated to check the learning – forgetting – relearning process. Overall PSC level increases with the pulse voltage. (b) The relative amplitude of PSC change is more for the potentiation step than the depression step. (c) table showing the time constants for the potentiation and depression. Both potentiation and depression curves are fitted with double exponentials as indicated in the text. Potentiation follows a faster growth ($t_{short,p}$) during initial pulsing and then has a slow variation for subsequent pulsing ($t_{long,p}$). A similar $t_{short,d}$ and $t_{long,d}$ can be associated with the depression curves.

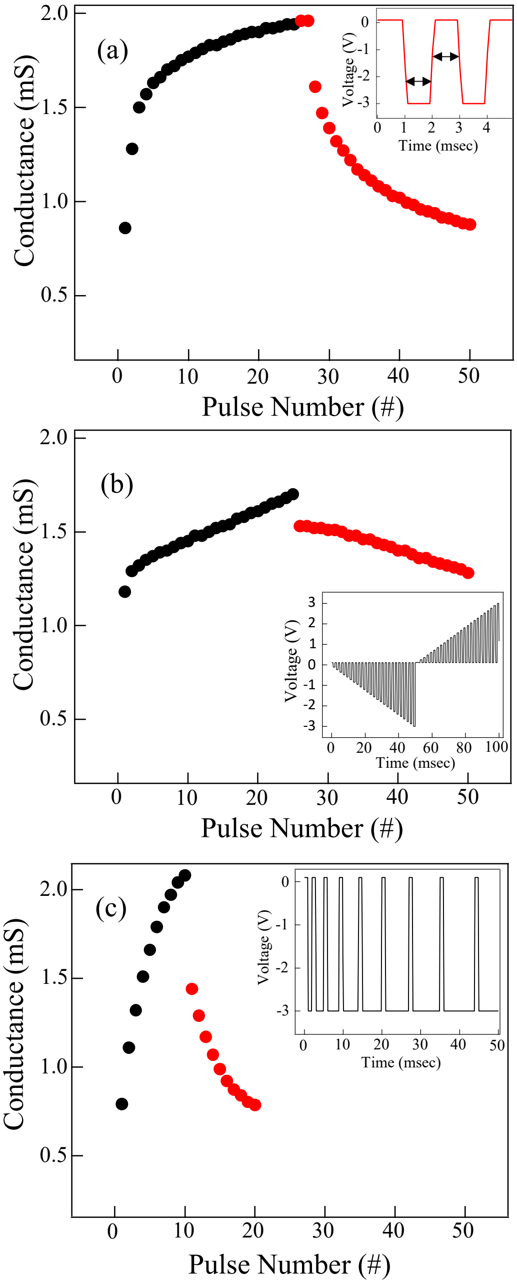


Figure S4 : Application of non-ideal voltage pulses to the device and the neuromorphic performance. (a) The normal constant voltage pulsing results in exponential growth and decay of the post synaptic current. (b) When progressively increasing voltage pulses are used, the potentiation and depression curves tend towards linearity. (c) For a given pulse voltage (-3 V), increasing the pulse width reduces the nonlinearity.

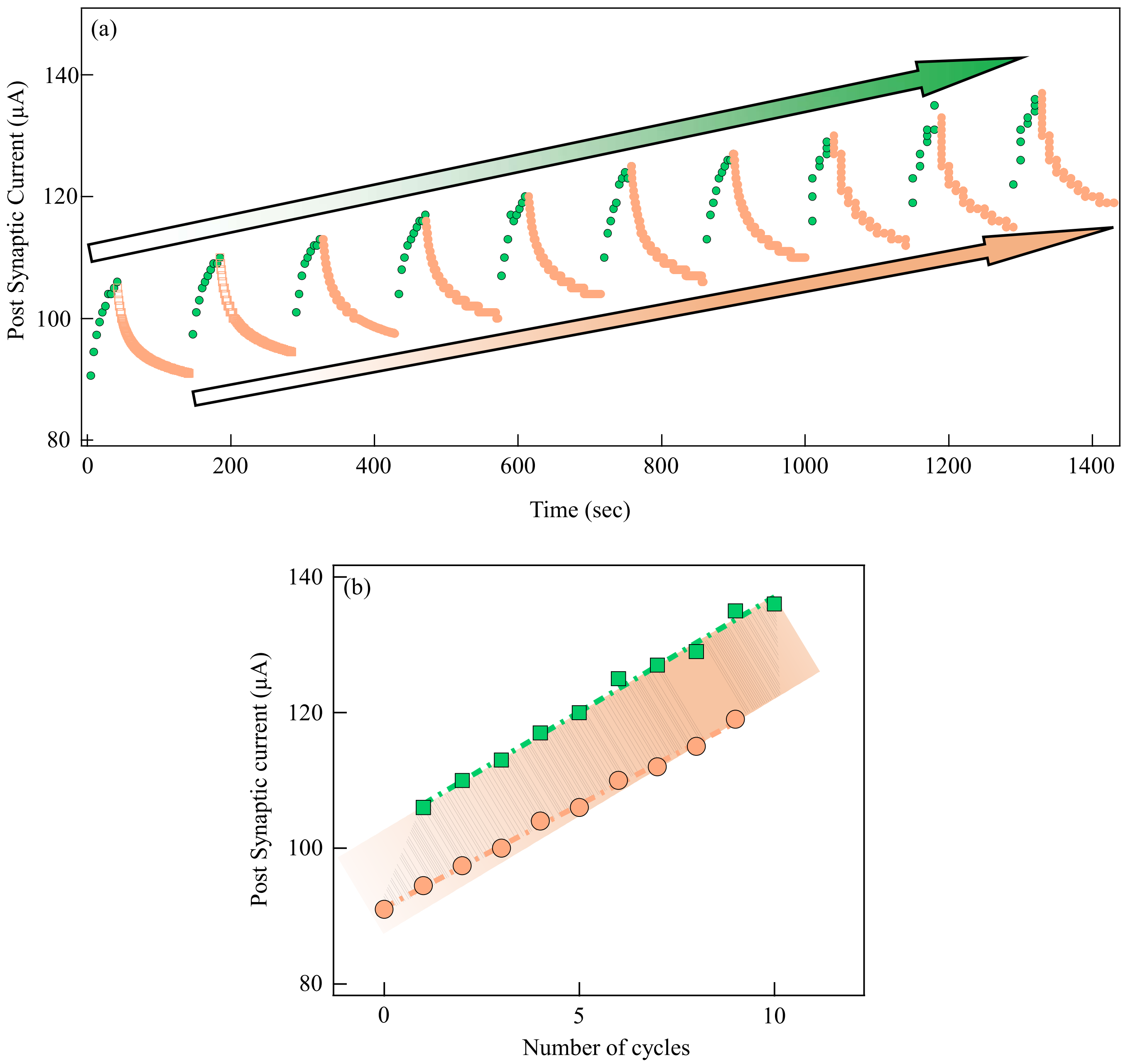


Figure S5 : Emulating the learning – forgetting – relearning curves for NiO nanoparticle based synapse. A series of 10 cycle operation increases the post synaptic current from 90.6 µA to 119 µA. For each Learning curve, 10 pulse () are applied and then the PSC is monitored with time. A linear increase in the PSC can be useful for memory function. (b) The PSC after pulsing (green) and PSC after monitoring for 2 min (orange). Both vary linearly with number of cycles showing an efficient biological synapse using NiO nanoparticles.