

Supporting Information

Flexible and Transparent Memristive Synapse Based on PVP/N-doped Carbon Quantum Dot Nanocomposites for Neuromorphic Computing

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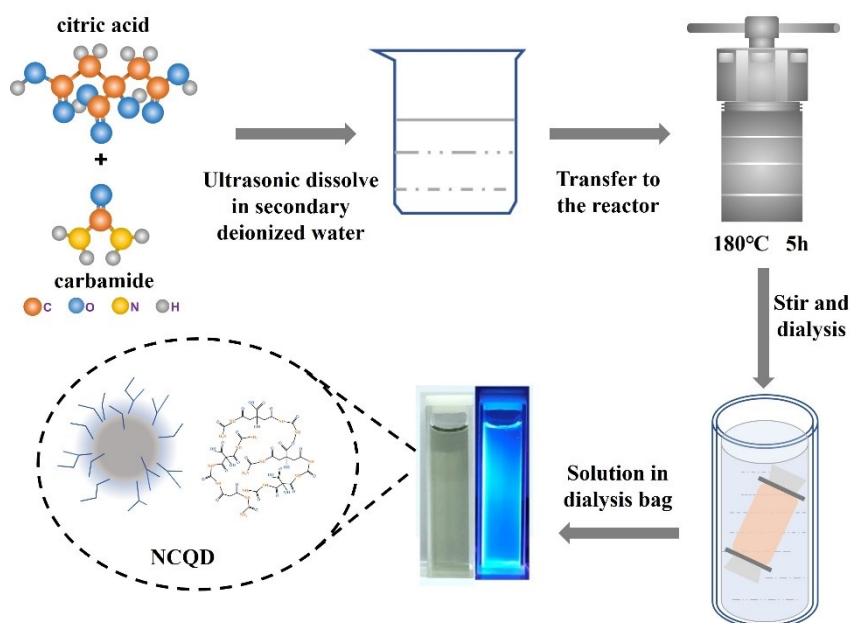


Figure S1. Schematic illustration depicting the fabrication process of NCQDs. The NCQDs were synthesized by hydrothermal treatment method from citric acid and urea: 1.4 g of citric acid and 1 g of urea were ultrasonically dissolved in 40 mL of secondary deionized water (the total nitrogen content in the organic mixture, that is, the nitrogen doped WN=9.61wt%) to form a transparent solution. Then the mixture solution was transferred into a high-pressure reactor at 180°C for 5 h with polytetrafluoroethylene as the substrate. Cool the reactant to room temperature naturally for obtaining a clear brown solution. Then use a dialysis bag with a molecular weight cut-off of 3500 Da to dialyze for 12 h. Finally, NCQDs powder is obtained after freeze-drying.

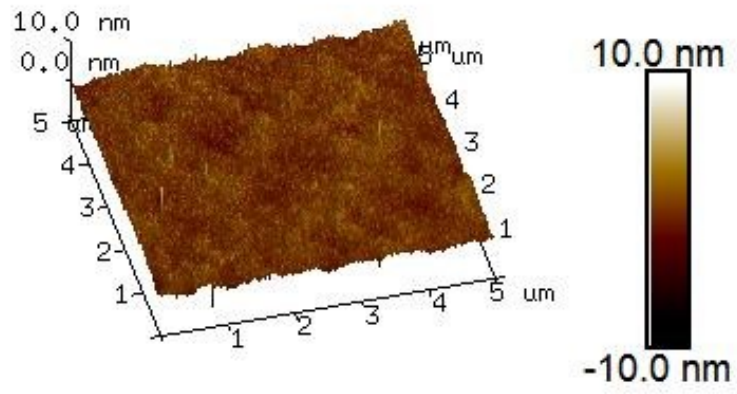


Figure S2. The surface morphology of PVP-NCQD film through AFM images.

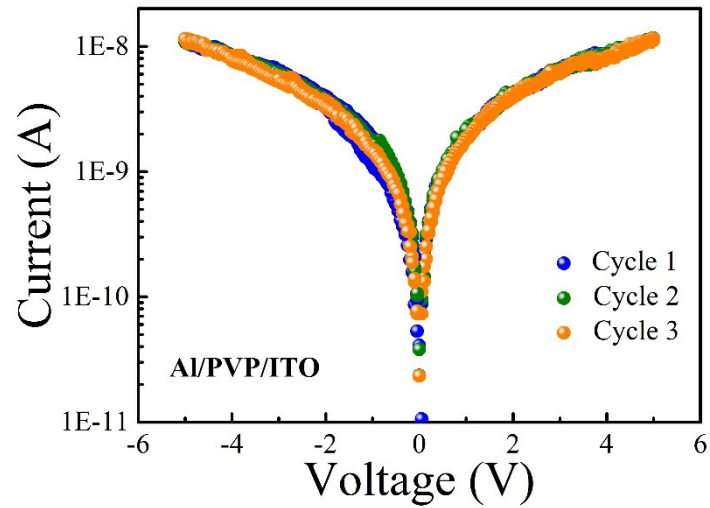


Figure S3. I-V curves Al/PVP/ITO memristor without inserting NCQDs into PVP film. For the multiple I-V cycles of both SET and Reset process, there are no obvious RS behavior in the devices without inserting NCQDs into PVP film. The results indicate that the PVP layer itself is unable to provide charge trapping centers to induce the RS characterization.

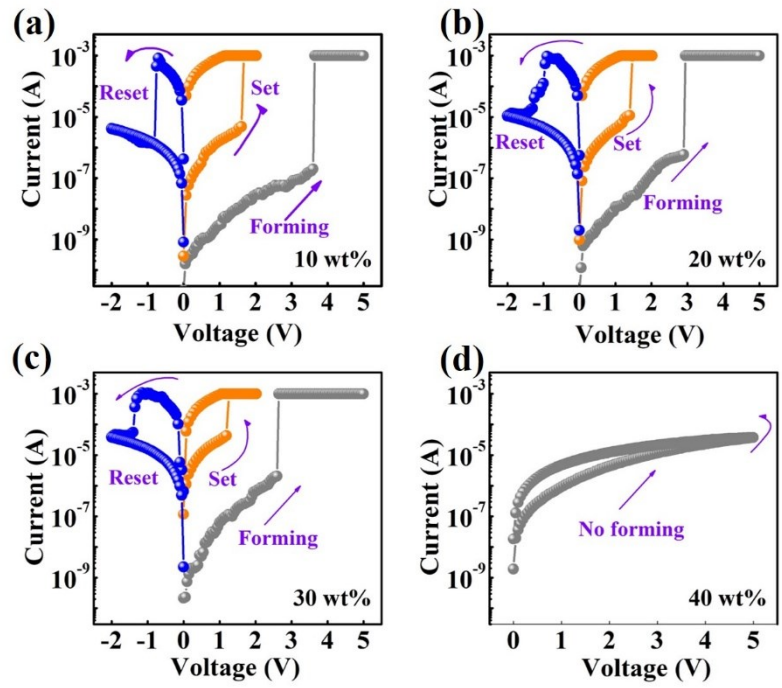


Figure S4. I-V scanning characteristic curve of the device with (a) 10wt% (a) 20wt% (b) 30wt% and (c) 40wt% NCQDs doping concentration.

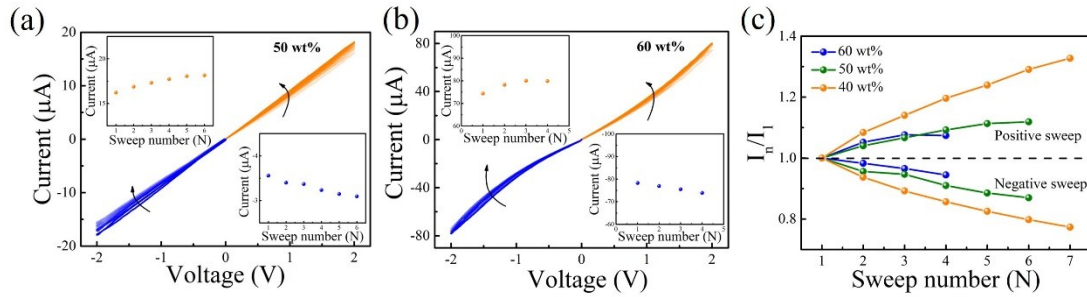


Figure S5. I-V curves Al/PVP-NCQDs/ITO memristor with (a) 50 wt% and (b) 60 wt% NCQDs concentration. (c) The varying of current after continuous voltage sweeps in three devices with 40 wt%, 50 wt% and 60 wt% NCQDs concentration. Compared to the device with 40 wt% NCQDs concentration, there are a less obvious current variation under continuous voltage sweep with 50 wt% and 60 wt% NCQDs concentration as shown Figures S5 (a) and (b). Figure S5 (c) presents the intuitive statistics of current variables with sweep voltage for three high-doping concentration devices. Obviously, it is found that the device with 40 wt% NCQDs concentration has the largest current variation, and the current variation still does not reach saturation after the 7th sweep.

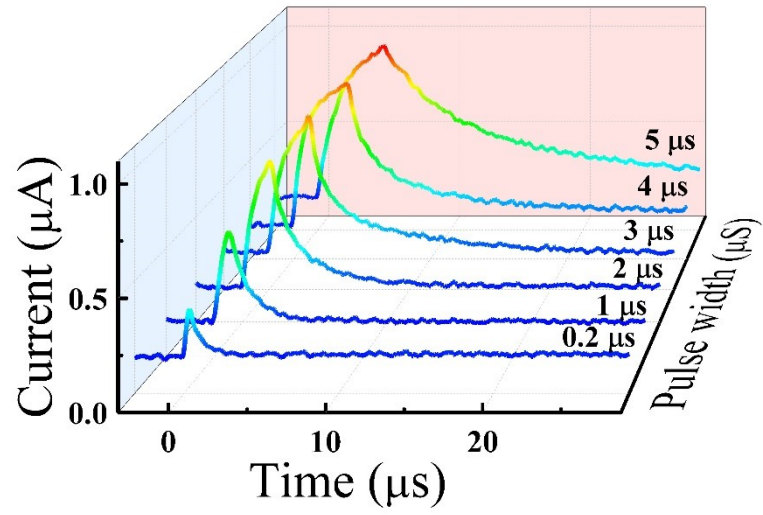


Figure S6. A transition from STP to LTP appears through pulse width.

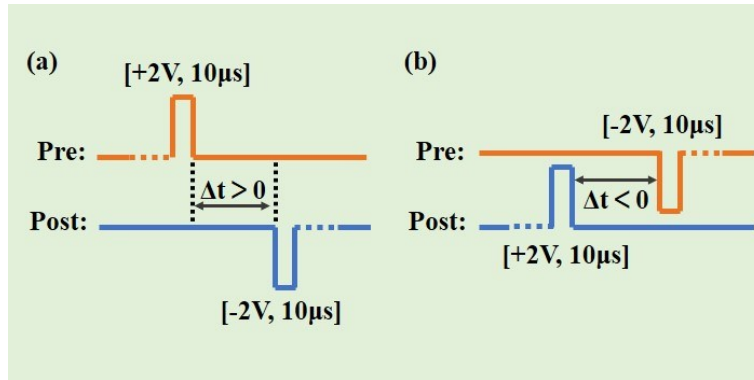


Figure S7. The presynaptic/postsynaptic spike was set with the pulse amplitude of 2V/-2 V and a pulse width of 10 μ s, which was applied on the top/bottom electrode for stimulation. In order to measure the long vaule, the initial and final states of the device were read before and 1000ns after applying the paired pulses, respectively marked as G_0 and G_{end} . ΔG was defined as $\Delta G = G_{\text{end}} - G_0 / G_0 \times 100\%$. (a) If the presynaptic spike occurs earlier than the postsynaptic spike, the spike timing between them was defined as $\Delta t > 0$, which results in LTP. (b) On the other hand, if the postsynaptic spike occurs earlier than the presynaptic spike, the spike timing between them was defined as $\Delta t < 0$, which leads to LTD.

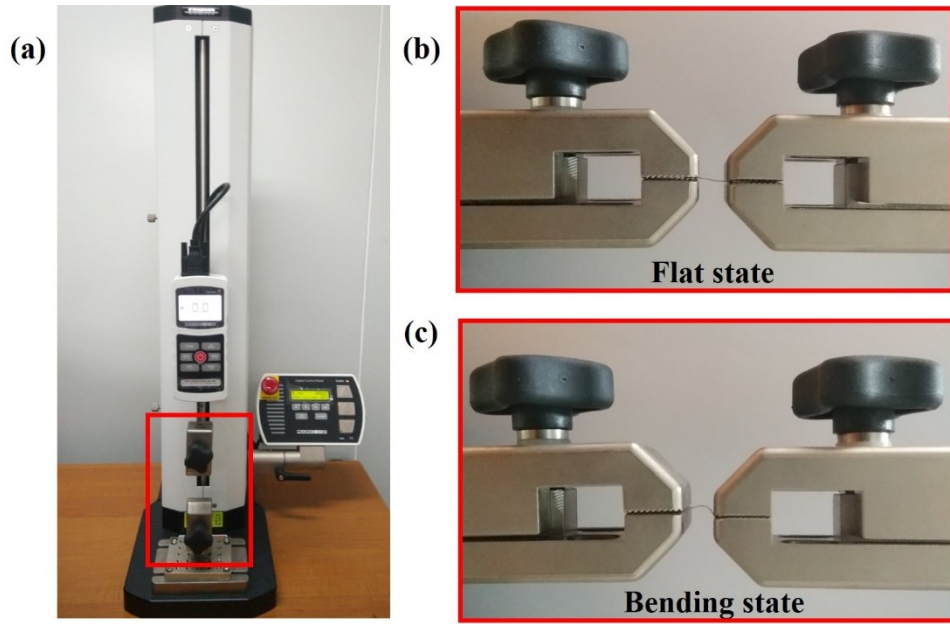


Figure S8. (a) The photograph of the dynamometer (Mark-10) and the highly configurable electric stand (ESM303). The photograph of the Al/PVP-NCQD/ITO synaptic device in (b) flat state and (c) bending state. The bending angle can be set by adjusting the distance between the two brackets and repeated bending number can be controlled by the process setting.