Physical Reservoir Device for Supervised Learning by Random Network of Single-Walled Carbon Nanotube/Porphyrin-Polyoxometalate

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[Introduction] Based on the previously reported theoretical model of a random network (RNW) of single-walled carbon nanotube (SWNT)/polyoxometalate (POM) reservoir[1], we hereby report the fabrication of a physical reservoir computing (RC) device using RNW of SWNT/porphyrin-polyoxometalate ($SV_2W_{10}O_{40}[H_4TPP]$)[2] (Por-POM) complex. Experimentally we show that by inputting time-series tactile grasping object data from Toyota Human Support Robot (HSR)[3], into the RNW of SWNT/Por-POM reservoir we can generate multiple non-linear high dimensional outputs and train them successively to achieve one-hot vector binary classification of different objects.

[Method] The vacuum-filtrated sonicated dispersion of SWNT/Por-POM in ethanol was transferred onto photolithographically patterned Al micro-electrodes. The filter paper was dissolved via acetone vapors to form the random thin-film network. I-V was performed using a semiconductor analyzer. A custom-built probe set-up driven by LabVIEW software was used to generate time-series outputs from the Toyota HSR input tactile grasping data. All experimental measurements were performed at ambient conditions.

[Result and discussion] Non-linearity accompanied by negative differential resistance (NDR) peak around 1.8V is seen in Fig. 1a. Such dynamical effect arises from redox states in the Por-POM complex giving rise to charge-discharge at the SWNT/Por-POM interface. The behavior leads to Spatio-temporal input data mapping to high dimensional outputs, as seen for grasped objects of hedgehog (HH) and block (BL) in Fig. 1b with different spike-like outputs indicating separable feature extraction. By utilizing the non-linear, high dimensional and separable properties of the device, we finally show in Fig. 1c that after supervised training, a binary testing dataset of HH and BL was successfully classified using one-hot vector encoding, where the correctly classified object, HH, follows the target vector value '1', and BL, the target vector '0'. We believe that a physical reservoir network with such intrinsic properties can prove important for more complex supervised classification tasks. Along with large network scalability, the results also emphasize the straightforward supervised RC training architecture opening opportunities for low-dimensional molecular materials towards developing artificial-intelligence systems in the near future.

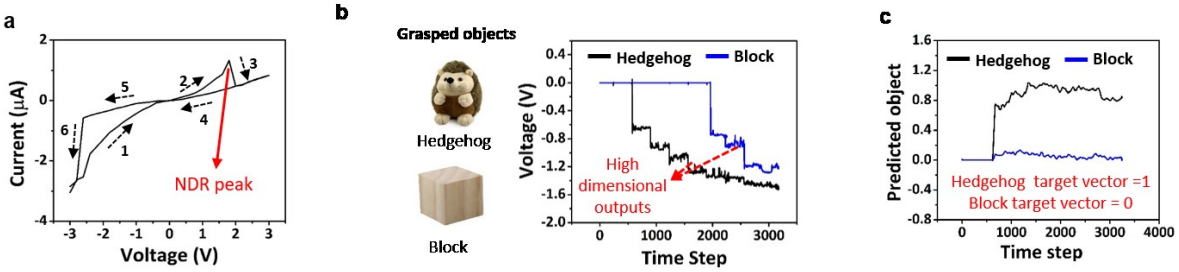

Fig. 1 (a) Non-linear I-V with NDR peak, a redox phenomenon of Por-POM. (b) Right shows the toys grasped by Toyota HSR and left shows the high dimensional spiking time-series outputs generated from hedgehog (black) and block (blue) toys. (c) Test dataset one-hot vector binary classification where the true positive object predicted is a hedgehog (black) with supervised target vector '1' and true negative predicted block (blue) with value '0'.

Keywords: Reservoir computing, single-walled carbon nanotube, $SV_2W_{10}O_{40}[H_4TPP]$, polyoxometalate.

References: [1] H. Tanaka et al., *Nature. Commun.* **9**, 2693 (2018). [2] T. Ogawa et al., *J. Mater. Chem. C* **8**, 14423–14430 (2020). [3] T. Yamamoto et al., *ROBOMECH J.* **6**, (2019)