Reservoir computing with Single-Walled Carbon Nanotube/ Polyoxometalate Random Network

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[Introduction] Reservoir computing has emerged as a new class of neural network for solving cognitive tasks of prediction and classification efficiently. Recently, the focus is on creating hardware platform with diverse physical systems that reflects inherent reservoir properties of non-linearity, memory effect and high-dimensionality[1]. Herein, we develop a reservoir hardware device using randomly connected networks of single-walled carbon nanotube (SWNT)/porphyrin-polyoxometalate (Por-POM) by following a similar theoretical model to a previous research[2]. We affirm the characteristic reservoir properties of this system and finally performed a waveform generation task to prove its credibility as a reservoir computer[3].

[Method] SWNT/ Por-POM ($SV_2W_{10}O_{40}[H_4TPP]$) in the ratio 1:20 by weight was sonicated in ethanol. It was transferred on a glass substrate containing Al sputtered micro electrodes patterned using photolithography, by vacuum filtrating the dispersion through a micro-cellulose filter paper followed by dissolution of the filter paper via acetone vapors. I-V and a rudimentary reservoir task of waveform generation were performed using a semiconductor analyzer and a custom built probe set up driven by Labview software. All measurements were performed at room temperature and pressure.

[Result and discussion] Successful functionalization of SWNT/Por-POM complex was confirmed using AFM. The pinched hysteresis in I-V analysis (Fig. 1a) confirms non-linearity with a memory effect arising from multiple redox charge-discharge states of Por-POM species. The phase shifted sine waves produced at multiple output electrodes (Fig. 1b) and the deduction of higher harmonic frequencies by FFT analysis confirmed high dimensionality. Based on these findings, waveform generation task[3] from a sine to triangle (Fig. 1c), sawtooth and square (Fig. 1d) wave was performed by training only the output weights and linearly combining the different outputs. The mean square error (MSE) was calculated that gave the fitting accuracy of the generated and target wave. The Triangle wave showed the best result with an accuracy of 99.8% (MSE = 0.013) followed by square and sawtooth indicating infinite harmonics are required to produce better results. Further analysis on increasing the output electrodes and NARMA prediction tasks are being carried out for developing a full-fledged reservoir system that can help in speech recognition task in near future.

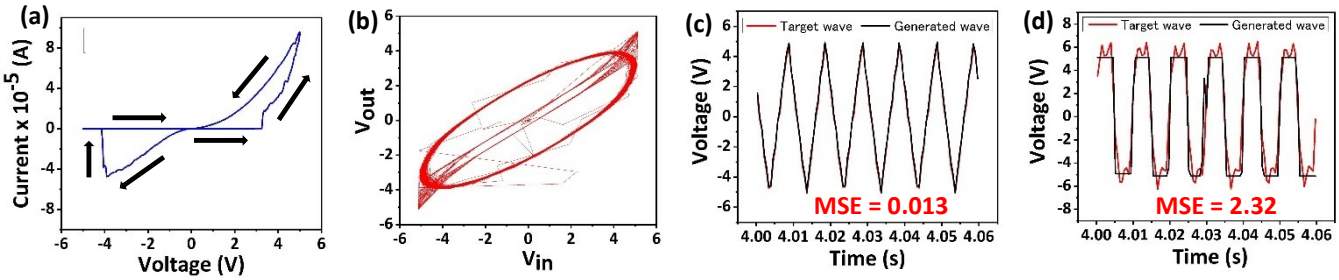

Fig. 1 (a) I-V showing non-linear memory effect due to redox of Por-POM. (b) Phase shifted sine wave from one output electrode. Information is retained in the system. (c), (d) Fitting of output sine waves to triangle and square wave through linear regression. Low MSE of triangle indicates better learning.

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

References: [1] G. Tanaka et al., *Neural Netw.*, **115**, 100-123 (2019). [2] H. Tanaka et al., *Nature. Commun.* **9**, 2693 (2018). [3] E. C. Demis et al., *Jpn. J. Appl. Phys.*, **55**, 1102B2 (2016).