In-materio supervised Boolean logic operation by random network of single-walled carbon nanotube/porphyrin-polyoxometalate

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[Introduction] Theoretical studies on random network (RNW) of single-walled carbon nanotube (SWNT)/polyoxometalate (POM) has emerged as an in-materio reservoir computing (RC) paradigm recently[1] owing to their redox based non-linear dynamics. Considering this inherent property, we hereby take a step further to fabricate a physical reservoir device using RNW of SWNT/porphyrin-polyoxometalate ($SV_2W_{10}O_{40}[H_4TPP]$)[2] (Por-POM) complex and experimentally demonstrate the SWNT/Por-POM's ability to perform supervised in-materio RC Boolean logic operations. By optimizing only the readout weights, the device was able to successfully reconstruct the target Boolean functions of OR, AND, and XOR gates with the highest accuracy of 98%, thereby marking its compatible for future brain-like large-scale bio-inspired unconventional computing.

[Method] Sonicated dispersion of SWNT/Por-POM in ethanol was vacuum-filtered to get the RNW structure on filter paper. The fabricated RNW was then transferred onto a photolithographically patterned Al micro-electrode (MEA) by dissolving the filter paper with acetone vapors at 80°C to get the desired physical reservoir device. The device was finally integrated with a custom-built probe set-up driven by LabVIEW software to carry out the RC task of Boolean logic optimization at ambient conditions.

[Result and discussion] Figure 1a shows the schematic of the SWNT/Por-POM in-materio RC Boolean logic optimization. Two inputs of binary '0' and '1' was fed to the SWNT/Por-POM reservoir simultaneously and multiple high–dimensional outputs were collected. A weighted linear readout of all the reservoir voltage output states were then used to reconstruct target Boolean functions of OR, AND, and XOR gates with an example of OR gate shown in Fig. 1a. The training was supervised using a multiple linear regression where each 'n' output weights ($w_1, w_2, \ldots w_n$) were optimized to fit the desired Boolean target till the mean squared error between the Y_{res} and Y_{target} was minimized. A successful OR reconstruction is shown in Fig. 1b, where after training (red line) an epoch of 20 s, the optimized weights were able to trace an additional 20 s epoch (blue line) test data with an accuracy of 92%.

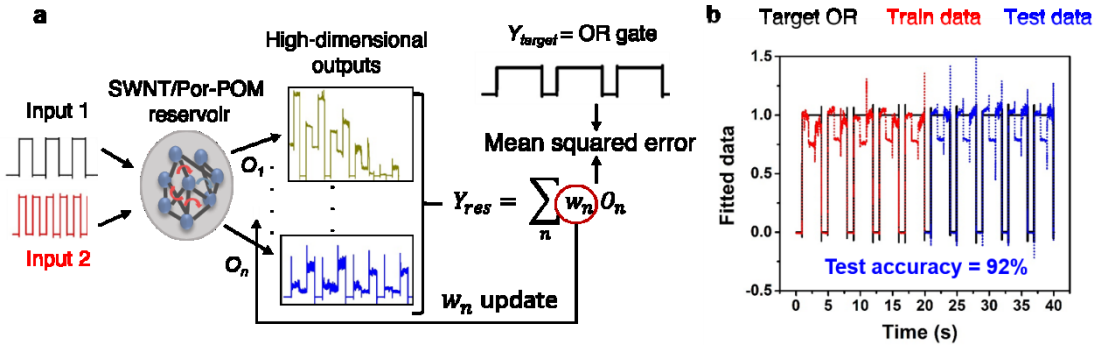

Fig. 1 (a) Schematic of in-materio RC for Boolean logic operation. Two inputs are fed to SWNT (black line)/Por-POM (blue circle) reservoir having recurrent connections (red arrows) and multiple high-dimensional outputs ($O_1 \ldots O_n$) were readout. Linear weighted combination was performed to give the resultant reservoir output Y_{res} and weights (W_n) were optimized with target Y_{target}-OR gate to get the best fit by minimizing the mean squared error between Y_{res} and Y_{target}. (b) OR gate Boolean optimization, where after training (red line) the optimized weights successfully fitted the test data (blue line) with 92% accuracy.

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

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