Electrochemical impedance spectroscopy of artificial protonic synaptic devices

Nada H.A. Besisa[1*], S. P. Pati[2], M. Tsuji[1], K. Tsuruda[1], S. Hamasuna[1], Takeaki Yajima[1]

[1]Department of Electrical and Electronic Engineering, Kyushu University, Fukuoka, Japan

[2]North-Eastern Hill University, India

***E-mail: nadaamin129@gmail.com**

Biological neural systems effectively process information in real-time using diverse slow dynamics. Replicating these dynamics in scalable electronic devices has been challenging, especially for operations on time scales ranging from seconds to minutes [1]. This study explores the use of slow proton dynamics in amorphous tungsten oxide (WO_3) for volatile resistance changes in a 2-terminal protonic device (Fig. 1a), aiming to replicate real-time information processing similar to biological neural systems. By applying a voltage below 1 V, hydrogenation or dehydrogenation of WO_3 occurs at a Pd electrode, causing significant changes in electronic conductance, which enables short-term information storage (fig. 1b). However, the mechanism behind the proton-induced conduction modulation whether it occurs primarily in the bulk or at the interface remained unclear. To address this, we conducted electrochemical impedance spectroscopy (EIS) within frequency range 100 kHz- 10 mHz, analyzed the voltage-dependent Nyquist plots (Fig. 1c-f), and current-dependent Nyquist plots (Fig. 2). These plots revealed two semicircles at different frequencies, corresponding to bulk and interfacial impedance. The results showed that both the bulk and the interface contribute to the conductance modulation, providing a deeper understanding of the device's electric transport behavior. The findings highlight the potential of using proton and electron dynamics in such devices for low-power neuromorphic computing, which could significantly advance real-time information processing and storage technologies.

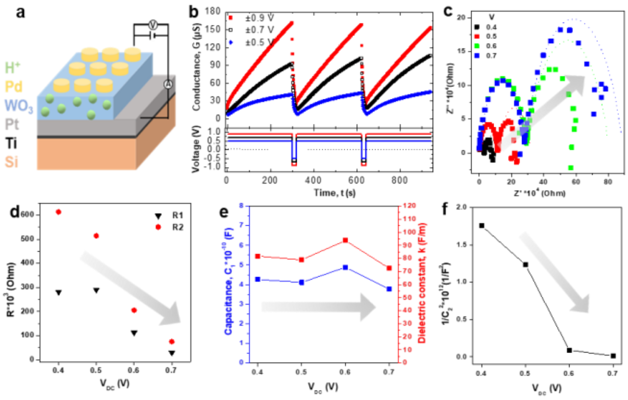

Fig. 1. Scheme of (a) 2-terminal protonic device. (b) Switching of protonic conductance by voltage. (c) Nyquist plots of (a) as a function of DC voltage after exposure to H_2. (d- f) corresponding R & C values.

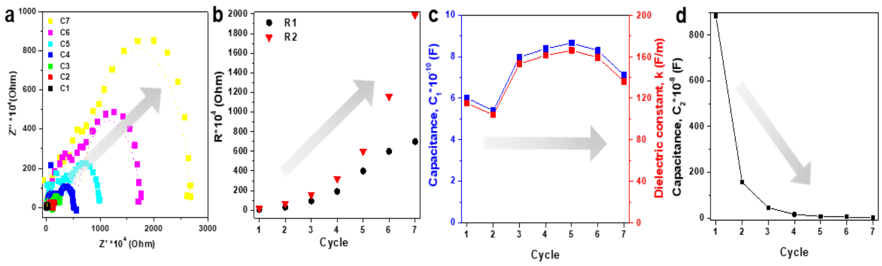

Fig. 2. (a) Nyquist plots as a function of current. (b), (c), & (d) corresponding R and C values.

References: [1] S. P. Pati, Y. Geng, S. Hamasuna, et al., 2024, 5:177. J. Comm. Mat.