PCSI

Room Ballroom South - Session PCSI-3WeM

Exploiting Ions in Devices

Moderator: Lincoln J. Lauhon, Northwestern University

11:40am **PCSI-3WeM-39 Non-volatile Redox Memory for Brain Inspired Computing**, *Elliot Fuller,* Sandia National Laboratories*; S Keene, A Melianas,* Stanford University*; Z Wang,* University of Massachusetts Amherst*; S Agarwal, Y Li,* Sandia National Laboratories*; Y Tuchman,* Stanford University*; C James, M Marinella,* Sandia National Laboratories*; J Yang,* University of Massachusetts Amherst*; A Salleo,* Stanford University*; A Talin,* Sandia National Laboratories

The end to Moore's law is driving interest in developing novel memory and logic devices with dramatically improved energy efficiency. Electrochemical systems can improve efficiency and imbue novel functionality through ion-induced transformations that are inaccessible to traditional semiconductor devices. Here, I will discuss two electrochemical systems that are combined to execute neuromorphic computing: one based upon proton insertion/extraction and redox reaction in a polymer matrix for synaptic weight storage[1, 2], and a second based upon ion migration and diffusion for synapse addressability and retention[3]. The first device is a synaptic transistor based upon PEDOT:PSS (Fig. 1 green, blue, orange) that is programmed via protonation/de-protonation of the channel. Addressable programming of the polymer synapse is mediated by current injection through a Ag-based diffusive electrochemical-metallization cell (d-EMC) (Fig. 1, purple). Combined these systems comprise a non-volatile redox memory (NVRM) with unique advantages over other memory proposed for neuromorphic computing (i.e. phase change cells and filament forming metal oxides). For example, NVRM is capable of operating at voltages <500mV with currents <10nA. Due to low circuit parasitics and linear and symmetric programmability (Fig. 2), NVRM is capable of efficient online learning with fully-parallel inference and weight update operations. A path towards realizing a fully flexible and biocompatible neuromorphic array will be discussed.

[1] E. J. Fuller, *et al.*, Advanced Materials*,* 2017

[2] Y. van de Burgt, et al., Nature Materials, 2017

[3] Midya, et al., Advanced Materials, 2017

11:45am **PCSI-3WeM-40 Non-volatile Electrochemical Memory Operating near the Thermal Voltage Limit**, *Yiyang Li,* E Fuller, S Agarwal, A Talin, Sandia National Laboratories

Non-volatile memories like flash, phase-change, and filament forming metal oxides are desirable as synapses for neuromorphic analog computation, which can consume much less power than a digital processor. One criterion for non-volatile memory is to minimize the switching voltage, both to reduce energy consumption and to prevent dielectric breakdowns. Due to the Boltzmann distribution of electrons, it is unclear if any memory can switch significantly below 1V; developing non-volatile memory operating near the thermal voltage limit is a grand challenge.

In this work, we use two silicon-free electrochemical devices to build non-volatile memory that operates below 300 mV (Fig. 1a). The first device is an ion insertion transistor which electrochemically shuttles lithium ions and electrons between the gate and the channel, analogous to a battery. Because the ions are mobile and move with the electrons, the process is charge neutral, and up to 10^{21}cm^{-3}of electrons and ions can be reversibly shuttled between the gate and channel without electrostatic charging. The second device is a diffusive memristor operating based on Ag$^+$migration and filament formation in the ON state, and diffusive filament dissolution to the OFF state. The low activation energy for Ag$^+$motion enables the device to switch with low applied voltages. The combination of high charge density of the ion insertion transistor and low leakage current of the diffusive memristor enables these two electrochemical devices to retain memory. Because both devices operate at low voltage, we can linearly tune the electronic conductance using sub-300-mV voltage pulses (Fig. 1b). This device is also compatible with a V/2 crossbar select scheme without a select transistor, and demonstrates that non-volatile synaptic memory near the thermal voltage limit is attainable for low-power electronics.

11:50am **PCSI-3WeM-41 Simultaneous Topographical and Electrochemical Mapping using Scanning Ion Conductance Microscopy – Scanning Electrochemical Miscrosocpy (SICM-SECM)**, *W Shi, Byong Kim, K Lee,* Park Systems*; G Mendoza,* Park Systems, Mexico

Lately, scanning ion conductance microscopy (SICM), has emerged as a versatile non-contact imaging tool. To obtain spatially-resolved electrochemical information, scanning electrochemical microscopy (SECM), also known as the chemical microscope, has been developed [1]. Hybrid SICM-SECM techniques have been developed, in which the SICM compartment provides the accurate probe-sample distance control, while the SECM compartment measures the faradaic current for electrochemical information collection [2].

In this work, we demonstrate the use of an Atomic Force Microscopy (Park NX10) in combination with an ammeter for concurrent topography imaging and electrochemical mapping. The SICM-SECM probe consisted of a Au crescent electrode (AuE) on the peripheral of a nanopipette. High resolution probe-substrate distance control was obtained by the ion current feedback from SICM, while simultaneous electrochemical signal collection was achieved via the AuE from SECM. As a proof-of-concept experiment, a Au/Pyrex pattern standard sample was imaged with the SICM-SECM technique. The Au bar and the Pyrex substrate were clearly resolved from the SICM topography image, with the bar height and pitch width closely matching the actual values. In terms of the electrochemical property mapping, higher Faradaic current was seen when the probe was scanned over Au bar as a result of redox cycling, while lower Faradaic current was observed when the probe was over Pyrex substrate due to hindered diffusion. The capability of the SICM-SECM technique described here holds promise of many exciting applications in the field of electrochemistry, material science and battery research.

[1] P. K. Hansma, et al., *Science*, 1989, **243**, 641.

[2] Shi, W. et al., *Faraday discussions*, 2016, **193**, 81-97.

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