**Neuromorphic properties of amorphous carbon-based memristors**

*Thomas J. RaeberA\*, Anders J. BarlowB, Zijun C. ZhaoC, David R. McKenzieC,*

*James G. PartridgeA, Dougal G. McCullochA, Billy J. MurdochA*

ASchool of Science, RMIT University, Melbourne, Australia

BCentre for Materials and Surface Science (CMSS), Department of Chemistry and Physics, La Trobe University, Melbourne, Australia

CSchool of Physics, The University of Sydney, Sydney, Australia

Introduction

Memristors are being used as the building blocks for future technologies such as non-volatile memory, neuromorphic computing and as the basis for next generation sensing applications. Amorphous carbon-based memristors have gained attention through their recent addition to the International Technology Roadmap for Semiconductors (Chen 2014). Carbon-based devices exhibiting either unipolar or bipolar switching modes have been previously reported. Combining both unipolar and bipolar resistive switching characteristics can offer both increased endurance and increase the range of neurological functions that can be emulated. This concept has so far only been demonstrated in bilayer metal oxide systems (Stathopoulos *et al.* 2017). In this work, we investigate multilayer amorphous carbon-based memristors for their resistive switching and neuromorphic capabilities.

Methods

A series of elemental and oxygenated carbon-based resistive layers were deposited using a filtered cathodic vacuum arc. Oxygenation was achieved by varying the O2 partial pressure during deposition. The carbon films separated a Ag back contact and a lithographically defined Pt top contact. The devices were chemically and microstructurally characterised using transmission electron microscopy, electron energy loss spectroscopy and X-ray photoelectron spectroscopy. Electrical testing was performed in ambient and controlled conditions using a source/measure unit and environmental stage.

Results/Discussion

Unipolar and bipolar switching modes were achieved using the bilayer amorphous carbon devices. The two modes could be combined to create a 3-state memory system. Neurological functions including paired-pulse facilitation (PPF) and paired-pulse inhibition (PPI) were successfully emulated. PPI enables the devices to self-limit current allowing behaviour analogous to sensory gating in biological nervous systems. Additionally, the devices exhibited sensitivity to both photonic and temperature stimulation. It was shown that device programming and PPF could be achieved both optically and electronically. Variation of temperature enabled modulation of ON/OFF ratios and short-term memory characteristics. The thermal sensitivity of the devices suggested suitability for thermal nociceptors.

Conclusion

The novel carbon-based devices demonstrated in this work exhibited neuromorphic traits and sensitivity to various external stimuli. This suggest that the applications for these carbon-based devices can extend beyond simple memory to advanced neuromorphic computing and ‘smart’ sensors.

**References**

Chen, A. (2014) in Emerging research device roadmap and perspectives, 2014 IEEE International Conference on IC Design & Technology, 1–4.

Stathopoulos, S.; Khiat, A.; Trapatseli, M.; Cortese, S.; Serb, A.; Valov, I.; Prodromakis, T. (2017) Multibit memory operation of metal-oxide Bi-layer memristors, Sci. Rep., 7, 1–7.

\*Email: thomas.raeber@rmit.edu.au