Phase-Change and Carbon Based Materials for Advanced Memory and Computing Devices

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ……..

This work is dedicated to all my Family and Friends who helped me, encouraged me and pushed me forward through all these years of study.

Thank you.

Pei

Abstract

The aggressive scaling of CMOS technology, to reduce device size while also increasing device performance, has reached a point where continuing improvement is becoming increasingly problematic and alternative routes for the development of future memory and processing devices may be necessary; in this thesis the use of phase-change and carbon based materials as one such alternative route is investigated.

As pointed out by Ovshinsky [1, 2] some phase-change material should be capable of non-binary arithmetic processing, multi-value logic and biological (neuromorphic) type processing. In this thesis, generic, nanometre-sized, phase-change pseudo-devices were fabricated and utilised to perform various types of computational operations for the first time, including addition, subtraction, division, parallel factorization and logic using a novel resistive switching accumulator-type regime in the electrical domain. The same accumulator response is also shown to provide an electronic mimic of an integrate-and-fire type neuron. The accumulator-type regime uses fast electrical pulses to gradually crystallize a phase-change device in a finite number of steps and does not require a multilevel detection scheme.

The phase-change materials used in this study were protected by a capping layer of sputtered amorphous carbon. It was found that this amorphous carbon layer also underwent a form of resistive switching when subjected to electrical pulses. In particular, sputtered amorphous carbon layers were found to switch from an initially high resistivity state to a low resistivity state when a voltage pulse was locally applied using a Conductive Atomic Force Microscope (CAFM) tip. Further experiments on amorphous carbon vertical pseudo-devices and lithographically defined planar devices showed that it has potential as a new material for Resistive Random Access Memory (ReRam) applications. The switching mechanism was identified as clustering of the sp^2 hybridized carbon sites induced by Joule heating. It was not possible to reset the devices back to their initial high resistivity state presumably due to the highly conductive nature of sputtered amorphous carbon.

List of Publications

- Electrically induced switching and imaging of amorphous carbon thin films - *P. Hosseini, C. D. Wright, S. Milana, A. Ferrari. (Journal article, in preparation).*
- Beyond Von-Neumann Computing with Nanoscale Phase-Change Memory Devices - *CD Wright, P Hosseini, J Vasquez* - **Adv. Funct. Mat., 2012,** 10.1002/adfm.201202383
- Accumulation-based Arithmetic Computing with Phase-Change Materials and Devices - *C.D. Wright, P.Hosseini and J.A.Vazquez Diosdado.* **NVMTS 2012**, Singapore *(Invited Paper).*
- Phase-Change Processors, Memristors and Memflectors - *C. D. Wright, Y Liu, K. Kohary, M. M. Aziz, R. J. Hicken, L. Wang, P. Hosseini, J. Vazquez and P. Ashwin.* **MRS Spring 2012** *(Invited Paper).*
- Beyond Von-Nuemann computing with Phase-change materials and devices - *C.D. Wright, H. Bhaskaran, P.Hosseini and J.A.Vazquez Diosdado and G. Hernandez Rodriguez.* **MRS Spring 2013** *(Invited Paper).*
- Exploiting the memristive-like behaviour of phase-change materials and devices for arithmetic, logic and neuromorphoic processing - *C. D. Wright, J. AVázquez Diosdado, L. Wang, Y. Liu,P. Ashwin, K. I. Kohary, M. M. Aziz, P. Hosseini and R. J. Hicken.* **Nature Conf.: Frontiers in electronic materials. 2012** *(Invited session).*
- Nanoscale non von-Neumann computing using phase-change devices - *C.D. Wright, P. Hosseini.* **EPCOS 2012** *(Poster).*
- Nanomanipulation of Amorphous Carbon Conductivity - P. Hosseini, C. D. Wright. **ONYX11 Meeting**. June 2011 *(Poster).*
- Electrically induced switching and imaging of amorphous carbon thin films - *P. Hosseini, D.Anderson, A. Brown and C. D. Wright.* **ONYX12 Meeting**. May 2012 *(Poster).*

- Threshold switching via electric field induced crystallization in phase-change memory devices and Neuromorphic applications - *J. Vasquez, P. Hosseini and C. D. Wright.* **ONYX12 Meeting**. May 2012 *(Talk).*
- Carbon Based Memories - *P. Hosseini, C. D. Wright.* **ISOE 2011**. Oct 2011 (Poster).
- Phase-change and Carbon Based materials for biologically inspired computing and data storage - P. Hosseini. **UKICTPioneers2012**. *(Top3 Finalists Poster).*