

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

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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 neuromorphic 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*).

ABSTRACT	3
LIST OF PUBLICATIONS	4
1 INTRODUCTION	9
1.1 Memory: we need more, we need different	10
1.2 Status and challenges of current memory technologies	14
1.3 Emerging Memory systems: ReRam	21
1.4 Additional Functionalities: beyond Von Neumann architecture	28
1.5 Project Aim	32
1.6 Thesis synopsis	35
2 BACKGROUND ON PHASE-CHANGE AND CARBON BASED MATERIALS	37
2.1 Scope	38
2.2 Introduction to Phase-change Materials for memory applications	39
2.3 Phase-change Materials for arithmetic and biologically inspired computing	45
2.4 Introduction to Carbon materials	51
2.5 Amorphous Carbon materials	55
2.6 Amorphous Carbon materials for novel memory applications	60
3 METHODS	63
3.1 Scope	64
3.2 Sputtering deposition of amorphous carbon thin films	65
3.3 Atomic Force Microscopy and conductive imaging modes	71
3.4 The importance of the intermediate Ti layer	81
3.5 Raman spectroscopy of carbon materials	85
3.6 Secondary Ion Mass Spectroscopy for metal migration study	96
3.7 Amorphous carbon planar devices fabricated by Electron Beam Lithography	98
3.8 Electrical measurements test-systems for a-C planar devices	102
3.9 GST pseudo-device preparation	105
4 PHASE-CHANGE MEMORY DEVICES FOR BEYOND VON NEUMANN COMPUTING	110
4.1 Scope	111

4.2	Demonstration of an ultra-high density data storage system using a phase-change medium and a CAFM	112
4.3	Computing cell characterization	117
4.4	Addition operation	121
4.5	Subtraction operation	123
4.6	Parallel factorization	126
4.7	Implementing Serial Logic gates	129
4.8	Re-amorphization experiments on patterned GST medium	130
4.9	Capping layer role in memory switching	132
4.10	Discussion: Phase-change materials for beyond Von Neumann Computing	133
5	DEPOSITION AND STRUCTURAL CHARACTERIZATION OF AMORPHOUS CARBON THIN FILMS	136
5.1	Scope	137
5.2	Film resistivity with increasing deposition power	138
5.3	Film resistivity with increasing annealing temperatures	139
5.4	Film opacity with increasing annealing temperature	141
5.5	I_D/I_G peak ratio with increasing deposition power	143
5.6	I_D/I_G peak ratio with increasing annealing temperatures	144
5.7	G Peak position with increasing deposition power	145
5.8	G peak position with increasing annealing temperature	146
5.9	G peak FWHM with increasing deposition power	147
5.10	G peak FWHM with increasing annealing temperatures	148
5.11	Film roughness evolution with increasing deposition time	149
5.12	Film roughness with increasing deposition power	150
5.13	Discussion: Structural characterization of sputtered a-C thin films	151
6	ELECTRICAL CHARACTERIZATION OF CONTINUOUS AMORPHOUS CARBON THIN FILMS	157
6.1	Scope	158
6.2	I-V measurements on a-C films with increasing thickness	159
6.3	I-V measurements on a-C films with different resistivity	160
6.4	I-V measurements on a-C films with different back electrode materials	161

6.5	I-V measurements on a-C films with different bottom electrode thicknesses	163
6.6	I-V measurements on annealed a-C films	164
6.7	Pulse-induced resistance switching in a-C vertical pseudo-devices	167
6.8	Relation between pulse amplitude and resistivity change	172
6.9	a-C devices as a candidate for accumulation type arithmetic processing	173
6.10	I-V measurements on an all-carbon pseudo-device	175
6.11	Discussion: Electrical characterization of continuous a-C thin films	177
7	ELECTRICAL STUDY OF AMORPHOUS CARBON PLANAR DEVICES	181
7.1	Scope	182
7.2	Electrical measurements of a-C devices in various atmosphere conditions	183
7.3	Optical images of a-C planar devices switched in various atmosphere conditions	186
7.4	CAFM study of a-C planar devices switched in different ambient conditions	188
7.5	Electrical transport in a-C planar devices	197
7.6	Comparison between pre- and post-switching electrical transport in a-C planar devices	199
7.7	Rewriteability of a-C planar devices	201
7.8	Discussion: Electrical characterization of a-C planar devices	202
8	RESISTIVE SWITCHING MECHANISM IN A-C DEVICES	205
8.1	Scope	206
8.2	Optical Image of pulsed switched array	207
8.3	CAFM imaging of a pulse switched array	209
8.4	Raman map of a pulsed switched array	210
8.5	SIMS depth profiling of a pulsed switched array	212
8.6	Discussion: Resistive switching mechanism in a-C devices	214
9	CONCLUSIONS AND FURTHER WORK	217
9.1	Conclusions	218
9.2	Further Work	220
	References	223