DS 38: Focussed Session: Memristive Devices for Neuronal Systems I

Today's computer science is characterized by a time of upheaval. The extremely successful down scaling of CMOS devices and circuit integration during the last decades will soon face physical limits. The predictable fade away of Moore-law, puts advance device structures paired with conceptual new non-Boolean architectures, such as cellular automata, quantum computer or neuromorphic circuits, more and more into the spot light of research and industry. In this respect the symposium will focus on novel opportunities of memristive devices in the field of bio-inspired computing. This symposium aims to overview of the interdisciplinary, covering interfacial physics, and electronic properties and the theory of memristive devices up to the complex architecture in biological nerve systems. This symposium aims to provide an overview of the status quo of memristive devices in neural systems by some of the leading experts in the field. Moreover, all speakers will discuss and work out the most promising and most exciting future directions, such as cognitive computing and memristive brain chips.

Organizers: Hermann Kohlstedt (CAU Kiel), Ronald Tetzlaff (TU Dresden), and Thomas Mikolajick (TU Dresden)

Time: Thursday 9:30–13:15 Location: CHE 89

Topical Talk DS 38.1 Thu 9:30 CHE 89
Memristive devices for neuromorphic systems — •Martin Ziegler — Nanoelektronik, Technische Fakultät der Christian-Albrechts-Universität zu Kiel, Germany

Biological nerve systems of vertebrates and invertebrates outperform today's most powerful digital computers when it comes to pattern recognition, cognitive functionality or autonomous interaction with a steadily changing and noisy environment. Memristive devices offer attractive features to mimic biological functions of nerve systems in an elegant and efficient way. The talk provides an overview of recent developments in memristive devices and neuromorphic circuits based on memristive systems. In particular, it is shown how neural functionality can be emulate with memristive devices and how memory and learning processes can be replicate with electronic circuits based-on memristive devices.

Financial support by the German Research Foundation through FOR 2093 is gratefully acknowledged.

Topical Talk DS 38.2 Thu 10:00 CHE 89
Learning in Silico: neuromorphic models of long-term plasticity — •Elisabetta Chicca — Bielefeld University, Bielefeld, Germany

Synaptic plasticity empowers biological nervous systems with the ability to learn from experience and adjust to environmental changes. Such abilities are a must for artificial autonomous systems and therefore researchers have been devoting significant efforts to the understanding and modelling of plasticity mechanisms. In particular, the field of neuromorphic engineering focuses on the development of full-custom hybrid analog/digital electronic systems for the implementation of models of biological computation and learning in hardware. In this talk, I will give a short historical overview of the most important plasticity circuits developed following the approach originally proposed by Carver Mead in the late eighties. Afterwards, I will present recent advancements in this field.

DS 38.3 Thu 10:30 CHE 89
Emulation of neural synchrony with memristive devices — •Marina Ignatov, Martin Ziegler, Mirko Hansen, and Hermann Kohlstedt — AG Nanoelektronik, Christian-Albrechts-Universität zu Kiel, Germany

Conscious and perception are without doubt one of the most fascinating functionalities of the human brain and results from massive parallel computing in a huge self-organizing dynamical neural network. Neural synchrony is an elegant concept which tries to explain the underlying computing scheme by using dynamical network behaviours. In this talk we show that memristive devices allow a new degree of freedom to the concept of neural synchrony: a local memory which supports a transient connectivity. By using a 4-inch full device technology electrochemical metallization (ECM) cells with the layer sequence $Ag/TiO_{2-x}/Al$ are fabricated. Those devices are used to couple self-sustained van der Pol oscillators in an electronic circuit. As a result an autonomous frequency adaptation and phase locking is observed. The underlying circuit and device requirements and their impact to neuromorphic computing are discussed in this talk.

Financial support by the German Research Foundation through FOR 2093 is gratefully acknowledged.

[1] M. Ignatov et al., Appl. Phys. Lett. 108(8), 084105 (2016)

DS 38.4 Thu 10:45 CHE 89
Quantitative spectroscopic analysis of memristive thin films — •Julian Strobel[1], Mirko Hansen[2], Krishna Kanth Neelisetty[3], Venkata Sai Kiran Chakravadhanula[3], Hermann Kohlstedt[2], and Lorenz Kienle[1] — [1]Institut für Materialwissenschaft, Technische Fakultät der CAU Kiel, Kaiserstr. 2, 24143 Kiel — [2]Institut für Elektrotechnik, Technische Fakultät der CAU Kiel, Kaiserstr. 2, 24143 Kiel — [3]Institut für Nanotechnologie, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

Memristive NbOx/AlOx tunnel barriers have been analyzed by electron energy-loss spectroscopy to the effect of gaining information on the electronic structure. Slight oxidation of the bottom electrode, likely occurring during fabrication of the overlying oxide layers, is observed but is expected to have little to no effect on the I-V characteristics. The AlOx layer was found to exhibit states within the bandgap caused by oxygen vacancies. A model for quantification of the oxygen vacancies is presented and discussed with respect to expected accuracy.

DS 38.5 Thu 11:00 CHE 89
MemFlash: Memristive operation of MOSFETs with external capacitances — •Henning Winterfeld[1], Nico Himmel[1], Martin Ziegler[1], Henning Hanssen[2], Detlef Friedrich[2], Wolfgang Benecke[2], and Hermann Kohlstedt[1] — [1]Nanoelektronik, Technische Fakultät, Christian-Albrechts Universität zu Kiel, Germany — [2]Fraunhofer-Institut für Siliziumtechnologie (ISIT), Itzehoe, Germany

Memristive devices have the potential to act as key elements in neuromorphic circuits. However, system integration has turned out to be difficult, as it requires a wafer level fabrication technology. Therefore, MemFlash cells are an interesting alternative to state-of-the-art memristive devices. MemFlash cells are single floating gate transistors operating in a memristive operation mode. In this talk it will be shown that MOSFETs can act as MemFlash cells by using an external capacitor. Fabricated devices vary in channel length and width with tunneling windows between 4 μm^2 and 100 μm^2. Furthermore, tunnel barrier thicknesses between 3 nm up to 10 nm were realized. The elevation of charges through the tunneling window onto the floating gate via Fowler-Nordheim tunneling allows hysteresis measurements. Measurements show on-off resistance values of about 40 kOhm and 4.2 GOhm, respectively. The electrical characteristics of those devices will be presented, while based on this data, possible advantages and disadvantages of the MemFlash device with respect to conventional memristive devices will be discussed.

Financial support by the German Research Foundation through FOR 2093 is gratefully acknowledged.

15 min. break.

Topical Talk DS 38.6 Thu 11:30 CHE 89
Design and CMOS Co-Integration of ReRAM Devices and Crossbar Arrays for Neuromorphic Applications — •Yusuf Leblebici — Swiss Federal Institute of Technology (EPFL), Lausanne,

Switzerland

Resistive RAM (ReRAM) elements based on transition-metal oxide layers are rapidly becoming viable options for nonvolatile information storage and for neuromorphic operations, allowing easy integration with conventional CMOS technologies. In this talk, we will review the ongoing research at EPFL on the realization of various ReRAM elements based on TiOx, TaOx, WOx and HfOx layers tailored for low voltage operation, as well as the design and co-integration of the CMOS peripheral circuitry for the read/write operations. In particular, the chip embedding platform enabling post-processing of diced samples for fabrication of memristive elements will be discussed, and examples will be provided for potential neuromorphic functions such as spike-timing-dependent-plasticity (STDP) and back-propagation implemented on cross-bar arrays.

Topical Talk DS 38.7 Thu 12:00 CHE 89

Neuromorphic Memristive Systems — •Bernabe Linares-Barranco — Instituto de Microelectronica de Sevilla IMSE-CNM (CSIC), Av. Americo Vespucio s/n, 41092 Sevilla, Spain

Nanoscale memristors promise to be fabricated over CMOS substrates with densities of over $4x10^{12}$ elements per cm^2 (which corresponds to a 50nm pitch). This would provide an overwhelming memory density very tightly coupled to CMOS computing elements. There are many fields where this disruptive advantage can be exploited. One of them is neuromorphic computing and learning systems. In this talk we present some ideas on how to exploit this technological possibility for implementing hybrid memristive-CMOS systems. We will start by introducing event-driven spiking neural systems, how they can learn through Spike-Timing-Dependent-Plasticity (STDP), and how this can be exploited with combined memristor-CMOS chips. Recent state-of-the-art results will be shown.

DS 38.8 Thu 12:30 CHE 89

Gate-tunable, normally-on to normally-off memristance transition in patterned LaAlO3/SrTiO3 interfaces — Patrick Maier, •Fabian Hartmann, Judith Gabel, Maximilian Frank, Silke Kuhn, Philipp Scheiderer, Berengar Leikert, Michael Sing, Lukas Worschech, Ralph Claessen, and Sven Höfling — Physikalisches Institut and Röntgen Center for Complex Material Systems (RCCM), Universität Würzburg, Am Hubland, D-97074 Würzburg

The state- and time-dependent resistance of memristors enables the emulation of synaptic functionalities, and hence memristor-based artificial synapses may be implemented in novel, brain inspired computing architectures. We report reversible and irreversible control of memristive switching in patterned LaAlO3/SrTiO3 interfaces via gate voltages and annealing, respectively. The inherent memory functionality (memristance) can be switched on and off with back gate voltages of a few volts. Irreversible control of the memristive switching is demonstrated by annealing the device at 300 °C in nitrogen atmosphere, during which oxygen vacancies are created in the SrTiO3 substrate. These vacancies release mobile electrons that screen the electric field of the back gate. Tuning the amount of mobile electrons with the annealing time allows switching on and off the memristance at zero gate voltage leading to normally-on and normally-off memristors, respectively. The presented irreversible and reversible control of memristive characteristics may allow to compensate fabrication variabilities of memristors.

DS 38.9 Thu 12:45 CHE 89

Thin carbon nanotube (CNT) film networks and their memristive behaviors in cooperation with noble metal clusters — •Victor Kaidas, Alexander Vahl, Sandra Hansen, Fabian Schütt, Jürgen Carstensen, Sören Kaps, Franz Faupel, and Rainer Adelung — Institut für Materialwissenschaften der Christian Albrechts Universität, Kiel, Deutschland

Memristic devices have gained lot of attention since their discovery leading to many different fabrication ways. The first ones were based on the movement of oxygen vacancies or other charge carriers (e.g. Ag ions) in metal oxides induced by an applied field and a resulting drift in the respective matrix. As a consequence different matrix materials were investigated like polymers, biomaterials and carbon nanotubes (CNTs) in regards of their memristive effect in various systems, which is the main focus here as well. Our approach is based on a previous study in which semiconducting high aspect ratio materials in the micrometer regime and different hybridized carbon species were brought together and successfully checked for their memristive characteristics. Here we present a thin CNT film and the formation of a conducting network between two Au electrodes. To obtain the film different ways of applying the CNTs were used like spin, drop or spray coating until a sufficient network was achieved. By adding noble metal clusters into the network it is now possible to induce memristive effects by letting the corresponding ions move. Our long term goal is fabricating structures even with a higher range of interconnection with the outlook to obtain 3D memristive structures using this approach.

DS 38.10 Thu 13:00 CHE 89

Ion dynamics in double barrier memristive devices — •Sven Dirkmann[1], Mirko Hansen[2], Martin Ziegler[2], Enver Solan[3], Karlheinz Ochs[3], Hermann Kohlstedt[2], and Thomas Mussenbrock[4] — [1]Ruhr-Universität Bochum, Lehrstuhl für Theoretische Elektrotechnik, 44780 Bochum — [2]Christian-Albrechts-Universität zu Kiel, Nanoelektronik, 24143 Kiel — [3]Ruhr-Universität Bochum, Lehrstuhl für Digitale Kommunikationssysteme, 44780 Bochum — [4]Brandenburgische Technische Universität Cottbus-Senfenberg, Theoretische Elektrotechnik, 03046 Cottbus

In this work we analyze the role of ion transport for the dynamic behavior of a double barrier quantum mechanical memristive device using a consistent simulation model.[1,2] The device consists of an ultra-thin NbxOy solid state electrolyte sandwiched between an Al2O3 tunnel barrier and a Schottky-barrier at the NbxOy/Au interface. Many interesting features, as an intrinsic current compliance, a relatively long retention time and no need for an initialization step, make this device technologically interesting, particularly for applications in neuromorphic systems. The electron transport is mimicked by a lumped element circuit model consistently coupled with a 3D kinetic Monte Carlo model, describing the ion transport. The simulation results prove that the ionic motion within the NbxOy layer is the key factor for the resistive switching behavior.This work is funded by the DFG in the frame of Research Unit FOR2093 "Memristive Devices for Neural Systems".

[1] M. Hansen et al., Scientific Reports 5, 13753 (2015)
[2] S. Dirkmann et al., Scientific Reports 6, 35686 (2016)