DS 3: Phase Change / Resistive Switching

Time: Monday 9:30–13:15 Location: H8

DS 3.1 Mon 9:30 H8

MemFlash: Memristive operation mode of floating gate transistors — •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 great potential for the use as key elements in neuromorphic circuits. However, the system integration which requires a wafer level fabrication technology has turned out to be difficult. Therefore, MemFlash cells, i.e. single floating gate transistors operating in a memristive operation mode, are an interesting alternative to state-of-the-art memristive devices. Here, a semi-industrial fabrication process is presented, which allows us to tailor the device properties by using different gate stacks. 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 7 nm were realized. First hysteresis measurements show on-off resistance values of about 260 kOhm and 680 kOhm, respectively. The electrical characteristics of these 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.

DS 3.2 Mon 9:45 H8

Memristive Functionality of a SONOS Memory Transistor — •Nico Himmel^1, Hannes Mähne^2, Steffen Thiem^2, Henning Winterfeld^1, Martin Ziegler^1, and Hermann Kohlstedt^1 — ^{1}Nanoelektronik, Technische Fakultät der Christian-Albrechts Universität Kiel, Germany — ^{2}X-FAB Dresden GmbH Co. KG, Dresden, Germany

Charge trap transistors of silicon-oxide-nitride-oxide-polysilicon (SONOS) type can be operated as a memristive device. In the talk, a two terminal wiring scheme for single depletion SONOS cells with one additional resistor will be introduced. The all-electric operation principle and established silicon manufacturing process of SONOS devices at the Semiconductor Foundry XFAB promise reliable operation, low parameter spread and large integration density. Experimental current-voltage curves show a pinched hysteretic shape within $\pm 10\,\mathrm{V}$ with a polarity dependent asymmetry and $\mathrm{R_{off}/R_{on}} > 25$ at 0.5 V. In addition the circuit response to voltage pulses, which is relevant for neuromorphic applications, is discussed. The circuit design is an implementation of the MemFlash concept, as proposed for a memristive operation of floating gate transistors [1].

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

[1] M. Ziegler et al., APL **101**, 263504 (2012)

DS 3.3 Mon 10:00 H8

Memristive circuits for the emulation of neuronal dynamics — •Marina Ignatov, Martin Ziegler, Mirko Hansen, Adrian Petraru, and Hermann Kohlstedt — AG Nanoelektronik, Christian-Albrechts-Universität zu Kiel, Germany

We discuss the capabilities of memristive devices for the emulation of neural dynamics in electronic circuits. Therefore, a memristive spiking neuron model is presented [1] which has been experimentally implemented in a compact electronic circuit comprising memristive and memcapacitive devices. In more detail, the strongly correlated electron material vanadium dioxide (VO_2) and a chemical electromigration cell $Ag/TiO_{2-x}/Al$ have been employed to emulate neural spike coding, including firing frequency adaptation. The latter was first observed by E. D. Adrian in 1926 and is nowadays believed to be the basis of neural computing. Furthermore, the advantages of memristive oscillator systems for neural computing will be discussed. In this context, we present results on an electronic circuit which belongs to the class of van der Pol oscillators, which are considered as model systems to mimic higher brain functionalities.

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

[1] M. Ignatov et al., Front. Neurosci. 9: 376 (2015)

DS 3.4 Mon 10:15 H8

Memristive Devices for Neuromorphic Systems — •Mirko Hansen^1, Martin Ziegler^1, Finn Zahari^1, Lukas Kolberg^1, Sven Dirkmann^2, Thomas Mussenbrock^2, and Hermann Kohlstedt^1 — ^{1}AG Nanoelektronik, Christian-Albrechts-Universität zu Kiel, Germany — ^{2}Lehrstuhl für Theoretische Elektrotechnik, Ruhr-Universität Bochum, Germany

The intensified development of memristive devices for memory applications led to several other possible fields of operation. Among them, their use for neuromorphic systems is one of the most promising applications. While several neuron-based learning concepts have been successfully demonstrated using single devices, the realization of neuromorphic systems using many memristive devices remains challenging.

We present TiO_x and Nb_xO_y-based memristive devices [1] with different device properties. The devices are fabricated on 4 inch wafers using a four mask lithography process with etching and deposition steps to yield a large number of high quality devices. A wafer-scale electronic characterization of these devices allows obtaining device parameters from a large number of devices. These parameters are employed for a network simulation which is able to recognize patterns [2]. Based on simulations, essential device requirements and device parameters for neuromorphic systems will be discussed.

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

[1] M. Hansen et al., Scientific Reports, vol. 5, p. 13753 (2015)

[2] F. Zahari et al., AIMS Materials Science 2: 203-216 (2015)

DS 3.5 Mon 10:30 H8

Critical ReRAM Stack Parameters Controlling Complementary versus Bipolar Resistive Switching — •Alexander Schönhals^1, Dirk J. Wouters^1, Astrid Marchewka^1, Thomas Breuer^2, Katharina Skaja^2, Stephan Menzel^2, and Rainer Waser^{1,2} — ^{1}Institut für Werkstoffe der Elektrotechnik II, RWTH Aachen University, Aachen, Germany — ^{2}Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Jülich, Germany

Today's memory technologies in the semiconductor industry are approaching their scalability limits. As one of the leading candidates for the future non-volatile memory technology, redox based resistive switching memory (ReRAM) has attracted increased attention.

Resistance change in a valence change mechanism (VCM) based ReRAM cell can be achieved by applied voltage modulation and is accounted for a redistribution of the ionic species within the active layer. VCM-type Metal-Oxide ReRAM cell usually consists of a transition metal-oxide layer acting as an active switching layer and a metallic layer acting as a reservoir for oxygen scavenging. The thickness of the oxygen scavenging metal layer, forming the Ohmic contact in TaOx based ReRAM device, was found to be the critical experimental parameter controlling stable bipolar resistive switching versus the occurrence of single-cell complementary switching. Here it is argued that the physically controlling parameter is the effective work function difference between top and bottom electrode contact of the ReRAM cell. For a thin metal cap layer, oxidation increases the effective work function changing from Ohmic to a more blocking contact behavior.

DS 3.6 Mon 10:45 H8

Resistive switching in oxygen engineered TaO_x and $Ta{:}HfO_x$ based RRAM devices grown by MBE — •Merin Jissy Joseph^1, S.U. Sharath^1, Stefan Vogel^1, Erwin Hildebrandt^1, Philipp Komissinskiy^1, Thomas Schroeder^2, and Lambert Alff^1 — ^{1}Institute of Materials Science, Technische Universität Darmstadt, Germany — ^{2}IHP, Frankfurt (Oder), Germany

With conventional flash based non-volatile memories (NVM) gradually approaching its limitations of scaling, resistive random access memory (RRAM) based on CMOS compatible metal oxides (HfO_x, TaO_x etc.) is among the widely investigated choices of next generation NVM. Techniques like oxygen engineering [1] and doping is of interest in reducing the forming voltage and improving the effective device yield in HfO_x based RRAM devices. Resistive switching characteristics were investigated in TaO_x and $Ta{:}HfO_x$ thin films grown on titanium nitride (TiN) electrodes by reactive molecular beam epitaxy (MBE). TaO_x based devices show a strong dependence of the forming voltage on oxidation conditions. A comparison of amorphous and polycrystalline

Ta:HfO_x based devices showed tunable and opposite forming voltage trends with changing composition and doping, highlighting the role of grain-boundaries. One important result is that Ta doping increases the stability of the resistive states, irrespective of crystallinity. Under fixed oxidation conditions, Ta doping in HfO_x was found to reduce the forming voltage while at the same time the resistance ratio is even increased to above ten thousand (10.000).
[1] S. U. Sharath *et al.*, Appl. Phys. Lett. **104**, 063502 (2014).

DS 3.7 Mon 11:00 H8

Time domain analysis of resistive switching in $SrTiO_3$ — •Karsten Fleck[1,2], Camilla La Torre[1,2], Nabeel Aslam[2,3], Susanne Hoffman-Eifert[2,3], Ulrich Böttger[1,2], Rainer Waser[1,2,3], and Stephan Menzel[2,3] — [1]Institut für Werkstoffe der Elektrotechnik II, RWTH Aachen, Aachen, Germany — [2]JARA Fundamentals of Future Information Technology, Jülich, Germany — [3]PGI 7, Forschungszentrum Jülich GmbH, Jülich, Germany

The bipolar resistive switching in metal oxides has gained much attention for the potential application in memory and logic devices. Resistive random access memories based this effect (ReRAM) combine several advantages. Beside their good scalability, high endurance and fast switching they are also very energy efficient. ReRAM cells basically consist of a metal-insulator-metal structure that can be switched between a low and a high resistive state. During an initial electroforming step an oxygen-vacancy enriched highly conductive filament evolves in the oxide. By application of appropriately polarized voltages the oxygen vacancy concentration at one of the metal-oxide interfaces can either be decreased or increased thereby either disableing or enableing electronic conduction. This work presents an analysis of the current during resistive switching in Pt/$SrTiO_3$/TiN nano-crossbars covering the timescale from 10 ns up to 10^5 s. The $SrTiO_3$ layer is deposited by ALD. A pulse scheme is used for cycling thereby monitoring the transient currents. The results are compared to an electro-thermal compact-model thereby illustrating the importance of a thermal runaway due to Joule heating for fast switching.

15 min. break.

DS 3.8 Mon 11:30 H8

Resistive switching in oxygen engineered Al_2O_3/HfO_x based RRAM devices grown by MBE — •Stefan Vogel[1], S. U. Sharath[1], Erwin Hildebrandt[1], Jonas Hunka[1], Christian Wenger[2], Thomas Schroeder[2], and Lambert Alff[1] — [1]Institute of Materials Science, Technische Universität Darmstadt, Germany — [2]IHP, Frankfurt (Oder), Germany

Recently, resistive random access memory (RRAM) has gained a lot of attention due to its promising properties: fast switching times, high endurance, and low power consumption. RRAM devices are non-volatile memories (NVM) based on switching between a low and high resistance state (LRS/HRS) by conducting filaments (CF) which are formed and disrupted by applying voltages of different polarities. RRAM devices usually have a simple metal-insulator-metal stack (MIM) structure. Insulating transition metal oxides like hafnium oxide (HfO_2) are promising for embedded RRAM due to its established CMOS compatibility.

In-situ stacks of TiN/HfO_x with oxygen deficient stoichiometry were deposited by molecular beam epitaxy (MBE) using radical sources with different gases (oxygen and nitrogen) [1]. Device stacks of Pt/HfO_x/TiN with varying device areas were patterned using lithography. Since the forming process of the filament is crucial for good device endurance, the temperature of formation was varied to investigate its influence on the forming process and the endurance. The effect of Al_2O_3 interlayers acting as oxygen diffusion barriers on switching performance has also been investigated.
[1] S. U. Sharath *et al.*, Appl. Phys. Lett. **104**, 063502 (2014).

DS 3.9 Mon 11:45 H8

Non-volatile capacitive switching of BiFeO3-coated Si3N4 /Ge/Si structures — •Kefeng Li[1,2], Lars Rebohle[2], Nan Du[1], Tiangui You[1], Slawek Prucnal[2], Ilona Skorupa[1], Danilo Bürger[1], Thomas Schröder[3], Oliver G. Schmidt[1,4], and Heidemarie Schmidt[1] — [1]Faculty of Electrical and Information Engineering, TU Chemnitz — [2]Institute of Ion Beam Physics and Materials Research, HZDR — [3]Institut for Innovative Microelectronics, IHP Frankfurt/Oder — [4]Institute for Integrative Nanosciences, IFW Dresden

Multiferroic BiFeO3 (BFO) has a large remnant polarization [1]. Ca. 75 nm thick amorphous BFO layers have been grown by pulsed laser deposition at 25 °C on Si3N4/Ge/Si and afterwards recrystallized by applying a 20 ms long flash lamp annealing pulse in oxygen atmosphere [2]. Here we report on the non-volatile capacitive switching in Au/BFO/Si3N4/Ge/Si/Al structures between high capacitance state (HCS) and low capacitance state (LCS) which have a lower power consumption in comparison to the current-driven resistive switching between low resistance state and high resistance state in Au/BFO/Pt/Ti structures [3]. Whereas the HCS is rather stable for the BFO-coated and for the uncoated Si3N4/Ge/Si, the LCS is only stable for the BFO-coated Si3N4/Ge/Si. [1] S. Sakai, M.Takahashi, Materials, 3, 4950 (2010).[2] Subsecond Annealing of Advanced Materials, (Eds.: W. Skorupa, H. Schmidt), Springer Series in Materials Science, 2014.[3] Y. Shuai, S. Zhou, D. Bürger, M. Helm, H. Schmidt, J. Appl. Phys., 109, 124117 (2011)

DS 3.10 Mon 12:00 H8

Structural characterization of epitaxial trigonal Ge-Sb-Te grown by MOVPE — •Martin Schuck[1], Sally Riess[1], Hongchu Du[2], Manuel Bornhöfft[3], Gregor Mussler[1], Martina von der Ahe[1], Alexander Schwedt[2], Joachim Mayer[2,3], Hilde Hardtdegen[1], and Detlev Grützmacher[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institut (PGI-9), JARA, 52425 Jülich, Germany — [2]Forschungszentrum Jülich GmbH, Ernst Ruska Centre for Microscopy and Spectroscopy with Electrons (ER-C), JARA, 52425 Jülich, Germany — [3]RWTH Aachen University, Central Facility for Electron Microscopy (GFE), JARA, 52074 Aachen, Germany

Recently, we reported on the successful deposition of trigonal monocrystalline $Ge_1Sb_2Te_4$ on Si by MOVPE. The deposited material bears structural analogies to interfacial Phase-Change Memories (iPCM), where induced switching in the crystalline phase has been reported in highly textured crystalline $(Sb_2Te_3)_x(GeTe)_y$ super-lattices. Therefore trigonal Ge-Sb-Te may act as a model material for iPCM to elucidate the underlying switching effect.

Here we present the structural characterization of epitaxial trigonal $Ge_1Sb_2Te_4$ and $Ge_2Sb_2Te_5$ films on Si (111) deposited by MOVPE. The morphology, structure and composition was investigated using SEM, XRD, HAADF-STEM, EBSD and EDS. STEM investigations reveal highly ordered septuple and nonuple layers, respectively, separated by van der Waals gaps. The structural correlation between monocrystalline Ge-Sb-Te and iPCM will be discussed.

DS 3.11 Mon 12:15 H8

Metalorganic vapour phase deposition of indium-antimony-tellurium nanostructures — •Kristof Keller, Martin Schuck, Martina von der Ahe, Gregor Mussler, Hilde Hardtdegen, and Detlev Grützmacher — Forschungszentrum Jülich GmbH, Peter Grünberg Institute (PGI-9), JARA, 52425 Jülich, Germany

In the search for future non-volatile memories, phase change materials (PCM) are a promising prospect due to their fast switching speeds and high scalability. Alloys from the ternary system germanium-antimony-tellurium are mostly used commercially, so far. Compared to these materials, indium-antimony-tellurium, also a PCM, has advantages including higher crystallization and melting temperatures, leading to enhanced retention at elevated temperatures. Also lower reset currents and the capability of multilevel data storage were reported. Nanostructures like nanowires are called for as they are self-heating elements, thus facilitating the switching mechanism. They also reduce the volume of the switched material.
Here, we present the MOCVD growth of In-Sb-Te nanostructures on a Si substrate using dimethylaminopropyldimethyl-indium (DADI), trimethylindium (TMIn), triethylantimony (TESb) and diethyltellurium (DETe) as precursors and pure N_2 as carrier gas. The deposited nanostructures were characterized by means of scanning electron microscopy, energy dispersive X-ray spectroscopy and X-ray diffraction. The influence of reactor pressure, growth temperature and gas composition on the growth of the nanostructures will be presented in this contribution.

DS 3.12 Mon 12:30 H8

Phase transformation in epitaxial GST thin films grown on Si (111) by Pulsed Laser Deposition — •Isom Hilmi, Andriy Lotnyk, Erik Thelander, Jürgen W. Gerlach, Philipp Schumacher, and Bernd Rauschenbach — Leibniz Institut für Oberflächenmodifizierung (IOM); Leipzig

GeTe-Sb2Te3-based material has been widely applied as a phase change data storage media. Recently, a superlattice GeTe-Sb2Te3 system has been proven to have improved switching characteristics [1,2]. It leads to an investigation of deposition of more ordered or epitaxial Ge-Sb-Te based layers. In this work, the epitaxial layers of Ge2Sb2Te5 (GST) were deposited on Si (111) substrates using pulsed laser deposition (PLD) technique. The crystal structures of the post-annealed epitaxial films were studied by means of x-ray diffraction, energy dispersive and Cs-corrected scanning transmission electron microscopy. The surface morphology was observed by AFM in a taping mode. The as-deposited GST film contains both cubic and hexagonal (h-GST) grain structures. The significant structure change towards h-GST is observed for samples with longer post-annealing up to 7 h, which is, however, also accompanied by loss of Ge.

[1] R. E. Simpson et al., Nat. Nano. 6, 501, (2011). [2] F. Katmis et al., Cryst. Growth Des. 11, 4606, (2011)

DS 3.13 Mon 12:45 H8

Ab initio Simulations of Liquid Phase-Change Materials — •Mathias Schumacher[1], Hans Weber[2,3], Ivan Kaban[2,3], Riccardo Mazzarello[1,4], and Pal Jovari[5] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen University, Germany — [2]IFW Dresden, Institute for Complex Materials, Dresden, Germany — [3]Institute of Materials Science, TU Dresden, Germany — [4]JARA FIT and JARA HPC, RWTH Aachen, Germany — [5]Department of Complex Fluids, Institute for Solid State Physics and Optics, Wigner RCP of the H.A.S., Hungary

Phase-Change materials (PCMs) undergo fast and reversible transitions between the amorphous and crystalline phase at high temperature. This property is exploited in non-volatile phase-change memories and rewritable optical disks. The liquid state plays a role in both directions of the switching process: the amorphization occurs upon rapid quenching from the liquid state, whereas fast crystallization takes place from the supercooled liquid. Hence, detailed knowledge of the properties of liquid PCMs is crucial for the understanding of the switching phenomenon. Here we present large scale ab initio molecular dynamics (AIMD) simulations of liquid and supercooled liquid PCMs. We consider large models of GeTe, $Ge_2Sb_2Te_5$ and Ag, In-doped Sb_2Te containing about 500-600 atoms and carry out long simulations (of the order of 100 ps) at different temperatures, below and above the melting temperature. We extract structural and dynamic properties from these trajectories, including radial and angle distribution functions and viscosities. The results are in fair agreement with recent experiments.

DS 3.14 Mon 13:00 H8

Dielectric properties and AC conductivity of amorphous phase change materials — •chao chen[1], hanno volker[1], peter jost[1,2], marvin kaminski[2], and matthias wuttig[1,2] — [1]I. Physikalisches Institut (IA), RWTH Aachen University, 52056 Aachen, Germany — [2]JARA-FIT, RWTH Aachen University, Germany

Chalcogenide-based phase-change materials (PCMs) are popular for their widespread potential applications in both optical and electrical data storage devices [1]. These applications depend on the pronounced contrast of physical properties between the amorphous and crystalline phases and the ability to rapidly switch between these two phases. PCMs are non-volatile, with fast switching velocity (10 ns) and excellent endurance (10^{10} cycles), which ensures significant potential application for switches. Although the properties of crystalline PCMs have been intensively studied, the phenomena of electrical drift [2] and threshold switching [3] in the amorphous phase are still not well understood, which hampers the development of PCM-based electrical devices and multilevel storage. Several mutually incompatible models about electric transport, such as the small polaron model by Emin [4], the Poole Frenkel model [5], and a band transport model [6] have been developed to explain the behavior of amorphous PCMs. To provide crucial input parameters that should help to derive a unique model, the AC conductivity and dielectric constants of several amorphous PCMs have been studied to determine properties trends and develop a more systematic understanding.