DS 23: High-k Dielectric Materials - Synthesis, Properties, Applications
The posters can also be presented at Poster A on Tuesday morning (DS poster session).

Time: Wednesday 18:30–20:30 Location: Poster C

DS 23.1 Wed 18:30 Poster C

Leakage current in high-k thin film capacitor stacks — •Herbert Schroeder — IEM im Institut für Festkörperforschung und CNI, Forschungszentrum Jülich GmbH, D-52425 Jülich

High-permittivity thin insulating films of the perovskite-type mixed-oxides such as $SrTiO_3$ or $(Ba,Sr)TiO_3$ are candidates as capacitor dielectrics in advanced DRAM cells and as new gate materials in MOSFETs (see ITRS Roadmap). One of the most important issues for these applications is a sufficiently low leakage current to avoid malfunction of the devices. Although a large number of experimental data on leakage through metal-insulator-metal (MIM) thin film capacitor structures is published for perowskite-type mixed oxides, the mechanistic interpretation is quite inconsistent. In this contribution the experimental data will be compared to simulation studies for an advanced leakage current model combining the electronic carrier injection/ejection at the electrode interfaces (described by thermionic emission) with the film conduction properties of the thin dielectric film (modelled as wide band gap semiconductor). Many parameters are varied: Besides the externally given electric field, dielectric thickness and temperature, these are the usually unknown defect properties [type (donor, acceptor), concentration and in-gap energy level as well as type and degree of compensation] and that of the electrode interfaces. From the resulting trends guidelines for a low leakage MIM stack with high effective permittivity are extracted.

DS 23.2 Wed 18:30 Poster C

Induced Ferroelectricity in Strained Epitaxial $SrTiO_3$ Films on Various Substrates — Eugen Hollmann, Jürgen Schubert, Rolf Kutzner, and •Roger Wördenweber — Institut für Bio- und Nano-Systeme and cni, Forschungszentrum Jülich, D-52425 Jülich

Thin films of ferroelectric materials ($SrTiO_3$, $(Ba,Sr)TiO_3$ and others) are currently being used to develop active microwave devices (phase shifters, tunable high-Q resonators or filters) for cryogenic and room temperatures operation. In this contribution, the impact of strain on structure and ferroelectric properties of epitaxial $SrTiO_3$ films on various substrate materials - substrates with larger ($DyScO_3$) and smaller ($NdGaO_3$ and CeO_2/Al_2O_3) in-plane lattice constant, respectively - is analyzed. It is demonstrated that the mismatch of the lattices or, alternatively, the mismatch of the thermal expansion coefficients of films and substrate impose biaxial compressive or tensile strain to the $SrTiO_3$ films, respectively. The strain leads to a small tetragonal distortion of the $SrTiO_3$ lattice and has a large impact of the ferroelectric properties of the films. With decreasing film thickness and at low temperatures the permittivity deviates from the *classical* Curie-Weiss behavior. The thinnest sample shows an enhancement of the dielectric constant at room temperature by up to a factor of 3. Furthermore, strain induced ferroelectricity is observed which agrees with theoretical predictions. For electric fields parallel to the film surface induced ferroelectricity is observed for $SrTiO_3$ that is exposed to in-plane tensile strain, i.e., ferroelectricity is observed for temperatures up to 210 K and 325 K for strained $SrTiO_3$ on $CeO_2/Al2O_3$ and $DyScO_3$, respectively.

DS 23.3 Wed 18:30 Poster C

Solvothermal sol-gel process for synthesis of $Ba_{0.5}Sr_{0.5}TiO_3$ — •Dirk Spitzner[1], Emanuel Gutmann[1], Boris Mahltig[2], and Dirk C. Meyer[1] — [1]TU Dresden, Institut für Strukturphysik, 01062 Dresden — [2]Gesellschaft zur Förderung von Medizin-, Bio- und Umwelttechnologien, GMBU e.V., Department: Functional Coatings, Postfach 520165, 01317, Dresden

In the solid solution of barium strontium titanate (BST) the transition temperature from the paraelectric to ferroelectric phase and hence the electrical properties can be tuned over a wide range, what is of interest for various electronic applications. Beside vacuum deposition methods, thin films of BST can be synthesized by chemical solution deposition. We modified a classic sol-gel deposition process using barium-, strontium-acetate and titanium-isopropoxide as precursor in acetic acid and acetylacetone by introducing a solvothermal treatment of as-synthesized sols. The decomposition and crystallization behaviour in the resulting powders and films were analyzed by thermal analysis (TG, DTA), X-ray diffraction and X-ray reflectometry. In comparison to untreated sols a different transition behaviour is observed when the sols are prepared by using a solvothermal procedure.

DS 23.4 Wed 18:30 Poster C

Band gap determination of thin Praseodymiumoxide layers on Aluminiumoxynitride films — •Matthias Bergholz and Dieter Schmeisser — Brandenburgische Technische Universität Cottbus, Angewandte Physik - Sensorik, Konrad-Wachsmann-Allee 17, 03046 Cottbus, Germany

High-k dielectrics are important as never bevore in semiconductor industry. We investigate Pr_2O_3 as one representative of this group on Silicon and Silicon-Aluminium oxynitride substrates. In earlier work we observed the positive influence of this AlO_xN_y intermediate layer on the electrical properties of the Pr_2O_3 layer. Now we present in-situ EELS, XPS and UPS measurements of gradually grown thin Pr_2O_3 on AlO_xN_y. From these measurements we determine the band structure and find a very fast change of the band gap for the first few Ångström, coupled with n-type behaviour for the Pr_2O_3 film. These results are compared with RIXS measurements of a 5 nm Pr_2O_3 on a 1 nm thick AlO_xN_y layer.

DS 23.5 Wed 18:30 Poster C

X-ray photoemission spectroscopy of Aluminium Oxynitride on Si(001) and the rise as buffer layers — •Yevgen Burkov, Karsten Henkel, and Dieter Schmeisser — BTU Cottbus, Angewandte Physik - Sensorik, Konrad-Wachsmann-Allee 17, 03046 Cottbus, Germany

Praseodymium oxide (Pr_xO_y) is one of the candidate as high-k transistor gate dielectrics, but aluminium oxynitride (Al_xON_y) as buffer layer is needed to prevent diffusions from the silicon into Pr_xO_y and to hinder charge injection from the semiconductor into the insulator. The thermal stability and thickness dependence of aluminum oxynitride (Al_xON_y) has been investigated by synchrotron radiation photoemission spectroscopy (SR-PES). Al_xON_y layers were prepared by low energy ion-beam assisted deposition (LE-IBAD) at room temperature on a silicon substrate cleaned with HF-acid. Aluminium oxynitride is stable till 800°C. From photoemission spectra we can assess that silicon oxynitride is built as first and then the growth of Al_xON_y follows. Resonant inelastic X-ray scattering measurements with synchrotron radiation have been performed. The combination of X-ray absorption spectroscopy (XAS) and RIXS make possible to determinate the band gap of Al_xON_y.

DS 23.6 Wed 18:30 Poster C

Unified approach for the calculation of direct and Fowler-Nordheim tunneling current in multi-layered high-k gate dielectric stacks — •Mahyar Boostandoost, Ebrahim Nadimi, and Christian Radehaus — Technische Universität Chemnitz Fakultät für Elektrotechnik und Informationstechnik Professur für Opto- und Festkörperelektronik 09107 Chemnitz

A quantum mechanical model is developed to compute the tunneling current in the p-MOSFET, with multi-layered high-k gate stacks. A unified approach is applied to the calculation of direct and Fowler-Nordheim tunneling regimes. The model uses self-consistent approach, based on a numerical solution of the coupled Schrödinger and Poisson equations and an open boundary condition at dielectric/gate interface. The tunneling current will be derived using the lifetime of electrons in the quasi-bound states. The gate tunneling current of different high-k stacks including HfO_2, ZrO_2, Si_3N_4 and an intefacilal SiO_2 layer are compared. For a given equivalent oxide thickness, the gate leakage current decreases by increasing the high-k dielectric thickness or by decreasing the interlayer thickness. Crossing point in the I-V curves at high gate biases are observed for all gate stacks. We also investigate the influence of the effective mass on the tunneling current and presented the results considering different possible situations.

DS 23.7 Wed 18:30 Poster C

Tunneling effective mass in ultrathin silicon oxynitride gate dielectrics — •Ebrahim Nadimi[1], Christian Golz[2], Martin

Trentzsch[2], Lukas Herrman[2], Karsten Wieczorek[2], and Christian Radehaus[1] — [1]Technische Universität Chemnitz, Fakultät für Elektrotechnik und Informationstechnik, Reichenhainer Str. 70, D-09126 Chemnitz, Deutschland — [2]AMD Saxony LLC & Co. KG, Wilschdorfer Landstraße 101, D-01109 Dresden, Deutschland

In this work we study the dependence of the tunneling effective mass of electrons on gate dielectric nitrogen concentration and thickness in metal-oxide-semiconductor field-effect-transistors (MOSFETs) with lightly doped silicon oxynitride (SiOxNy) gates. The dependences of the effective mass on nitrogen concentration and dielectric thickness are extracted by fitting the computation results for the gate leakage current to the experimental data measured by us for samples with different thicknesses and nitrogen concentrations. The direct tunneling current is modeled by applying a Schrödinger-Poisson solver with one-side-open boundary condition. Nitrogen concentration and thickness of samples are determined using X-Ray photoemission spectroscopy (XPS). The obtained results show a strong dependence of the effective mass on the sample thicknesses and nitrogen concentration. The electron effective mass is found to increase as the thickness decreases and the higher nitrogen concentration causes a reduction in effective mass.

DS 23.8 Wed 18:30 Poster C

Optical characterization of HfO_2-based high-k gate stacks — •Martin Weisheit, René Hübner, Hans-Jürgen Engelmann, Inka Zienert, Susanne Ohsiek, Kornelia Dittmar, Michael Hecker, Martin Trentzsch, and Ehrenfried Zschech — AMD Saxony LLC & Co. KG, Wilschdorfer Landstraße 101, 01109 Dresden

HfO_2 is currently introduced as a high-k gate dielectric into large scale semiconductor production of logic devices. Along with HfO_2, a number of other new materials will have to be introduced into the gate stack, namely ultrathin work function layers and metal gates. This results in a complex gate stack that challenges traditional characterization techniques. In this presentation we demonstrate how a combination of complementary methods allows quantitative determination of relevant parameters. Important information can be derived from the optical properties of the stack - such as the bandgap of the HfO_2 - which are measured by Variable Angle Spectroscopic Ellipsometry (VASE). However, due to the very thin individual layers of the stack, independent determination of thickness and refractive index is difficult. Therefore, TEM and X-Ray Reflectivity are needed as complementary methods for an accurate measure of the layer thicknesses. Using the Drude model, VASE is then employed to characterize the electrical conductivity of the TiN metal gate layers, which is compared to Microscopic Four-Point Probe measurements and discussed with respect to chemical composition as determined by XPS and Auger electron spectroscopy. The work described in this presentation has been funded in line with the technology funding for regional development (ERDF) of the European Union and by funds of the Free State of Saxony.

DS 23.9 Wed 18:30 Poster C

Diagnostics of electrical surface parameters using conductive and electrostatic force microscopy — •Teodor Gotszalk[1], Grzegorz Wielgoszewski[1], Ehrenfried Zschech[2], and I. W. Rangelow[3] — [1]Wroclaw University of Technology, Faculty of Microsystem Electronics and Photonics, ul. Janiszewskiego 11/17, 50-372 Wroclaw, Poland — [2]AMD Saxony LLC & Co., Wilschdorfer Landstr. 101, D-01109 Dresden, Germany — [3]Technical University of Ilmenau, Gustav-Kirchoff-Strasse 1, D- 98 693 Germany

Failure analysis and reliability investigations of high-κ dielectrics films for the MOSFET transistors (e.g. silicon oxynitride or Hf oxide) films very often require high-resolution local measurements of electrical surface parameters. This kind of experiments can be performed using conductive atomic force microscopy, which provides simultaneous measurement of surface topography and current flowing through the investigated layer. In our experiments a precise measurement and control scanning probe system, which integrated a DC and AC low-noise current-to-voltage converter of picoampere resolution enabling high resolution of electrical conductance and capacitance in wide frequency range, was applied. In this presentation we will describe the architecture of the designed and applied experimental set-up. In addition we will also present results of simultaneous measurements of topography and tunneling current on silicon oxynitride ultra-thin films of different thickness and different composition, but also results of test measurements on highly oriented pyrolytic graphite (HOPG). We will also describe the possible usage of scanning electrostatic force microscopy, which in our opinion enables quantitative measurements of electrical voltages on the investigated surface of the microelectronic circuits and materials. In these experiments we applied near-field sensors with integrated piezoresistive and piezoelectrical deflection. In this way we simplified the architecture of the measurement system and enabled new applications on technological samples. In our talk we will describe the metrological properties of the applied sensors and instrumentation.

DS 23.10 Wed 18:30 Poster C

Fully depleted SOI-nMOSFETs with Gadolinium scandate as high-κ dielectric. — •M. Roeckerath[1], J. M. J. Lopes[1], T. Heeg[2], J. Schubert[1], and S. Mantl[1] — [1]Institute of Bio- and Nanosystems and Center of Nanoelectronic Systems for Information Technology, Research Centre Juelich, D-52425 Juelich, Germany — [2]Department of Materials Science and Engineering, The Pennsylvania State University, University Park, Pennsylvania 16802-5005, USA

Rare earth scandates are a promising class of materials as alternative high-κ gate dielectrics for future CMOS applications due to their good morphological and electrical properties (D. G. Schlom et. al., MRS Bull. 27, 198 (2002)). In particular, gadolinium scandate has recently attracted increasing attention since it exhibits a high thermal stability, a sufficiently large κ-value of $\sim$23 and is in contrast to other rare earth oxides not hygroscopic. In this work long channel n-metal-oxide-semiconductor field-effect transistors (nMOSFETs) on thin SOI ($\sim$25 nm) have been prepared with gadolinium scandate as high-κ gate dielectric and a TiN metal gate in a gate last process. The $GdScO_3$ films were deposited by electron beam evaporation from a stoichiometric ceramic target in high vacuum conditions. Prior to the deposition different surface treatments of the substrates were applied to vary the interface conditions. Readily fabricated devices were electrically characterized by DC-measurements. They reveal well behaved output and transfer characteristics with high I_{on}/I_{off} ratios of 10^6-10^8 and steep inverse subthreshold slopes of $\sim$66 mV/dec. Carrier mobilities comparable to other high-k dielectrics of $\sim$150 cm^2/Vs were determined.

DS 23.11 Wed 18:30 Poster C

XRD/GIXRD studies of Praseodymium Oxide on Si(111) — •Andreas Greuling[1], Thomas Weisemöller[1], Carsten Deiter[1], Joachim Wollschläger[1], and Thomas Schröder[2] — [1]Universität Osnabrück, Barbarastr. 7, D-49069 Osnabrück, Germany — [2]IHP-Microelectronics, Im Technologiepark 25, D-15236 Frankfurt(Oder), Germany

Praeseodymium sesquioxides ($\epsilon \approx 25$) are well suited for epitaxy on Si based technologies since several crystalline phases are lattice matched to Si substrates. It is known that one can deposit metastable hexagonal Pr_2O_3 on Si(111)[1] which can be transformed to the cubic Pr_2O_3 phase due to annealing with a low oxygen pressure. Here, we present CTR-Analysis of thin Praseodymium Oxide films (5nm/10nm) on Si(111)[2]. The Praseodymium Oxide was deposited on Si(111) at 625°C. Following epitaxy the h-Pr_2O_3/Si(111) samples were annealed at 10^5 Pa O_2. After that ex situ XRD and GIXRD experiments were performed at HASYLAB(DESY). We developed a simulation program which allows us to compute the intensity of a CTR using experimental data in order to fit the parameters of the underlying model. During our work we compared simulation runs of h-Pr_2O_3, c-Pr_2O_3 and PrO_2 on Si(111). Using our program for CTR-analysis we checked models with single phases and phase mixtures.

[1] H.J. Osten, J.P. Liu, E. Bugiel, H.J. Müssig, and P. Zaumseil, J. Cryst. Growth 235, 229 (2002).

[2] Samples were prepared at IHP.

DS 23.12 Wed 18:30 Poster C

In-situ ALD growth of Hafnium oxide films — •Konstantin Karavaev[1], Massimo Tallarida[1], Dieter Schmeisser[1], and Ehrenfried Zschech[2] — [1]Brandenburgische Technische Universität Cottbus, Angewandte Physik - Sensorik, Konrad-Wachsmann-Allee17, 03046 Cottbus, Germany — [2]AMD Saxony LLC & Co. KG, Center for Complex Analysis, Wilschdorfer Landstr. 101, D-01109 Dresden, Germany

We report on a novel system for in-situ atomic layer growth (ALD) of high-k dielectric films. First results were obtained for Hf-oxide samples by using Hf-tetrachloride as precursor and water as oxidizer. We compare the photoelectron spectra of Si2p, O1s and Hf4f of our in-situ prepared films with samples (ex-situ) prepared by industrial ALD reactors and discuss similarities and differences observed in the core level spectra of the various samples by considering the different growth conditions.