SEMICON Europa2015 | PE 2015
6–8 October
Dresden, Germany
semi

Emerging Materials and Processes

MOFs as Low-k Candidates for Future Technology Nodes

C. Wöll
Director
KIT, Karlsruhe, Germany

Abstract
Materials with good mechanical properties and low k dielectric constants are of paramount interest for the next generation of electronics, since for the needed increases in clock frequency low-k materials are a crucial ingredient. It is very difficult to achieve dielectric constants below k = 2 with conventional polymers. Here, we focus on a novel, highly tunable class of materials, metal-organic frameworks (MOFs). MOFs are highly porous hybrid materials consisting of organic linkers connected to inorganic metal (or metal/oxo) clusters. Due to their crystalline, highly ordered, and porous structures, MOFs exhibits a number of highly interesting properties. The Young's modulus of a particular MOF, HKUST-1, amounts to 9.3 GPa[1] Because of the very low mass density of MOFs, the static dielectric constants k is very small and can drop to values far below 2.[3]
We have introduced a novel method to grow SURMOFs, thin films of this exciting new class of porous solids, by liquid phase epitaxy (LPE) [2]. The solid state elastic and mechanical properties of SURMOFs, as well as their optical, electrical and electrochemical [4] properties have been investigated.[5] In addition, they are suited for photolithography [6].
References
[1] S. Bundschuh, O. Kraft, H.K. Arslan, H. Gliemann, P.G. Weidler, C. Wöll, Appl. Phys. Lett. 101, 101910 (2012)
[2] O. Shekhah, H. Wang, S. Kowarik, F. Schreiber, M. Paulus, M. Tolan, C. Sternemann, F. Evers, D. Zacher, R. A. Fischer, Ch. Wöll, J. Am. Chem. Soc. 129, 15118 (2007).
[3] E.Redel, Z. Wang, S.Walheim, J.Liu, H.Gliemann, Ch.Wöll, Appl. Phys. Lett., 103, 091903 (2013)
[4] V. Mugnaini, M. Tsotsalas, F. Bebensee, S. Grosjean, A. Shahnas, S. Bräse, J. Lahann, M. Buck, C. Wöll, Chem. Comm., 50, 11129 (2014)
[5] H. Gliemann, Ch. Wöll, Materials Today, 15, 110 (2012)
[6] S. Grosjean, D. Wagner, W. Guo, Z.-G. Gu, L. Heinke, H. Gliemann, S. Bräse, Ch. Wöll, Chem.Nano.Mat., DOI: 10.1002/cnma.201500031

Biography
Hochschulstudium und Stipendien
1979-1984 Physik-Studium (Dipl.) an der Universität Göttingen
1984-1987 Promotion am Max-Planck-Institut (MPI) für Strömungsforschung, Göttingen unter Anleitung von J. Peter Toennies
Stipendien während des Studiums und der Promotion:
1982-1987 Stipendium Studienstiftung des Deutschen Volkes

Berufliche Laufbahn
1988-1989 Postdoktorat, IBM-Forschungslaboratorien in San José, USA

1989-1992 wissenschaftlicher Mitarbeiter am Lehrstuhl für Angewandte Physikalische Chemie in Heidelberg
1992 Habilitation an der Fakultät für Physik und Astronomie der Universität Heidelberg
1992-1993 Hochschuldozent (C2) am Lehrstuhl für Angewandte Physikalische Chemie der Universität Heidelberg
1994 Umhabilitation von Heidelberg an die Fakultät für Physik der Georg-August-Universität Göttingen
1997-2009 Hochschulprofessor (C4), Lehrstuhl für Physikalische Chemie I der Ruhr-Universität Bochum
2001 Visiting Professor am Materials Research Laboratory der University of Illinois at Urbana-Champaign, USA
2006-2007 Visiting Professor am Materials Science Laboratory an der Nagoya University, Japan
2009- Direktor des Instituts für Funktionelle Grenzflächen (IFG) am Karlsruher Institut für Technologie (KIT, Campus Nord)

Funktionen
2000-2009 Sprecher des DFG-Sonderforschungsbereichs (SFB) 558 ***Metall-Substrat-Wechselwirkungen in der Heterogenen Katalyse"
2001-2007 Koordinator des DFG-Schwerpunktprogramms 1121 ***Organische Feldeffekttransistoren" (OFET)
2004-2007 Sprecher des Transferbereichs des SFB 558 ***CVD-Präparation von Cu/Zn/Al-Trägerkatalysatoren für die Methanolsynthese"
2006-2009 Koordinator des EU-STREP-Projektes ***Anchoring of metal-organic Frameworks, MOFs, to surfaces" (SURMOF, FP6)
2009- Mitglied des Senats des KIT
2011- Sprecher des Helmholtz-Programms BioInterfaces

Stipendien/Auszeichnungen
1988 Otto-Hahn-Medaille der Max-Planck-Gesellschaft für die im Rahmen der Promotion erfolgten Arbeiten ***zur Demonstration der Anwendungsmöglichkeiten der Helium-Atomstrahlmethode auf Oberflächenuntersuchungen"
1994-1996 Heisenbergstipendiat der Deutschen Forschungsgemeinschaft (DFG), Tätigkeit in Heidelberg und Göttingen (MPI für Strömungsforschung)
2013- Mitglied der Deutschen Akademie der Naturforscher Leopoldina

Mitgliedschaften
Herausgebergremien wissenschaftlicher Zeitschriften und Monographienserien
- Editorial Board Surface Review and Letters
- Editorial Board Progress in Surface Science
Wissenschaftliche Gesellschaften
- Gesellschaft Deutscher Chemiker
- Deutsche Physikalische Gesellschaft
- Deutsche Bunsengesellschaft für physikalische Chemie

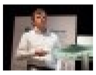
Gutachtertätigkeiten
- Gutachter der DFG, Studienstiftung des dt. Volkes, u.a.
- der NSF, des DOE (USA)
- Gutachter für den FWF (Österreich), den EPSRC (GB), die Israel Science Foundation, u.a.
- Gutachter im Zusammenhang mit Beförderungen und Berufungen an deutschen, europäischen und nordamerikanischen Universitäten

Forschungsaktivitäten
Photoelektronenspektroskopie (XPS, UPS) sowie Absorptionsspektroskopie im weichen Röntgenbereich (NEXAFS) an dünnen organischen Filmen und Adsorbatschichten auf Metallen, Halbleitern und Isolatoren, Messungen am Synchrotron BESSY in Berlin;
Herstellung, strukturelle und chemische Charakterisierung von ultradünnen organischen Filmen (Langmuir-Blodgett, selbstorganisierende Filme aus Alkanthiolen und Alkylsilanen) auf metallischen (Au,Cu) und oxidischen (Si) Substraten, Infrarotspektroskopie an organischen Dünnstschichten auf metallischen und oxidischen Substraten, Flüssigphasenepitaxie von metallorganischen Gerüstverbindungen (MOFs bzw.

SURMOFs) auf organischen Oberflächen, Beladen der epitaktischen Schichten mit Gastmolekülen

Publikationsaktivitäten
Ca. 400 Veröffentlichungen, 2 Patente, 1 Buch (Herausgeber)

Prospects of Emerging 2D Transition Metal Films for Applications in Electronics



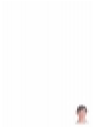
G. Duesberg
PI
CRANN, Trinity College Dublin, Chemistry, Dublin, Ireland

Abstract
The reduction of dimensionality has revealed exciting properties in 2D materials such as graphene and Transition Metal Dichalcogenides (TMDs). The potential for their applications in electronics, has been demonstrated, however, most of these studies have been carried out on individual devices, often relying on time consuming low yield techniques such as mechanical exfoliation and electron-beam (e-beam) lithography. Furthermore, the stability of TMDs and their integration with existing semiconductor technology is a major challenge for their successful incorporation into useful applications.
Reliable large scale synthesis, functionalisation and passivation of this new class of materials will be discussed in this presentation. Firstly, the synthesis of large scale TMD films via two methods compatible with semiconductor production lines will be presented. Thermally Assisted Conversion (TAC) of various metal layers to their sulfides and selenides is shown. The samples are produced on silicon chips and were subjected to structural and spectroscopic characterization. TAC allows good control over their thickness and morphology. Secondly, we report on the direct CVD growth on SiO_2 of TMD monolayers in a micro-reactor set-up. These highly crystalline TMDs were tested in simple transistor configurations. The deposition of subsequent layers on top of the TMD for gating and passivation by Atomic Layer Deposition (ALD) has also been achieved. This process involves chemical functionalisation of TMD layers on silicon; a crucial step for device integration.
With this large scale processes at hand, it is possible to structure and electrically address the TMD films in a manner similar to SiO technology yielding simple devices such as transistors, diodes and sensors. This integration of 2D materials into hybrid devices with conventional semiconductors processes allows us to retrieve electrical performance data in such processed TMD channels.

Biography
Prof. Georg S. Duesberg graduated in Physical Chemistry from the University of Kassel, Germany in 1996. He was researcher at the Max-Planck-Institute for Solid State Research, Stuttgart and Trinity College Dublin from 1997 - 2001 after which he received his PhD from the University of Tübingen in 2001. From 2001 - 2005 he worked at the Infineon AG, in the Corporate Research Department in Munich. From 2005 - 2007 Prof. Duesberg was in the Thin Films Department at Qimonda AG, Dresden. In 2007 Georg took on a position in the School of Chemistry of Trinity College Dublin and as a Principal Investigator in CRANN. Since 2011 he is Professor and Director of Research in the School of Chemistry. Prof. Duesberg has co-authored more than 165 publications with more than 9000 citations (H-index 43) and has filed more then 25 patents.

Prof. Duesberg´s research focuses on making novel devices to exploit the unique properties of low-dimensional structures. These Hybrid devices have applications in ICT, sensing and bio-chemistry as well as energy conversion and storage. For example novel electrodes, switches, sensors are developed and integrated with state-of-the-art silicon processing techniques. Recently Professor Duesberg's team focuses on the synthesis and integration of novel 2D materials for electronic applications.

Monolayer controlled deposition of 2D transition metal dichalcogenides on large area substrates

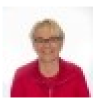


A. Delabie
Professor
KU Leuven (University of Leuven), Leuven, Belgium

Abstract
Two-dimensional (2D) transition metal dichalcogenides (MX2, with M a transition metal of group 4 - 7 and X a chalcogen) have versatile properties that complement those of graphene. Depending on the metal and chalcogen, these 2D materials exhibit insulating, metallic, semi-metallic or semiconducting properties. The anisotropy in their electrical, chemical, mechanical and thermal properties is of interest for applications ranging from nano-electronics to sensing and photonics. MoS2, MoSe2, WS2, and WSe2 are 2D semiconductors that attract significant interest for ultra-scaled nano-electronic devices because of their large band gap values, low dielectric constants, lack of dangling bonds and structural stability. In contrast to graphene, the presence of a band gap in MX2 allows fabrication of transistors with high Ion/Ioff ratio. Further exploiting the potential of MX2 and enabling integration in nano-electronic devices requires the development of deposition techniques for MX2 that provide monolayer growth control on large area substrates. Next to Chemical Vapor Deposition (CVD), Atomic Layer Deposition (ALD) is a promising technique because its deposition principle ensures growth control at the atomic level on large area substrates. We will discuss the CVD and ALD of WS2 from the WF6 and H2S precursors. The deposition of WS2 on Al2O3 substrates is enabled at low temperature (300-450ºC) by either Si layers or H2 plasma as reducing agents. The 2D structure of thin WS2 layers (2-3 monolayers) is obtained at low deposition temperature without using a template or anneal, as indicated by Raman Spectroscopy and Transmission Electron Microscopy. Nevertheless, the layers are polycrystalline with a rather small grain size. The orientation of the WS2 basal planes is parallel to the substrate at 300ºC and depends on temperature. We will discuss the need for a better understanding of the nucleation and growth mechanisms, as this will enable improvement of the crystallinity.

Biography
Annelies Delabie obtained a master degree in chemistry in 1997 and a PhD degree in science in 2001 from the University of Leuven (KULeuven) in Belgium. In 2001, she joined imec, research institute for nano-electronics and nanotechnology in Belgium. As a senior scientist, she investigates the fundamentals and applications of thin films and their deposition techniques, with a focus on Atomic Layer Deposition (ALD). Since 2012, she is also appointed associate professor at the chemistry department of the KU Leuven, where she started the research group "Nano-engineered Thin Films". She is a member of the American Vacuum Society (AVS) ALD conference committee and the ALD applications symposium of the Electrochemical Society. She is (co-) author of 9 patents and more than 160 scientific publications in peer reviewed journals, with an h-factor of 30.

Selective Deposition as Enabler for Shrinking Device Dimensions



S. Haukka
Executive Scientist
ASM Microchemistry Ltd., Helsinki, Finland

Abstract
The shrinking device dimensions in semiconductor manufacturing call for new innovative processing approaches. One of these considered is selective deposition which has gained increasing interest among semiconductor manufacturers today. Selective deposition would be highly beneficial in various ways, for instance, it would allow a decrease in lithography and etch steps reducing the cost of processing and enable enhanced scaling in narrow structures making bottom up fill possible. Chemical vapor deposition (CVD) and especially atomic layer deposition (ALD) as very surface sensitive techniques are considered enabling techniques.
In most of the selective deposition schemes of today a passivation is used for the surface on which no deposition is desired. The most known method is to use SAM´s (self-assembled monolayers) which are

silicon compounds with long carbon chains. Depending on the type of SAM one can passivate either the metal oxide, metal or silicon surface. Thus, the use of SAM allows for instance a metal layer be selectively deposited on metal surface over dielectric surface. Furthermore, it has been shown that without SAM a dielectric layer can selectively be deposited on hydrophilic polymer over a more hydrophobic polymer.
In this paper, the various selective deposition approaches and passivation means are reviewed. In addition, results from the selective deposition of metal on metal over dielectric surface in a Cu capping application and from selective strengthening of DSA (direct self-assembly) layers are presented.

Biography
Dr. Suvi Haukka is currently employed as an Executive Scientist for ALD applications for ASM International, and she is based in Helsinki, Finland where the R&D site of ASM, ASM Microchemistry is located. For over twenty years she has worked in various capacities, including Research Scientist, Catalyst Technology Manager, Process Development Manager and R&D Manager, which all have been related to atomic layer deposition (ALD). In particular, her work has focused on ALD and applications of it for semiconductor equipment, processes, and devices as well as development of ALD apparatus. Over the course of her career, she has been an author on over 70 scientific papers, primarily concerning ALD processes, applications and apparatus. In addition, she is an inventor of more than 100 ALD patents and patent applications in the field of semiconductor fabrication. In 1994 Suvi Haukka earned a Doctor of Philosophy degree from the Laboratory of Analytical Chemistry, University of Helsinki, Finland.

Next Generation Ferroelectric Field Effect Transistors enabled by Ferroelectric Hafnium Oxide

T. Mikolajick
scientific director
NaMLab Gmbh / TU Dresden, Dresden, Germany

Abstract
Ferroelectrics are very interesting for nonvolatile memories. The progress is limited by the low compatibility of ferroelectrics like PZT with CMOS processing. Therefore 1T/1C ferroelectric memories are not scaling below 130 nm and 1T ferroelectric FETs are still struggling with low retention and very thick memory stacks. Hafnium oxide, a standard material in sub 45nm CMOS, can show ferroelectric hysteresis with promising characteristics. By adding a few percent of silicon and annealing the films in a mechanically confined manner Boescke et al. demonstrated ferroelectric hysteresis in hafnium oxide for the first time. Recently a large number of dopants including Y, Al, Gd and Sr have been used to induce ferroelectricity in HfO2. In the first part of this talk the different doping elements that have been shown to enable ferroelectricity will be compared and general trends will be established. The second part will focus on the memory relevant characterization data. Finally the application in 1T FETs will be demonstrated and the potential to solve principal issues of ferroelectric FETs will be illustrated.

Biography
Thomas Mikolajick received the Diploma (Dipl.-Ing.) in electrical engineering from the University Erlangen-Nuremberg in 1990 and his phD in electrical engineering in 1996. From 1996 till 2006 he was in the semiconductor industry developing CMOS processes,ferroelectric memories, emerging non-volatile memories and Flash memories first at Siemens Semiconcuctor and later at Infineon. In late 2006 he moved back to academia taking over a professorship for material science of electron devices and sensors at the University of Technology Freiberg, and in October 2009 he started at Technische Universität Dresden were he now holds a professorship for nanoelectronic materials in combination with the position of scientific director at NaMLab GmbH. Since April 2010 he is the coordinator of the "Cool Silicon" Cluster in Dresden. Prof. Mikolajick is author or co-author of about 220 Publications in scientific journals or at scientific conferences and inventor or co-inventor of about 50 patents.

Spin-based nanoelectronic devices for mobile Informaion-Communication Technology

A. Deac
Group Leader
Helmholtz-Zentrum Dresden - Rossendorf, Dresden, Germany

Abstract
Perhaps the best known (or most successfully implemented) spin-based device is the hard-disk read-head. Indeed, the discovery of giant magnetoresistance enabled a paradigm shift in the miniaturization of magnetic storage technology, which was disruptive enough to earn its discoverers a Nobel price [1]. More recently, it has been demonstrated that non-volatile, ultra-fast spin-based memory bit devices can be designed so that they can scale down to more than one fifth of all other available technologies, including SRAM [2]. Other spin-based nanoelectronics devices currently under consideration - which will be discussed here - range from tuneable radio-frequency oscillators to magnetic field sensors, negative resistors, amplifiers, write heads and random number generators.

[1] http://www.nobelprize.org/nobel_prizes/physics/laureates/2007/index.html
[2] http://www.avalanche-technology.com/technology/ram

Biography
Alina Deac is currently the leader of the Spintronics Group at the Helmholtz-Zentrum Dresden - Rossendorf in Dresden, Germany. During the last 15 years, her research has been focused on spin-torque induced phenomena and their potential applications for mobile ICT devices. After obtaining her PhD in Physics at the Universite Joseph Fourier Grenoble, France in 2005, she pursued her career by working with top-notch institutions in Japan, US and Switzerland. She is a Senior Member of the IEEE Magnetics Society and an expert in the field of spintronics for the EU.