Emerging Materials
Room Arteveldeforum & Pedro de Gante - Session EM-MoP
Emerging Materials Poster Session

EM-MoP-2 Calcium and Vanadium Mixed Oxides With ALD, ***Fabian Krahl,*** *K. Nielsch,* Leibniz Institute for Solid State and Materials Research Dresden, Germany

Ternary oxides can show a wide range of very interesting physical properties and several have already been successfully deposited with ALD[1]. One that, to our knowledge, hasn't yet been reported with ALD is $CaVO_3$, ALD-processes for calcium and vanadium oxides have been reported already in the early 1990s and 2000respectively[2,3].

$CaVO_3$ is a correlated metal. These materials with strongly correlated charge carriers hold promise for a new type of transparent conductor (as opposed to highly doped wide bandgap materials like indium tin oxide)[4]. VO_2 and $CaVO_3$ also show a metal-insulator transition depending on film thickness which could make it an interesting phase change material[5–7].

An ALD process of $CaVO_3$ could therefore be a great step towards the utilization and further research of this material because ALD is scalable and has great control over the thickness and composition of the deposited films. Here we want to present the status of our work with the ALD of CaO, V_xO_y and the mixed $Ca_xV_yO_z$ Oxides.

References

[1] A.J.M. Mackus, J.R. Schneider, C. MacIsaac, J.G. Baker, and S.F. Bent, Chem. Mater. **31**, 1142 (2019).

[2] J. Aarik, A. Aidla, A. Jaek, M. Leskelä, and L. Niinistö, Applied Surface Science **75**, 33 (1994).

[3] J.C. Badot, S. Ribes, E.B. Yousfi, V. Vivier, J.P. Pereira-Ramos, N. Baffier, and D. Lincotb, Electrochem. Solid-State Lett. **3**, 485 (2000).

[4] L. Zhang, Y. Zhou, L. Guo, W. Zhao, A. Barnes, H.-T. Zhang, C. Eaton, Y. Zheng, M. Brahlek, H.F. Haneef, N.J. Podraza, M.H.W. Chan, V. Gopalan, K.M. Rabe, and R. Engel-Herbert, Nature Mater **15**, 204 (2016).

[5] S. Beck, G. Sclauzero, U. Chopra, and C. Ederer, Phys. Rev. B **97**, 075107 (2018).

[6] M. Brahlek, L. Zhang, J. Lapano, H.-T. Zhang, R. Engel-Herbert, N. Shukla, S. Datta, H. Paik, and D.G. Schlom, MRS Communications **7**, 27 (2017).

[7] G. Rampelberg, M. Schaekers, K. Martens, Q. Xie, D. Deduytsche, B. De Schutter, N. Blasco, J. Kittl, and C. Detavernier, Appl. Phys. Lett. **98**, 162902 (2011).

EM-MoP-3 Atomic Layer Deposition of Highly Pure Metals for Memory Devices Preparation, ***Haojie Zhang,*** *B. Kalkofen, S. Parkin,* Max Planck Institute of Microstructure Physics, Germany

Solid-state non-volatile memory devices have been seen as one of the most promising candidates to replace the stat-of-the-art data storage media (e.g. hard disk drives). The expansion of memory devices from two-dimensional (2D) to three-dimensional (3D) can further increase the capacity and storage density of memory devices. Therefore, atomic layer deposition (ALD) of highly magnetic metals films is crucial for the design and preparation of 3D memory devices. In this work, we develop ALD recipes to deposit highly pure and smooth metals layers, including Pt, Co, and Ni. The deposited metal layers with optimized ALD recipes exhibit superior conductivity and magnetic property. Our developed recipes have huge potential to be used for other applications, such as batteries, renewable energy conversion.

EM-MoP-4 Liquid Atomic Layer Deposition of Cu_2 (Bdc)$_2$ (Dabco) Through 3D-Printed Microfluidic Chips, ***Octavio Graniel,*** *D. Muñoz-Rojas,* University Grenoble Alpes, CNRS, Grenoble INP, LMGP, France; *J. Puigmartí-Luis,* Departament de Ciència dels Materials i Química Física, Institut de Química Teòrica i Computacional, ICREA, Catalan Institution for Research and Advanced Studies, Spain

In recent years, liquid atomic layer deposition (LALD)[1] has emerged as a much simpler and versatile strategy to overcome some of the current constraints of its gas phase homolog for the deposition of metal-organic frameworks (MOF) thin films (e.g. thermal decomposition of precursors at high temperatures, poor control over the crystallinity).

This work describes the automated deposition of Cu_2 (bdc)$_2$ (dabco) thin films on silicon and glass substrates using a 3D-printed microfluidic chip. Films with preferred (001) and (100) orientations were obtained by changing the temperature of the reaction, the concentration of the reactants, and the dimensions of the microfluidic reactor as demonstrated by GIXRD measurements. In addition, the area of the thin film was successfully controlled by changing the flow rates of the precursors in a continuous flow mode.

1O. Graniel, J. Puigmartí-Luis and D. Muñoz-Rojas, *Dalt. Trans.*, 2021, **50**, 6373–6381.

EM-MoP-7 Atomic Layer Deposition of Yttrium Iron Garnet (YIG) for 3D Spintronics, ***Michaela Lammel,*** Institute for Metallic Materials, Leibniz Institute of Solid State and Materials Science, Germany; *D. Scheffler,* Institut für Festkörper- und Materialphysik, Technische Universität Dresden, Germany; *D. Pohl,* Dresden Center for Nanoanalysis (DCN), cfaed, Technische Universität Dresden, Germany; *P. Swekis,* Max-Planck Institute for Chemical Physics of Solids, Germany; *S. Reitzig,* Institut für angewandte Physik, Technische Universität Dresden, Germany; *S. Piontek,* Institute for Metallic Materials, Leibniz Institute of Solid State and Materials Science, Germany; *H. Reichlova, R. Schlitz,* Institut für Festkörper- und Materialphysik, Technische Universität Dresden, Germany; *K. Geishendorf,* Institute for Metallic Materials, Leibniz Institute of Solid State and Materials Science, Germany; *L. Siegl,* Universität Konstanz, Germany; *B. Rellinghaus,* Dresden Center for Nanoanalysis (DCN), cfaed, Technische Universität Dresden, Germany; *L. Eng,* Institut für angewandte Physik, Technische Universität Dresden, Germany; *K. Nielsch,* Institute for Metallic Materials, Leibniz Institute of Solid State and Materials Science, Germany; *S. Goennenwein,* Universität Konstanz, Germany; *A. Thomas,* Institut für Festkörper- und Materialphysik, Technische Universität Dresden, Germany

During the last decade, three-dimensional (3D) nanostructures have gained increasing interest in the field of nanoscience. On the one hand, this development is driven by the desire to create ever denser microelectronic circuit structures. Truly 3D nanostructures will be key to go beyond stacked planar layers, which are commonplace in today's chip architectures. These structures then have electronic functionality in all three spatial directions, enabling for example ultra-high density memory concepts such as racetrack memory. On the other hand, nanoscale 3D structures bring along novel magnetization configurations and interesting physical effects arising from their "non-flat" geometry. Atomic layer deposition (ALD) is ideally suited for the fabrication of such truly 3D magnetic nanostructures due to its conformal coating capability.

We here demonstrate the fabrication of the ferrimagnetic insulator yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG) via atomic layer deposition. YIG is a prototypical magnetic insulator used in the field of spintronics, since it combines a small coercive field, a large spin diffusion length and very low magnetization damping. We realize the ALD-based fabrication of YIG thin films by a supercycle approach based on the deposition of nanolaminates and show that our ALD-YIG films exhibit excellent structural and magnetic properties - comparable to those of high quality YIG thin films obtained by conventional, directional deposition methods. By validating the conformal 3D deposition of the ALD-YIG thin films, we highlight the usability of our ALD process for the fabrication of 3D nanostructures consisting of high quality YIG. Our findings provide the foundation for a variety of novel experiments on magnetic nanostructures using one of the best suited materials.

EM-MoP-13 ALD of Sulfide- and Selenide-Based Layered 2D Materials, ***Samik Mukherjee,*** *K. Nielsch,* Leibniz IFW Dresden, Germany

Layered two-dimensional (2D) materials exhibit many exotic physical, chemical, and electronic properties,[1] which allows them to create exciting new opportunities as a test-bed for many fundamental theories of materials science,[2,3] as well as pave the path for a wide variety of applications, such as optoelectronic and nanoelectronic devices,[4–6] clean energy harvesting,[7] catalysis materials,[8] bioengineering,[9] and others. As an additional paradigm, a precise layering of quasi-2D building blocks of different materials in well-controlled sequences can provide an additional degree of complexity in terms of materials design and harnessing novel nano- and quantum-scale phenomena.

This work will discuss the current progress regarding the ALD synthesis of sulfides and selenides of tin, molybdenum, and tungsten on bare silicon and oxide-capped silicon (001) substrates. A comparative study, in terms of the structure, the morphology, and the growth rate of the films, for chloride and dimethylamido-based metallic precursors, will be presented.

Some of the initial results of the ALD synthesis of 2D multi-layered films will be discussed. The work will also highlight the alteration to the crystal structure, morphology, and orientation of the as-grown films, brought about by post-growth annealing treatments.

Reference:

[1] S.Z. Butler, S.M. Hollen, L. Cao, Y. Cui, J.A. Gupta, H.R. Gutiérrez, T.F. Heinz, S.S. Hong, J. Huang, A.F. Ismach, E. Johnston-Halperin, M. Kuno, V. V. Plashnitsa, R.D. Robinson, R.S. Ruoff, S. Salahuddin, J. Shan, L. Shi, M.G. Spencer, M. Terrones, W. Windl, and J.E. Goldberger, ACS Nano **7**, 2898 (2013).

[2] X.X. Zhang, Y. You, S.Y.F. Zhao, and T.F. Heinz, Phys. Rev. Lett. **115**, 257403 (2015).

[3] C. Jin, E.C. Regan, A. Yan, M. Iqbal Bakti Utama, D. Wang, S. Zhao, Y. Qin, S. Yang, Z. Zheng, S. Shi, K. Watanabe, T. Taniguchi, S. Tongay, A. Zettl, and F. Wang, Nat. 2019 5677746 **567**, 76 (2019).

[4] J. Cheng, C. Wang, X. Zou, and L. Liao, Adv. Opt. Mater. **7**, 1800441 (2019).

[5] J. Li, L. Niu, Z. Zheng, and F. Yan, Adv. Mater. **26**, 5239 (2014).

[6] Y. Jin, D.H. Keum, S.J. An, J. Kim, H.S. Lee, and Y.H. Lee, Adv. Mater. **27**, 5534 (2015).

[7] M.J. Lee, J.H. Ahn, J.H. Sung, H. Heo, S.G. Jeon, W. Lee, J.Y. Song, K.H. Hong, B. Choi, S.H. Lee, and M.H. Jo, Nat. Commun. 2016 71 **7**, 1 (2016).

[8] D. Deng, K.S. Novoselov, Q. Fu, N. Zheng, Z. Tian, and X. Bao, Nat. Nanotechnol. 2016 113 **11**, 218 (2016).

[9] M. Xu, D. Fujita, and N. Hanagata, Small **5**, 2638 (2009).

EM-MoP-14 Plasma Enhanced Atomic Layer Deposition of Scandium Nitride*, **Thomas Larrabee**, G. Rayner,* Kurt J. Lesker Company*; N. Strnad,* U.S. Army Research Laboratory*; N. O'Toole,* Kurt J. Lesker Company

Scandium nitride is a III-V semiconductor from group III and group XV, with properties distinct from those of more common III-Vs from group XIII and group XV.(1)Among the most important applications of ScN, however, is when it is alloyed with AlN to form $Al_{(1-x)}Sc_xN$.Thin films of $Al_{(1-x)}Sc_xN$ have shown enhanced piezoelectricity(2), and recently ferroelectricity(3), enabling novel electronic devices, such as FE-FETs(4).While ScN has been deposited by a variety of techniques including hybrid vapor-phase epitaxy (HVPE), magnetron sputtering, MBE, and MOCVD, an ALD technique would have advantages for CMOS integration --- including low temperature, wide-area uniformity, 3D conformality, precise thickness control, etc.While Sc_2O_3 ALD has been reported(5), to the best of our knowledge, this represents the first example of ScN by an ALD technique.

Scandium nitride was deposited at 250 °C from tris(N,N'-di-isopropylformamidinato)scandium(III) ($Sc(amd)_3$) and N_2/Ar plasma in a Kurt J. Lesker ALD150LX plasma-enhanced ALD reactor.The $Sc(amd)_3$ was delivered from a source held at 160 °C.XPS results demonstrate 1:1 Sc to N composition, with a small amount of carbon (3.8%) and very low oxygen in the bulk of the film (~1%).In nitride PEALD, ultra-high purity (UHP) process conditions have been shown to be necessary to obtain low oxygen content in readily oxidizable thin films, such as TiN(6), which we believe is critical to low-impurity ScN PEALD.Grazing incidence X-ray diffraction (GIXRD) shows evidence of polycrystalline ScN at this growth temperature from a film grown on Si (with native oxide), with peaks corresponding to the (200), (220), (311), and (222) peaks of reference cubic ScN.A UHP process for ScN with compatible temperature window for PEALD of AlN, such as this, is anticipated to enable ultra-thin ALD-grown $Al_{(1-x)}Sc_xN$ for applications in 3D piezoelectric MEMS devices and/or ferroelectric memory which would be difficult or impossible to achieve via existing non-ALD deposition techniques.

[1]Biswas, B.; and Sava, B. *Physical Review Materials***3**, 020301 (2019).

[2]Akiyama, M.; et al.*Adv. Mater.***21**, 593 (2009).

[3]Ficktner, S.; Wolff, N.; Lofink, F,; Kienle, L.; and Wagner, B.*J. Appl. Phys.***125**, 114103 (2019).

[4]Liu, X.; et al. *Nano. Lett.***21**, 3753-3761 (2021).

[5]Wang, X.; et al. *Appl. Phys. Lett.***101**, 232109 (2012).

[6]Rayner, Jr., G.B.; O'Toole, N.; Shallenberger, J.; Johs, B. *J.Vac. Sci. Technol. A***38**, 062408 (2020).

EM-MoP-15 Yttrium Fluoride Coatings*, **Carlo Waldfried**,* Entegris, Inc.

There is a desire to produce ALD coatings of yttrium-fluoride materials, such as YOF and YF_3, but the implementation of such coatings is challenging and requires special considerations in the choice of precursor chemicals and reactants as well as ALD tool designs due to the corrosive nature of these processes.We will be presenting an approach to produce thin films of ALD-based YOF and YF_3 by depositing ALD Y_2O_3 and then converting the oxide film into YOF and/or YF_3 with a post-coat chemical vapor (non-plasma) conversion process. Utilizing this method YF_3 and YOF layers with thicknesses of more than 100nm have been produced and applied to high aspect ratio structures.

Film structure, composition, chemical bonding arrangement and morphology have been studied using techniques such as XPS, XRD, EDAX, and FIB SEM. It is believed that the fluoride is formed by an O-> F exchange reaction, converting the Y_2O_3 into YF_3 or YOF.

Furthermore, we will discuss how blends of YF_3 and YOF, with a gradual transition of the composition from YF_3 to YOF and Y_2O_3 can be obtained and how that may be advantageous for the implementation of such fluoride coatings.

Author Index

Bold page numbers indicate presenter