NCCAVS
PLASMA APPLICATIONS GROUP (PAG) USERS GROUP MEETING
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Topic: Advances in Atomic Layer Deposition (ALD)

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LAM RESEARCH

Meeting Date: Wednesday, September 13, 2017

Time: 1:15 – 4:30pm

Location *(New Address)*:
SEMI Global Headquarters
673 South Milpitas Blvd.
Milpitas, CA 95035

Chairs: Daphne Pappas, Lam Research
Jeff Shields, Adesto Technologies
Lucia Feng, OF Group

AGENDA

1:15 - 1:20 pm Welcome

1:20 – 2:05 pm “Use of Plasmas in Atomic Layer Deposition Processes”,
Mark J. Sowa, Veeco - CNT

Abstract: This talk will introduce the audience to the use of plasmas in Atomic Layer Deposition (ALD) processing and discuss various Plasma-Enhanced ALD (PEALD) processes, materials, and applications.

ALD is a thin film deposition technique which can produce films exhibiting excellent material qualities with atomic level thickness control. Additional benefits include high uniformity over large area substrates and conformality on high aspect ratio structures. These desirable characteristics are achieved by sequentially exposing the substrate to surface saturating doses of complementary chemical precursors separated by inert purge gas steps to prevent gas phase reactions. The precursor chemically reacts with surface moieties produced from the previous precursor exposure and also prepares the surface for reaction with the next precursor dose.

ALD processes replacing the molecular co-reactant with highly reactive radicals produced by a plasma source have been developed. These widely studied Plasma-Enhanced ALD (PEALD) processes have several potential advantages over traditional thermal ALD including: lower temperature processing, improved film properties, more film composition options, reduced purge times, and reduced nucleation times.

Nearly 150 PEALD materials are reported in the literature. The most common PEALD film is Al_2O_3 which is typically deposited with trimethylaluminum and O_2 plasma. Oxygen plasma is used for the PEALD of other oxides, most commonly HfO_2, SiO_2, TiO_2, ZnO, and ZrO_2 and some noble metals such as Pt. Due to the low reactivity of thermal ALD nitride co-reactants, such as NH_3, PEALD is commonly investigated for growth of nitride materials. Examples of PEALD nitrides studied in our R&D facility will be discussed including conductors (TiN, CoN, and WN), superconductors (NbN, NbTiN, MoN), dielectrics (SiN, AlN), and ultra-hard materials (VTiN).

Most plasma ALD hardware configurations strive to limit the role of charged species on the depositing film either through a remote plasma source location or grounded grids to limit the flux of ions and electrons to the substrate. However, a finite flux of charged species to the substrate is typically present and an RF substrate bias to increase/control the energy of substrate ion bombardment has been identified as an additional process control knob to influence the properties of PEALD films. Stoichiometry, density, impurities, growth rate per cycle, and crystallinity are characteristics influenced through RF substrate bias.

The presence of plasma in proximity to the deposition substrate allows for process information to be derived from Optical Emission Spectroscopy (OES) data. Emission spectra can indicate reaction products which can be used to derive insight into reaction mechanisms. Additionally, spectral feature transients can be used to identify process endpoint for recipe optimization.

Biography: Mark received his Bachelor of Science in chemical engineering from the University of Illinois in 1992 and went on to receive a Ph.D. in chemical engineering from Princeton University in 1998 for his work on the selective SiO_2 etch mechanism in high-density, fluorocarbon plasmas. Following a postdoctoral appointment at the Microelectronics Development Laboratory at Sandia National Laboratory, Mark joined Praxair as a Development Associate in their Electronic Materials R&D group. In 2008 Mark joined Cambridge NanoTech as the Technical Lead on their then new plasma atomic layer deposition (ALD) system. Over the last nine years as Cambridge NanoTech was acquired by Ultratech in 2012 and subsequently recently acquired by Veeco, Mark has authored five publications and presented work at fourteen conferences while supporting the sales and customer activities of 100+ plasma ALD systems.

2:05 – 2:50 pm "Atomic Layer Deposition of Ferroelectric and Threshold Switching Materials for Next Generation Nonvolatile Memory", Karl Littau, Intermolecular Inc.

Abstract: As the demand for faster, cheaper, lower power, and generally higher performance devices continues unabated toward the end of this decade and into the next, the integrated circuit industry is turning toward a diverse array of new functional materials. Non-volatile memory (NVM) in particular is driving the development of new non-linear, state-change elements such as ferroelectrics, resistive memory, and threshold switches. Atomic Layer Deposition (ALD) is one of the few processes that delivers both the conformality and compositional control required for these materials. In this talk we discuss the recent developments of ALD ferroelectric HfO_2 thin films as well as threshold switching selector materials for NVM applications.

Biography: Dr. Karl Littau is a Physical Chemist and with expertise in thin film deposition, ALD, CVD, surface and gas phase chemistry, and solid state physics. He holds a BS in Chemistry from UC Berkeley and a PhD in Physical Chemistry from Stanford University. He has held positions at AT&T Bell Laboratories, Applied Materials, Inc., Xerox's Palo Alto Research Center, Stanford University, and is currently Senior Principal Scientist in the CTO organization at Intermolecular Inc. where Dr. Littau has been directing research and development of new Atomic Layer Deposition chemistries and new materials for advanced IC devices and emerging technologies.

2:50 - 3:15 pm Break and Networking

3:15 - 3:40 pm "Dopant-Rich Films on Si: A New Frontier For Thermal ALD Processes"
Michael I. Current, Current Scientific, San Jose, CA

Abstract: Thermal ALD of conformal, dopant-rich films on Si is an attractive first step for controlled doping of 3D device structures with thermal or recoil implant drive-in of the surface film. In spite of this obvious application, this approach was a completely unexplored area for thermal ALD until mid-2014. Following initial studies of thermal ALD film growth mechanisms with density functional calculations, exothermic paths were identified and explored for both B and P doping. Experimental studies of B_2F_4 and BF_3 as a dopant rich films deposited with TMA and H_2O components developed a stable growth sequence that was highly conformal on a model extreme 3D surface. Thermal annealing of B-containing films resulted in shallow SIMS profiles on planar surfaces. Monte-Carlo calculations of recoil mixing indicated highly efficient dopant drive-in for both plasma and beam line implantation methods.

Coworkers on this study included T.E. Seidel, Seitek50, Palm Coast, FL, J. W. Elam and A. U. Mane, Argonne National Laboratory, Argonne, IL, A. Goldberg and M. D. Halls, Schrodinger, Inc., San Diego, CA and Joseph Despres, Oleg Byl, Ying Tang, and Joseph Sweeney, Entegris, Danbury, CT.

Biography – Michael I. Current has been actively involved in ion beam processing, mainly ion implantation, and related metrologies for over 40 years. The focus of much of his work has been related to process issues that develop from the design and operational conditions in ion beam and plasma implantation tools for IC fabrication. Recent work includes studies of ion and neutral beams for implantation, deposition and etching of nano-scale and quantum confined materials, and the use of high-energy proton beams and layer transfer methods for wafer-level stacking of fully-metallized IC devices for 3DICs. Following his PhD in solid-state physics from Rensselaer Polytechnic Institute, he has worked for Phillips/Signetics, Xerox/PARC, Applied Materials, Frontier Semiconductor and numerous start ups and has been a visiting faculty member at Cornell, Kyoto, Santa Clara and National Cheng Kung Universities. Dr. Current has written over 240 technical papers and book chapters, 8 patents and is a longtime member of the MRS and AVS.

3:40 – 4:25 pm “Atomic Layer Deposition with Activated Species: Applications in Gallium Nitride Power Devices and Silicon-Based Artificial Photosynthesis”
Professor Paul C. McIntyre, Department of Materials Science and Engineering, Stanford University, CA

Abstract: This talk will summarize recent research in which either a radical-rich remote nitrogen plasma or ozone have provided activated species required for low-temperature deposition of functional thin films by atomic layer deposition (ALD). In one project, nitrogen incorporation in Al_2O_3 to provide negative fixed charge has been investigated as a path to produce enhancement mode (E-mode) GaN MOSHEMT devices. A uniform distribution of nitrogen content across the AlO_xN_y dielectric has been obtained using N_2 plasma enhanced ALD. Insertion of a 2 nm thick Al_2O_3 interlayer greatly decreases the trap density at insulator/GaN interface. The oxynitride dielectric produces a positive threshold voltage for AlGaN/GaN MOS high electron mobility transistors, required for E-mode operation.

A second project examines metal-insulator-semiconductor structures that are promising candidates for integrated solar driven water splitting. Traditionally, the metal layer in these devices serves a dual purpose, catalyzing water oxidation while also setting the built-in field for extracting photogenerated carriers from the semiconductor. Recently, incorporation of additional protection layers into the MIS junction has made it possible to use semiconductor materials, such as silicon, that would normally be unstable under the conditions required for water oxidation. We have discovered that thin film alloys of TiO_2 and IrO_2, synthesized with an ozone super-cycle ALD process, exhibit both high electrical conductivity and photovoltage > 600 mV on nSi. Additionally, these alloys are capable of catalyzing oxygen evolution. Thus, TiO_2-IrO_2 alloys have the potential to be an “all-in-one” catalyst, Schottky contact, and corrosion resistant protection layer for high quality semiconductor photoanodes.

Biography: Paul McIntyre is Rick and Melinda Reed Professor in the School of Engineering, Chair of the Department of Materials Science and Engineering and Senior Fellow of the Precourt Institute for Energy at Stanford University. He was previously Member of the Technical Staff of the central research laboratories of Texas Instruments, and was a Director’s-Funded Postdoctoral Fellow at Los Alamos National Laboratory. At Stanford, McIntyre leads a research team of graduate students, postdoctoral researchers and adjunct professors who perform basic studies of nanostructured inorganic materials for applications in electronics and energy technologies. He is best known for his work on metal oxide/semiconductor interfaces, functional metal oxide thin films, atomic layer deposition, and semiconductor nanowires. McIntyre is an author of approximately 220 archival journal papers and an inventor of 8 US patents. He has given over 120 invited presentations, plenary talks and tutorial lectures on these topics. He has received two IBM Faculty Awards, a Charles Lee Powell Foundation Faculty Scholarship and an SRC Inventor Recognition Award. McIntyre was a GCEP Distinguished Lecturer in 2010 and received the Woody White Award of the Materials Research Society in 2011. In 2016, he was the inaugural Colorado School of Mines/NREL Materials Science Distinguished Lecturer.

All presentations will be requested to be posted on the PAG Proceedings webpage.

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