Sunday Afternoon, July 23, 2023

Tutorial
Room Grand Ballroom H-K - Session TS-SuA

Tutorial Session

Moderators: Prof. Seán Barry, Carleton University, Dr. Scott Clendenning, Intel Corporation

1:00pm **TS-SuA-1 Design Rules for Precursors and Why You Should Break Them*, Seán Barry,*** Carleton University, Canada **INVITED**

1:45pm **TS-SuA-4 A Brief Introduction to Low-Temperature Plasmas: Physics, Diagnostics, and Applications in Atomic Layer Processing*, Mari Napari,*** King's College London, UK **INVITED**

The wide use of plasmas in materials processing is due to two essential features of low-temperature plasma discharges, one is the capability to efficiently generate chemically active species, and the other is the formation of energetic ions, accelerated to energies up to hundreds of electron volts adjacent to the deposition or etching surfaces. Plasma-enhanced (or plasma-assisted) atomic layer deposition and etching (ALD, ALE) are considered to exploit mainly the first of these features, though the role of energetic ions in the processes should not be undermined.

Plasmas are complex environments and the comprehension of both the physical and chemical aspects of the plasma, and the plasma-surface interaction are important. The contribution of the different plasma species (radicals, ions, VUV/UV radiation) on the film growth or etching processes depend significantly on how the plasma is generated, as well as on reactor geometry and vacuum conditions. Therefore it is relevant to understand how these influence the plasma, and how to determine the optimal conditions for your plasma-enhanced atomic layer process, e.g. when high aspect ratio structures or sensitive substrate materials are required.

In this tutorial I will give a brief introduction to fundamental principles of partially ionized, chemically reactive plasma discharges and their applications in atomic layer processing. I will introduce the basic concepts of low-temperature plasmas, such as electron temperature and -density, plasma potential and particle flux across the plasma-surface sheath layer. I will also present a selection of useful plasma diagnostics techniques that can be used directly or indirectly to determine the plasma parameters. In the last part of my talk I will present the different types of plasma sources typically used in ALD/ALE reactors, and discuss their advantages and disadvantages using examples from recent published work on different plasma-enhanced ALD and ALE processes.

2:30pm **TS-SuA-7 The Application of Atomic Layer Deposition for Batteries*, Lei Cheng,*** Argonne National Laboratory **INVITED**

Atomic layer deposition (ALD) has found many applications and emerged as a useful technique for fabricating and improving the performance of energy storage devices, owing to the distinct advantages of the deposition method (conformality, compositional and thickness control, low reaction temperature) and the potential for roll-to-roll manufacturing. ALD has been used to synthesize and fabricate active components of batteries, such as oxide and organic electrodes. More commonly, ALD is used as a powerful surface and interface engineering tool to improve battery material properties. For example, it has been used to create artificial cathode electrolyte interfaces (CEI) to prevent transition metal dissolution from the cathode and prohibit parasitic side reactions resulting from surface electrolyte decomposition. In this tutorial talk, I will discuss examples and strategies for using ALD to improve battery performances in both state-of-the-art Li-ion batteries and next-generation batteries, such as Li-S and solid-state.

3:30pm **TS-SuA-11 Surface Reaction Mechanisms of Thermal and Plasma-Enhanced Atomic Layer Etching (Ale) Processes*, Satoshi Hamaguchi,*** Osaka University, Japan **INVITED**

Atomic layer etching (ALE) is a cyclic process of removing a monolayer or a very thin layer of material in each cycle. As the miniaturization of semiconductor devices approaches the atomic scale, the formation of device structures, especially those in three dimensions, on a material surface poses extreme challenges to manufacturing. ALE is considered to offer one of the most effective solutions to such challenges. ALE can be roughly classified into two categories. One is thermal ALE, where the energy to remove a thin layer in the desorption step is provided by thermal energy. In most cases, thermal ALE offers isotropic etching. The other is plasma-enhanced ALE (PE-ALE), which typically uses ion energy and momentum transfer from plasmas to the surface to remove a thin layer of material in the desorption step. PE-ALE is typically a uni-directional (i.e., anisotropic) etch. A well-known example of the former is the thermal ALE of metals, where organic molecules or organometallic molecules are used to remove metal atoms from the surface by the formation of metal complexes or ligand exchange. The latter examples include PE-ALE of silicon (Si)-based materials such as Si, silicon dioxide, and silicon nitride, by halogen, fluorocarbon, and hydrofluorocarbon plasma irradiation, respectively. Thermal, and therefore anisotropic, ALE of Si-based materials also exists. In this tutorial presentation, I will discuss the surface reaction mechanisms of such processes, referring to recent studies on this subject analyzed with numerical simulations as well as surface reaction experiments.

4:15pm **TS-SuA-14 Surface Functionalization of Powder Materials using Fluidized Bed Reactor ALD*, Se-Hun Kwon,*** Pusan National University, Republic of Korea **INVITED**

Surface functionalization plays an important role in various powder materials with large surface area to volume ratios. And, effective and precise surface functionalization of powder materials are essential for obtaining a desired properties in various industrial and scientific applications. Recently, atomic layer deposition (ALD) has emerged as a powerful technique for surface functionalization of powder materials due to its noteworthy merits such as atomically precise thickness and composition control of ultrathin films with extremely high uniformity. Up to now, various ALD systems using different types of reactors, including a static bed, agitated bed, and fluidized bed, have been developed to deposit coating materials on powder materials. A static bed reactor ALD is typically limited to a small amount of powders because it is difficult for the gas phase precursor to diffuse into the powder bed when a large amount of powder is utilized, leading to non-uniform coatings on the powder surfaces. Therefore, two competitive ALD systems, agitated bed and fluidized bed reactors (FBR)-ALD systems, are considered as more suitable setting for the ALD coating of powder materials. And, this tutorial aims at comprehensively reviewing the fluidized bed reactor (FBR)-ALD techniques. The main advantages of FBR-ALD are including the efficient gas transport for gas-solid interactions and well-mixed solid particles, which can provide precursor reactions with all the surface sites of powder materials and can be used for the production of large quantities of surface functionalized powders. Nevertheless, many challenges are still remaining in the field of FBR-ALD. In this tutorial, therefore, the basics principles of FBR-ALD will be firstly described, and then some technical challenges involved during the FBR-ALD process and recent efforts to overcome them will be discussed. Finally, some promising examples of surface functionalization of powder materials using FBR-ALD will be highlighted.

5:00pm **TS-SuA-17 Atomic Layer Deposition of Active and Passive Films for Electronic Devices*, John Ekerdt,*** University of Texas at Austin **INVITED**

This tutorial will provide the participants with an understanding of the principles that underpin atomic layer deposition (ALD) and will illustrate applications of these principles in the growth of films employed in electronic devices and in key processing steps in device manufacturing.This tutorial is designed to introduce these principles and provide a broad perspective to new workers and researchers to the ever-expanding area of ALD.This talk will cover ALD of dielectric materials, simple (binary) and complex (ternary/quaternary) oxides, and metals.

ALD is a chemical growth process that requires at least two different reactants, whose delivery to the growth surface is done in alternating steps with an intervening evacuation/purge step to restrict the reactions to the growing film surface.This talk will touch on the inorganic, physical, surface and materials chemistry that form the basis for precursor (reactant) selection and the general process approach.In general, the first reactant needs to adsorb in a self-limiting manner up to a monolayer of coverage – a key aspect that allows for conformal thin film deposition over planar surfaces and high aspect ratio 3D structures.The second reactant then reacts with what is adsorbed and converts it chemically into the compound of interest, such as an oxide, nitride, or metal, and presents a surface with reactive groups/sites that enable the first reactant to adsorb.Examples of these reactions and experimental approaches/analytical probes that are used to follow the steps and establish the process parameters (dose/exposure time, evacuation time, temperature) will be presented.ALD processes can be thermal in nature and/or one of the reactants can be plasma activated and examples of both will be discussed.

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