NCCAVS
PLASMA APPLICATIONS GROUP (PAG) USERS GROUP MEETING
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FREE ADMISSION—No need to register, just show up!!

Topic: Workshop on Atomic Layer Etching (ALE)

Meeting Date: Monday, August 20, 2018

Time: 1:15 – 5:00pm

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

Platinum Sponsor: UC Components

Chairs: David Coumou, MKS Instruments and Daphne Pappas, Lam Research

AGENDA

1:15 - 1:20 pm Welcome

1:20 – 2:05 pm "Perspectives on Recent Advances in Atomic Layer Etching",
Alok Ranjan, TEL Technology Center, America, LLC

Abstract: With shrinking critical dimensions, dry etch faces more and more challenges. Minimizing each of aspect ratio dependent etching (ARDE), bowing, undercut, selectivity, and within die uniformly across a wafer are met by trading off one requirement against another. The problem of trade-offs is especially critical for 10nm and beyond technology. At the root of the problem is that roles radical flux, ion flux and ion energy play may be both good and bad. Increasing one parameter helps meeting one requirement but hinders meeting the other. Self-limiting processes like atomic layer etching (ALE) promise a way to escape the problem of balancing trade-offs. ALE was realized in the mid-1990s but the industrial implementation did not occur due to inherent slowness and precision loss from improper balance of self-limiting passivation and its removal processes. In recent years, interest in ALE has revived and strides have been made by etch equipment manufacturers primarily through temporal, spatial or combination of these two pulsing approaches. Moderate success has been reported with some of the trade-offs purported to be managed. Difficulty meeting requirements is due to the inability of plasma technologies to control ion energy at low and precise values. In this presentation, we demonstrate that ALE can achieve zero ARDE and infinite selectivity with ability to control profile. Experimental results will highlight that careful consideration of surface process physics is required to achieve ALE and not simply "slow etching". ALE using three approaches for radical adsorption (1. chemisorption, 2. polymer deposition and 3. surface modification) and desorption using 3 approaches (1. ion bombardment 2. substrate heating and 3. Chemical removal of modified layer) will be addressed with insights to solve critical problems associated to Si (Gate, Fin), SiO_2 (Self-Aligned Contact), SiN (Gate Spacer, SIT spacer) etch.

2:05 – 2:50 pm "Computational Modeling as a Tool to Optimize and Understand the Atomic Layer Etching Process", Chad M. Huard and Ankur Agarwal, KLA Tencor

Abstract: As critical dimensions shrink to truly atomic scales, plasma etching processes face several limiting challenges. These include aspect ratio dependent etching (ARDE), uniformity, selectivity and damage. Optimizing a process to minimize one of these challenges often requires trade-offs to be made in other areas.
Computational modeling of the plasma etching process offers a way to optimize and understand process physics in a different and complimentary way to design of experiments. To demonstrate this, results will be shown from a computational study exploring the benefits of atomic layer etching (ALE) in silicon and

silicon dioxide. Results indicate that ALE using ideal process conditions (which are not obtainable in experiments) can produce highly optimized results. When etching silicon, ideal process conditions result in all of the etching originating from self-limited pathways, eliminating ARDE and non-uniformity. When etching oxide, even when using ideal process conditions, the etch rate depends on the total fluence of polymerizing fluorocarbon radicals, reducing some of the benefits of ALE. When realistic reactant fluxes are used instead of ideal conditions, the presence of continuous etching pathways further reduces some of the benefits of the ALE process. Despite this, ALE, even in close-to-conventional equipment, can offer significant improvements over similar continuous etching processes. Computational modeling offers an ideal method for exploring the ALE parameter space to optimize a process for a given design criteria, or to understand the underlying physics involved.

2:50 - 3:15 pm Break and Networking

3:15 - 3:40 pm "Mechanisms for Thermal Atomic Layer Etching",
Steven M. George, University of Colorado

Abstract: Atomic layer etching (ALE) is a thin film removal technique based on sequential, self-limiting surface reactions. This talk will discuss different mechanisms for the thermal ALE of metal oxides, metal nitrides and elemental metals. The talk will first present Al2O3 ALE using HF and Al(CH3)3 as the reactants to demonstrate the etching of metal oxides based on fluorination and ligand-exchange reactions. TiN ALE using O3 and HF as the reactants will then be discussed to show the etching of metal nitrides based on oxidation and fluorination to a volatile fluoride. Lastly, W ALE using O3, BCl3 and HF as the reactants will be presented to illustrate the etching of elemental metals based on oxidation, conversion to a different metal oxide and fluorination to a volatile fluoride. These etching mechanisms greatly expand the number of materials that can be etched using thermal ALE.

3:40 – 4:25 pm "Methods to Enable Plasma Etching of Transition Metals With Atomic Scale Precision", Nathan Marchack, Benjamin Walusiak, Keith Hernandez, John M. Papalia, Sebastian U. Engelmann and E. A. Joseph, IBM Research Division, IBM T. J. Watson Research Center

Abstract: Advances in the semiconductor industry, historically based on Moore's Law and Dennard scaling, have become increasingly challenging as device technology moves beyond the 7nm node. The ever-continuing trend to shrink device sizes coupled with the advent of novel materials, multi-component materials or even nanoscale materials, is growing the need for the ultimate etch solution: etching with atomic layer precision. Atomic layer etching is a promising path to answer the processing demands of new devices at the angstrom scale. [1] Self-limiting reactions, discrete reaction & activation steps, or extremely low ion energy etch plasmas are some of the pathways being pursued for precise sub-nanometer material removal. TiN and TaN are materials often utilized in non-volatile memory applications as hardmasks for the patterning of the active memory layers and ultra-high selectivity to the organic mask is critical to maintaining dimensional control. In this presentation, we will review work employing a plasma-enhanced atomic layer etch (PE-ALE) process with sequential cycles of Cl2 (deposition) and He/H2 (etch) chemistries, separated by purge steps, to pattern TiN and TaN lines using an organic planarizing layer (OPL) mask. Compared to a continuous wave Cl2 plasma, the PE-ALE process demonstrated virtually no metal residue on the OPL mask and SiOx stop layer; as well as a powerful knob for tuning the profile and CD of the features by controlling the purge times between cycles. [2] Other critical factors affecting etch profile such as the carrier gas and loading effects will be explored with respect to their effects on redeposition and surface composition of the etched metal films.

[1] K. J. Kanarik, T. Lill, E. Hudson, S. Tan, S. Sriraman, J. Marks, V. Vahedi,
and R. A. Gottscho, Journal of Vacuum Science & Technology A, 33(2), 020802 (2015)
[2] N. Marchack, J. M. Papalia, S. Engelmann, and E.A. Joseph,
Journal of Vacuum Science & Technology A 35, 05C314 (2017)

All presentations will be posted on the PAG Proceedings webpage approximately 1-2 weeks following the meeting.

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