Atomic Layer Etching
Room Hall 3F - Session ALE2-WeM
Selectivity, Metrology and Diagnostics in ALE

Moderators: Adrie Mackus, Eindhoven University, Netherlands, **Gregory N. Parsons**, North Carolina State University

10:45am **ALE2-WeM-12 Interest and Potential of Atomic Layer Etching for Selective Deposition***, T. Chevolleau,* CEA/LETI-University Grenoble Alpes, France*; M. Jaffal,* University Grenoble Alpes, CNRS, LTM, France*; R. Gassilloud,* CEA/LETI-University Grenoble Alpes, France*; N. Possème,* ST Microelectronics, France*; C. Vallée,* University of Albany*;* ***Marceline Bonvalot,*** University Grenoble Alpes, CNRS, LTM, France **INVITED**

Selective deposition processes have attracted increased research interest in recent years due to their ability to precisely deposit thin films on specific substrate areas (for area-selective deposition) or on surfaces with specific orientations (for topographical selective deposition). These processes require a growth kinetic controlled by precursor/surface interactions with an atomic-scale precision, which usually relies on Atomic Layer Deposition (ALD) techniques with or without plasma assistance (PEALD).

Several approaches have been proposed for selective deposition involving surface inhibition treatments with specific chemical agents (such as self-assembled molecules, small molecule inhibitors, plasma treatment) that increase the nucleation delay during subsequent ALD growth. However, the inhibition behavior eventually deteriorates after exposure to a few ALD cycles, necessitating the removal of nuclei formed on non-growth surfaces and the systematic regeneration of the inhibitor.

Another pathway for selective deposition is to combine ALD with Atomic Layer Etching (ALE). ALE involves self-limiting reactions that occur in a cyclic manner and consisting in a surface modification step followed by a removal step of the previously modified layer. Such a process results in the controlled and selective removal of a thin material layer.

In this presentation, we will focus on the interest and capabilities of ALE or quasi-ALE process for selective deposition. Based on several application examples such as liner deposition, we will highlight potential and related issues by coupling ALD and ALE for topographical selective deposition (growth and etch per cycle, selectivity with respect to the underneath layer, cross contamination...). We will also discuss about tools strategy to combine both ALD and ALE processes.

11:15am **ALE2-WeM-14 Insight into SF_6/H_2 Plasma Mixtures to Expand the Capabilities of ALE***,* ***Guillaume Krieger****, S. Peeters, B. Vonken, N. Chittock, A. Mackus, E. Kessels,* Eindhoven University of Technology, The Netherlands*; H. Knoops,* Oxford Instruments Plasma Technology, The Netherlands

The continuous downscaling of nanoelectronics combined with the ever-increasing diversity in materials and 3D geometries calls for highly precise and selective etching processes. Therefore the atomic layer etching (ALE) community must continue to develop a diverse toolbox of processes to enable both anisotropic and isotropic etching of the library of materials required in IC fabrication. Within this toolbox, recent works involving SF_6:H_2 plasma mixtures have demonstrated promising results for the etching of Si- and Ti-based materials[1,2], with improved selectivity. However the etching mechanism is not yet well understood. Notably, the plasma species responsible for the onset of etching at a specific SF_6:H_2 ratio need to be identified.

Here, we present our first results from quadrupole mass spectroscopy (QMS) and optical emission spectroscopy (OES) measurements on SF_6:H_2 plasma mixtures. The plasma power, pressure and SF_6:H_2 ratio have been varied to observe their respective influence on the plasma composition. OES measurements show a high F radical emission intensity for SF_6 rich plasma mixtures. QMS measurements reveal a maximum intensity of the m/z=20 signal, which could be related to the presence of HF, for a ratio of $SF_6/(SF_6+H_2)$ between 0.24 and 0.3. At this same ratio of plasma mixture, the signal of the m/z=34 mass (*i.e* H_2S) drops drastically while the m/z=89 signal (*i.e* SF_3^+ acting as a fingerprint for SF_6) starts to increase. Interestingly, under the same conditions, this specific range of gas ratios coincides with the etching onset of TaN at $SF_6/(SF_6+H_2)\approx0.25$. Furthermore, when an oxygen gas exposure step is added in the process, the oxidized TaO_xN_y top-layer can be etched at a smaller $SF_6/(SF_6+H_2)$ ratio≈0.2, equivalent to the etching onset of SiO_2. These results show similarities to the selective ALE process reported by Hossain *et al.*[1] between TiN and TiO_2, occurring at a $SF_6/(SF_6+H_2)\approx0.17$, close to the ratio we report for TaN. By identifying the main trends in the plasma species present in the SF_6/H_2 plasma and comparing these observations to the ALE process window, we aim to improve the understanding of the underlying etching mechanisms. A greater knowledge of this process will help to extend this ALE chemistry to a wider range of materials.

References:

1. Hossain, A. A. *et al., JVST A***41**, 062601 (2023).
2. Pankratiev, P. A. *et al., J. Phys.: Conf. Ser.***1697**, 012222 (2020).

11:30am **ALE2-WeM-15 Retarding-Field Energy Analyzer as a Tool to Find the Process Window for Plasma-Assisted Atomic Layer Etching and Quasi-Atomic Layer Etching***,* ***Yoana Ilarionova****, R. Jam, I. Sharma, O. Danielson, S. Ju, A. Muhammad, D. Suyatin, A. Karimi, J. Sundqvist,* AlixLabs AB, Sweden

As the fabrication of chips gets more demanding, atomic layer etching (ALE) provides a controlled way of etching without the surface damage typically associated with reactive-ion etching (RIE). ALE features 2 main steps – surface modification and etch. If inert-ion plasma is chosen to etch, ion energy makes the difference between ALE and physical sputtering. This is why the ion energy distribution function (IEDF) is a very important property when designing plasma-assisted ALE processes.

In this study, we used retarding-field energy analyzer (RFEA) System from Impedans Ltd for IEDF measurements. This enabled us to effectively find and tune the ALE process windows for Si and III-V materials. The experiments were done with Ar plasma in a few standard etch chambers for inductively-coupled plasma reactive ion etching (ICP-RIE) from different vendors. We examined how different process parameters and their interplay influence the IEDF. This is very important for understanding the right combination of process parameters for ALE and the limitations of quasi-ALE processes that can be achieved with this equipment. This also guides in finding the right hardware modifications for improving the ALE processes and their stability in conventional equipment readily available in research labs and semiconductor fabs. This is also valuable for designing dedicated hardware for ALE processes, especially for industry.

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