Spectroscopic Ellipsometry
Room 209 F W - Session EL2-TuA

Spectroscopic Ellipsometry Novel Methodologies

Moderators: Ufuk Kilic, University of Nebraska - Lincoln, **Mathias Schubert**, University of Nebraska - Lincoln

4:00pm **EL2-TuA-8 In Situ Spectroscopic Ellipsometry Studies of Selective Thermal Dry Etching**, ***Marcel Junige***, *Steven M. George,* University of Colorado Boulder **INVITED**

Thermal dry etching uses gas-phase reactants in a vacuum and physicochemical reactions based on thermal activation, providing isotropic material removal for lateral patterning without line of sight. Thermal dry etching covers atomic layer etching (ALE) and spontaneous etching. ALE is defined by self-limiting reactions, separated by purge steps. These half-reactions modify and sequentially volatilize a thin film surface, thereby removing material digitally one ultra-thin layer per cycle. Conversely, spontaneous etching is characterized by a sustained reaction of a thin film surface with one etchant only, thereby removing a targeted material with a continuous etch rate.

This invited talk reviews exemplary studies of thermal ALE and spontaneous etching, utilizing *in situ* spectroscopic ellipsometry (iSE) to reveal thickness changes, self-limiting behavior, synergy between half-reactions, and selectivity between different materials. An iSE instrument (J.A. Woollam Co.) acquired ellipsometric spectra for 5 s at the end of reactant purge steps. Interference enhancement enabled thickness precision of ±0.01 Å.

Al_2O_3 thermal ALE using sequential hydrogen fluoride (HF)/trimethylaluminum (TMA) exposures exhibited a linear etch per cycle (EPC) at 275℃. After initial fluorination, consecutive HF exposures gave virtually no Al_2O_3 thickness loss. This self-limiting behavior corresponded to ideal ALE synergy because all material removal resulted solely from a favorable interaction of the HF/TMA sequence and no etching occurred by either HF or TMA alone. SiO_2 thermal ALE using sequential TMA/HF exposures likewise exhibited a linear EPC at 275℃. Consecutive HF exposures displayed negligible SiO_2 thickness loss, especially after eliminating H_2O during the fluorination step. This self-limiting behavior revealed near-ideal synergy for SiO_2 ALE.

SiN_x thermal ALE using sequential TMA/HF exposures discovered no ALE synergy because consecutive exposures of HF alone caused predominant SiN_x spontaneous etching. This difference between near-ideal versus no ALE synergy obtained great inherent selectivity between major SiN_x versus minor SiO_2 spontaneous etching using anhydrous HF vapor at 275℃. Using anhydrous HF at temperatures >150℃ also discovered facile spontaneous etching of single-crystalline, poly-crystalline, and amorphous Si films with high selectivity compared to SiO_2 retention.

In contrast, co-adsorbing polar molecules with anhydrous HF had a drastic effect. Co-dosing NH_3+HF at 275℃ obtained exceptional selectivity for rapid SiO_2 versus negligible SiN_x spontaneous etching. Similarly, co-adsorbing dimethylamine with HF at 200℃ enabled substantial SiO_2 spontaneous etching.

4:30pm **EL2-TuA-10 Artificial Intelligence for Ellipsometric Analysis of Liquid Mixtures Using Multi-Bounce ATR-FTIR**, ***Jeremy VanDerslice***, J.A. Woollam Co.*; Alyssa Mock, Madison Coleman, Mar Diehl, Madison Meaney, Tyler Adams,* Weber State University

Artificial intelligence is emerging as a valuable tool in optical metrology, offering a new avenue for data interpretation in model-based techniques like ellipsometry. Optical models used to describe thin films traditionally measured by ellipsometers often require careful initialization or involve significant computational cost. In these cases, AI methods can assist by providing initial parameter estimates or, in some applications, by replacing the physical model entirely. One such application benefiting from the combination of ellipsometry and predictive data interpretation is the concentration analysis of liquid mixtures using Fourier-transform infrared (FT-IR) ellipsometry in a multi-bounce prism configured for attenuated total reflection (ATR) measurements. In this approach, neural networks learn the nonlinear relationships between ellipsometric measurements and analyte concentrations in these mixtures. This capability is particularly relevant in industries relying on optical techniques for liquid analysis. In the wine and beverage industry, for example, concentrations of ethanol, sugars, phenolic compounds, organic acids, and other analytes are commonly measured using reflection or transmission intensity. While the existing intensity-based methods offer non-destructive analysis, they generally exhibit lower sensitivity to absorption features specific to each analyte compared to polarization-based measurements, which suggests a reduced sensitivity threshold compared to ellipsometry. The use of predictive neural networks, in combination with ellipsometry, enables enhanced determination of analyte concentrations within a liquid mixture without requiring prior expertise in ellipsometry.

4:45pm **EL2-TuA-11 Stimulated Brillouin Scattering for Semiconductor Metrology**, ***Matthew Sartin***, *Deric Session, Robin Mair, Michael Kotelyanskii, Manjusha Mehendale, George Antonelli,* Onto Innovation

Picosecond laser ultrasonics has been used as an in-line semiconductor metrology for opaque film thickness for almost 30 years. In transparent on opaque or semi-transparent material systems, a stimulated Brillouin scattering feature is present. It has been used in the semiconductor industry to map the in-wafer uniformity of the sound velocity and thus elastic modulus in both insulators and semiconductors. Although the underlying physics are well documented in the literature, the details of signal generation in different geometries at different wavelengths are often overlooked or misinterpreted. We shall present an analytical model and measurements at 1030/1060 nm using a dual frequency comb configuration on a metal film (W and TaN) on silicon substrate both from the metal and silicon side.This material system is instructive in demonstrating the difference in the underlying physics and opportunities.

5:00pm **EL2-TuA-12 Laser Ellipsometry: A Half Century Old New Technique**, ***Alexander Ruder***, *Deric Session, Marieke Ordway, Fei Shen, Michael Kotelyanskii, Manjusha Mehendale, G. Andrew Antonelli,* Onto Innovation

Laser sources played an important role in the introduction of ellipsometry to the semiconductor industry. This method was largely displaced by spectroscopic methods. Over the past five years, there has been a resurgence of interest in laser ellipsometry particularly for high precision measurements of ultra-thin dielectric films. Advances in laser, phase modulation, optical-design, and electronic instrumentation enable significant improvement in precision and stability relative to previous generations. The industrial requirements and operating principle for an exemplar of this new class of systems will be reviewed. Examples of measurements on thin films including high-k gate dielectrics shall be provided.

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