ALD Applications
Room Grand Ballroom H-K - Session AA2-TuM

MEMS, Actuators, Hard Films

Moderators: Prof. Anjana Devi, Ruhr University Bochum, Viljami Pore, ASM

10:45am **AA2-TuM-12 ALD for MEMS Sensors and Actuators***, **Luca Lamagna,*** STMicroelectronics, Italy **INVITED**

Atomic layer deposition (ALD) has undoubtfully become one of the leading technologies employed for the deposition of nanometer-scale films at an industrial level. ALD allows for the deposition of conformal ultra-thin layers with an extremely precise thickness control. Moreover, ALD processes have been scaled on large area substrates, making this technique very promising for the industrial high throughput need. With ALD it is possible to develop and optimize the growth of novel ultra-thin dielectric, metal, and complex ternary compounds films.

Microelectromechanical systems (MEMS) have been attracted since the very beginning by ALD as a deposition technology that can address with its outstanding conformality the deposition on 3D complex structures. ALD turned out to be also a powerful approach to significantly increase the material selection available for MEMS processing. Simultaneously, ALD came up with the potentiality to offer layers with functional and tunable properties for the more disparate applications. Indeed, ALD is also able to realize thin functional layers that can be employed for specific surface engineering.

We will review the relationship between ALD processes and MEMS technology in terms of equipment and processes and we will provide an outlook for the future applications of ALD on advanced MEMS sensors and actuators.

11:15am **AA2-TuM-14 Applications of Piezoelectric, Ferroelectric, and Antiferroelectric Thin Films Grown by Atomic Layer Deposition***, **Nicholas Strnad,*** DEVCOM Army Research Laboratory*; G. Fox,* Fox Materials Consulting, LLC*; T. Tharpe,* Oak Ridge Associated Universities*; R. Knight, R. Rudy, J. Pulskamp,* DEVCOM Army Research Laboratory

Piezoelectric materials offer efficient transduction of electrical and mechanical forces and have been implemented in many commercial products including medical ultrasound transducers, ink-jet print heads, atomic force microscope cantilever drives, and radio-frequency filters (thin-film bulk acoustic resonators, or FBARs). Actuators for microelectromechanical systems (MEMS) that utilize piezoelectric thin films offer larger forces and displacements compared to electrostatic actuators, and higher operating frequencies compared to thermal actuators. Despite the performance advantages offered by piezoelectric thin films, there are few reported ALD processes that have yielded viable piezoelectric properties. This presentation addresses several knowledge gaps in the field of ALD piezoelectric thin films. First, we present ALD processes for some of the most commercially relevant piezoelectric and ferroelectric thin films, including aluminum nitride (AlN), lead zirconate-titanate (PZT), additional Pb-containing perovskites (lead hafnate-titanate or PHT, lead hafnate or PHO), and $Hf_{1-x}Zr_xO_2$ (HZO). Second, we present methods of characterizing the effective transverse piezoelectric coefficient ($e_{31,f}$) which is critical for actuators but is underreported in the literature compared to the effective longitudinal piezoelectric strain constant ($d_{33,f}$). Third, we present new MEMS actuator concepts and initial fabrication results that leverage 3D, conformal ALD piezoelectric thin films that will lead to greater performance (up to 200x larger piezoelectric energy density) compared to traditional planar piezoelectric-enabled MEMS actuators. These new actuator concepts require aggressive aspect ratio scaling, sidewall-selective depositions, and 3D patterning, which presents new challenges and opportunities for atomic layer processing technologies.

11:30am **AA2-TuM-15 Effect of RF Substrate Biasing in Tuning the Tribological Properties of Plasma Enhanced Atomic Layer Deposited Titanium Vanadium Nitride Thin Films***, **Md Istiaque Chowdhury,*** Lehigh University*; M. Sowa,* Veeco Instruments Inc.*; K. Van Meter,* Florida International University*; A. Kozen,* University of Maryland, College Park*; S. Lazarte, B. Krick,* Florida International University*; N. Strandwitz,* Lehigh University

Ultra-low wear rates, approaching those of diamond, have recently been reported for transition metal nitride thin films deposited by plasma enhanced atomic layer deposition (PEALD). Apart from low wear, these films exhibit low electrical resistivities (~100 μΩ cm) comparable to metals (1-100 μΩ cm) and high chemical stability, which opens them up for applications in MEMs, NEMs, as electrodes, etc. Our aim is to understand the synthesis-structure-property relationships of these films by introducing substrate bias during deposition. The substrate bias helps regulate the energy distribution of the incoming plasma ions, which plays a vital role in modifying the resultant structure of the film and ultimately influence the functional properties. Researchers are using substrate biasing to modulate the ion-surface interaction in PEALD films but the correlation between the bias and the resultant structure and properties are not linear.

In this study, the magnitude of RF substrate bias, $|V_{bias}|$, was varied from 0 to 40 V during PEALD growth of ternary $Ti_xV_{(1-x)}N$ thin films to observe how $|V_{bias}|$ correlates with structure and tribological properties. Tetrakis (dimethylamido) titanium, tetrakis(dimethylamido) vanadium, and N_2 plasma were used as precursors. The growth rate per metal precursor exposure was 0.5-0.6 Å/cycle. The film densities approached 95% of the theoretical density as estimated by X-ray reflectivity. The electrical resistivity was evaluated to be 130-170 μΩ cm by four-point probe measurements. X-ray diffraction measurements revealed that the films have a cubic rocksalt crystal structure formed by a solid solution of TiN and VN. The crystal quality, indicated by the Bragg peak intensity, changed non-monotonically with $|V_{bias}|$. The (200) peak had the highest intensity for $|V_{bias}|$=20 V which was reflected in the minimum wear rate (10^{-8} mm^3/Nm) observed at this $|V_{bias}|$. The distribution of ion energies of the bombarding plasma was modified by $|V_{bias}|$, which provides an additional boost of energy to the adatoms promoting the crystal growth up to $|V_{bias}|$=20 V. Beyond 20 V, the additional energy from the bias causes continuous re-nucleation resulting in poor crystal quality, thus increasing the wear rate. The impact of $|V_{bias}|$ on tuning tribological properties of PEALD films have not been extensively studied, but it has been demonstrated that the residual stress of PEALD nitride films can be switched from compressive to tensile with $|V_{bias}|$. Substrate biasing can be a very useful tool to tune the tribological properties of PEALD nitride films and potentially create ultra-low wear materials.

11:45am **AA2-TuM-16 Towards ALD of hard AlTiN coatings***, **Pamburayi Mpofu,*** Linköping University, Sweden*; J. Lauridsen, O. Alm, T. Larsson,* Seco Tools AB, Sweden*; H. Högberg, H. Pedersen,* Linköping University, Sweden

AlN has a wide bandgap (6.2 eV), high dielectric constant (k ∼ 9), high electrical resistivity (ρ ∼ 1011–1013 Ω cm), and a very good thermal conductivity (2.85W/K cm)[1] making it interesting for microelectronics and optoelectronics. AlN is also used in microelectromechanical systems (MEMS devices) because of its piezoelectric properties. As AlN has good miscibility with other nitrides, it also has the potential to be used in ternary materials with e.g., Ga, In, Ti, or Hf, increasing the range of its possible applications.

One such material is meta-stable $Al_xTi_{1-x}N$ where the cubic rock salt structure of TiN is preserved even with x = 0.9. $Al_xTi_{1-x}N$ primarily finds use as hard material in protective coatings, often on cemented carbide tools. While ALD of AlN has been reported several times, reports on ALD of ternary materials comprising AlN are scarce. $Al_xTi_{1-x}N$ has only three entries in the Atomic Limits database[2], for semiconductor-related applications. Our aim is to explore the possibility of using ALD, for the first time, to deposit hard protective coatings of $Al_xTi_{1-x}N$. We aim to explore both an ABC-type ALD cycle with $AlMe_3$, $Ti(NMe_2)_4$, and NH_3, and an AB-type ALD cycle with co-evaporation of $Al(NMe_2)_3$ and $Ti(NMe_2)_4$.

We will present an ALD comparison study of AlN, from a hard coating perspective. We compare $Al(NMe_2)_3$ and $AlMe_3$ as Al precursors and NH_3 with and without plasma activation as the N precursor. In addition to standard Si (100) substrates, we also deposit on cemented carbide, i.e., tungsten carbide particles sintered in a cobalt matrix, with and without a TiN coating. We studied the AlN ALD process in the temperature range from 100 to 400 °C with the aim to optimize the process for crystalline quality rather than electronic properties. Polycrystalline, stoichiometric, and high-purity AlN films have been obtained when using $AlMe_3$ (both plasma and thermal) but with varying thicknesses, growths per cycle, saturation times, nucleation delays, and temperature windows. Films prepared via the plasma route exhibit improved properties concerning the growth rate per cycle, total cycle duration, and homogeneity. By comparing our experimental results to recent modeling results from density functional theory methods, we can show strong evidence for the surface chemical mechanism of TMA on an NH_2-terminated AlN surface.

We will also describe our initial results from depositions of $Al_xTi_{1-x}N$ using the ALD approaches outlined above.

Refs.:

1. Kot, M. et al. J. Vac. Sci. Technol. A 37, 020913 (2019).

2. https://www.atomiclimits.com/alddatabase/

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