Friday Morning, September 26, 2025

Plasma Science and Technology
Room 201 ABCD W - Session PS1-FrM

Plasma Processes for Coatings and Thin Films

Moderators: Francois Reniers, Université libre de Bruxelles, **Scott Walton**, Naval Research Laboratory

8:15am **PS1-FrM-1 First-Principles Study on Film Stress Mechanisms of Amorphous Carbon: The Role of Bond Hybridization*, Yusuke Ando,*** Nagoya University, Japan*; Hu Li, Jianping Zhao,* Tokyo Electron America, Inc.*; Masaaki Matsukuma,* Tokyo Electron Technology Solutions Ltd., Japan*; Kenji Ishikawa,* Nagoya University, Japan*; Peter Ventzek,* Tokyo Electron America, Inc.

Amorphous carbon (a-C) is a highly versatile material with tunable properties, including hardness, electrical conductivity and optical transparency, which can be tailored through control over its fraction of hybridized bonds and its content of hydrogen. Among a-C materials, hydrogenated amorphous carbon (a-C:H) has been widely utilized as an etching hard mask in semiconductor fabrication processes due to its superior resistance to fluorinated gas plasma and its facile removal via oxygen plasma treatment.

With the continuous advancement of semiconductor fabrication technology, particularly in 3D flash memory devices, increasing number of stacking layers necessitates the development of high-aspect ratio etching techniques. To meet this requirements, a-C hard masks must exhibit enhanced etch resistance to withstand prolonged plasma exposure while maintaining controlled residual stress to prevent delamination and wafer bending. a-C films are typically deposited via plasma enhanced chemical vapor deposition (PECVD) with hydrocarbon-based plasma, and experimental observation shows that bias voltages promoted an increased sp^3-C fraction and higher film density, thereby improving etch resistance. However, this increase in density is also accompanied by elevated residual stress, presenting a critical trade-off between etch resistance and mechanical stability. A fundamental understanding of stress generation and relaxation mechanisms is essential for optimizing a-C hard masks for advanced semiconductor applications.

While experimental investigations have provided valuable insights into stress behavior, the underlying structural factors governing stress generation remain insufficiently understood from a theoretical perspective.

In this study, as a first step, we have systematically analyzed influence of hybridized bonding configurations on residual stress of carbon films. By employing first-principles calculation, we modeled and evaluated various defective diamond-like carbon structures with identical densities, allowing us to isolate and compare the effects of geometrical properties other than density on stress generations. Our results indicate that, to varying degrees, a lower sp^3-C fraction and shorter mean bond length contribute to increased compressive stress. These conclusions are tested on hydrogenated systems as well. Based on these findings, we propose a mechanism of stress-relief that can guide process optimization in fabricating high-performance a-C hard masks.

8:30am **PS1-FrM-2 Atmospheric Microplasma-Driven CVD for Highly Crystalline Carbon Nanotube Synthesis*, Guohai Chen,*** *Takashi Tsuji, Shunsuke Sakurai, Don Futaba, Kenji Hata,* National Institute of Advanced Industrial Science and Technology (AIST), Japan

Microplasma-assisted chemical vapor deposition (CVD) provides a powerful platform for advancing carbon nanotube (CNT) synthesis by enabling localized, high-energy reactions that promote controlled nucleation and growth, essential for harnessing CNTs' extraordinary properties across diverse applications [1-5]. We present a multi-step atmospheric microplasma CVD system that incorporates abrupt interaction steps to precisely initiate and terminate nanoparticle (NP) aggregation through the coordination of microplasma and carbon reactant gas flow, thereby achieving the synthesis of highly crystalline CNTs [6-9].

Using this platform, we systematically investigated the roles of hydrogen and catalyst precursors under microplasma conditions. Hydrogen was found to play a critical role in moderating plasma chemistry, as revealed by a simple reaction pathway model: without hydrogen, excessive electron-induced decomposition suppressed catalyst NP formation and caused catalyst deactivation; with hydrogen, energy transfer shifted toward thermal pathways, enabling controlled NP formation and subsequent CNT nucleation. Optical emission spectroscopy validated these mechanistic insights [8]. We also studied the effect of catalyst precursor ligands on NP growth kinetics and CNT quality. Iron pentacarbonyl ($Fe(CO)_5$) produced smaller, more uniform NPs and resulted in higher-purity CNTs with greater yield compared to ferrocene ($Fe(C_5H_5)_2$), despite similar CNT structural features [9]. These findings highlight the significant influence of both hydrogen and precursor chemistry on catalyst behavior under microplasma conditions.

In addition to synthesis, we briefly introduce practical CNT applications, including a neural probe based on a mm-tall, high aspect ratio (60:1) CNT post array [10], and a through-silicon-via interposer integrating CNT-Cu composites, offering copper-level electrical conductivity and silicon-level thermal expansion [11].

Our study demonstrates the potential of atmospheric microplasma for precise, tunable CNT synthesis, offering new pathways for nanomaterial fabrication through plasma process engineering.

Keywords: Carbon nanotube, microplasma, crystallinity, precursor, optical emission spectroscopy

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Please see the Supplementary Document for the figure and reference list.

8:45am **PS1-FrM-3 AVS John Thornton Award Talk: Creating a Dream Team: Thin Films, Plasma Chemistry, Holistic Approaches, and Non-Traditional Pathways*, Ellen R. Fisher,*** University of New Mexico **INVITED**

Today, plasma processing is a well-known and powerful technique to modify the surface of materials, and create new materials, especially thin films.John A. Thornton was a pioneer in developing plasma processing of thin films.He was also a dedicated educator, having mentored numerous students.In this presentation, we present a holistic approach to plasma processing of thin films, linking the gas phase, the gas-surface interface, and relevant materials characterization.Often, the ultimate goal of these plasma-modification studies is to explore various pathways to tune and tailor the surface of a material, while maintaining bulk properties and material integrity for a desired application. Specific systems discussed will include semiconductor materials, membrane coatings, and metal oxides.Similarly, the development of the next generation of inventors and discoverers requires alternative approaches and new tools.To that end, the use of the science of team science (SciTS) tools and approaches provides alternative pathways to tune and tailor the environment necessary for creating effective teams.This can be realized by being the Archintor™ of a team's networks.Social network analysis (SNA) allows teams to discover how team members connect, including through learning, collaboration, and leadership networks.Fundamental SNA concepts and Archintor™ examples will be presented from real science and engineering teams, providing unique insight into the development and deployment of productive teams. Collectively, these studies exemplify the comprehensive approach to solving challenges in the plasma community, a tribute to the legacy of John A. Thornton.

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