New Horizons in Coatings and Thin Films
Room On Demand - Session F3

2D Materials: Synthesis, Characterization, and Applications

F3-1 Low-Temperature Synthesis of Vertically Standing Graphene by Microwave-Chemical Vapour Deposition*, I. Vasconcelos Joviano dos Santos,* ***Justyna Kulczyk-Malecka (J.Kulczyk-Malecka@mmu.ac.uk)****, S. Rowley-Neale, C. Banks, P. Kelly,* Manchester Metropolitan University, UK

Graphene is the most commonly studied 2D material due to its exceptional physical and chemical properties, originating from its atomic structure. However, the successful graphene applications are driven by the ability to synthesise it at high growth rates and low temperatures, which enable large-scale production on a variety of substrates. The synthesis of vertically standing graphene (VSG) is of particular interest due to its exposed sharp edges, non-stacking morphology and large surface-to-volume ratio, leading to advanced technological applications including sensors, flexible electronic devices and fuel cells. Plasma-enhanced chemical vapour deposition (PE-CVD) has emerged as a promising technique to synthesise graphene at lower temperatures. The plasma energy drives the CVD precursor decomposition and reaction kinetics, allowing better control over the deposition parameters that tailor graphene properties.

This study presents the growth of VSG on Si wafers in a single step process at relatively low temperatures (<300ºC). The samples were synthesised in a bespoke PE-CVD reactor, using a microwave (MW) source to decompose CH_4, H_2 and Ar gas mixtures, and drive the growth process without applying an additional heating source to the substrate. Deposition conditions, such as MW power, gas ratio, and substrate-to-plasma distance were studied to determine their significance on VSG growth, morphology and electrochemical performance. Samples were characterized by SEM, Raman and XPS, which confirmed the vertical nature and sp^2 hybridisation of the deposited graphene. Cyclic voltammetry (CV) was used to determine the intrinsic electrochemical properties of VSG, such as heterogeneous electron transfer coefficient (kº) and the electroactive area (A_{active}). The VSG deposited in this study shows a large surface area, exposed sharp edges and non-stacking morphology. These characteristics are attractive for the development of energy generation and storage devices, such as fuel cells and super-capacitors.

F3-2 Better than Homoepitaxy? van der Waals Layer Assisted Growth of Thin Films*, Koichi Tanaka (koichitanaka@ucla.edu),* University of California Los Angeles, USA*; K. Hojo,* Nagoya University, Japan*; A. Deshpande, P. Arias, M. Liao, Y. Wang, H. Zaid, A. Aleman, M. Goorsky, S. Kodambaka,* University of California Los Angeles, USA

It is generally assumed, and often true, that homoepitaxy yields higher crystalline quality thin films than heteroepitaxy. Studies conducted nearly three decades ago have shown that layered materials, owing to weak van der Waals (vdW) bonding across the layers, can aid in heteroepitaxial growth of layered as well as non-layered materials. In the recent years, two-dimensional (2D) layered materials have been shown to promote 'remote epitaxy', where the 2D layer present at the substrate-film interface does not hinder the epitaxial registry between the film and the substrate. Here, we demonstrate that 2D hexagonal boron nitride (hBN, a = 0.250 nm and c = 0.667 nm) buffer layers improves the crystallinity of sputter-deposited thin films. We provide evidence for this phenomenon via heteroepitaxial growth of body centered cubic metal (Mo), hexagonal MoS_2, and trigonal Ta_2C thin films on hBN-covered Al_2O_3(0001) substrates. Furthermore, our studies indicate that inserting hBN layers at regular intervals results in highly-0002-orientated growth and suppression of polycrystallinity in thicker Ta_2C films.

All our experiments are carried out in an ultra-high vacuum system equipped with facilities for direct current (dc) magnetron sputtering and chemical vapor deposition. hBN layers are grown on single-crystalline Al_2O_3(0001) substrates via pyrolytic cracking of borazine. Mo and Ta_2C thin films are deposited, respectively, via sputtering of Mo and TaC targets in pure Ar discharges, while MoS_2 layers are grown by reactive sputtering of Mo target in Ar-H_2S gas mixtures. The as-deposited layers are characterized using x-ray diffraction (XRD), transmission electron microscopy (TEM), and x-ray photoelectron spectroscopy (XPS). We observe the growth of single-crystalline Mo(110), MoS_2(0001), and Ta_2C(0001) thin films with notable differences in all the layers deposited on hBN-covered Al_2O_3 (0001) compared to those grown on bare substrates: significantly stronger reflection intensities ω-2θ XRD scans with smaller full-width half maxima and observation of Laue oscillations around the primary peaks. Our results indicate that hBN layers enhance the crystallinity of sputter-deposited thin films.

F3-3 Graphene Deposition on Copper Using Concentrated Solar-Thermal Heating*, Abdalla Alghfeli (alghfeli@g.ucla.edu),* *M. Abuseada, T. Fisher,* University of California at Los Angeles, USA

Manufacturing processes are often highly energy-intensive, even when the energy is primarily used for simple heating processes. This energy tends to derive from local utilities, which currently employ a blend of sources ranging from fossil fuels to renewable wind and solar photovoltaics, among others. When the end manufacturing need is thermal energy, direct solar-thermal capture provides a compelling option, but one that has rarely been employed to date. Here, we report a solar-thermal process using a simulated solar concentrator to demonstrate the ability of such a source to produce a high-value product, namely graphene on copper. Material deposition occurs at a surface and requires knowledge of material science, manufacturing, and heat transfer modeling. In this study, we employ a 10 kW_e concentrated solar source (solar simulator) capable of producing an adjustable high heat flux distribution (up to 4.5 MW/m^2, or 4,500 suns) in order to produce graphene rapidly on copper foil by chemical vapor deposition. The custom-built reactor consists of a xenon short arc lamp (that closely approximates the solar spectrum) placed at a truncated reflector's first focal point to concentrate source radiation with a Lorentzian-like heat flux distribution on the reflector's second focal point. Through the use of a controllable DC power supply and shutter, incident heat flux can be controlled and varied. Copper substrates are placed on a well-insulated mount that allows for varying the substrate's focal position, and hence heat flux distribution. We use the concentrated solar source to study the effect of heating and photocatalysis on the deposition product, and we begin to optimize the process by modeling substrate heat transfer processes that depend highly on optical and local thermal conditions. The process is monitored by optical emission spectroscopy, including an IR camera, pyrometer, and near-IR spectrometer, to determine appropriate gas recipes (flowrate and relative concentrations of methane and hydrogen) and other operating conditions, such as vacuum pressure, that yield high-quality product. The graphene produced through this process is further analyzed with scanning electron and Raman microscopy to assess the uniformity of graphene deposition as well as its quality, which is associated with the intensity ratio between Raman peaks of C-C in-plane vibrations and graphene lattice defects. Upon optimizing the operating conditions, graphene deposition will be extended to a larger and continuous scale through the use of a roll-to-roll solar chemical vapor deposition.

Author Index

Bold page numbers indicate presenter