One-dimensional hBN/CNT Van der Waals Heterostructures Fabricated by Atomic Layer Deposition

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Graphene's isolation has led to a strong interest in two-dimensional (2D) materials and the ability to stack them into van der Waals (VdW) heterostructures has opened up a wide field of applications based on these new materials. Neither too weak nor too strong, VdW coupling allows connecting two different materials to combine their intrinsic properties and/or to create new ones. The interest in this coupling is currently extending beyond 2D materials, with 1D VdW heterostructures that consist of coaxial stacking of two or more distinct materials. The two-dimensional electron confinement associated with VdW stacking is expected to improve/modify the physical and chemical properties of the final material compared to the initial ones. In particular, Hexagonal Boron Nitride (hBN) is generating much interest as it is isostructural to graphene with a large bandgap, excellent thermal stability, and photoluminescence intensity in the visible or UV spectral regions; thus, coaxial stacking of hBN onto carbon nanotubes (CNTs) can enrich optoelectronic properties of the initial structures [1]. Fabricating these high-quality hBN/CNT heterostructures requires a synthesis approach capable of precisely controlling the epitaxial deposition onto supports at the atomic scale. Based on self-limiting gas-surface reactions, Atomic Layer Deposition (ALD) has proven to be ideally suited for fabricating functional hetero-nanostructures, such as carbon nanotube-based materials [2]. Herein, a two-step ALD process of hBN is utilized for fabricating hBN/CNT heterostructures based on polymer-derived ceramics chemistry [3]. Briefly, a pre-ceramic layer of polyborazine is successfully deposited on single-wall or multi-wall CNTs within the first ALD step and then annealed at high temperatures in the second step to convert the polyborazine into crystalline hBN. The resulting BN-coated CNTs are thoroughly investigated employing advanced characterization techniques. Specifically, high-resolution transmission electron microscopy exhibits the fabrication of highly crystalline hBN/CNT heterostructures, and electron energy loss spectroscopy permits us to observe a conformal and homogeneous coating of hBN layers onto single-wall and multi-wall CNTs. The influence of the ALD parameters and post-annealing treatment on BN growth (thickness, number of layers, homogeneity) and structure (amorphous, turbostratic, hexagonal phase) is explored in detail as well as the impact of the starting carbon material on the final heterostructures in terms of morphology and crystallinity. Particular attention is paid to successfully fabricate 1D VdW heterostructures made of few-layer hBN coated-single wall carbon nanotubes. The Raman and photoluminescence spectroscopies are performed to evaluate the structural and optical properties of the obtained heterostructures.

References

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