Carbon 1D/2D Nanoelectronics: Advances in Synthesis and Integration

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Carbon-based materials have outstanding potential in nanoelectronics due to their small size, high carrier mobility, low intrinsic capacitance, and unique mechanical properties. We present incremental advances in carbon nanotube synthesis and in graphene applications. These advances include novel lateral growth of carbon nanotubes (CNTs) with fair alignment, demonstrations of limited control of CNT chirality distribution, a study of the reliability and robustness of graphene, and a characterization of atomic layer deposition (ALD) onto these carbon materials.

In CNT growth, a novel way to grow dense, lateral CNTs with fair alignment is shown using a growth rate enhancement effect which we deem “synergetic CNT growth.” This effect originates from local diffusion of active precursor amongst different catalyst features in dense patterns. The implications of this effect include empirical support of CNT growth mechanisms depicting growth as a surface reaction (1)-(3) rather than as dissolution of elemental material into metal catalyst.

Also in CNT growth, synthesis methods using isopropanol as precursor are demonstrated which allow for shifts in the overall chirality distribution (4). This growth paradigm is enabled by a deeper understanding of CNT growth and harnessing the use of larger alcohols for growth. Control of the chirality distribution allows for ensembles of CNTs ranging from a 69%-90% semiconducting under certain growth conditions.

In graphene applications, we characterize graphene’s reliability under current stress. We demonstrate that the mean-time-to-fail of graphene subjected to a current density of $20 MA/cm^2$ at 250 °C is 6 hrs (5). The main failure mode is shown to be defect formation. As interconnect, graphene outperforms SiCN-capped Cu, but is deficient in comparison to CoWP-capped Cu. These experiments suggest the need for studies of graphene with capping layers for further performance improvements.

Last, we investigate post-processing on these carbon materials, in particular the effects of ALD of Al_2O_3 and HfO_2 onto them. The impact of the ALD-grown films on CNTs is characterized by transmission electron microscopy and by Raman, x-ray photoelectron (XPS), and x-ray diffraction spectroscopy. The dielectric materials first nucleate at defect sites and grow into islands which eventually merge with one another. The stress induced into a CNT encapsulated by ALD-deposited dielectrics and the quality of the carbon/dielectric interface are described. XPS measurements show disorder is introduced into CNTs by the dielectric coating, suggesting modest functionalization of the CNTs.

References

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