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# Utilization of large-area graphene/CNT architectures in photonic and energy storage applications

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## Abstract

We investigate chemical vapor deposition (CVD)-grown graphene and carbon nanotubes (CNTs). First, we study the CVD growth kinetics of graphene domains at atmospheric pressure. We utilize electron backscattered diffraction, scanning electron microscopy and Raman spectroscopy to determine an as-yet unexplored growth mode and demonstrate its dependency on the underlying Cu crystal structure especially in the high $CH_4$:$H_2$ regime. Our findings indicate that the Cu-graphene complex is predominant mechanistically at atmospheric pressure, which is an important step towards tailoring graphene properties via substrate engineering. Next, we elucidate the photo physics in substrate-supported CVD-graphene and fully air-suspended CVD-graphene. We find that fully suspended CVD-grown graphene devices are dominated by the photoelectric effect, which is promising towards CVD-grown graphene photodetectors approaching THz cut-off frequencies. Particularly, our finding suggests that the device design (fully or partially supported) can be engineered towards a specific application area of graphene photodetectors. Finally, we explore the energy storage applications of CVD graphene and carbon nanotube architectures. The key challenge in fabricating high capacitance super capacitors lies in being able to effectively realize the entire chemically active surface area of the nanomaterial. We grow CNTs directly on graphene to facilitate low intrinsic resistance between the CNTs and graphene layers, while complimenting the efficient charged ion diffusion and electrical double layer formation of the graphene layers. This research is a step towards the promise of as-yet unachieved 3D multi-stack architectures with graphene layers separated by directly grown vertical carbon nanotube interconnects.

## Biography

E. H. Yang is Director of the multi-user Micro Device Laboratory (MDL) at Stevens Institute of Technology. He is currently an Associate Editor and a Member of the Editorial Board of several journals, including the IEEE Sensors Journal. Formerly, he worked at NASA's Jet Propulsion Laboratory as a Senior Member of Engineering Staff. Since joining Stevens as an Associate Professor in 2006, he has established two distinct, yet technically intersecting research programs focused on fundamentals and applications of graphene, carbon nanotubes, and smart polymers. Dr. Yang is currently the PI of a number of research, education and equipment grants. He is the Division Chair of Executive Committee in the ASME MEMS Division.