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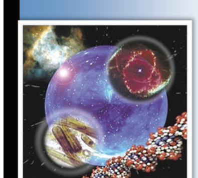
Monodisperse Carbon Nanomaterial Heterostructures

Improvements in carbon nanomaterial monodispersity have yielded corresponding enhancements in the performance of electronic, optoelectronic, sensing, and energy technologies. However, in all of these cases, carbon nanomaterials are just one of many materials that are employed, suggesting that further device improvements can be achieved by focusing on the integration of disparate nanomaterials into heterostructures with well-defined interfaces. For example, organic self-assembled monolayers on graphene act as effective seeding layers for atomic layer deposited (ALD) dielectrics, resulting in metal-oxide-graphene capacitors with wafer-scale reliability and uniformity comparable to ALD dielectrics on silicon. Similarly, the traditional trade-off between on/off ratio and mobility in semiconducting carbon nanotube (CNT) thin-film transistors (TFTs) is overcome by replacing conventional inorganic gate dielectrics with hybrid organic-inorganic self-assembled nanodielectrics, yielding on/off ratios approaching 10^6 while concurrently achieving mobilities of ~150 cm^2/V-s. By utilizing unconventional gate electrode materials (e.g., Ni), the threshold voltage of semiconducting CNT TFTs can be further tuned, thus enabling the realization of CNT CMOS logic gates with sub-nanowatt static power dissipation and full rail-to-rail voltage swing. Finally, p-type semiconducting CNT thin films are integrated with n-type single-layer MoS_2 to form p-n heterojunction diodes. The atomically thin nature of single-layer MoS_2 implies that an applied gate bias can electrostatically modulate both sides of the p-n heterojunction concurrently, thereby providing 5 orders of magnitude gate-tunability over the diode rectification ratio in addition to unprecedented anti-ambipolar behavior when operated as a three-terminal device. Overall, this work establishes that carbon nanomaterial applications can be substantially enhanced and diversified into new areas through precise integration into heterostructure devices.



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