FM-AFM Study on the Adsorption and Intercalation States of Polyoxyethylene Stearyl Ether in Carbon Nanotube Network

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Carbon nanotubes (CNTs) have emerged as promising components of next-generation thermoelectric (TE) materials in wearable electronics and self-powered Internet-of-Things devices, owing to their high electrical conductivity and mechanical flexibility. Their intrinsically high thermal conductivity, however, limits the attainable TE efficiency. One practical strategy to mitigate this limitation is to introduce non-ionic surfactants that modify the formation of CNT bundles and their interfacial structure. Polyoxyethylene (50) stearyl ether has been reported to enhance CNT alignment and TE performance while suppressing thermal conductivity, resulting in an improved power factor and thermoelectric figure of merit (ZT) [1].

To elucidate the nanoscale mechanisms underlying these improvements, we visualized the adsorption and intercalation of the surfactant molecules on single-wall CNT networks by frequency-modulation atomic force microscopy (FM-AFM) in a dry N_2 atmosphere. Figure 1 displays a topography image of a CNT network acquired by FM-AFM. Height profiles distinguish (a) single-bundle and (b) triple-bundle SWCNTs, each exhibiting protrusions whose heights correspond to the thickness of the adsorbed surfactant molecule on the tube surfaces. Profiles at (c) CNT–CNT junctions display an additional height increase, indicating intercalation of surfactant molecules between adjacent bundles. Despite the inevitable tip-induced lateral broadening (morphological dilation) in AFM imaging of nanoscale three-dimensional structures, quantitative comparison of the measured cross-sections with profiles computed by classical molecular mechanics confirms that the observed protrusions originate from a helically wrapped surfactant monolayer or localized clusters. These results demonstrate how surfactant molecules adsorb at CNT interfaces in ways that can disrupt continuous heat-conduction pathways.

This study shows that FM-AFM, when interpreted with molecular mechanics, can reveal soft-matter structures even on curved nanostructures and emphasizes the critical role of molecular-scale imaging in guiding the development of CNT-based TE materials.

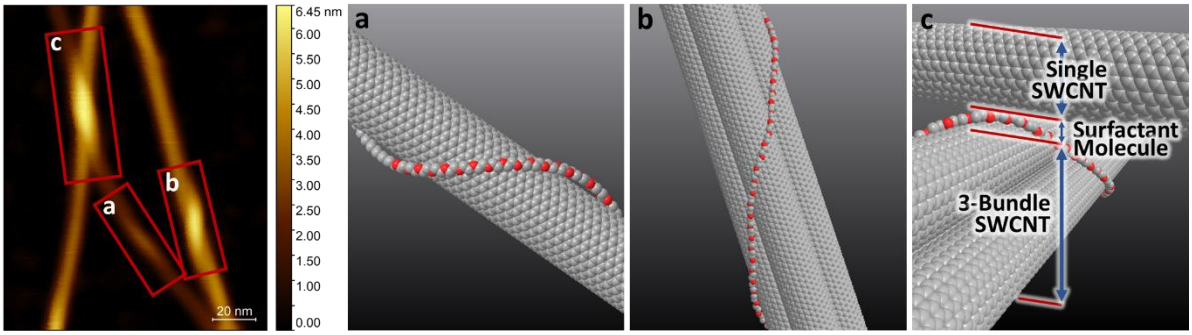

Figure 1. FM-AFM Image and 3-D Molecular Models of Polyoxyethylene (50) Stearyl Ether Adsorption and Intercalation on SWCNTs.

References

[1] A. N. Nguyen, et al. ACS Appl. Nano Mater. **7**, 9880 (2024).