Axial Direction Structure Thermal Domain Size of Highly Aligned Single-Walled Carbon Nanotube Bundles

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Single-walled carbon nanotubes (SWCNTs) exhibit unique characteristics arising from their small diameter, structure chirality, and monolayer wall. Although a SWCNT could very rarely have a single-crystal structure, the determination of its crystallite size has been challenging due to its nanoscale scattering cross-section. Understanding the structural defects and crystallite size along the axial direction is crucial to comprehending the energy carrier transport in SWCNTs. The extremely small cross-section size of SWCNTs makes it impossible to measure their crystallite size in this direction, even using the grazing incidence x-ray diffractometry (XRD), which is intended to increase the intensity. This study characterizes the average structure thermal domain (STD) size of SWCNTs for the first time. This characteristic size represents the average mean free path of low-momentum phonons, which is determined through the low-momentum phonon scattering rather than traditional beam scattering methods (e.g., neutron and x-ray). The characterization involves measuring the thermal diffusivity of suspended individual SWCNT bundles with diameters less than 7 nm over a micro-trench on silicon substrate in the axial direction from room temperature down to 77 K. This is accomplished using the frequency-domain energy transport state-resolved Raman (FET-Raman) technique. It employs continuous-wave and amplitude-modulated square-wave lasers with a specific frequency to eliminate the need for the exact temperature rise and the sample's laser absorption. Then the obtained thermal diffusivity values are converted to thermal reffusivity to investigate the phonon-defect scattering effect. The residual thermal reffusivity at the 0 K limit is determined to be 6449 and 4795 $s \cdot m^{-2}$ for two different bundles, demonstrating abundant defects in sample. It also reflects the sole structure-phonon scattering since the phonon density is reduced to a negligible level at the 0 K limit. The corresponding average STD sizes are calculated to be 46.0 and 61.9 nm, respectively. Due to the lack of other structure domain size information to compare for SWCNT, we compare the STD size of other micro/nanoscale materials with their crystallite size by XRD to interpret our findings.