In-Situ and Real-Time Thermal Characterization of Individual Water-Filled Nanotubes Inside a Scanning Transmission Electron Microscope

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In-situ thermal properties measurements inside an electron microscope can play an irreplaceable role in establishing the property-structure relationship. In this work, we have developed an experimental set-up that allows in-situ and real-time thermal characterization of a single nanotube or nanowire inside a scanning transmission electron microscope (STEM). In this set-up, the two ends of the 1D nanomaterial are bonded on a tungsten nanomanipulator and a suspended platinum nanofilm, respectively. The platinum nanofilm serves simultaneously as a heater and a resistance thermometer, allowing highly sensitive thermal measurements. The platinum nanofilm is located at the edge of the silicon wafer, so the electron beam can be transmitted through the 1D material and detected by the STEM detector, which enables real-time observation of the inner nanostructure. We have confirmed that the heating effect of the electron beam irradiation is negligible in our set-up. Using this approach, we measured the thermal conductance of individual water-filled CNTs while observing the inside liquid-gas two-phase structure. The CNT with more water inside exhibited a higher effective thermal conductivity because the large amount of filled water can provide more heat transfer paths. Besides, we observed ultrastable liquid phases inside the CNT, which did not show any noticeable phase change even when the current applied to the platinum nanofilm increased until the junction between the sensor and the CNT reached approximately 250°C.