Interface Thermal Resistance at Single-Walled Carbon Nanotube/Silicon Interface by Raman Thermometry

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The energy transport at the nanoscale is often dictated by the contact resistance across the interface. Despite its importance, such ~ nm contact width brings large complexity to any experimental method. Here, we report the interface thermal resistance (ITR) between a single-walled carbon nanotube (SWCNT) bundle and a silicon substrate. We employ a novel technique termed energy transport state-resolved Raman (ET-Raman). This technique offers an advantage over conventional Raman techniques by ruling out the dependency on the sample's optical absorption and Raman temperature coefficients, yielding a more accurate probing and less exhaustive one. To achieve this, we rely on probing and relating the sample's thermal response under two distinct energy transport states: a steady-state and a transient one. The former is attained using a continuous wave laser, whereas the latter is achieved by modulating the laser to have a pulse duration of 20 ns, with laser off-time of 1 μs to ensure thermal relaxation. This is crucial to avoid heat accumulation, and hence, maintain the distinction between the two energy transport states. This method allows for having the relative temperature rise in the transient state relative to the steady state, without the need of the actual temperature rise. A finite-volume based numerical method is used to simulate the experiment and solve the heat equation under laser irradiation. The experimental results are mapped out onto the simulation results to extract the ITR values of two distinct locations in the sample. As known, the sample's structure plays a significant role in determining the ITR. An atomic force microscope (AFM) is used to measure the nominal dimensions of the SWCNT bundle, where the height varies from 3.16 to 4.4 nm at the two locations of interest. To resolve the internal structure, we conduct a comprehensive analysis of the Raman spectrum, in particular the low frequency phonons known as the radial breathing mode (RBM) which are commonly used to determine the diameters of different SWCNTs and hence the internal structure. We observe a nonuniform distribution of the diameters as revealed by the RBM Raman scan along the bundle's axis, which is consistent with the AFM measurement variation. This nonuniformity has been reflected on the ITR values which are obtained as $(2.75 \pm 0.19) \cdot 10^3$ and $(1.39 \pm 0.52) \cdot 10^3$ $K{\cdot}m{\cdot}W^{-1}$ for the first and second location, respectively. A qualitative model for calculating the ITR is implemented which suggests a loose contact between the sample and the substrate. We expect this to have been developed due to the nonuniformity of the sample. The larger size location shows a lower ITR, consistent with theoretical predictions due to larger contact area. The reported values are of the same order of magnitude of ITR for exfoliated 2D materials in the literature.