RF-to-Millimeter-wave Conductivity Spectra of Single-Walled Carbon Nanotubes

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There have been several theoretical proposals that single-walled carbon nanotubes (SWCNTs) may have very unique and highly desirable electrodynamic properties for microwave-thru-terahertz applications.[1,2] These properties arise from the combination of very high purity achievable and quasi-one-dimensional nature of the electronic conduction in SWCNTs, as evidenced by reports of quantized DC conductance in short (few μm length) SWCNTs.[3] If electrical conductance in SWCNTs is quantum ballistic in nature, then the AC response can conceivably have ultra-low intrinsic loss and be able to follow frequencies far higher than conventional metals and semiconductors. It has been proposed that such ballistic conduction can be used to make SWCNTs a very wide bandwidth submillimeter-wave mixer.[4] Some recent experimental reports on the RF and microwave properties of SWCNTs report either a frequency-independent loss or a loss that falls below measurement uncertainties.[5,6,7] However, most of these measurements suffer from poor signal-to-noise arising from large systematic uncertainties and/or large instrumental loss.

We report on a detailed investigation of the AC response of small arrays of SWCNTs from 0.01 to 50 GHz using a coplanar waveguide (CPW) platform compatible with both broadband *S*-parameter measurements and directed assembly of SWCNTs. Utilizing AC dielectrophoresis and lithographic masking techniques, small numbers of SWCNTs, prepared with and without surfactants, were assembled in regular, localized arrays across the gaps between CPW signal and ground electrodes. This aligns the SWCNTs with the propagating electric field polarization and so maximizes coupling of the SWCNTs to the electromagnetic field. The complex conductivity of the SWCNT array is deduced from vector network analyzer measurements of the change in *S*-parameters, ΔS, of a CPW before and after SWCNT assembly. Using careful calibration, the ratios of ΔS_{11} and ΔS_{21} to random errors are of order 20 dB and the ratios of ΔS_{11} and ΔS_{21} to systematic errors is at least 10 dB.

At room temperature, we have found direct evidence that 1 to 3 μm long SWCNTs have clear, frequency-dependent loss that scales roughly as $f^{1/2}$, qualitatively similar to skin-depth loss. The SWCNTs also have a non-trivial frequency-dependent reactance. A detailed analysis of this data will be presented.

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