Identifying Nanotube Permittivity through Microwave Cavity Techniques

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Ballistic transport is expected in carbon nanotubes; however, the measurement of the transport properties of carbon nanotubes poses a significant problem. When attempting to measure resistivity by attaching electrodes to nanotubes, one must deal with the contact resistivity between the nanotube and the electrodes. If the nanotube under observation is touching any other nanotubes, contact resistance between the nanotubes will also cause problems. Because of their small size, avoiding these contact resistance problems through four-lead measurement does not work. Measurement using a microwave cavity addresses this problem. Using a network analyzer, one can monitor the microwave absorption within a cavity resonator. The bandwidth and peak frequency depend on the size and shape of the cavity as well as the dielectric constant inside the cavity. After characterization of the empty cavity, measurements are taken again with a nanotube sample inside the cavity. The sample contains a low density of nanotubes aligned in one direction, which greatly reduces the chance of nanotube to nanotube contact resistance. By analyzing any shift in the microwave absorption curve with nanotubes in the cavity, one can deduce the permittivity of carbon nanotubes without attaching electrodes.

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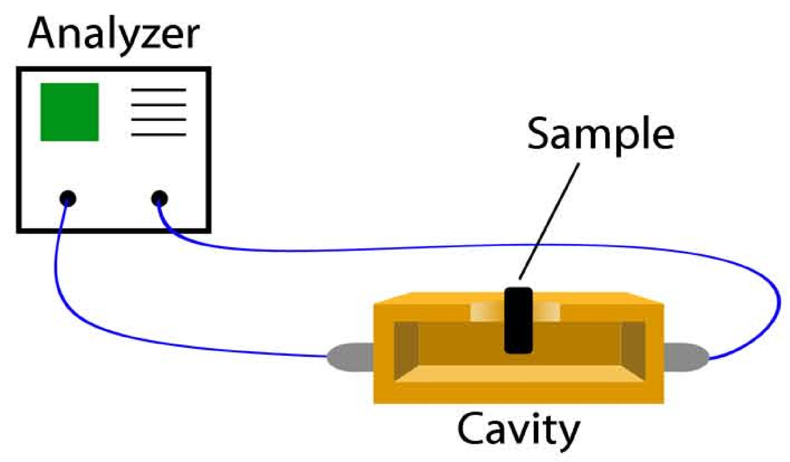
Introduction

Carbon nanotube structure and size produces many novel properties but also inhibits the study of some of these properties. For example, nanotubes are expected to exhibit ballistic transport, but the direct measurement of their resistivity is difficult.

Contact resistance with electrodes prevents the accurate recording of resistivity, and a nanotube's size prohibits using four-terminal measurement. Contact resistance from one nanotube to another also creates difficulties.

Proposed Technique

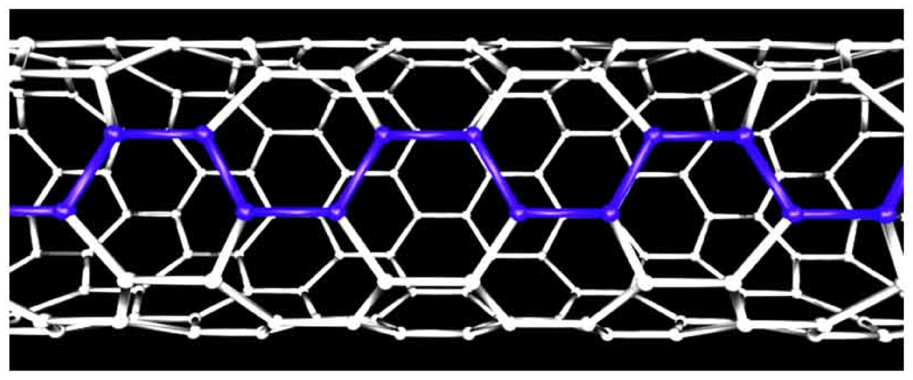
This project uses a non-contacting microwave cavity technique to identify the permittivity of a nanotube sample, which relates to its resistivity. Furthermore, the sample contains a low concentration of nanotubes aligned in a single direction, preventing contact resistance between nanotubes and providing a method for the effects of orientation on permittivity.



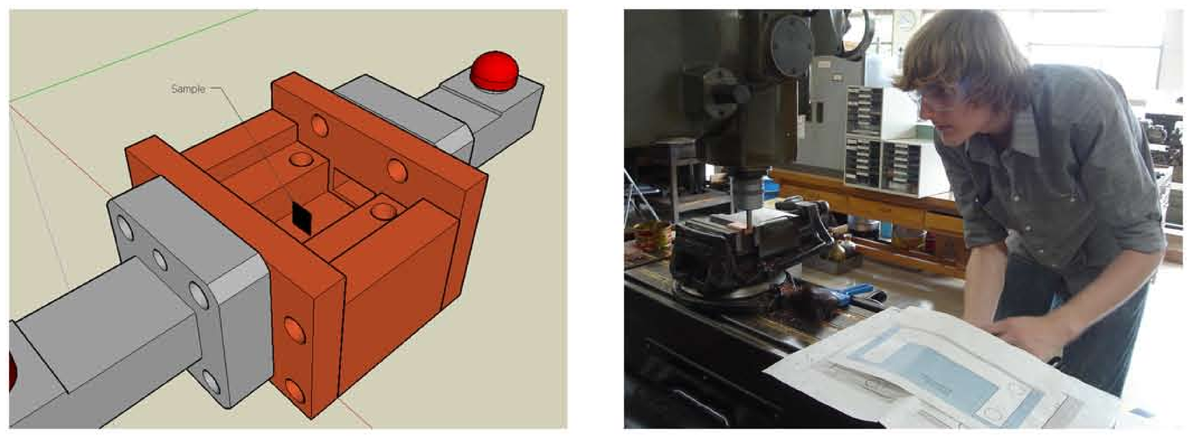
Change in resonance reveals permittivity.

Project Goals

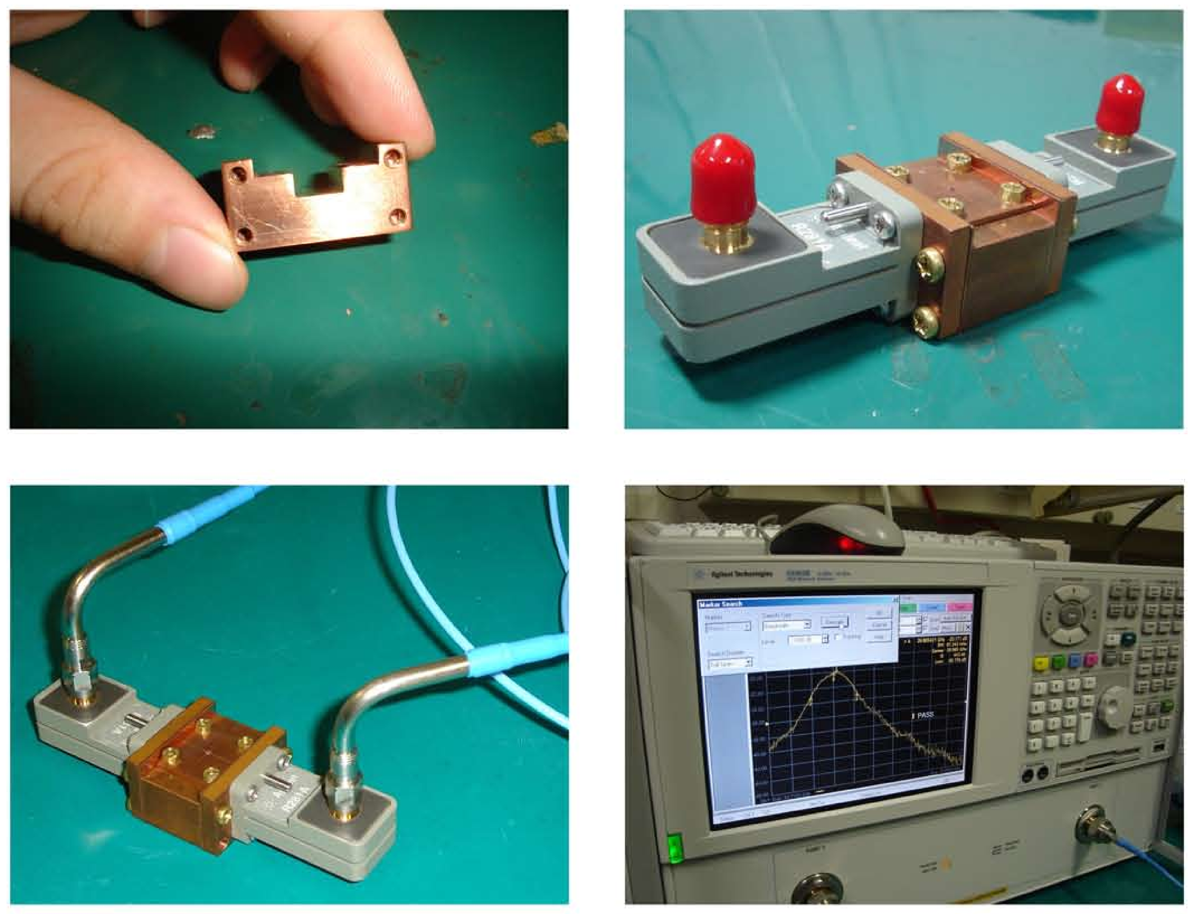
- Design a cavity resonator suitable for use with nanotube samples
- Observe the nanotubes' affect on resonance frequency and bandwidth
- Deduce sample permittivity in room temperature conditions
- Examine effect of nanotube orientation on permittivity results



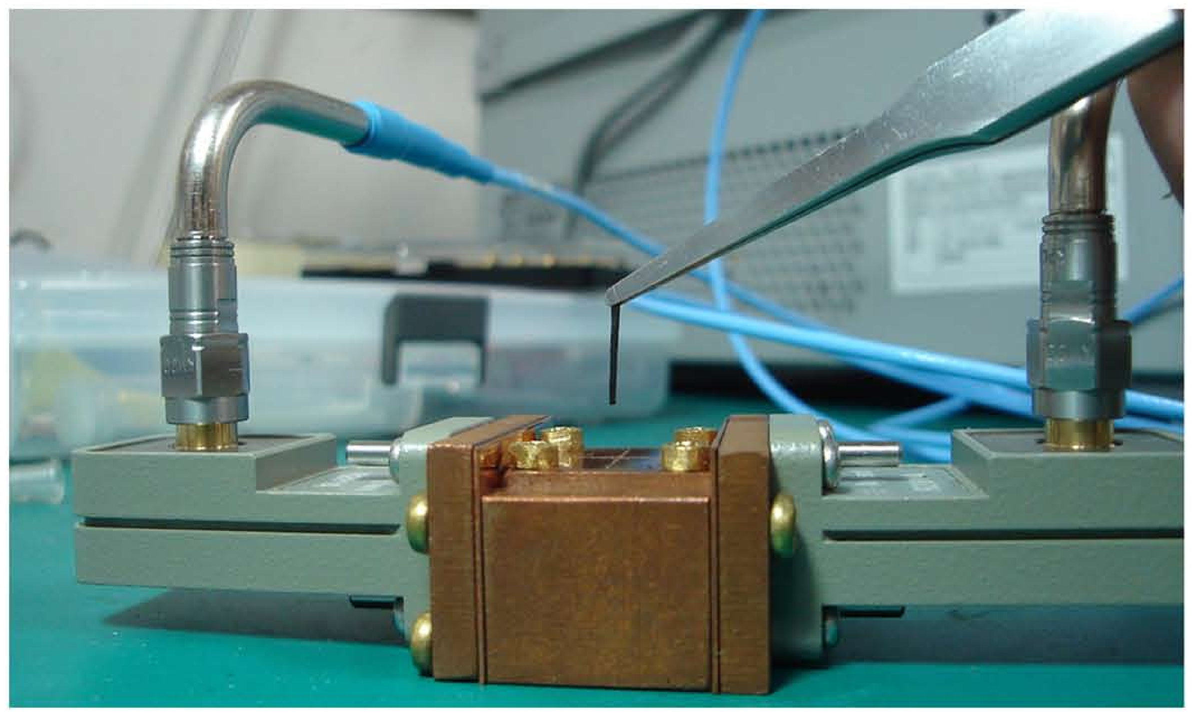
Procedure



Building a cavity to maximize resonance signal.



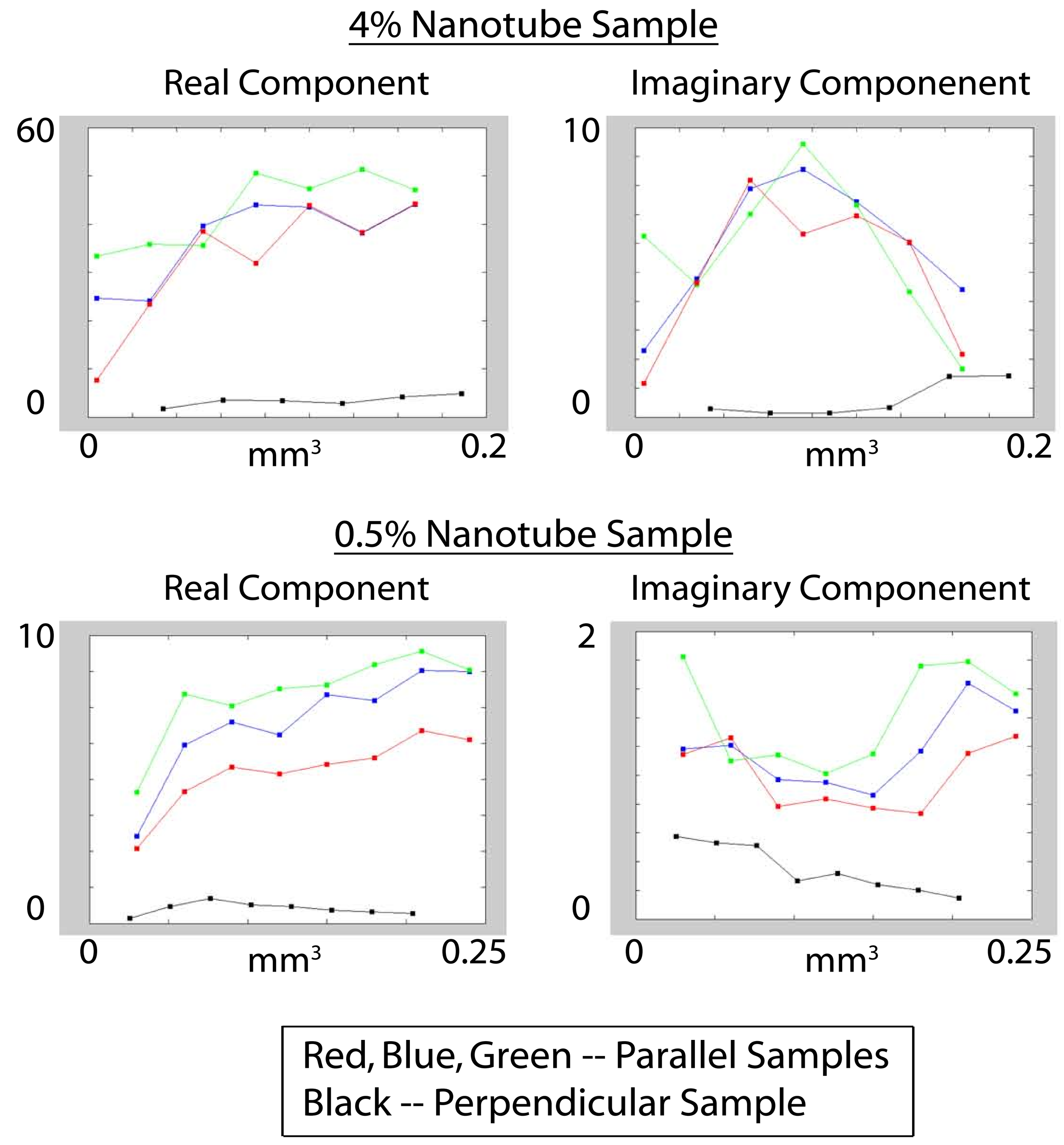
The center frequency and bandwidth of the resonance are first recorded for the empty cavity, then the signal change caused by loading a nanotube sample is measured.



By analyzing the change in resonance, the permittivity of the nanotube sample can be calculated. Testing using nanotube samples of perpendicular orientation was used to identify the importance of orientation in the field.

$$\varepsilon' = 1 - \frac{1}{\alpha_\varepsilon} \frac{(f_L - f_0)}{f_L} \frac{V}{\Delta V} \qquad \varepsilon'' = \frac{1}{2\alpha_\varepsilon} \left(\frac{1}{Q_L} - \frac{1}{Q_0} \right) \frac{V}{\Delta V}$$

Results



Conclusion

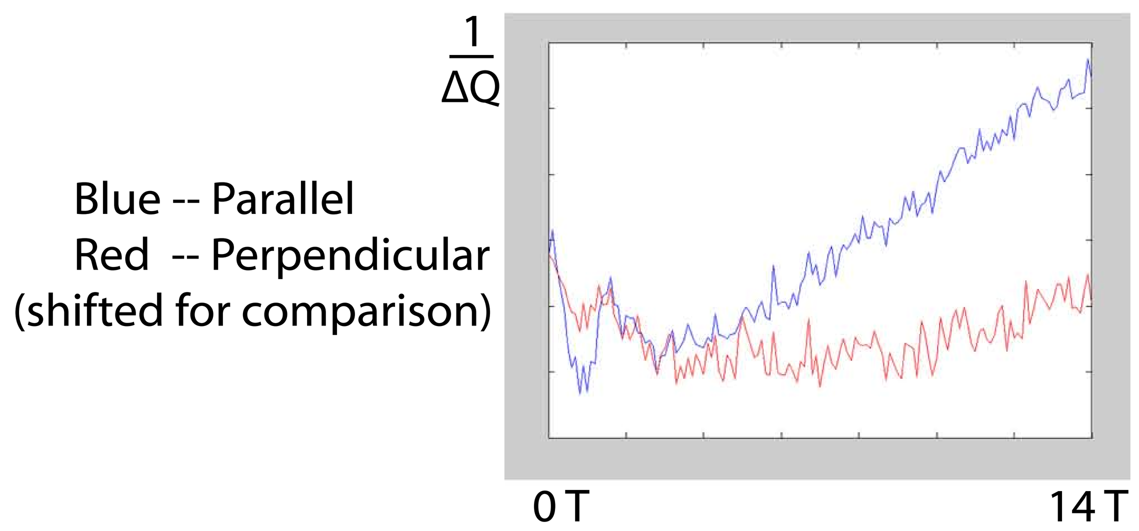
Mean permittivity for a 4% nanotube sample: **37.5** (real) and **5.59** (imaginary)

Mean permittivity for a 0.5% nanotube sample: **7.39** (real) and **1.20** (imaginary)

Variation at low volumes results from leak near the loading hole. Variation at high volumes occurs as the noise to signal ratio increases. For both concentrations, changing the sample orientation strongly affects the permittivity.

Further Research

Related research at Tohoku University has used similar methods to study nanotube behavior in high magnetic fields. The dielectric properties of nanotubes appear to change in these cases.



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