SUMMER NANOTECHNOLOGY STUDY PROGRAM IN JAPAN

# Identifying Nanotube Permittivity through Microwave Cavity Techniques

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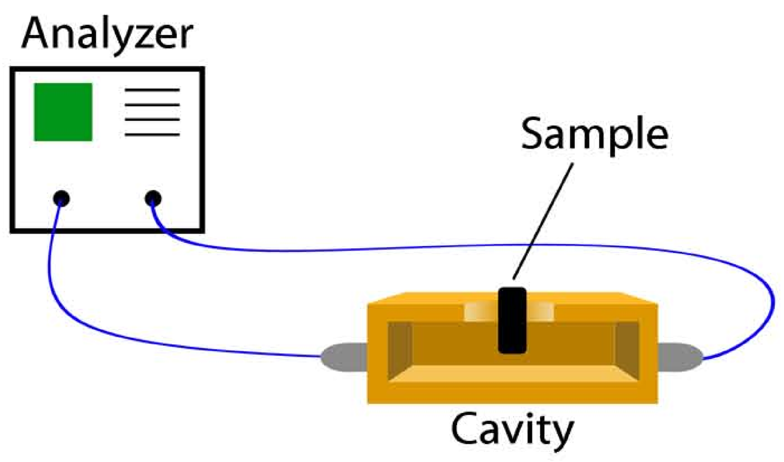
## Introduction

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

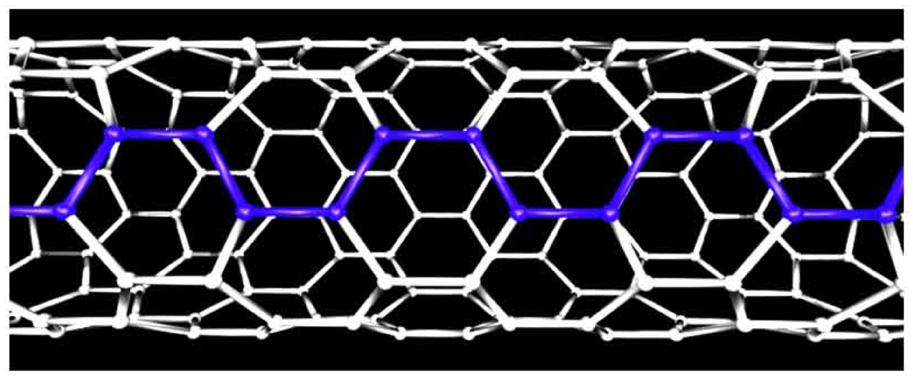
This project uses a non-contacting microwave cavity technique to identify the permittivity of a nanotube sample, which relates to its resistivity. Furthermore, the sample contains a low concentration of nanotubes aligned in a single direction, preventing contact resistance between nanotubes and providing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



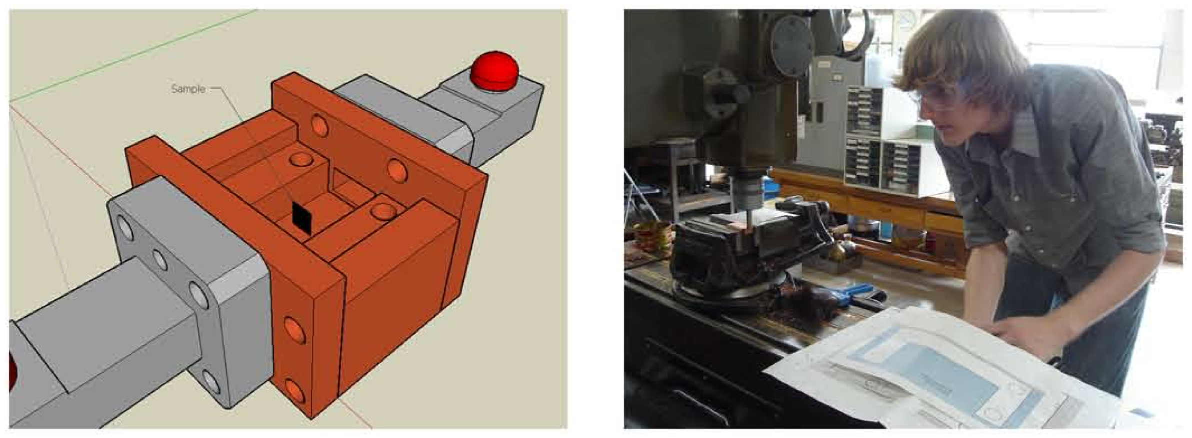

Change in resonance reveals permittivity.

## Project Goals

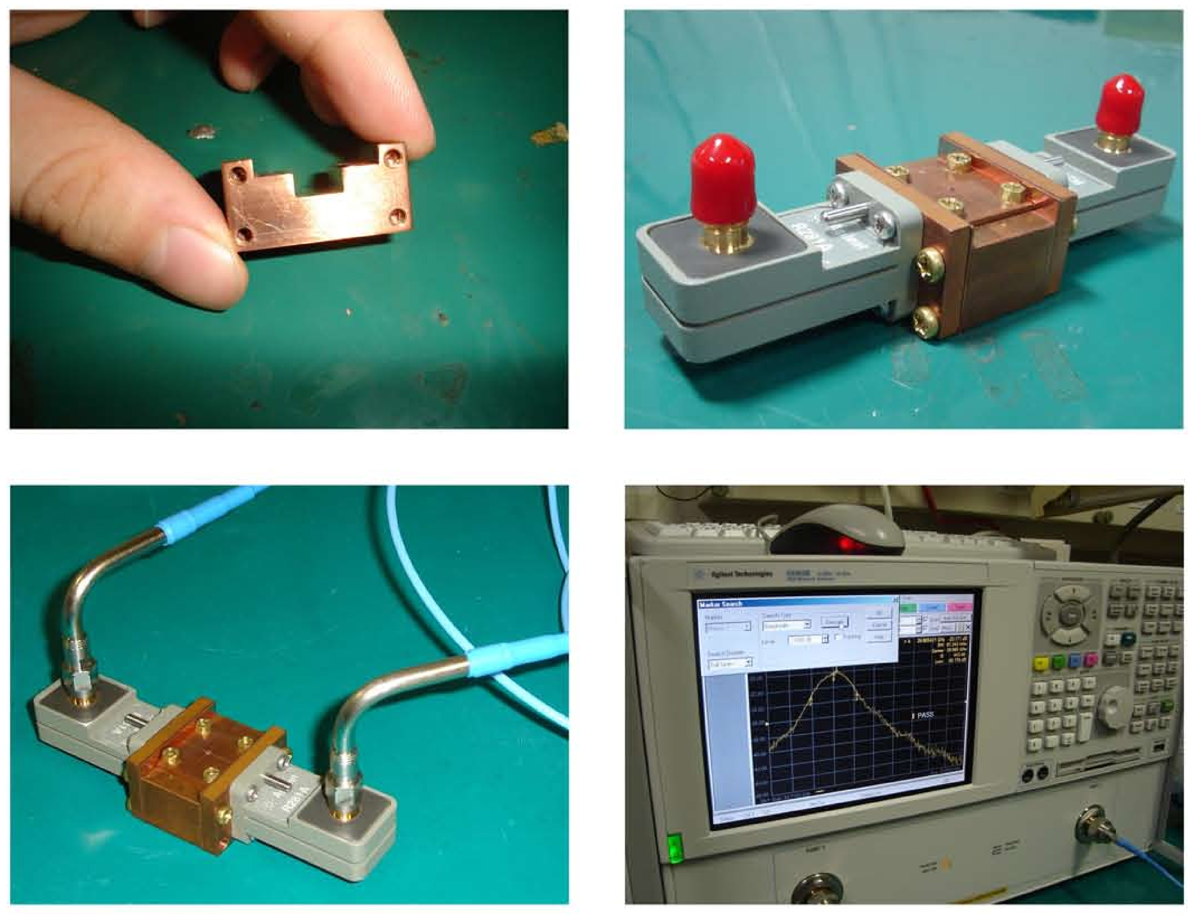
- Design a cavity resonator suitable for use with nanotube samples
- Observe the nanotubes' affect on resonance frequency and bandwidth
- Deduce sample permittivity in room temperature conditions
- Examine effect of nanotube orientation on permittivity results



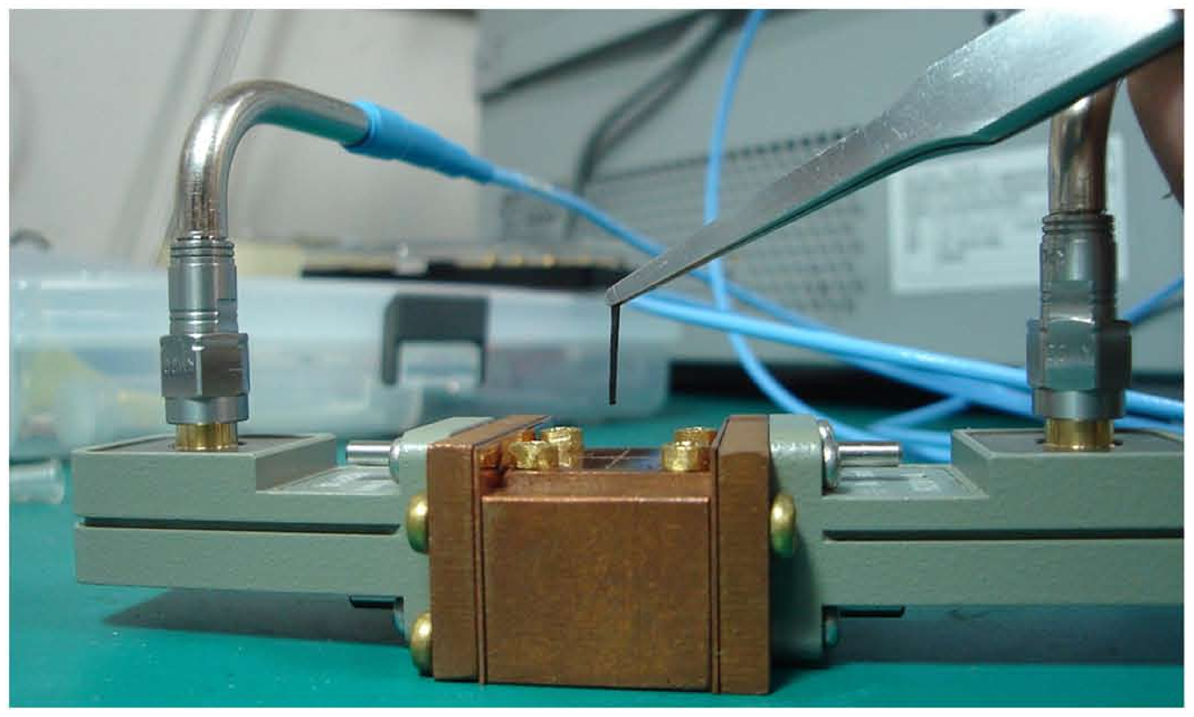
## Procedure



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.

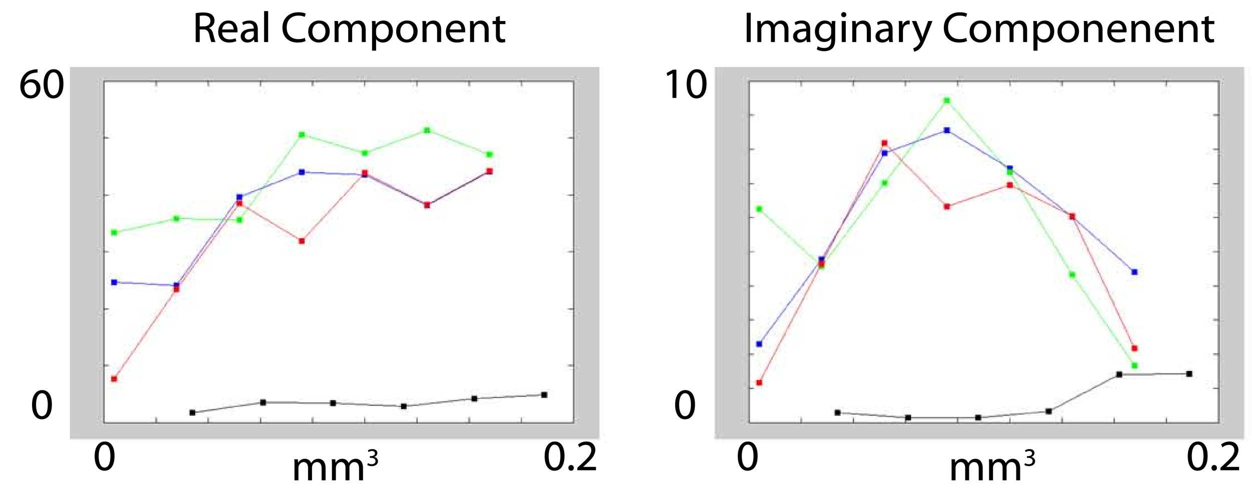


By analyzing the change in resonance, the permittivity of the nanotube sample can be calculated. Testing using nanotube samples of perpendicular orientation was used to identify the importance of orientation in the field.

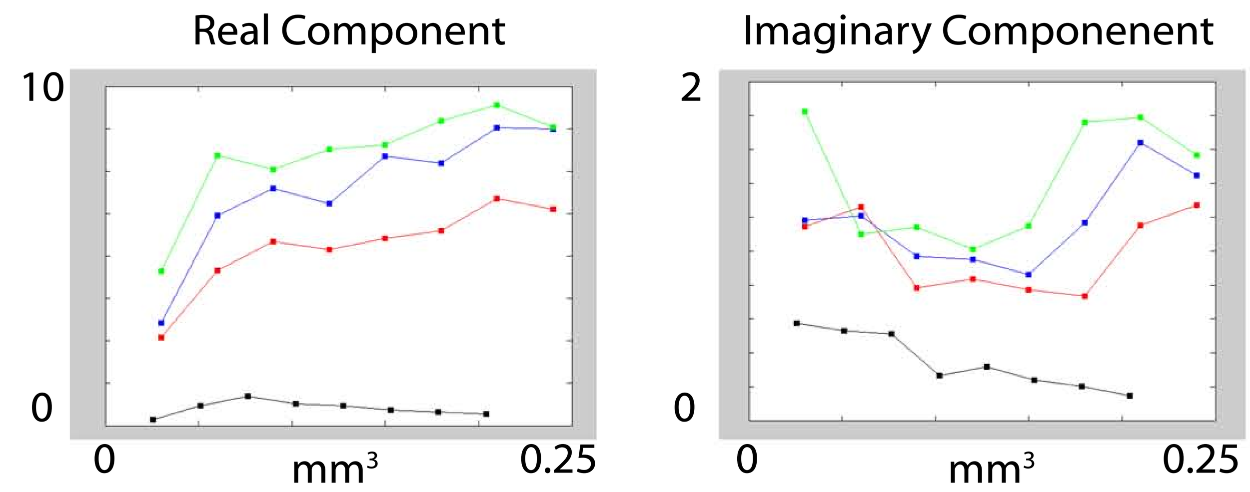
$$\varepsilon' = 1 - \frac{1}{\alpha_\varepsilon}\frac{(f_L - f_0)}{f_L}\frac{V}{\Delta V} \qquad \varepsilon'' = \frac{1}{2\alpha_\varepsilon}\left(\frac{1}{Q_L} - \frac{1}{Q_0}\right)\frac{V}{\Delta V}$$

## Results

4% Nanotube Sample




0.5% Nanotube Sample




Red, Blue, Green -- Parallel Samples
Black -- Perpendicular Sample

## Conclusion

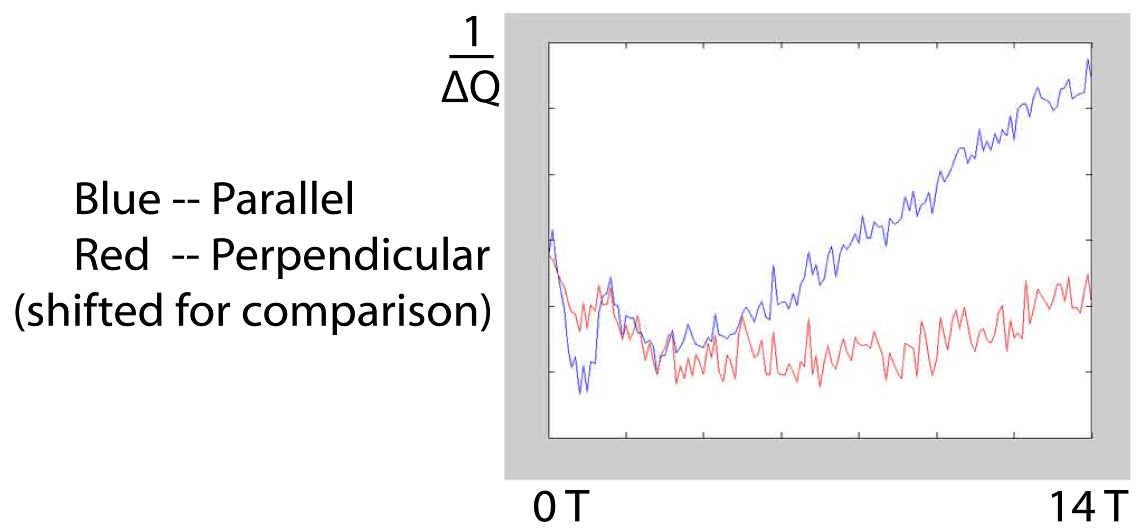
Mean permittivity for a 4% nanotube sample: **37.5** (real) and **5.59** (imaginary)

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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