Finding Dielectric Constant of Nanomaterials Using Fourier Transform Infrared Spectroscopy

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Abstract:

The main focus of this research group is on getting material characterization of nanomaterials through Fourier transform infrared spectroscopy (FTIR). Due to the fact that FTIR mainly gives reflection coefficient vs. wave number, the transmission line theory is used to produce the sample and sample holder, and to transform data from FTIR into dielectric constants. The focus of this project is to first design the structure of the sample and the sample holder so that transmission line theory can be applied. This is important since ascertaining the thickness of the sample holder that will be hold the sample is key in getting as close as possible to the actual dielectric constant. The second focus is to design a simple diaphragm made of silicon nitride. Since we already know the dielectric constant of silicon nitride, this test will allow us to see how close the dielectric constant from FTIR is to the official one. The third step is to use the diaphragm as a sample holder and drop cast a layer of Ge nanowires made by the UTA CHE department. Then we will measure the dielectric of the Ge nanowires utilizing the above methods.

Introduction:

The main point of this research is to find a simpler and different way to gather basic material characterizations, conductivity and dielectric constant, of nanomaterials, instead of the traditional way of using electrical contact to measure the current and voltage and calculate material characterization from the data measured. This is important because in order for a material to be able to be used in actual applications, its basic properties need to be known. After doing some research and discussion with Professor Neikirk's group, this research group figured out that FTIR, combined with transmission line theory, can be used to calculate dielectric constant. The group also noted that FTIR measurements are more effective on materials that are very transparent or absorbing. Those types of materials are also good for making detectors and electromagnetic structures [1,3,4,7].

Strategy:

The strategy was to first perform FTIR measurements on silicon nitride, with a known dielectric constant, to make sure that the equations derived from transmission line theory work and produce the desired result. Then FTIR measurements would be performed on a nanomaterial, Ge nanowires. The structure of the material samples were designed according to the quarter wave transformer circuit from the transmission line theory. Figure 1 shows the circuit of the Ge nanowire sample. Figure 2 shows the equations used to calculate dielectric constant from the Ge nanowire sample. Figure 3 shows the side view of the structure of the Ge nanowire sample [1,5].

Figure 1

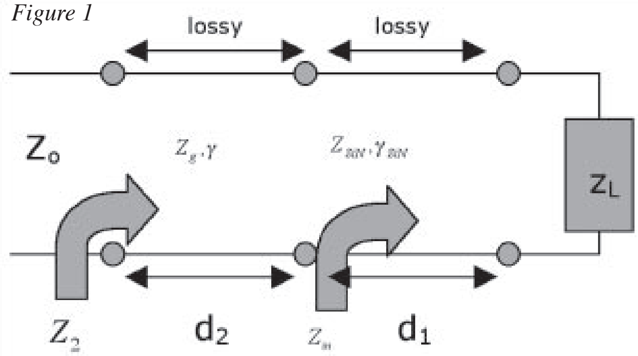

Figure 2

$$|\Gamma| = \left|\frac{Z_2 - Z_1}{Z_2 - Z_1}\right| \Rightarrow Z_2 = \left(\frac{1+\Gamma}{1-\Gamma}\right) \times Z_1$$

$$Z_2 = Z_g \times \left(\frac{Z_1 + Z_g(\tanh(\gamma d))}{Z_g + Z_1(\tanh(\gamma d))}\right)$$

$$Z_g = \sqrt{\frac{j\omega\mu_0}{\sigma + j\omega\varepsilon_0(\varepsilon' - j\varepsilon'')}} \quad , \quad \sigma = \sqrt{R_g \times d_2}$$

$$\left(\frac{1+\Gamma}{1-\Gamma}\right) \times Z_2 = Z_g \times \left(\frac{Z_1 + Z_g(\tanh(\gamma d))}{Z_g + Z_1(\tanh(\gamma d))}\right)$$

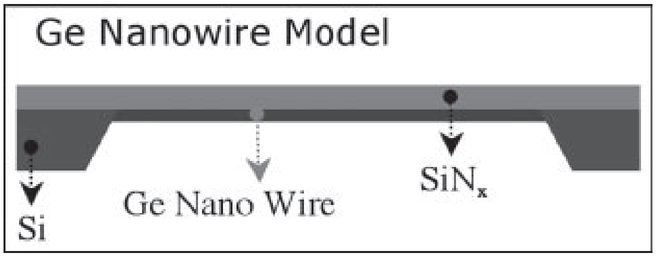

Figure 3

Experimental Procedures:

The procedure for part one was basic. The first few steps included depositing silicon rich silicon nitride on the waver and spinning resists onto the waver. The last few steps included mask alignment, develop, exposure, RIE dry etching, and KOH anisotropic wet etching. The end result looked like Figure 3 without the Ge nanowires. For part two, a silicon nitride sample was made. Then the Ge nanowire powder obtain from Prof. Korgel's group was mixed with chloroform or IPA solution. The mixed solution was then drop cast onto the back side of the silicon nitride sample. FTIR was then used to collect reflection coefficient from the different samples [2].

Results and Conclusions:

Unfortunately, the FTIR machine was not equipped to measure the reflection coefficient required by the equations. Only Foster Miller, a private company working with Prof. Neikirk, had the FTIR machine that could measure the reflection coefficient. But even with the measurement from Foster Miller, the data only had the magnitude and not the phase. This was a problem because the equations required the reflection coefficient as a complex number. Thus we could only measure transmittance vs. wavenumber of the samples and compare them to the measurement from Foster Miller to check to see if the FTIR test is performed correctly and the trend of dielectric constants as a function of wavenumber. Figure 4 shows the results from the silicon nitride sample. The transmittance of all the samples should have been at the same height to confirm the trend. The fact that they were at different heights was caused by the different ration of silicon vs nitride. For the Ge nanowire sample, we were not able to drop cast an uniform layer of Ge nanowire. Thus the data was incoherent because FTIR does not work on uneven surfaces. Furthermore, doing construction, it was noted that Ge nanowires mixed with IPA are less likely to cause the silicon nitride sample acting as a sample holder to break [6].

Future Work:

First, a FTIR with the ability to measure reflection coefficient and phase is required to do further work. Second, a better sample holder needs to be developed to hold the nanowire sample without breaking easily. Third, better casting techniques need to be found so that an even layer of nanowires can be achieved. Lastly, other type of nanomaterials will be used to perform the same experiment to see if dielectric constants can be calculated and see which materials are good for the FTIR measurement.

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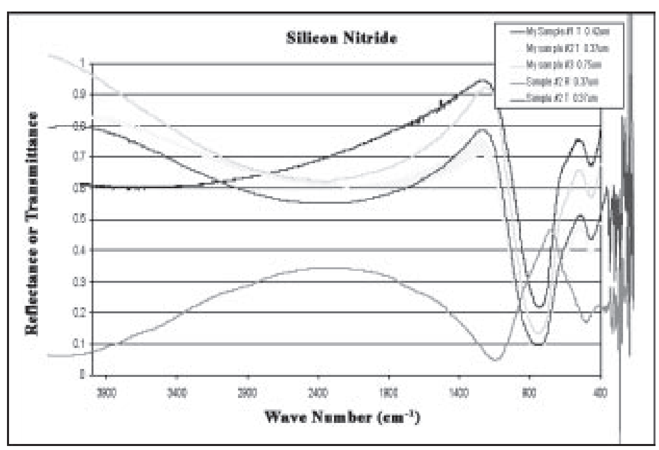

Figure 4