INTRODUCTION

The electrical properties of many materials are not well characterized at frequencies in
the near Terahertz regime. As the applications of Terahertz radiation are multiplying, the lack of
a good model for the behavior of both dielectrics and conductors is a problem. To address this, a
computational model is being developed based on coupling an Ensemble Monte Carlo simulation
with a Finite Difference Time Domain electromagnetic simulation to model conductivity in both
silicon and metals. In conjunction with this computational simulation, a method to conduct
conductivity measurements in the near terahertz regime in the lab has been developed. The high
quality factor ($Q$) resonant cavity will confirm the results of the computational simulation, as
well as working independently to measure any other items of interest.

BACKGROUND

This silicon study has two main purposes. First, it is a test of the resonant cavity's
capabilities, before the resonant cavity shifts to its intended purpose of measuring metals.
Second, it provides in-house data to compare with the theoretical model demonstrated by Willis,
Hagness, and Knezevic (Willis 2010). In the process of fulfilling our two main goals, we also
add one more data point to the scattershot silicon data that exists in the literature for near-
Ohba 1988, more papers here).
Open cavity resonators were proposed more than 20 years ago for making near-terahertz/far infrared measurements (Afsar 1984), but almost no silicon data measured with an open cavity resonator has been published. Most silicon data in the literature for near-terahertz was measured using Fourier transform infrared spectroscopy or interferometry. While only the real component of the conductivity can be determined from the resonance peak's quality factor, the high quality factor obtainable with an open cavity allows samples with similar conductivities to be distinguished.

For our open cavity resonator, we chose a semi-confocal design. A semi-confocal resonator consists of a flat mirror facing a spherical mirror (see figure 1). To determine a silicon sample's conductivity, a resonance peak is obtained and analyzed to find the resonator's quality factor \( Q \). The quality factor is defined as

\[
Q = \frac{\omega_0}{\kappa}
\]

Where \( \omega_0 \) is the center frequency of the resonance peak, and \( \kappa \) is the fractional energy lost per second in the cavity. A single pass from the spherical mirror to the flat mirror, with a silicon sample in the cavity (henceforth known as a loaded cavity), takes

\[
t = \frac{L - x}{c} + \frac{x}{v_{\text{sample}}}
\]

seconds, where \( x \) is the sample thickness and \( v_{\text{sample}} \) is the speed of light in the sample. The fractional energy lost per pass is

\[
1 - e^{-ax}
\]

making
the fractional energy lost per second, and

\[ Q_{\text{sample}} = \frac{2\pi f t_1}{1 - e^{-\alpha x}} \]

the quality factor due to resistive losses in the sample.

The total quality factor \( Q \) of a resonance peak is composed of the individual quality factors due to the different sources of loss. The cavity has coupling losses, diffraction losses, resistive losses in the sample, resistive losses in the spherical mirror, and atmospheric losses, and all these losses have an associated \( Q \). The relationship is

\[ \frac{1}{Q_{\text{loaded}}} = \frac{1}{Q_{\text{coup}}} + \frac{1}{Q_{\text{diff}}} + \frac{1}{Q_{\text{sample}}} + \frac{1}{Q_{\text{mirror}}} + \frac{1}{Q_{\text{atm}}}. \]

The only known value in the above expression is \( Q_{\text{loaded}} \), which can be computed directly from a measured resonance peak. We do not know \( Q_{\text{sample}} \), which is necessary for finding the silicon sample's conductivity. To work around this, two data points are needed: a resonance peak from a loaded cavity, and a resonance peak from an unloaded cavity. The unloaded cavity consists of a flat mirror facing a spherical mirror, without a silicon sample. Its resonance peak quality factor \( Q_{\text{unloaded}} \) consists of all of the above \( Q \)s, except for \( Q_{\text{sample}} \). Thus,

\[ \frac{1}{Q_{\text{sample}}} = \frac{1}{Q_{\text{loaded}}} - \frac{1}{Q_{\text{unloaded}}}. \]

Now that \( Q_{\text{sample}} \) is known, the conductivity of the sample can be solved for. Rearrange equation 5,

\[ 1 - \frac{2\pi f t_1}{Q_{\text{sample}}} = e^{-\alpha x}. \]

Taking the natural log of both sides and solving for \( \alpha \) gives
\begin{equation}
\alpha = \frac{-1}{x} \ln \left( 1 - \frac{2\pi f_i}{Q_{\text{sample}}} \right).
\end{equation}

Using the low-loss approximation for \( \alpha \),

\begin{equation}
\alpha = \frac{\sigma}{2 \eta_{\text{real}}}
\end{equation}

where \( \eta_{\text{real}} \) is the characteristic impedance of the sample, the sample's conductivity is given by

\begin{equation}
\sigma = \frac{-2}{\eta_{\text{real}} x} \ln \left( 1 - \frac{2\pi f_i}{Q_{\text{sample}}} \right).
\end{equation}

This sets the framework for the experiment, with system and procedure design based around acquiring loaded and unloaded cavity data discussed in the next two sections.
EXPERIMENTAL DESIGN AND CONSTRUCTION

The resonant cavity is one component of a larger experimental setup. Overall, the experiment is composed of a PC, a lock-in amplifier, a microwave synthesizer, a 10 Hz TTL signal source, an amplifier multiplier chain (AMC) near-terahertz signal source, a Golay cell detector, a focusing system, and the resonant cavity itself. The focusing system consists of two wire grids which act as beam splitters, and two focusing mirrors. The resonant cavity consists of a large copper spherical mirror, a flat mirror, and a 5µm thick PTFE film to couple the signal into and out of the cavity. See Fig. 1.

Figure 1: Current experiment diagram (system version 4). The dashed line indicates the beam path. In previous system versions, the Golay cell was replaced with a pyroelectric detector.
The PC runs a LabView program which drives the experiment. The program sets the microwave synthesizer’s output frequency, averages and records the signal amplitude from the lock-in amplifier, then steps to the next synthesizer frequency. The output of the microwave synthesizer is fed into the AMC, which multiplies its frequency by 36 (400 GHz AMC) or 48 (650 GHz AMC), modulates the high frequency signal in synch with the 10 Hz TTL clock signal, then outputs the multiplied modulated signal through a diagonal horn antenna. The output signal is polarized such that it passes through the first wire grid, bounces off the focusing mirror, and then is split in half by the second wire grid. Half the signal then continues to the second focusing mirror, where it is directed into the cavity and hits the PTFE coupling film. The majority of the signal passes through the PTFE coupling film and into a beam dump, while a small percentage of the signal couples into the cavity, and bounces between the copper spherical mirror and the flat mirror. When the cavity’s resonant frequency is reached, signal couples out of the cavity through the PTFE film, reversing the input path until it hits the first (horizontal) wire grid, and due to a rotation in polarization bounces off the wire grid and into the Golay cell detector. The output of the Golay cell feeds into the lock-in amplifier, which locks onto the 10 Hz modulation of the signal, amplifying the 10 Hz component while rejecting noise. The LabView program records the synthesizer frequency and the average signal amplitude as detected by the lock in amplifier over several seconds before moving to the next frequency step.

Design, construction, and alignment of the resonant cavity system was an iterative process. The first iteration of the cavity was designed to operate at 100 GHz and involved coupling the near-terahertz radiation through holes in the mirror instead of with a thin coupling film. Even when using a network analyzer to source and detect the signal, the nonlinear
transition from in-mirror waveguide to air within the cavity proved impossible to calibrate for, yielding an intriguing resonance peak shape that was unusable for our purposes. See fig. 2.

![Cavity Version One resonance peak](image)

**Figure 2:** Resonance peak from cavity version one

Version two of the resonant cavity was designed and built after the network analyzer experiments. It was the first version to resemble the cavity system in its final form, as switching from the network analyzer as source and detector to the AMC as source and a separate pyroelectric detector required the introduction of the 10 Hz TTL clock signal, lock-in amplifier, focusing system, and thin film coupling. This version was designed to operate at a single frequency, incorporating a motorized stage to adjust the flat mirror location, adjusting the cavity size to achieve resonance. However, the ±7.5 µm repeatability of motorized stage was insufficient for reliable measurements, the pyroelectric detector was not sensitive enough to the
return signal while being too sensitive to ambient electromagnetic noise, and the coupling film was exceedingly difficult to adjust. Repeatability also suffered due to air currents. To address this, a protective box was constructed which enclosed the source, detector, focusing system and cavity.

![Cavity Version Two resonance peaks](image)

**Figure 3:** Resonance peaks from cavity version two, taken on 1/19/2010

Version three of the system addressed the repeatability issue of version two by replacing stage movement with frequency scanning, allowing the flat mirror to be fixed in place. The pyroelectric detector was replaced with a much more sensitive Golay cell detector, increasing the sensitivity of the system to the 10 Hz signal while simultaneously decreasing the sensitivity to
noise. However, initial alignment of the coupling film was still an arduous process, and there was no way to compensate for misalignment of the signal source.

**Figure 4:** Resonance peaks from cavity version three

System version four introduced solutions for both of those problems, with a redesigned coupling film holder and both rotation and tilt adjustments for the AMC. Version four also included an upgraded enclosure to reduce atmospheric effects and increase the cavity $Q$ by decreasing humidity. The airtight enclosure was constructed of acrylic sheets, and uses a bulkhead panel to bring cables in and out of the enclosure. When purged with nitrogen and packed with 1 pound of molecular sieve desiccant, the new enclosure allows for the reduction of relative humidity below measurable levels, from a starting point of 70% relative humidity. See figure 5.
Figure 5: Resonance peaks from system version four, under normal atmospheric conditions (70% relative humidity) and dry conditions (1% relative humidity)
Alignment procedures for various system components were developed in parallel with the resonant cavity system. Starting with version two, the optical system was assembled on a 1” grid optical workstation. Components were visually aligned with the rows of screw holes, then bolted down. The coupling film was placed at approximately 45°. To align it further, the flat mirror was replaced with the pyroelectric detector and the coupling film rotation was adjusted until maximum power was detected by the pyroelectric detector. (See figure 6) The flat mirror and pyroelectric detector were then returned to their positions in figure 1, and a peak scan was initiated. If no resonance peaks were found, the location and rotation of the beam splitter were adjusted, and another peak scan was taken. This process was repeated until resonance was achieved. As this process was based on trial and error, it was not repeatable, and yielded only low quality factors on the order of $5 \times 10^4$.

**Figure 6:** Alignment position for resonant cavity in system versions two and three
Laser alignment was introduced with version four of the resonant cavity system. The focusing system became a critical part of laser alignment, as it is built on a base plate, independent of the optical table, with holes for alignment pegs. The extra holes allow the focusing system alignment to be internally consistent, independent of the optical table. Using the focusing system base plate and taping a gold plated glass slide and a target to one of the focusing system’s brass blocks, the laser can be brought into alignment with the focusing system. First the laser’s angle is adjusted so the reflection from the gold slide reflects directly back onto the laser, then the laser’s position is adjusted until the laser spot hits the center of the target. When both of these criteria are fulfilled, the laser is in alignment with the focusing system. Next, mirror-finished pieces of gold-plated silicon wafer are attached to flat regions on the AMC and the copper spherical mirror. Both the AMC and the mirror can then be aligned by adjusting their rotations, then positions, until the reflection from the gold wafer pieces is bounced back directly onto the laser. See figure 7 for a diagram of the procedure. Finally, the coupling film is aligned by placing a full gold-plated wafer into the film holder frame, and adjusting the frame’s rotation and position until the laser spot bounces off the gold-plated wafer and directly into the center of the large copper spherical mirror. This alignment procedure removes the guesswork from the setup of previous versions of the system, and allows high quality resonances to be achieved with high repeatability.
Figure 7: Laser alignment procedure for the current version of the cavity system

EXPERIMENT PROCEDURE

Four silicon samples were selected to measure for this report. They were all N-type wafers, as the computer model can only simulate N-type silicon. Samples were selected with one each in the 40-60 ohm-cm, 91-109 ohm-cm, 300-500 ohm-cm, and 800-1200 ohm-cm DC resistivity ranges. Two samples in each of the 40-60 ohm-cm, 300-500 ohm-cm, and 800-1200 ohm-cm ranges had their DC resistivity measured directly using a four point probe station, the results of which can be seen in table 1. However, no samples in the 91-109 ohm-cm range had their exact DC resistivity measured, as they arrived late due to a broken shipment. The DC
resistivity values for the wafers were used to compute exact doping densities for each wafer, and those numbers were used to seed the computational model written by Keely Willis, the results of which can also be seen in table 1.

Table 1: Measured DC and computed near-THz resistivities

<table>
<thead>
<tr>
<th>Wafer</th>
<th>Given resistivity (ohm-cm)</th>
<th>Given thickness (μm)</th>
<th>Measured Sheet Resistance (ohm/Sq)</th>
<th>DC Resistivity (ohm-cm)</th>
<th>Computational Model Resistivity (Simulation run at 650 GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40-60</td>
<td>210±10</td>
<td>2231.125</td>
<td>46.85±2.23</td>
<td>51.782 - j*53.768</td>
</tr>
<tr>
<td>B</td>
<td>40-60</td>
<td>210±10</td>
<td>2234.625</td>
<td>46.93±2.23</td>
<td>51.838 - j*54.248</td>
</tr>
<tr>
<td>E</td>
<td>300-500</td>
<td>270±10</td>
<td>13182.38</td>
<td>355.92±19.77</td>
<td>402.363 - j*408.219</td>
</tr>
<tr>
<td>F</td>
<td>300-500</td>
<td>270±10</td>
<td>13321.38</td>
<td>359.68±19.98</td>
<td>406.938 - j*416.493</td>
</tr>
<tr>
<td>G</td>
<td>800-1200</td>
<td>180±10</td>
<td>55561.25</td>
<td>1000.10±55.56</td>
<td>1107.950 - j*1145.755</td>
</tr>
<tr>
<td>H</td>
<td>800-1200</td>
<td>180±10</td>
<td>56256.25</td>
<td>1012.61±56.26</td>
<td>1131.477 - j*1177.741</td>
</tr>
<tr>
<td>I</td>
<td>91-109</td>
<td>410±10</td>
<td>-</td>
<td>-</td>
<td>[113.695±10.281]-j*[118.9795±11.3045]</td>
</tr>
<tr>
<td>J</td>
<td>91-109</td>
<td>410±10</td>
<td>-</td>
<td>-</td>
<td>[127.195±3.219]-j*[118.9795±11.3045]</td>
</tr>
</tbody>
</table>

The near-Terahertz measurements for this report were made using version four of the cavity system. The system was first laser aligned as described in the previous section. Following the alignment, the stainless steel sample holder had four squares of gold plated wafer placed on it. One of those was left bare as the basic unloaded cavity sample, and the other three were covered with samples B, F, and G. See figure 8 for sample layout. The plain gold sample and sample G were measured first, using the acrylic enclosure, under dry (<2% relative humidity) conditions. Sample G was swapped with sample I, and the system was re-maximized for the lower resistivity (higher conductivity) samples. Again the bare gold sample was run first, then samples B, F, and I. Between each sample change, the humidity level inside the enclosure was allowed to drop below 2% humidity before initiating the measurement run.
A single measurement run consists of a two GHz frequency sweep between 648 GHz and 650 GHz in increments of 0.48 MHz, and takes approximately 12 hours. Each data point consists of a frequency change by one increment, a pause of 1500 ms to wait for the signal amplitude to settle, a command to the lock-in amplifier to auto adjust to the current phase of the signal, another pause of 4500 ms for the signal amplitude to settle, and finally 5 seconds of data acquisition. The signal amplitude is averaged over those 5 seconds, and that is the value which is recorded as the data point for that frequency. If the standard deviation of the data acquired is larger than $8 \times 10^{-5}$ volts, then the data point is retaken instead of being recorded.
DATA AND ANALYSIS

Each frequency sweep results in four clusters of resonance peaks spaced approximately 0.5 GHz apart. Each cluster has a clear primary peak, and there are clear primary clusters with higher intensity than secondary clusters. This correlates well with the estimated fundamental mode spacing of 1 GHz, which seems to indicate that the primary clusters correspond to the fundamental mode, and the secondary clusters correspond to a secondary (ring) mode, which can be seen in cross sections taken of the input signal (see figure 9). Better alignment of the sample holder, beam splitter, and spherical mirror seem to reduce both the number of peaks in each cluster and the amplitude of the entire secondary cluster, while increasing the amplitude of the primary peak of the primary cluster.

Figure 9: Beam profile near the focal point of the focusing system output mirror. The secondary ring mode can be seen clearly.
The resonance peaks are Lorentzian in form, allowing the data to be curve fit. MATLAB’s `lsqcurvefit` function was used to find the fit, in the form of a scaled, shifted Lorentzian. The fit equation used is

$$y = \frac{a}{\pi b \left[ 1 + \left( \frac{x - c}{b} \right)^2 \right]} + d$$

where $a$ is the scaling factor, $b$ is the peak’s half-width-half-maximum, $c$ is the center frequency of the peak, and $d$ is the vertical peak shift due to noise. Given a set of $x$ and $y$ values, MATLAB returned values for $a$, $b$, $c$, and $d$. The resonance peak’s quality factor can be determined from its center frequency and full-width-half-maximum: $Q = \frac{c}{2b}$, with values for $b$ and $c$ coming from the MATLAB curve fit.

![Unloaded cavity sweep](image)
Figure 10: A full unloaded cavity sweep

Having found an experimental value for the quality factor, only the cavity size still needs to be determined from experimental data before applying equation (11) from the background section to solve for a sample’s conductivity. The cavity size can be determined with great accuracy from the unloaded cavity (plain gold sample) run, see figure 10. Using a run that is long enough to capture two fundamental mode resonances, a system of linear equations can be set up using the fact that resonances occur when an integral number of wavelengths fit inside the cavity. Solving the system of linear equations yields \( n = \frac{\lambda_2}{\lambda_1 - \lambda_2} \) where \( n \) is the number of half wavelengths, \( \lambda_1 \) is the wavelength at peak 1, and \( \lambda_2 \) is the wavelength at peak 2. The cavity size \( L \) can then be found with \( L = n \frac{\lambda_1}{2} = (n + 1) \frac{\lambda_2}{2} \).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Run date</th>
<th>Quality Factor ( Q )</th>
<th>Unloaded quality factor</th>
<th>Cavity size (cm)</th>
<th>Experimental conductivity (S/m)</th>
<th>Simulated conductivity (S/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>8/31/2010</td>
<td>7.35e4</td>
<td>3.86e5</td>
<td>14.0788</td>
<td>1.85 ± .09</td>
<td>1.93</td>
</tr>
<tr>
<td>F</td>
<td>8/31/2010</td>
<td>2.39e5</td>
<td>3.86e5</td>
<td>14.0788</td>
<td>.2065 ± .0115</td>
<td>.2457</td>
</tr>
<tr>
<td>G</td>
<td>8/16/2010</td>
<td>3.37e5</td>
<td>3.99e5</td>
<td>14.0475</td>
<td>.0877 ± .0048</td>
<td>.0903</td>
</tr>
<tr>
<td>I</td>
<td>8/31/2010</td>
<td>8.10e4</td>
<td>3.86e5</td>
<td>14.0788</td>
<td>.8406 ± .0203</td>
<td>.8066</td>
</tr>
</tbody>
</table>

Table 2 summarizes the findings of the data runs. Conductivities and resistivities for all four wafer samples were determined following the method outlined above. As can be seen, the experimental data and the computational simulation data are in reasonably close agreement, and the discrepancies can be explained by sources of error inherent in the experiment.

The uncertainty listed in table 2 for the experimentally determined conductivity is due to uncertainty in sample thickness. Other, less quantifiable errors exist throughout the data as well. Depending on the time since the desiccant was changed and the time allowed for the enclosure to
dry out, humidity can vary between measurements as the enclosure must be opened to change samples. 1-2% differences in relative humidity can change the quality factor by a small amount, as can be seen in the unloaded quality factor for sample G as opposed to samples B, F, and I. The gold plated wafers below the silicon samples may also vary in thickness by up to 10 μm, changing the cavity size, and contributing to error in the final conductivity values. Finally, vibration from the HSX experiment greatly affects the quality factor of the resonance peaks. The vibrations from its fly wheels in the room below the experiment are significant enough that the vibration isolation station cannot damp them completely, and data cannot be acquired while the HSX is running. Standard deviations greatly increase when the HSX is running, and whether the HSX is on or off can even be determined by looking at a plot of the standard deviations of each experimental data point.

Figures 11 and 12 show how the experimental data compares with the simulation data and the Drude model. As can be seen, the Drude model deviates from the actual conductivity of silicon at 650 GHz, with the disagreement increasing as the conductivity increases. The computer simulation takes into account quantum mechanical events (which are not accounted for by the purely classical Drude model), and agrees with the experimental data for silicon.
Figure 11: The Drude model, plotted at different doping densities, compared with our experimental silicon data at 650 GHz.
Figure 12: Experimental data compared with simulation data and the Drude model.

FUTURE WORK AND IMPROVEMENTS

This experiment provides a solid foundation for future experiments. The next step in silicon measurements is to acquire data at different frequencies. Initially, a 400 GHz Virginia Diodes source owned by the group can be swapped with the 650 GHz source used for these measurements, yielding a second point of comparison to the Drude model and the computer simulation. The group also owns a 100 GHz Gunn diode source which could be tried as well, though there may be problems with wave front mismatch with mirror curvature. Higher frequency measurements may also be possible, though increased attenuation due to conductive losses may make samples B and I too thick to successfully measure at higher frequencies.
Another possible area of pursuit is adding a fifth data point at a higher conductivity. Originally, a fifth sample with approximately a 10 ohm-cm resistivity was going to be measured at 650 GHz. However, the higher conductivity required an extremely small sample thickness, and measurements were never pursued due to difficulty handling samples on the order of 10 μm thick. Finally, a simple improvement to this paper would be to measure the exact DC resistivity of the 91-109 ohm-cm samples (samples I and J), and run those numbers through the computer simulation.

Another potential area of investigation is P-type silicon. From discussions with Willis, modifying the computer simulation to run P-type samples as well as N-type samples would not be difficult, though it would be time-intensive. As N- and P-type samples with the same DC resistivity have very different doping densities, their manner deviation from the Drude model may be different, and other conduction phenomena may be occurring. An early sample of 100 ohm-cm P-type silicon was run, and it exhibited lower conductivity at 650 GHz than the corresponding 100 ohm-cm N-type sample that was later run. While the P-type sample exhibited large peaks, the 100 ohm-cm sample’s peaks were nearly extinguished by conduction losses. Finally, attempting to dope silicon to the point that it acts as a mirror in the cavity instead of a dielectric could provide an interesting experiment.

Detailed measurements of absorption by water vapor or other gasses can be made with the resonant cavity as well. The air tight acrylic enclosure allows the cavity to operate in an environment isolated from the room. Theses silicon runs have been made under nitrogen with the goal of minimizing humidity in the cavity as much as possible, however with the recent addition of a digital humidity and temperature data logger, measurements can be made with the object of comparing changes in the cavity’s quality factor to the level of humidity in the
enclosure. A detailed model of absorption due to humidity can be produced from those measurements, which can be taken at any frequency for which we have a source. As the enclosure is air tight, other gasses such as oxygen, hydrogen, argon, or helium could be introduced into the enclosure to investigate their absorption of electromagnetic radiation over the same spectrum of frequencies.

For the cavity in general, sources of error can be minimized; presently a motorized sample changer is being designed to obviate the need to open the enclosure to change samples. A new version of the cavity is also in the design phase, which will allow for sample alignment to be adjusted, greatly reducing error due to misalignment of the cavity. The newly designed spherical mirror will also reduce losses due to curvature mismatch, increasing the cavity’s $Q$ to the point that thinner films can be used to couple the beam into the cavity, decreasing coupling loss, and increasing the cavity’s $Q$ even farther. The goal is to approach the theoretical maximum quality factor for the resonator at our frequencies, enabling high sensitivity measurements of metal samples, eventually being able to determine the sample’s surface roughness from its conductivity. In the mean time, any dielectric samples of interest can be measured at 650 GHz using the current version of the resonant cavity, as they do not require the same sensitivity that metal measurements do.

**CONCLUSION**

The high-$Q$ resonator is a useful tool for measuring material properties in the near terahertz regime. Conductivity of dielectric samples can be determined from raw resonance peak data with reasonable accuracy. As misalignment is reduced, increasing the cavity’s quality factor, and sources of error are reduced, increasing the cavity’s repeatability, this high-$Q$
resonator can be used to measure the properties of metals in addition to dielectrics. It is very versatile, as nearly any flat sample can be inserted in the cavity and measured.

These silicon measurements agree with the consensus in the literature, which is that the Drude model breaks down in the near terahertz regime. We observed deviation from the Drude model which did not exist in a computational model written to include quantum effects on conduction in silicon. We have confirmed the accuracy of the computational model, and proven the resonator as a reasonable measurement tool.
CONCLUSION

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(retrieved 8/26/2010)