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Observations of Quantized Conductance over Nanowires

Nick Davenport
ndavenport@pugetsound.edu

Observations of Quantized Conductance over Nanowires

By Nick Davenport, Advised by Dr. Greg Elliott, Summer 2013

Purpose:

The purpose of this research was to examine the effect of quantized conductance across nanowires through etching.

Background:

The classical model of conductance occurs when the length and width of the wire, *L* and *W* respectively, are much greater than the mean free path of the electron, *l*. This is shown in Figure 1 below.

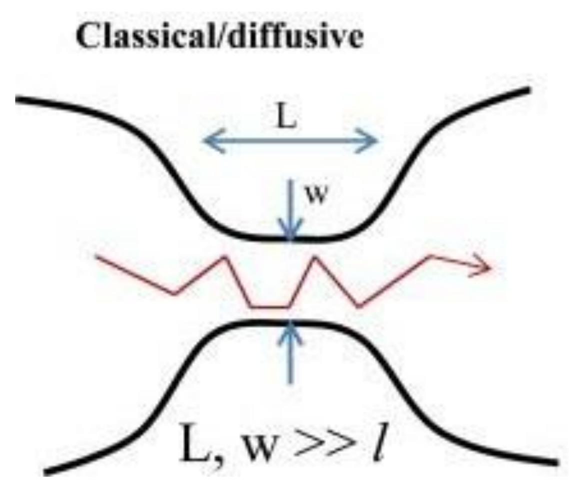

Figure 1: The classical limit of electrons traveling through a wire. The red line is the path of the electron.

The classical conductance can be described as $G = \sigma A / L$, where σ is the intrinsic conductivity of the wire, *A* is the cross-sectional area, and *L* is the length of the wire. This model of conductance fails once the diameter of the wire becomes comparable to the mean scattering length of the electron and becomes a nanowire, shown in Figure 2.

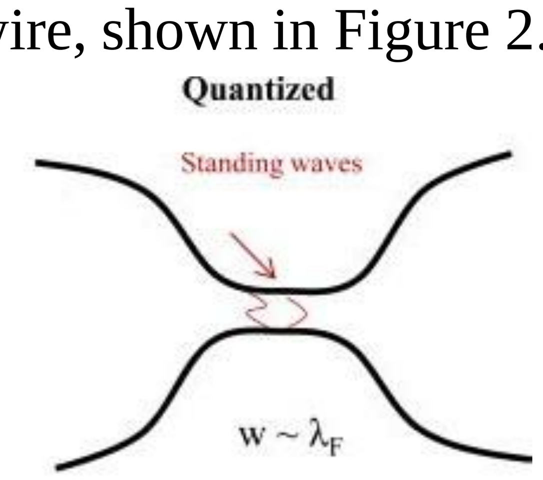

Figure 2: The limit of electrons traveling through a nanowire

Once this happens, the conductance becomes steps of $G = 2e^2/h$ and is independent of both material and geometry of the wire (1).

Procedure:

This experiment consisted of two parts. The first part of the experiment to set up and observe the conductance using a previously reported Mechanically Controlled Break Junction (MCBJ) technique (1) . The second part of the experiment was to etch a wire with nitric acid and take conductivitydata right before the wire completely dissolved.

We performed the MCBJ technique by attaching a .004" thick gold wire down to a .008" thick insulated metal strip shown in Figure 3.

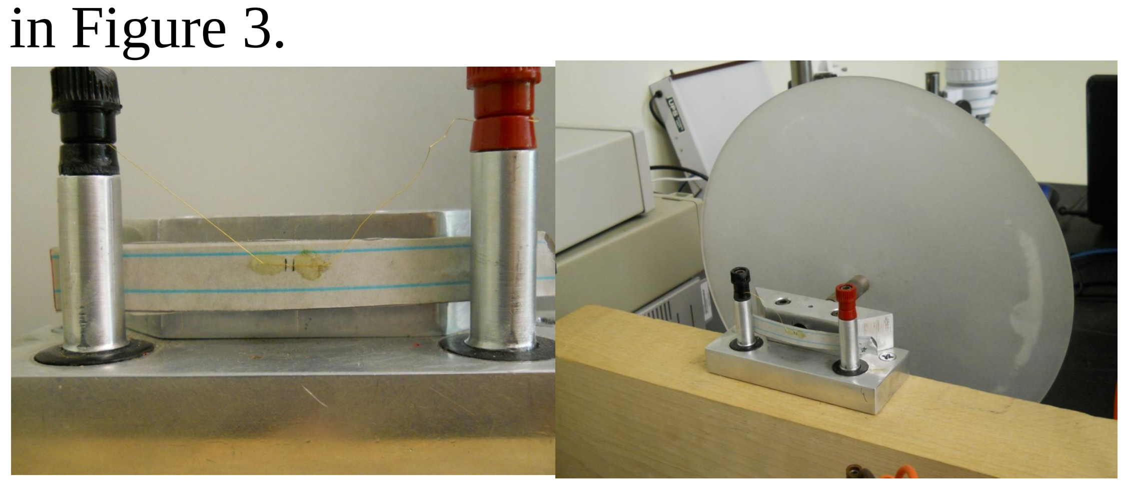

Figure 3: the gold wire attached to the metal strip and then put in the bending apparatus.

The insulated metal strip was then placed between a micrometer and plastic disk, which were used to bend the metal strip. We then attached a 100kΩ resistor in series with the wire as a current limiter so we could measure the current and voltage, as shown in Figure 4.

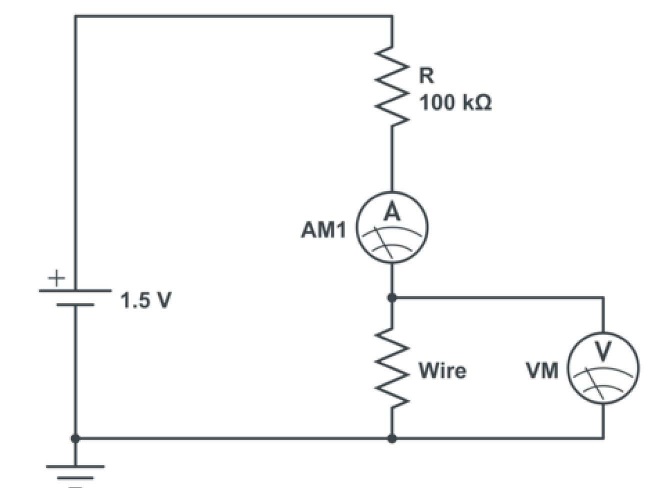

Figure 4: Circuit diagram used for both the MCBJ and etching techniques

The wire was notched so when the disk was bent, the wire would splinter and create a nanocontact.

For the second part of the experiment, we planned to create a nanowire through etching. We soldered a .002" silver wire to a standard chip socket, and then attached the socket to a base (shown in Figure 5) where we set up the same circuit diagram as we did for the MCBJ technique. Then we would etch the wire using varying concentrations of nitric acid. We monitored the voltage and current output, using the same LabVIEW program as we did for the first part of the experiment.

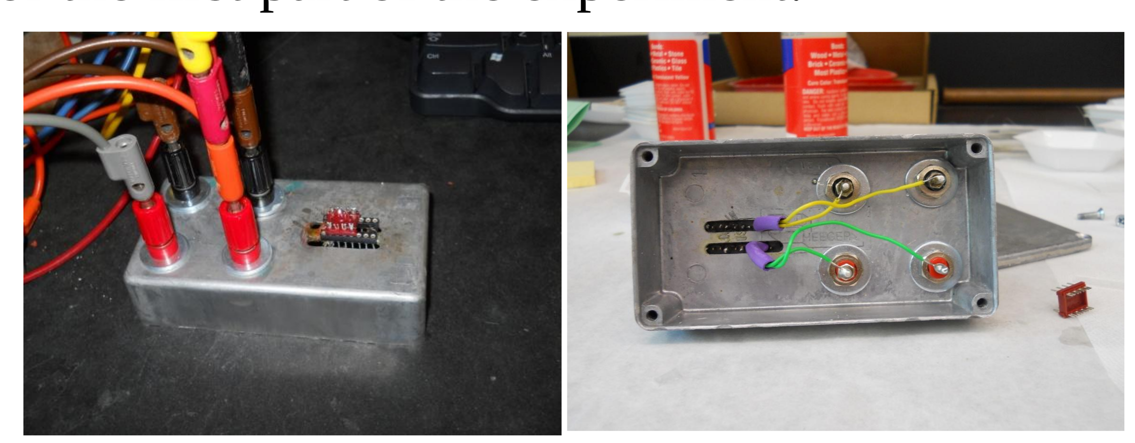

Figure 5: The setup for the etching part of the experiment

Results:

Our results for the MCBJ technique are shown in Figure 6.

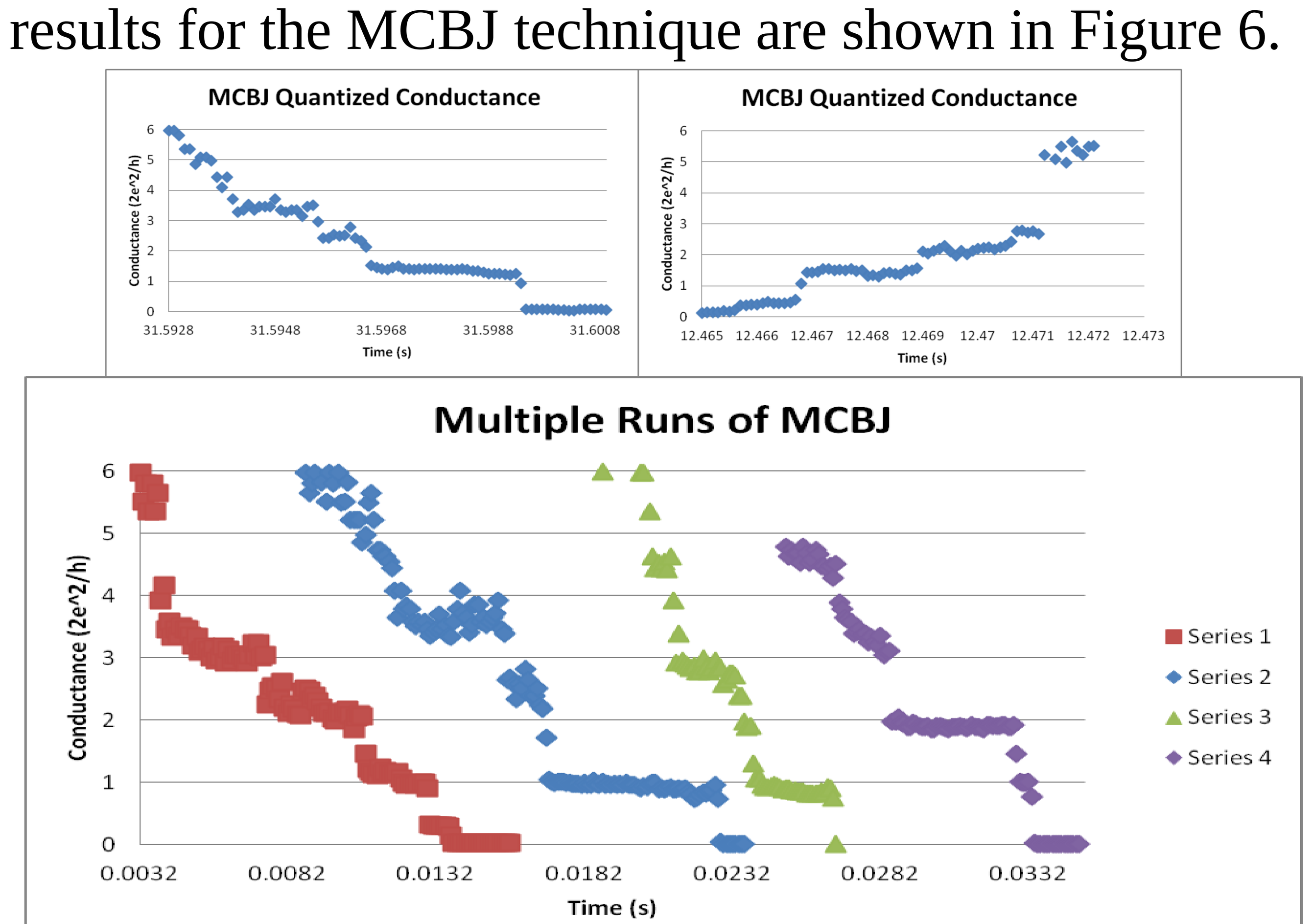

Figure 6: The results from the MCBJ technique

The MCBJ technique does display clear steps of conductance in steps of $2e^2/h$, which supports the theory of quantized conductance. However, these steps aren't exact integer steps of quantized conductance. This is most likely because of some extra vibration when the wire initially separates or comes back together. Our results from the etching part of this experiment are shown in Figure 7.

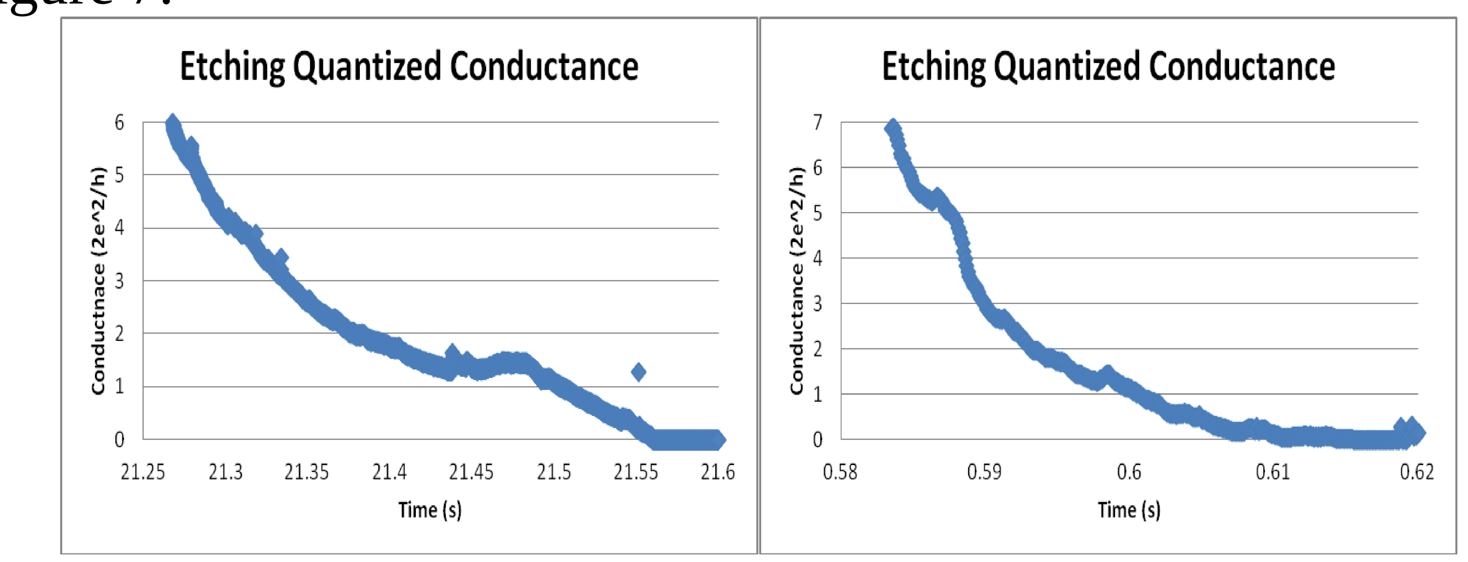

Figure 7: The results from the etching technique

From these results, it is clear that the etching process does not show any quantized steps. While there might appear to be some ledges in the data, they were not repeatable from any of our runs. The two graphs in Figure 7 are the result of the end of the etching process of the silver wire with 1:1 nitric acid. We ran this part of the experiment with both silver and copper wires as well as different concentrations of acid, and none of the different combinations resulted in the quantized steps we saw from the MCBJ technique.

We assumed that the etching process would yield a very similar result to the MCBJ technique because in a brief moment before the wire completely dissolved, it would be a nanowire. However, since this is not the case, we must be overlooking something. It is possible, since most metals are "oxidized readily by nitric acid" that the nitric acid diffused the silver (and copper) wires with oxygen as it etched the wire away (2). This would result in the nanowire at the end of the etching process being something other than pure silver. This would mean that the lattice structure of the metal would have changed, inhibiting the flow of electrons more than normal. The MCBJ does not result in a changed material, and so shows the quantized steps.

Conclusion:

Our research shows that creating a nanowire through the process of etching does not result in the quantized steps, unlike the MCBJ technique. To continue researching quantized conductance and nanowires, it would be necessary to discover a controlled, efficient way of necking down the wire without changing the intrinsic conductive property of the material.

Acknowledgements:

I would like to thank Dr. Greg Elliott for all of his help on this project as well as the rest of the department of physics faculty for their support.

References:

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2. N. R. Dhar, "Action of Nitric Acid on Metals," *The Journal of Physical Chemistry* 29, no. 2 (January 1, 1924: 142-159