Capacitance

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I. INTRODUCTION

The tunnel diode is a heavily doped P-N junction semiconductor device. The semiconducting device is doped in such a way as to narrow the depletion zone enough for electron to tunnel *through* the barrier. Recall from quantum mechanics that the tunneling electron's wave function exponentially decreases inside a potential barrier. When unbiased, the highest occupied state in the conduction band on the N side is at the same energy level as that in the valence band on the P side.

By applying a forward bias potential to the diode, we lower the potential difference across the junction. Therefore, conduction band electrons will tunnel to *available* unoccupied states in the P side. When tunneled to the P side valence band, I believe thermal effects promote this electron to the conduction band. We then have a current flowing through the diode.

Boundary conditions set by the lattice result in forbidden energies in a semiconductor. This region lies between the valance and conduction band of a semiconductor device. Any electron with such a forbidden energy cannot exist in the lattice.
We conducted two experiments using the same circuit under different conditions to see macroscopic effects of a tunnel diode circuit and the effect of phonons in tunneling. The phonon experiment was ran with the circuit in liquid nitrogen and used a complex measuring circuit. The other experiment was done by recording voltage and current readings.

II. MATERIALS AND METHODS

A. Phonon Energy Experiment

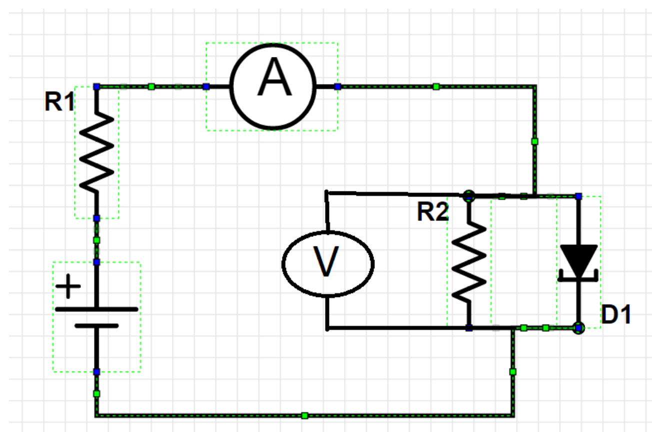
This experiment required the use of a lock-in amplifier and a Keithley 2000 multimeter for measuring quantities because typical voltmeters and ammeters are not sensitive enough to detect the narrow range of values we were working with. The maximum sensitivity of this multimeter is $0.1\mu V$.

The tunnel diode circuit was submerged in liquid nitrogen to reduce the thermal effects of being at room temperature. Data recording was automated using a premade LabView program. The computer was interfaced to the measuring circuit via a General Purpose Interface Bus. This set up was pre-configured for us.

B. General Properties of the Tunnel Diode

We connected the circuit from figure 7 (shown below). R1 is rated at 4600 Ω and was connected to protect the tunnel diode by limiting the circuits current. R2 was rated at 68Ω and connected in parallel to the tunnel diode. The diode was connected forward bias.

We took seventy two data points, from 0.00V and



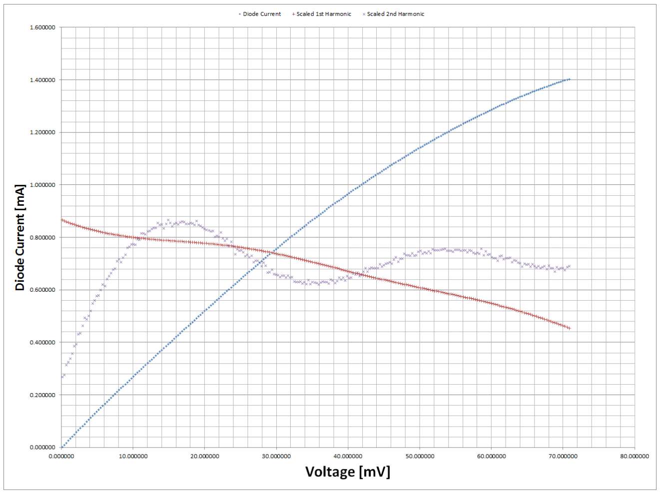
700.0mV in 10mV increments. At some point in our data collection, we *jumped* the power supply terminals giving two power supplies in series because we reached the maximum output of one power supply.

III. DATA

A. Phonon Energy Experiment

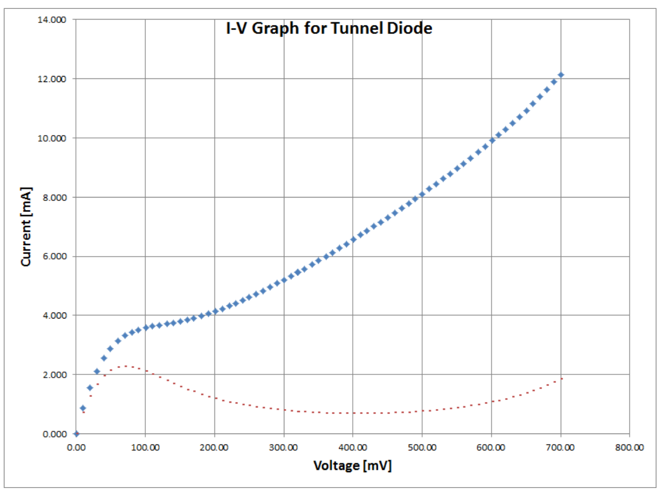
250 data points were recorded for this experiment. The diode current was calculated and plotted vs diode voltage. The 1st harmonic and 2nd harmonic were scaled by $\frac{1}{100}\times$ and $10\times$, respectively.

I scaled the harmonics by their values to match the significant digits with the calculated current. The first noticeable maxima occurs between 16mV and 18mV. The second noticeable maxima occurs between 52mV and 58mV. The known phonon energies of 18.4meV (very strong inflection) and 57.6meV (very strong inflection) fall into these intervals. Weak inflection can be seen around 46mV and 62mV.



B. General Properties of the Tunnel Diode

There were 73 data points taken for this experiment, shown on the last pages. A scaled graph is shown below and a full sized graph on the last pages.

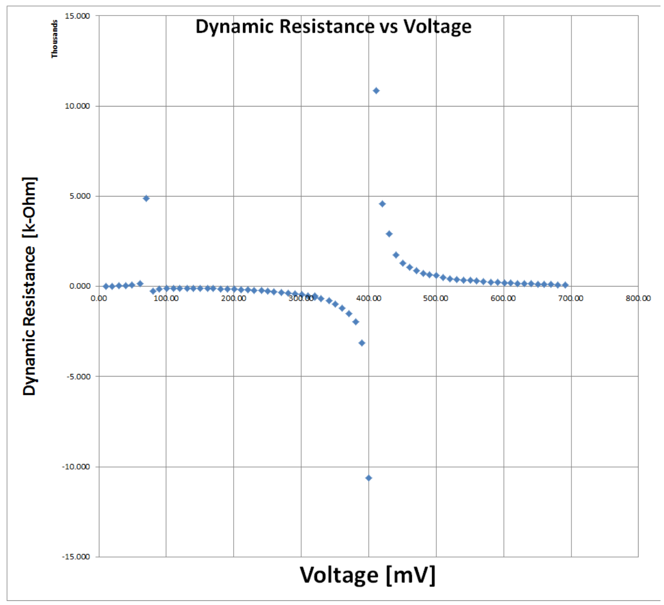


The blue dots represent data we took. The green color dots is the calculated diode current given by:

$$I_{diode} = I_{total} - \frac{V}{R}$$

I also calculated the dynamic resistance for the *inner* data points. Meaning the dynamic resistance for voltages *not* 0.00V and 700.0mV were not calculated. I used the relation:

$$R_d = \frac{\Delta V}{\Delta I}$$



The dynamic resistance for +10mv, +200mV, and +600mV were:

- 15.948 Ω
- -156.317 Ω
- 211.287 Ω

,respectively.

Negative dynamic resistance was *calculated* for voltages between 80.36mV and 390.2mV. This interval corresponds to when the I-V plot is decreasing and concave up.

IV. DISCUSSION

Why $\frac{dI}{dV}$ and $\frac{d^2I}{dV^2}$ were used to analyze dynamic resistance wasn't clear at first. I initially thought that a negative dynamic resistance meant that the current was boosted by tunneling phenomena somehow. That the diode behaved as a "anti-resistor". But conductance is $Resistance^{-1}$. But negative conductance didn't make sense. Then I noticed the tangent line at the data point is the dynamic resistance:

$$
\begin{aligned}
R_d &= lim\frac{\Delta V}{\Delta I} \\
&= \frac{dV}{dI}
\end{aligned}
$$

Therefore,

$$Conductance = \frac{dI}{dV}$$

An increase in conductivity corresponds to known phonon energies. The second derivative was used to help make the plot features more visible. I think lattice vibrations help promote valence band electrons to the conduction band.