ece340_lab2

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September 11, 2014

1 Objective

In this lab, we will investigate the effect of thermally-generated free charge carriers on the reverse-bias current through a diode.

2 Theory

2.1 Silicon *pn* diode

The silicon *pn* junction diode has an ideal current-voltage relationship of:

(1)

$$I_D = I_s \left(e^{V_D \cdot q/(k_B T)} - 1 \right)$$

The term $k_B T/q$ is known as the *thermal voltage* V_T and is approximately $26\mathrm{mV}$ at room temperature. I_S is called the *saturation current*. For reverse-bias (negative) voltages larger than a few hundred mV, the diode current can be considered $\approx -I_S$, to a first-approximation.

Besides the $1/T$ term explicitly showing up in the equation's exponent, the saturation current is a strong function of temperature as well. It can be calculated from geometrical and material parameters as:

(2)

$$I_S = Aqn_i^2 \left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right)$$

where A is the device's cross-section area, L_n and L_p are electron and hole "diffusion lengths," respectively. These parameters can be considered constants here.

The Einstein Relation can be proven to relate the ratio of the diffusion constant to mobility in a material as:

(3)

$$\frac{D_{n,p}}{\mu_{n,p}} = \frac{k_B T}{q} = V_T$$

Solving for the diffusion constant, $D_{n,p} = \mu_{n,p} \frac{k_B T}{q}$, re-write the saturation current and factor out temperature:

(4)

$$I_S = Aqn_i^2 T \left(\frac{\mu_n k_B}{qN_A L_n} + \frac{\mu_p k_B}{qN_D L_p} \right)$$

Ignore the fact that mobility changes with temperature due to several effects, reaching a maximum at an intermediate temperature.

The intrinsic carrier density also varies with temperature:

(5)

$$n_i^2 = BT^3 e^{-E_G/(k_b T)}$$

so,

(6)

$$I_S = AqBT^4 e^{-E_G/(k_b T)} \left(\frac{\mu_n k_B}{qN_A L_n} + \frac{\mu_p k_B}{qN_D L_p} \right)$$

We are interested in the temperature dependence of I_S for a specific device, so collapse all the temperature-independent terms into a single constant:

(7)

$$I_S(T) = C \cdot T^4 e^{-E_G/(k_b T)}$$

2.2 Thermistors

Thermistors are devices which (are intended to) change their resistance with temperature. Their obvious application is to measure temperature. Other interesting applications include measurement of air speed and density in aircraft as the airstream cools the device. Their resistance is dependent on temperature as approximately:

$$R(T) = R_R \exp \left[B \left(\frac{1}{T} - \frac{1}{T_R} \right) \right]$$

where B is a constant for the specific device, and R_R and T_R are the resistance at the rated temperature. See the file “NTC-general-technical-information.pdf” on Blackboard for more information.

A more accurate determination of resistance or temperature is obtained from using actual values and temperatures provided in tables in the device’s datasheet and interpolating between the values. Page 2 of the “NTC-standardizedrt.pdf” file on Blackboard describes the calculations and gives an example. We are using the $1\text{k}\Omega$ rated thermistor, whose data table is number “1009” in the datasheet, file “NTC_Leaded_disks_M891.pdf” on Blackboard.

3 Procedure

1. Use both the $+6\mathrm{V}$ and $0 - 20\mathrm{V}$ outputs of the power supply and two channels on the oscilloscope. Connect equipment to the "special device" as shown in Figure 1. Turn both voltage outputs to zero before turning on the power supply.

- Note that the connection to the diode is not necessarily intuitive. The currents we will be measuring will be a maximum of a few hundred nA, well below the range of our available ammeters. With this connection scheme, the saturation current I_S is forced to go through the $10\mathrm{M}\Omega$ input resistance of the oscilloscope/probe. It is operating as a *current shunt*. The voltage measured across this resistance is proportional to the current through it via "Ohms Law". Figure 2 gives an illustration.

2. Raise the $+6\mathrm{V}$ output to $+6\mathrm{V}$.
3. Touch the "Default Setup" key on the scope to start from a standard configuration.
4. Touch the "Acquire" key and change the Acquire Mode to "High Res". The manual says the scope displays the average of the actual samples taken by the front-end for each displayed pixel instead of only the first sample in the interval.
5. Change the trigger system to trigger on the edge of the "Line" source. This is the $60\mathrm{Hz}$ power input frequency. The signals we are interested in are DC only, but the probe will pick up a large amount of powerline interference as you can see on the screen. This keeps the display stable so we can average-out the display and make more precise measurements.
6. Setup the channel measuring the voltage across the thermistor to show both the signal and the channel's $0\mathrm{V}$ level.
7. Using the measurement functions, display both the full-screen averages of both channel voltages.
8. Observe these measurements and record them when they stop slowly changing up or down.
9. Increase the $0 - 20\mathrm{V}$ output in $1\mathrm{V}$ increments.

- At each increment, wait for the temperature to reach equilibrium, indicated when both measurements stop changing.
- These changes will be slow and small at first.
- Stop increasing the heater voltage when you reach $15\mathrm{V}$. This amount of power (heat) is already 4 times greater than the maximum rated power of the heating resistors. (The device needs to survive all day…)

3.1 Analysis

Use Excel to perform these calculations.

1. Using circuit analysis and the thermistor datasheet, determine the thermistor resistance and measured temperature for each of your V_{thm} measurements.
2. Calculate the heat power supplied to the device at each measurement.
3. Using circuit analysis, calculate the diode saturation current I_S as measured by the oscilloscope probe V_{Is}.

From these calculated numbers, generate the following plots:

1. I_S (measured) vs. temperature
   - On this figure, also plot the theoretical value of I_S versus temperature. Choose a constant C which best matches your measured data.
   - Compare the measured and theoretical plots and comment on them.
2. Temperature vs. heat power
   - Calculate the slope as $^\circ\mathrm{C}/W$

3.2 Report

Refer to the document "DRAFT Lab Report Guidelines 2014.pdf" on Blackboard for the format for your report.