CALIFORNIA POLYTECHNIC STATE UNIVERSITY

Solid State Physics Laboratory

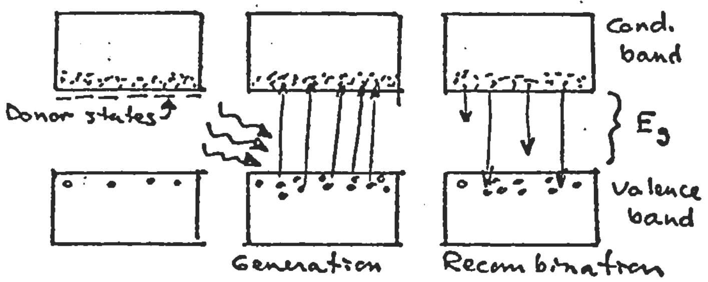
Experiment 17: LIFETIME OF MINORITY CARRIERS

SCOPE:

Minority charge carriers will be produced in both n-type and p-type germanium by optical stimulation using a pulsed light source. The average "lifetime" of the resulting electron=hole pairs will be determined by observing the time-dependence of the electrical conductivity.

INTRODUCTION:

In a semiconductor in thermal equilibrium, there is a continual process of electron-hole pair generation and recombination with a resulting thermal equilibrium concentration of carriers. The recombination rate can be determined by generating an excess concentration of electron-hole pais (a non-equilibrium condition) and observing the return to the equilibrium concentration by monitoring the cnange in electrical conductivity.



The non-equilibrium excess concentration of charge carriers is generated optically using a pulsed strobe light. Electrons are optically stimulated across the band gap with a corresponding increase in electrical conductivity due to both electrons and holes.

The electron-hole recombination occurs in order to restore the thermal equilibrium carrier concentration when the light is off. The rate at which recombination occurs is proportional to the concentration of excess carriers—a situation that produces the usual exponential decay equation. That is, $(dn/dt) = -(1/\tau)n(t)$ yields the time dependent excess carrier concentration $n(t) = n_e \exp(-t/\tau)$, where n_e is the excess concentration when $t=0$ (the time the strobe light shuts off) and τ is the mean lifetime of excess electron-hole pairs—or recombination time.

In extrinsic semiconductors, the recombination time is the lifetime of the minority carriers. By diffusion, the minority carriers drift an average distance of $L = (D\tau)^{1/2}$, where $D = (kT/e)\mu$ is the diffusion constant, before recombining. In an n-type semiconductor, the minority carriers are holes, so the hole mobility is used in determining the diffusion constant.

THE EXPERIMENT:

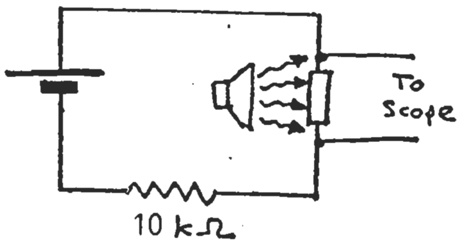
The apparatus consists of a small box containing three extrinsic semiconducting crystals each of which can be selected by a switch to be in series with a resistor, very large compared to the specimen's resistance, and a battery. The voltage across the specimen is then monitored on an oscilloscope.

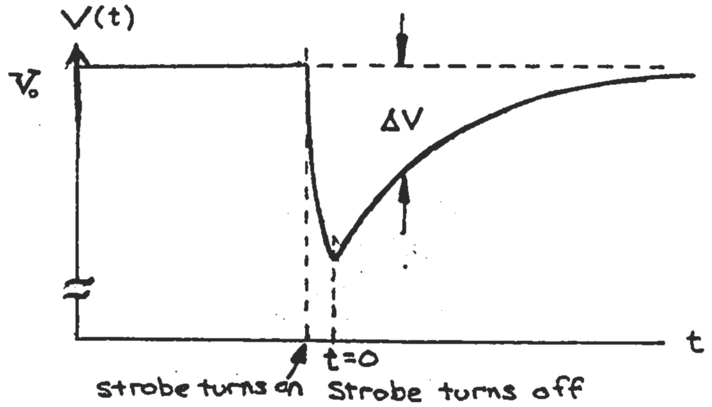
Because the specimen resistance is small compared to the large series resistor, the current through the semiconductor is essentially constant. The voltage drop due to the change in electrical conductivity is therefore proportional to the sample resistance, or inversely proportional to the conductivity of the material.

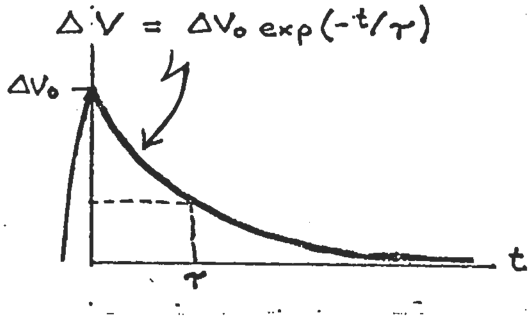
The conductivity of the semiconductor is given by $\sigma = \sigma_o + n_e e (\mu_e + \mu_h) \exp(-t/\tau)$ where σ_o is the equilibrium conductivity and μ_e and μ_h are the electron and hole mobilities, respectively. The sample voltage can be written approximately as

$$V = V_o - \Delta V_o \exp(-t/\tau)$$

where ΔV_o is the total change in sample voltage due to optically stimulated electron-hole pairs.







If one considers only the time-dependent <u>change</u> in sample voltage when the strobe light is turned off, then

$$\Delta V = \Delta V_o \exp(-t/\tau)$$

The recombination time τ can be determined directly from the (calibrated) scope display or from the slope of a graph of $\ln(\Delta V)$ vs t.

REPORT:

Determine the recombination time for each of the three specimens identified in the folder at the lab station.

Determine the diffusion length for each of the three specimens. (Use room temperature in Kelvin for T, and for electron and hole mobilities use the representative values $\mu_e = 0.33\ m^2/v\cdot s$ and $\mu_h = 0.15\ m^2/v\cdot s$.)

REFERENCES:

Azaroff and Brophy, Electronic Processes in Materials

Hutchison and Baird, The Physics of Engineering Solids, pp. 378-382.