Solid State Electronic Devices

The Haynes-Shockley Experiment

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1 Introduction

Minority carriers in semiconductors can, as well as majority carriers, contribute to current through diffusion. The goal of this experiment is to measure drift, diffusion and lifetime of excess carriers in a Si semiconductor.

2 Procedure

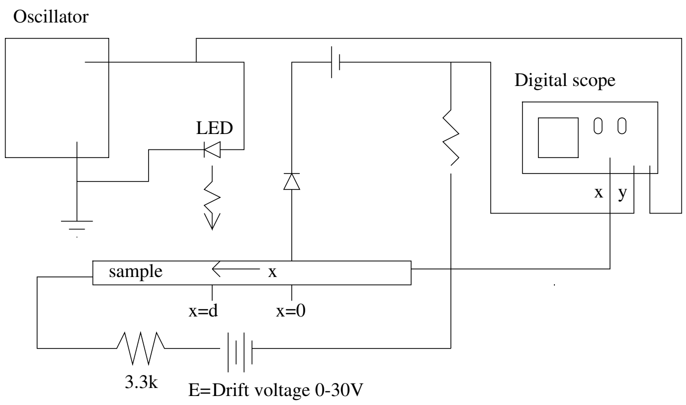

Figure 1: Experiment setup

Instruments used in the experiment:

- HP 54603B 60 MHz Oscilloscope
- Home made box, special for this experiment

- Weir 4000 30V 2A
- Fluke 8020A Multimeter
- Star LC-10 multifont printer

The sample is n-type Si. The LED emits short light pulses on the semiconductor.

3 Measurements and Conclusion

3.1 Drift velocity

By changing the path length x of the pulse and mesureing the drift time t_d the drift velocity v_d can be calculated from

$$x = v_d t_d = \mu_p \varepsilon t_d \quad (1)$$

where ε is the electric field in the sample and μ_p is the hole mobility.

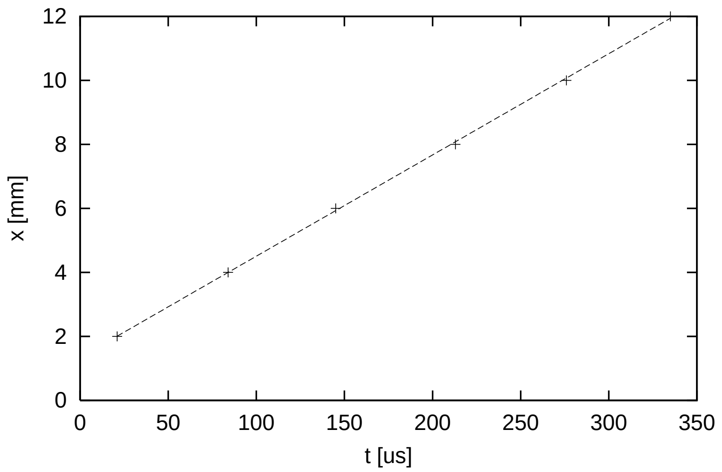

Figure 2: E = 15 V

The plots on figures 2, 3, 4 and 5 shows x as function of t_d for 4 different values drift voltage. The following table shows calculated values of v_d and ε:

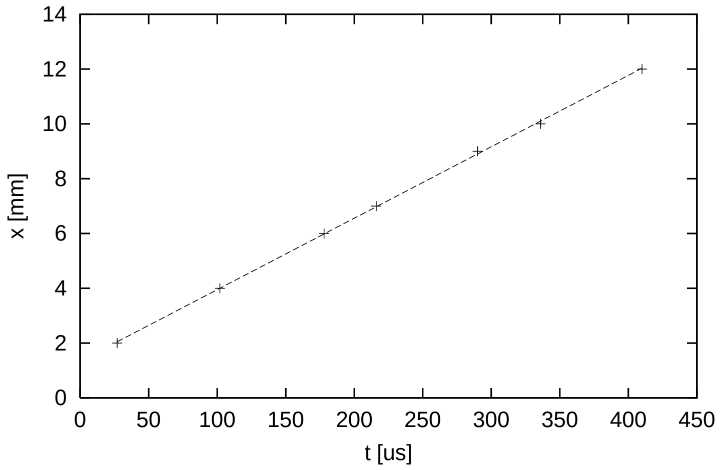

Figure 3: E = 12 V

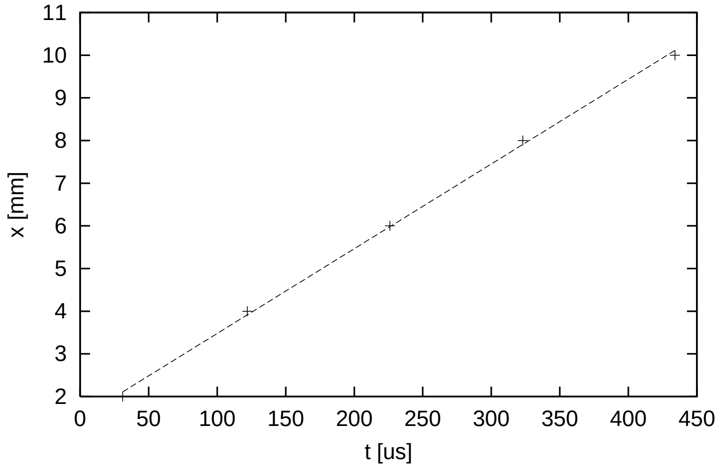

Figure 4: E = 9 V

E[V]	v_d	ε [V/m]
15	31.6 $\pm$0.2	652
12	26.0 $\pm$0.2	521
9	19.9 $\pm$0.4	391
7	16.6 $\pm$0.4	304

Knowing the sample length $l = 23mm$ the electric field is

$$\varepsilon = \frac{E}{l} \tag{2}$$

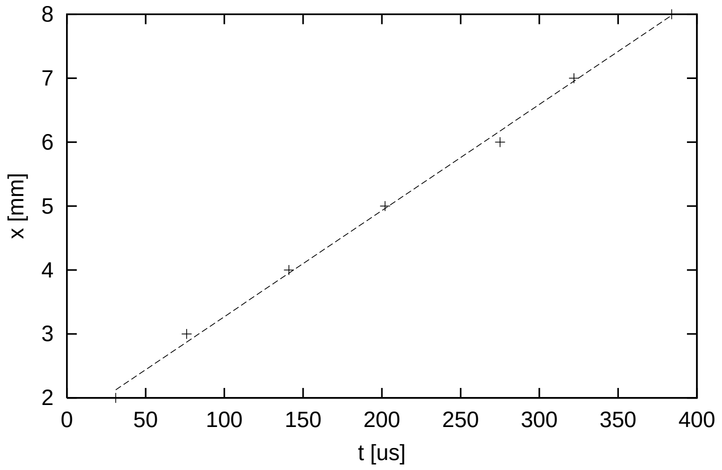

Figure 5: E = 7 V

In figure 6 the drift velocity v_d is plotted as function of the electric field ε.

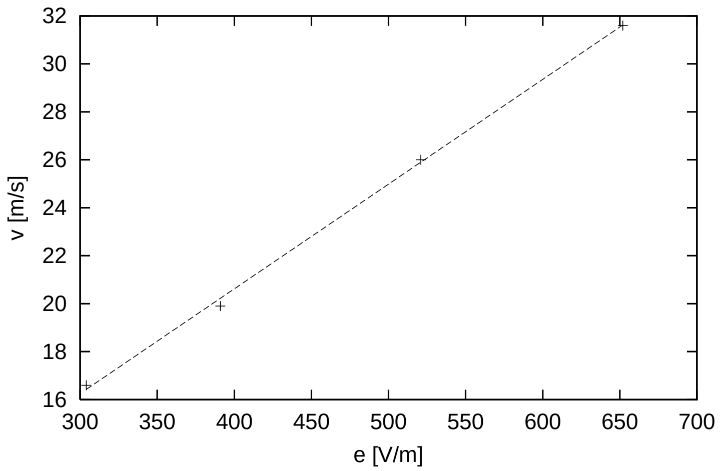

Figure 6: v_d as function of ε

Obviously the data points fit to a straight line which means that the drift velocity is proportional to the electric field. Therefore the slope gives the hole mobility μ_p according to equation 1. From the slope $\mu_p = 0.043 \pm 0.001 \frac{m^2}{sV}$.

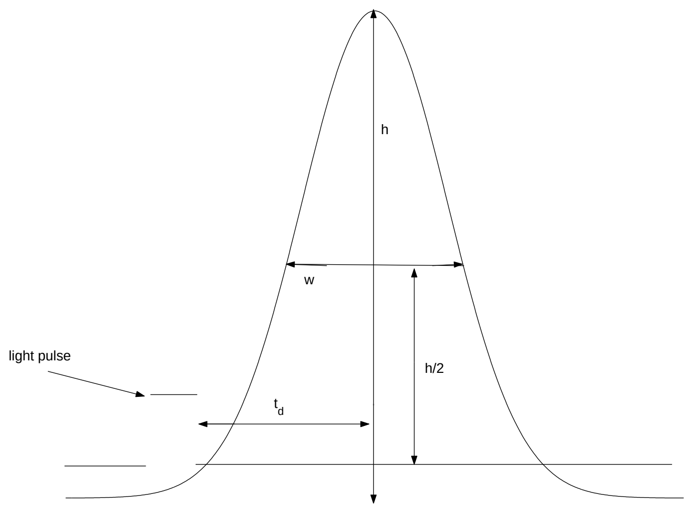

Figure 7: The image on the scope's monitor. w is the pulse width, h the pulse height and t_d the drift time

3.2 Diffusion constant

As the light pulse moves across the sample it becomes wider caused by diffusion. The diffusion constant D_h is

$$D_h = \frac{(w)^2}{16 ln 2 t_d} = \frac{(w)^2}{11.1 t_d} \tag{3}$$

We measure w and t_d as in figure 7 and plot $\frac{w^2}{11.1}$ a function of t_d on figures 8, 9 and 10. The slope gives the diffusion constant (eq 3).

E[V]	$D_h[\mu s]$
15	0.79 ± 0.03
12	1.00 ± 0.04
9	2.7 ± 0.5

As one can see, the diffusion constant grows with increasing drift voltage.

3.3 Excess holes liftime from pulse area

The pulse area A can be approximated proportional to width multiplied with height. The area is related to drift time τ_d according to

$$A = p_0 e^{-\frac{t_d}{\tau}} \tag{4}$$

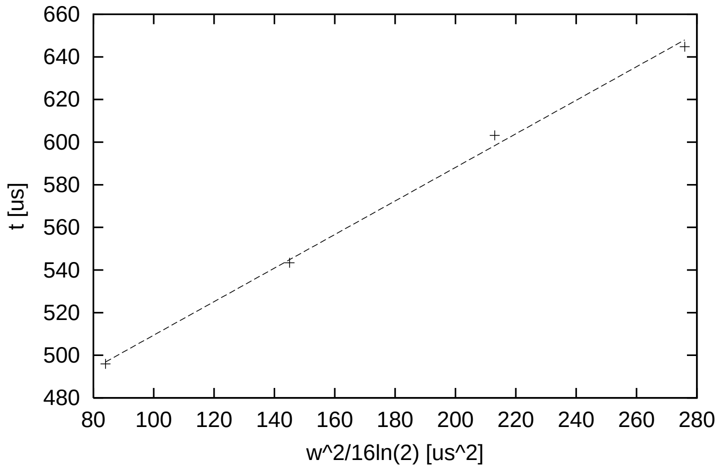

Figure 8: E = 15 V

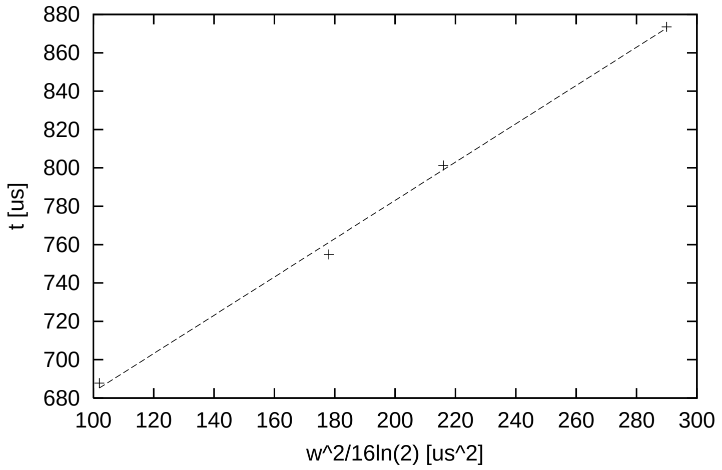

Figure 9: E = 12 V

that is:

$$ln(A) = ln(p_0) - \frac{t_d}{\tau}$$

Then plotting $ln(wh)$ as a function of t_d gives the slope $-\frac{1}{\tau}$.The plots are shown in figures 11, 12 and 13. We put calculated values of τ in the follwoing table:

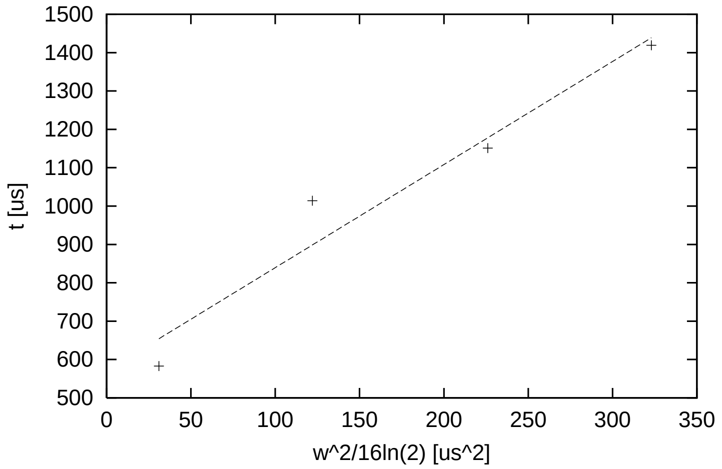

Figure 10: E = 9 V

E[V]	τ[s]
15	$1.0 * 10^{-4} \pm 0.1 * 10^{-4}$
12	$1.0 * 10^{-4} \pm 0.1 * 10^{-4}$
9	$1.1 * 10^{-4} \pm 0.1 * 10^{-4}$

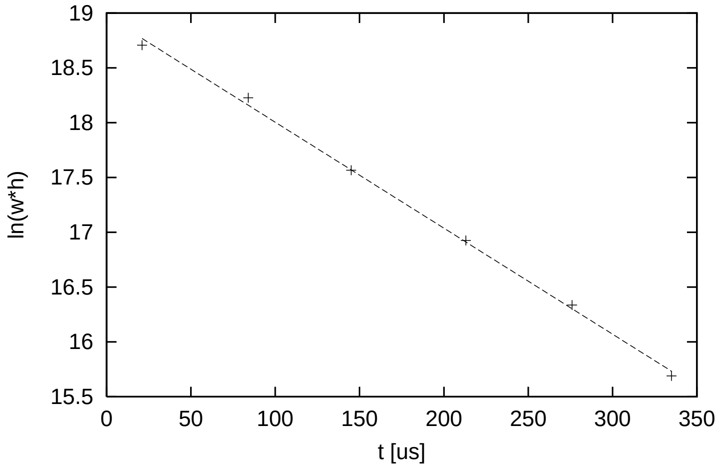

Figure 11: E = 15 V

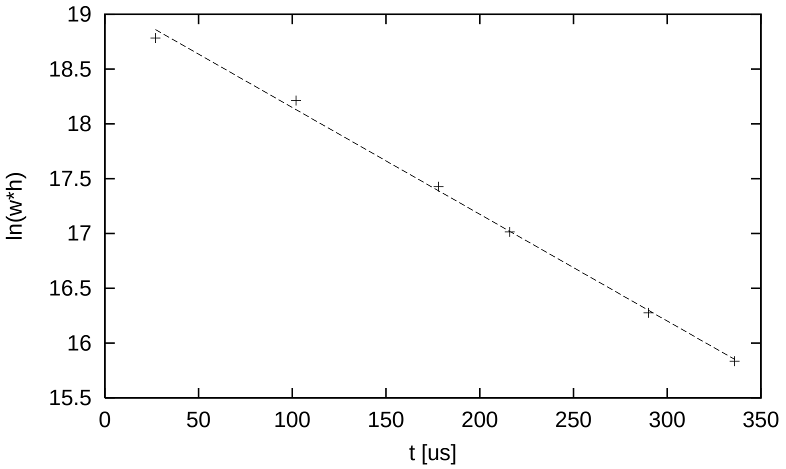

Figure 12: E = 12 V

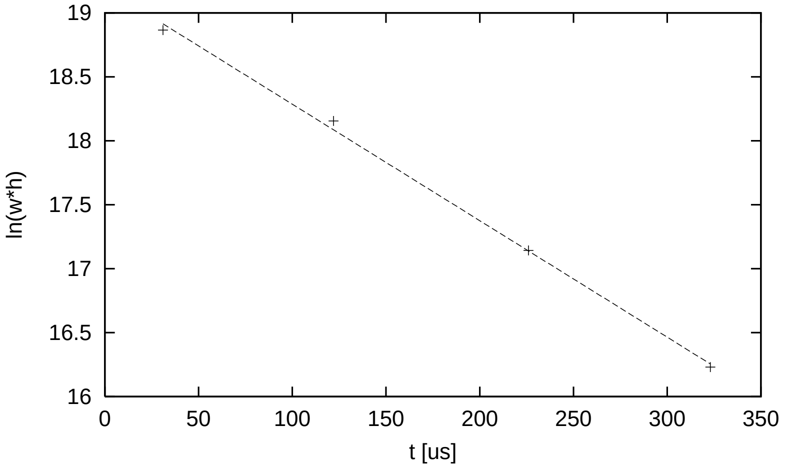

Figure 13: E = 9V

3.4 Liftime from change in pulse voltage

Conduction of the sample is

$$\sigma = [n\mu_n + p\mu_p]e = [(n_0 + \Delta n)\mu_n + \Delta p\mu_p]e = \sigma_0 + \Delta\sigma \tag{5}$$

therefore the resistance

$$R = \frac{1}{\sigma} = \frac{1}{\sigma_0 + \Delta\sigma} \tag{6}$$

For a small change in cunduction ($\Delta\sigma \gg \sigma_0$) it is possible to measure the lifetime τ directly by connecting in series an equal size resistance. The curve on the occilloscope is similar to the one in figure 14. That is

$$V \propto R = e^{\frac{-t}{\tau_d}} \tag{7}$$

Then plotting $ln(E)$ as function of t we have the lifetime constant:

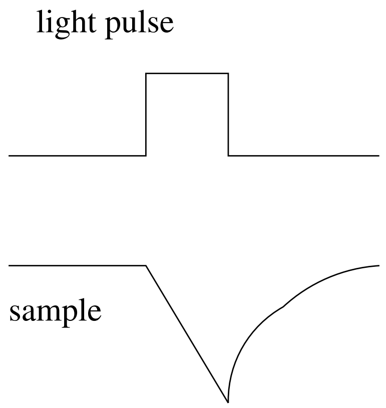

Figure 14: The curve when liftime is measured directly.

$$\tau = 1.4 * 10^{-4} \pm 0.1 * 10^{-4}$$

These two methods are not easily compared because only one measurement was made for the second method against four for the first. The lifetime doesn't match exacly. Perhaps it it's caused by systematic error in the first approach because we are making an approximation when measuring the area of the pulse. Therefore our conclusion is that the second method is more precise.