Haynes-Shockley experiment

Practical work P3, solid state physics

# Introduction

The Haynes-Shockley experiment gives us information about the mobility, diffusion and lifetimes of minority charge carriers in semiconductors. In this case we look at a p-type silica semiconductor, meaning the minority charge carriers are the electrons.

Measuring these properties of the semiconductor we first apply an electric field over the semi-conductor resulting in an electron drift in the opposite direction of the electric field. To gain information an injection pulse is applied meaning the pulse will travel thru the semiconductor to a collector at a certain distance away from the injection port.

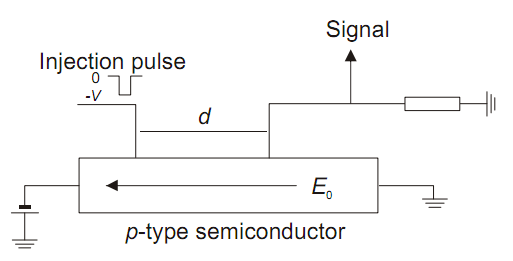


Figure 1 Schematic drawing of the Haynes-Shockley experiment with a p-type

# Practical work

## Assignment 1

### Introduction

The Ohmic contacts on the chip do not behave ideally. Therefore it is not possible to calculate the electric field within the microstructure through simple division of the voltage between the Ohmic contacts by the distance between them.

In this assignment we measured the internal potential to make a gauge-curve for the electric field. We assumed the potential in the chip between the emitter and the collectors to behave linearly, i.e. the electric field is constant. The only quantity we needed to measure is the difference in internal potential between emitter and the last collector.

Meaning an injection pulse with a frequency of 10kHz is applied

### Experimental method

To determine the behavior of the Ohmic contacts first a potential is set over the semiconductor and kept constant during measurement. After this the injection pulse voltage is altered and the resultant differential probe voltage is measured. This is done using an oscilloscope which averages the measurements to reduce noise and determines the peaks in terms of voltage.

## Assignment 2

The setup used for assignment 2 is schematically indicated in Figure 1. The electric field was set at -10V, the injection peak was set sufficiently high at a frequency of about 3MHz.

The injection pulse voltage was then varied and the difference in time between injection pulse and arrival at the collector was measured using an oscilloscope.

# Results & Discussion

## Assignment 1: Electric field

Figure 2 Internal potential, 7.5V

Figure 3 Internal potential, 10V

Figure 4 Internal potential, 12.5V

Figure 2, Figure 3 and Figure 4 depict the linear part of the internal potential measured at a steady electric field but varying the input voltage. During measurements it became clear that the setting of voltage and adjusting the offset are of great influence on the precision of the measurement. Only slight changes result in great differences in measurements enlarging the possibilities of errors in measurements significantly.

Since we want the difference in internal potential (ΔV) between the emitter-emitter and Collector-Collector measurements we need to know the difference in the x-direction. Ideally the linear part of the measurement will yield exactly the same slope. However in practice this is not the case (see Figure 2, Figure 3 and Figure 4), to correct for this we averaged the slope between the two measurements and corrected the second term. Yielding the data depicted in Table 1 where C-C the collector-collector and E-E the emitter-emitter measurements are.

From these results the electric field could be determined; this was done by dividing the internal potential by the distance between the two contacts, i.e. 900µm.

Table 1 Internal potential

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Potential (V) | Measurement | Formula (corrected) | ΔV (V) | E (V/m) |
| 7.5 | C-C |  | 1,74 | 1937 |
| E-E |  |
| 10 | C-C |  | 0,95 | 1052 |
| E-E |  |
| 12.5 | C-C |  | 1,30 | 1443 |
| E-E |  |

## Assignment 2: Charge carrier mobility

During this measurement the pulse voltage was varied at 300MHz, resulting in two peaks on the oscilloscope. The first peak was roughly the same shape as the input peak, which indicates that the origin of this peak also lies there. Meaning that when the input pulse is generated it changes the potential over the semi-conductor, thus changing the electric field, which directly shows on the oscilloscope. The second peak is a more curved one, also this is the peak we are interested in because it depicts the traveling of charge carriers from emitter to collector. The time it takes for the input signal to reach the collector is used in following calculations. This was done using the provided formula from the manual

Where μ is the mobility of the minority charge carriers, and d, E0 and t0 defined as distance between emitter and collector, electric field and the time needed for the pulse to reach the collector. During measurement the potential was kept steady at 10V, which translates to an electric field of 1052 V/m as determined in §3.1

Figure 5 Mobility vs. travel time vs. pulse voltage - 300μm

Figure 6 Mobility vs. travel time vs. pulse voltage - 600μm

Figure 7 Mobility vs. travel time vs. pulse voltage - 900μm

As can be seen in Figure 5, Figure 6 and Figure 7 decreases the mobility of the charge carriers when the pulse voltage increases. It can be discussed that this is due to the distortion of the electric field as described earlier. This distortion causes the electric field to decrease causing the charge carriers to take longer to reach the collector.

So for calculating the minority charge carrier mobility we take the linear part at lower voltages and use the earlier mentioned formula.

For 300μ we get

600μm

900μm

# Assignment 3: Charge carrier lifetime

The charge carrier mobility measured during assignment 2 was 0.951 to 1.50 m2/V·s which translates to 9510-15000 cm2/V·s whilst literature mentions values around 450 cm2/V·s. This difference can be due to the measurement errors when determining the electric field, which when compared does not show the behavior expected. Also effects from doping and impurities are of great influence on charge carrier behavior.

To calculate the charge carrier lifetime we can use the following equation

Using the measured value for μ, i.e. 12100 cm2/V·s, and the effective mass of the holes which is 3,52·10-31 combined with the charge of a single electron as 1.60·10-19, resulting in a charge carrier lifetime of 27ns. This value is determined first of all by the material itself, it is a material property. However greatly influenced by impurities, meaning it can be used as a measure to determine the purity of the material or the degree of doping.

# Conclusion

The Haynes Shockley experiment was performed with a p-type semiconductor. Using a provided experimental setup the electric field resultant from a set potential was measured and found to be very sensitive to errors during measurement. The voltage used throughout the following experiments was 10V which generates an electric field of 1052 V/m. However compared to the other values for

These data were then used to determine charge carrier mobility which yielded values ranging from 0.951 to 1.50 m2/V·s. Using these values we were able to calculate the charge carrier life time, i.e. 27ns.