INVESTIGATION OF IMPACT IONIZATION OF PHOTODIODE USING THE LUCKY DRIFT THEORY

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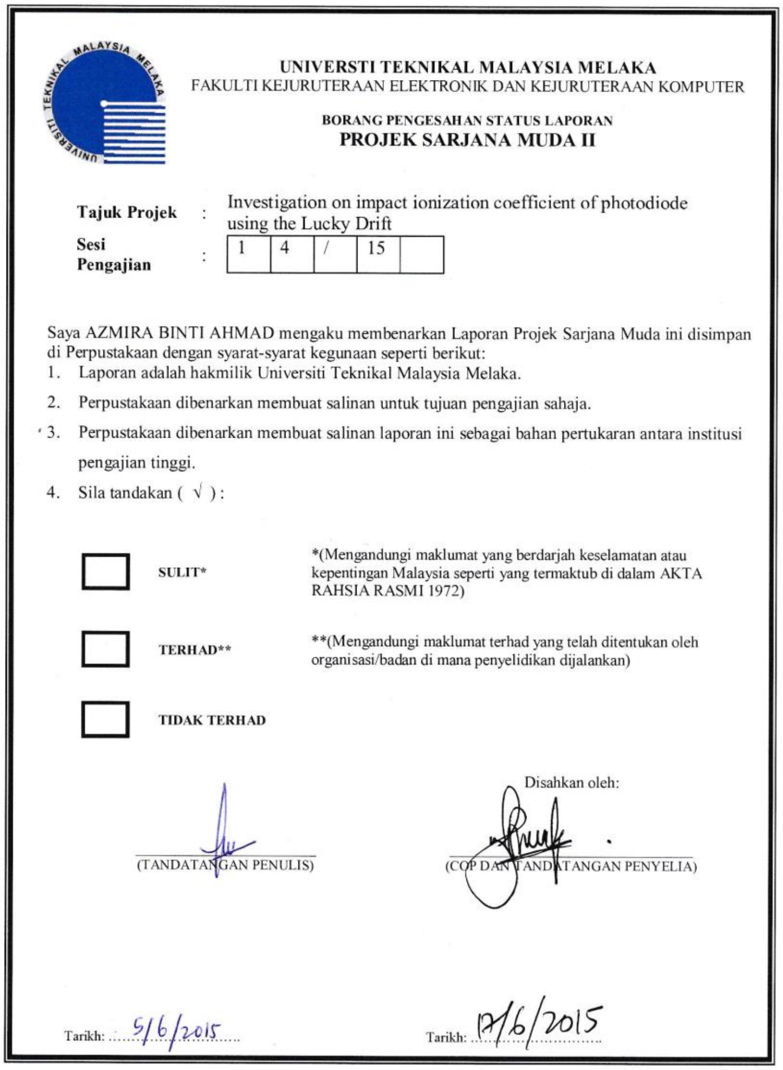

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I dedicate my dissertation work to my family and my supervisors. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears. I also dedicate this dissertation to my many friends and who have supported me throughout the process. I will always appreciate all they have done, especially my Supervisors En Abdul Rahman bin Rahim for helping me develop my technology skills,for the many hours of proofreading, and guide me until finish the thesis. I also dedicate this work and give special thanks to all, my parents, my friend, my lecturer and my supervisors.

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ABSTRACT

The temperature dependence of electron and hole impact ionization in Gallium Arsenide (GAas) and Silicon has been determined from photo multiplication measurements at temperature between 20k to 300k.it is found that impact ionization is suppressed by increasing temperature because of the increase in phonon scattering. Gallium Arsenide (GAas) and Silicon (Si) are the materials were using to investigation. The C programming act as a tool to calculate and manipulate the temperature dependence of impact ionization coefficient for electrons and holes based on Lucky Drift theory. Based on the results was found and proved the calculated ionisation coefficient with soft threshold energy present a much better than hard threshold energy. From the project also provide to get a best data, the various value of temperature was using. Then also used to find the temperature dependence of electron multiplication and breakdown voltage.

ABSTRAK

Suhu pergantungan untuk electron dan lubang pengionan impak dalam Gallium Arsenide(GAas) dan Silicon (Si) di tentukan daripada ukuran foto pendaraban pada suhu di antara 20k ke 300k. ini kerana dipercayai bahawa pengionan impak telah menurun oleh kenaikan suhu oleh kerana kenaikan didalam penyerakan fonon. Gallium Arsenide (GAas) dan Silicon (Si) adalah bahan yang digunakan dalam penyiastan. Kaedah C program bertindak sebagai alat untuk mengira dan memanupulasikan suhu pergantungan oleh pekali pengionan impak electron dan luabang berdasarkan daripada Lucky Drift teori. Berdasarkan keputusan yang diterima, didapati dan telah dibuktikan bahawa mengira pengionan imapak dengan tenaga ambang lembut lebih baik berbanding tenaga ambang keras. Daripada projek ini juga membuktikan untuk mendapatkan data yang terbaik, perbezaan nilai suhu pergantungan dalam electron pendaraban dan voltan pecahan juga digunakan.

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CHAPTER 1

INTRODUCTION

1.1 Background

The multilayeres structures and knowledge of ionization coefficients in bulk semiconductors is required for the design of avalanche photodiodes[1]. In a new world and new technologies specially in electronics devices and circuit, impact ionization process act a main process. Avalanche multiplication resulting from impact ionization is an important process in several types of devices and in avalanche photodiodes (APDs) where it provides internal current gain. As this process is incorporated in many electronic devices. The benefits from this process can give us to know its behaviour in exact detail. Besides that we can add some knowledge and can generate the technology for a better world. Experimental measurement of ionization coefficients is difficult and time consuming and so a simple theoretical calculation would be useful. There have been many attempts at such a calculation and these have had various degrees of success.

Based on the title of project, this project will investigate on impact ionisation coefficients of a photodiode by using Lucky Drift Theory. The main objective of this project to investigate the temperature dependence of impact ionisation coefficient for electrons and holes based on Lucky Drift theory. The keyword 'temperature dependence' was describes from the fact that impact ionisation process is reactive and act as a function of temperature. The impact ionization process depends on temperature, largerly via scattering from optical phonons of energy. Furthermore, despite heatsinking

,power devices generally operate at temperatures above ambient while other devices, such as photon counting APDs, often require cooling to suppress dark count. It is therefore of interest to characterize the temperature dependence of impact ionization to predict accurately device behaviour and optimize device design. Impact ionization is conventionally described in terms of coefficients β and α for electrons and holes respectively, which are the reciprocal of the mean distance between successive ionization events.

Numerical calculations have been more successful. Monte carlo techniques have also been applied to multilayered structures[2]. However numerical calculations, especially Monte Carlo techniques require a large amount of computing power and there still a need for a simple analytic model. One of the simpler model is the Lucky Drift theory and this paper will discuss in details how successful and accurate the theory is in determining the ionisation coefficient behaviour in semiconductor material particularly in Gallium Arsenide (GaAs) and silicon (Si).

This analysis is mainly a simulation process. The C programming acts as a tool to manipulate data according to Lucky Drift model to finally produces a series of data that to be compared to experimental data. Eventually, it was expected to predict the characteristic of avalanche multiplication process i.e multiplication and breakdown voltages as a function of temperature.

1.2 Objectives of this project

The main goal of thie research and objectives need to be achieved as identified at the start of the project. These are listed as follow :

- To investigate the temperature dependence of impact ionization coefficient for electrons and holes based on Lucky Drift theory.
- To obtain any agreement and discrepancy between the calculated ionization coefficient using Lucky Drift.
- To implement experiment in C and record the data.

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1.3 Problem Statement

Experimental measurement of ionization coefficient is difficult and time consuming and so a simple therotical calculation would be useful. There have been many attempts at such a calculation and these have had various degress of success. Monte carlo techniques have also been applied to multilayered structures. However numerical calculations especially Monte Carlo techniques require large amount of computing power and there is still need for a simple analytic model[2]. The resulting difference between energy and momentum relaxation rates is crucial to the lucky drift model for impact ionization.

From this project, has a some error during the simulation period which is the process used in getting the perfect fit particulary the least square fit can contribute to the errors in calculated the best fit. This occur when at very low electric fields and produced extremely high α(β) at the very high elctric fields or low α(β). The polyonimal least square fit is one of the other method to comparing the curves. Besides that, errors might also occured by bad process of parameters in guessing their values. To avoid it occur, the good knowledge and enaough information of the impact ionization behaviour and the effect of each parameter especially *p* to α(β) in realation with different materials. The another error is the bad agreements which is for Si might caused by the model itself in which we can obtained the inaccuracy of this model. We can observed when applied to different type of materials. Upgraded to the model might decrease the error withal the grounds factors are unclear.

1.4 Scope of Project

The scope of this project is to investigate the ionisation coefficients for both electron and hole were predicted at variuos temperature which values then used to find the temperature dependence of electron multiplication and breakdown voltages. C programming was used to calculate the temperature dependence of impact ionization coefficient for electrons and holes based on Lucky Drift theory. From this project also focus to obtained alaytical expression for the field dependence of the impact ionization coefficient is applied to the interpretation of experimental data. Experimental data was found and it was proved that impact ionisation coefficient with soft threshold energy provide a better fit for both materials compared to hard threshold energy. The last steps from this project, the result from simulating are compared with analytical soluttions of previous research.

1.5 Report Structure

This thesis is a combination of five chapters that contain the introduction, literature review, methodology, result and discussion and the last chapter is conclusion and recommendation of the project.

Chapter 1 is an introduction to the project. In this chapter, we will explain the background and objectives of the project. The concept behind the project and overall overview of the project also will be discussed within this chapter.

Chapter 2 tells about the literature review of the analysis the temperature dependence of impact ionisation process by using lucky drift of previous research done.

Chapter 3 will explain about the project methodologies of the project. This chapter will show the simplified the measuremnts and calculation need to be focused on.

Chapters 4 describe the expected result from this project and justify its performance to make sure it meets the objectives of the research.

Finally, Chapter 5 concludes the whole research and proposes the future progress for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Avalanche Gain

Avalanche gain occurs in avalanche photodiode (APD). An avalanche photodiode (APD) is a highly sensitive semiconductor electronic device that exploits the photo electric effect to convert light to electricity [3]. At such high energies is dominant scattering mechanisms arise from internal with optical phonons [3]. The electron hole pairs occurs when photo generated carriers, being injected into the depletion region (intrinsic region or i-region) travel at high velocity and when they attain sufficient energy from the field , an ionising collision with lattice. These pairs are known a secondary carriers. A secondary carriers will drift in opposite direction in electric field together with primary carrier. Impact ionization occurs when , the process of transmitted and will produce another carriers,then will continue until they reach the p type or n type region. Avalanche multiplication resulting from impact ionisation. From electric field independent can show to describe in term of impact ionisation coefficient.

In APDs, the electric field is connected in reverse bias at magnitude near to breakdown voltage in order to provide the avalanche gain. It is applied to an undoped i-region between p and n regions. This i-layer will have a very low density or fully depleted at zero carriers so that the carriers can drift very quickly and the bias will drop almost entirely at the junction.

Figure 2.1 (a) represent a electron multiplication started by electron injection via p-region.

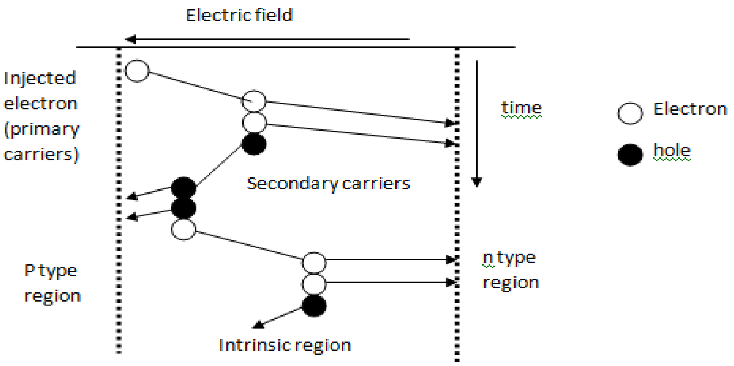


Figure 2.1 (a) : electron multiplication in the i-region of a PIN avalanche photodiode

Impact ionization is a typical non-equilibrium process which requires a large electric field. An electron (or hole) in the conduction (or valence) band gains its energy by external electric fields and becomes so highly energetic that it can create an electron hole pair by colliding with an electron in the valence band and exciting it to the conduction band. Impact ionisation coefficient is conventionally denoted by symbol α and β for electrons and holes respectively [4]. Multiplication is when α equal to β and most desired condition is when α or β equal to zero. Most semiconductors both electron and holes contribute to multiplication process, so that real multiplication process is somewhere between these extremes just considered.

The multiplication of electron is given by this equation :

$$M_n = \frac{\left[1-\left(\frac{\beta}{\alpha}\right)\right]\exp\left\{\alpha W\left[1-\left(\frac{\beta}{\alpha}\right)\right]\right\}}{1-\left(\frac{\beta}{\alpha}\right)\exp\left\{\alpha W\left[1-\left(\frac{\beta}{\alpha}\right)\right]\right\}} \qquad (1.0)$$

W is the width of the intrinsic region

2.2 Temperature dependence of impact ionisation

Avalanche multiplication resulting from impact ionization is an important process is several types of devices, such as transistors, where it limits the maximum operating power and in avalanche photodiodes (APDs), where it provides internal gain[4]. The impact ionization is supressed by increasing temperature because of the increase in phonons scattering. The impact ionization process depends on temperature, largely via scattering from optical phonons of energy, where population of phonons is given by :

$$n=\frac{1}{\exp\left[\frac{hw}{kT}\right]-1} \qquad (2.0)$$

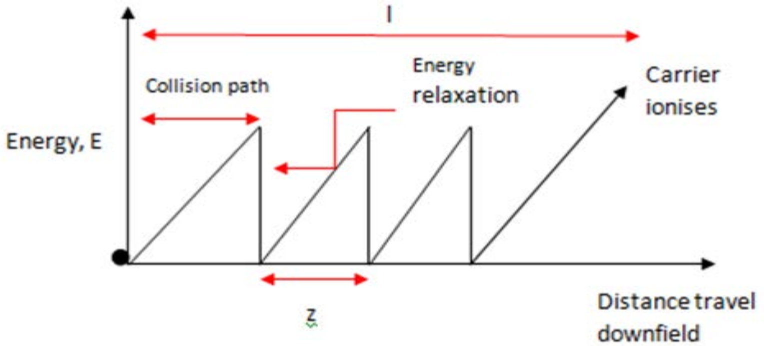
Based on previous research ,first investigation from Chang and Sze into the temperature dependence of ionization coefficients in GaAs, in which coefficients were shown to change in a highly nonuniform way with temperature[5]. Mars future their work by predicting ionization coefficients as a function of temperature however the agreement between measured breakdown and predicted voltages was poor[6].

2.3 Lucky Drift theory

Lucky drift theory was introduced by Ridley in 1983 to produce to be adaptable to multilayered structures [7]. The main feature of this theory is the separation of momentum and energy relaxing collisions and calculate the probability of an electron avoiding an energy relaxing collision while gaining a certain energy from the electric field [8].

Carriers moving in electric field will undergo a change in momentum along the way to achieve impact ionization. The resulting difference between energy and momentum-relaxation rates is crucial to the lucky drift model for impact ionization [7][9]. Burt defines for the purpose of the model, two separates types of collisions. One in which all momentum is lost and ones in which all energy is lost [10].

An electron starts off at zero energy and moves downfield with a combination of lucky drift motion until it suffers an energy relaxing collision. The electron then returns to zero energy and subsequently gains energy relaxing collision and so on [8]. The motion finisih one of two possible ways, if it is “lucky” balllistic or “lucky” drift motion it will finish in impact ionization and if its unlucky,energy relaxation[11].



<l> = <N><z>

<l> mean free path of impact ionization

<z> distance travelled downfield in each attempt

<N> average number of attempt to undergo energy relaxation to finally ionization

Figure 2.3 (a) : Carrier moving downfield from Lucky Drift viewpoint

Burt assumes, for simplicity that all electrons or holes which reach the threshold energy , E will ionize that is all carriers which reach $z=l_o$ where [11]

$$l_0 = \frac{E_{th}}{\varepsilon\epsilon} \qquad (3.0)$$

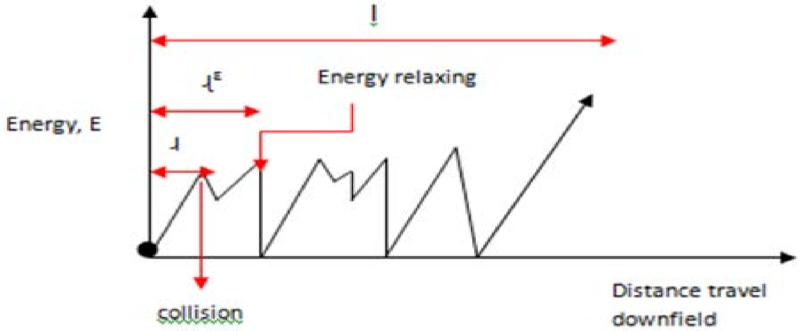


Figure 2.3 (b) : show the relation between mean free path of collision,energy relaxation and impact ionisation

The probability of lucky drift to reach the threshold energy will take into consideration the mean free path of collison (λ), mean free path of energy relaxation (λ_E), ionisation and phonons scattering rates, drift velocity and some other atrributes. It can be show in figure 2.3 (b)

(λ_E) is the mean free path for energy relaxation. If we assume an energy independent mean free path between collisions (λ) and parabolic bands then the mean free path for enrgy relaxation is also independent of energy.

$$\lambda_E = \frac{(2n+1)e\varepsilon\lambda^2}{2hw} \qquad (4.0)$$

The mean free path for momentum relaxation is given by the mean free path between collisions(λ)[7].

$$\lambda = \frac{\lambda_n}{2n+1} \qquad (5.0)$$

The mean free path for ionization, is given by equation if the carrier is drifting at a velocity of vd (λ)

The drift velocity is obtained by

$$V_d\ (E) = \frac{e\varepsilon\tau_m(E)}{m\ *}$$

Final form of α(β) can ultimately be shown as follow :

$$\alpha(\beta) = \frac{f\lambda_E(\lambda_E) - \lambda f(\lambda)}{\lambda_E^2[1 - f(\lambda_E)] - \lambda^2[1 - f(\lambda)]} \qquad (6.0)$$

Where,

$$\left.\begin{array}{l} exp=(-\frac{l_0}{\lambda})[1 - \pi\frac{(al_{0\lambda_E})^{\frac{1}{3}}}{\lambda}\ \boldsymbol{X\ Hi}\left(\frac{(al_{0\lambda_E})^{\frac{1}{3}}}{\lambda}\right)] \\ \\ exp=(-\frac{l_0}{\lambda_E})[1 - \pi\frac{(al_{0\lambda_E})^{\frac{1}{3}}}{\lambda_E}\ \boldsymbol{X\ Hi}\left(\frac{(al_{0\lambda_E})^{\frac{1}{3}}}{\lambda_E}\right)] \end{array}\right\} \qquad (7.0)$$

Hi(x) is a related airy fuction and has been evaluated using tthe following approximation

$$1-\boldsymbol{\pi}sHi(-s)=exp(-s) \qquad (8.0)$$

2.4 Softness of threshold

The effect of the ionization threshold softness on the temperature variation of impact ionization coefficients is examined theoretically. It is found that increasing the softness reduces the temperature dependence of ionization because temperature induced heating or cooling of the carrier distribution results in a smaller change in the ionization scattering rate sampled. [12]