國立清華大學 電機工程學系
實作專題研究成果摘要

TCAD Simulation for AC-LGAD
AC-LGAD 的 TCAD 模擬

Major Category: Optoelectronics Field 光電領域
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Abstract

Low Gain Avalanche Detectors or LGADs are a type of silicon based sensors designed to achieve precise time measurements while maintaining relatively low internal signal gain. They are modified PIN diodes with an additional gain layer that provides controlled avalanche multiplication. This paper presents a TCAD Sentaurus study of Low Gain Avalanche Detectors or LGADs and aims to understand the device geometry as well as the different parameters that affect electric field distribution and breakdown characteristics. Starting from the simulation of a simplified LGAD structure consisting of n++ layer, p+ gain layer, p- substrate as well as the p++ layer, which were built using the sde tool provided in TCAD Sentaurus. Analytical doping profiles are used to sweep the p+ gain layer concentration while observing the IV characteristics, breakdown voltage, and electric field distribution in svisual. Through these simulations, a gain layer concentration of around 5.3e17 was observed to provide a high field multiplication region while also maintaining a controlled breakdown. The structure is then extended to also include junction termination extension or JTE, guard rings and p stop implants. The effects of JTE width and JTE to P stop spacing were also evaluated. The results of this paper demonstrates how appropriate edge termination design can prevent premature breakdown as well as the choice of gain layer doping in order to optimize LGAD sensors for precise timing applications.

本文利用 TCAD Sentaurus 對 Low Gain Avalanche Detectors (LGADs) 進行模擬研究，目的是了解元件幾何結構以及摻雜分布如何影響電場分布與崩潰特性。首先從一個簡化的 LGAD 結構模擬開始，此結構由 n++ layer、p+ gain layer、p− substrate 以及 p++ layer 組成，並使用 TCAD Sentaurus 中的 sde 工具建立。採用 analytical doping profiles 對 p+ gain layer 的摻雜濃度進行掃描，同時在 svisual 中觀察 I–V 特性、崩潰電壓以及電場分布。透過這些模擬，發現當 gain layer 摻雜濃度約為 5.3e17 時，可以形成高電場倍增區域，同時維持可控制的崩潰行為。接著將結構擴充，加入 JTE、Guard Ring 和 P stop，並評估 JTE 寬度以及 JTE 與 P stop 間距的影響。結果顯示，適當的邊緣終止設計能有效避免過早崩潰，並為 gain layer doping 的選擇提供依據，以優化 LGAD 感測器在精確時間量測應用中的表現。

1. Introduction

1-1. Background

Low Gain Avalanche Detectors are a type of silicon based sensors which are designed to achieve precise time measurements while also maintaining relatively low internal signal gain. LGADs are modified PIN diodes with an additional gain layer that provides controlled avalanche multiplication. There are 4 main components of an LGAD sensor, (1) n++ Cathode Layer, this is the charge collecting electrode which is highly doped to ensure low contact resistance, (2) p+ Gain Layer, this is a shallow highly doped p-type layer which generates an intense electric field leading to avalanche multiplication of charge carriers. (3) p- Substrate, this is the layer where charge carriers drift towards the electrode and the thickness of this layer affects time resolution. (4) p++ Anode Layer, this is a highly doped p-type layer that serves as the biasing contact for the sensor.

LGAD sensors operate based on the principle of avalanche charge multiplication which occurs in the gain layer. When a charged particle passes through the LGAD sensor, it ionizes the silicon atoms and creates electron-hole pairs. By applying reverse bias voltage, this creates a strong E-field across the p-substrate and causes electrons to move towards the n++ Cathode and holes towards the p+ gain layer. As the holes enter the gain layer, they experience a very high E-field. This accelerates the holes and causes them to collide with silicon atoms and thus creating more electron-hole pairs. This is also known as the avalanche effect. This results in an amplified signal which makes it easier to detect.

1-2. Purpose

This paper will discuss the simulation process of Low Gain Avalanche Diodes using TCAD Sentaurus SDE, svisual, and sdevice. It will discuss the structure design and creation of LGADs as well as simulation results for different doping concentrations, JTE widths, and JTE to P stop distances. Through analyzing the electric field distribution as well as the current density distribution, we can confirm that our device simulation is correct and its feasibility in practice.

2. Method

The method of simulation for LGAD is done in TCAD Sentaurus. The SDE tool was used to create the structure and allowed for wider specification of the device including its materials, doping concentrations, size, etc. Following the structure of LGAD, the materials for each layer can be specified as well as its width and height. Figure 1 is the SDE structure, mesh and doping concentration of LGAD made without JTE, Guard Ring and P stop.

One important part of creating the structure of the LGAD in the sde tool is mesh. Mesh is a crucial part of the simulation as it has a big effect on the result. A mesh that is too thin will cause the graphs to be rough and inaccurate whereas a mesh that is too complex will prevent the simulation from processing. In order to create the mesh that is thick in necessary areas and thin in others, the Ref/Eval Window tool in SDE is used to separate different regions of the LGAD in order to make the mesh more specified for each region. This allows for a more specified mesh for each region based on how important it is. The regions where thick mesh is required is in the junctions as well as the active area of the LGAD. If mesh is done properly for these regions, doping concentration, E- field distribution will be more smooth and accurate. Therefore , when creating the mesh for the LGAD design, these two areas were given a thicker mesh as can be seen in the Figure below.

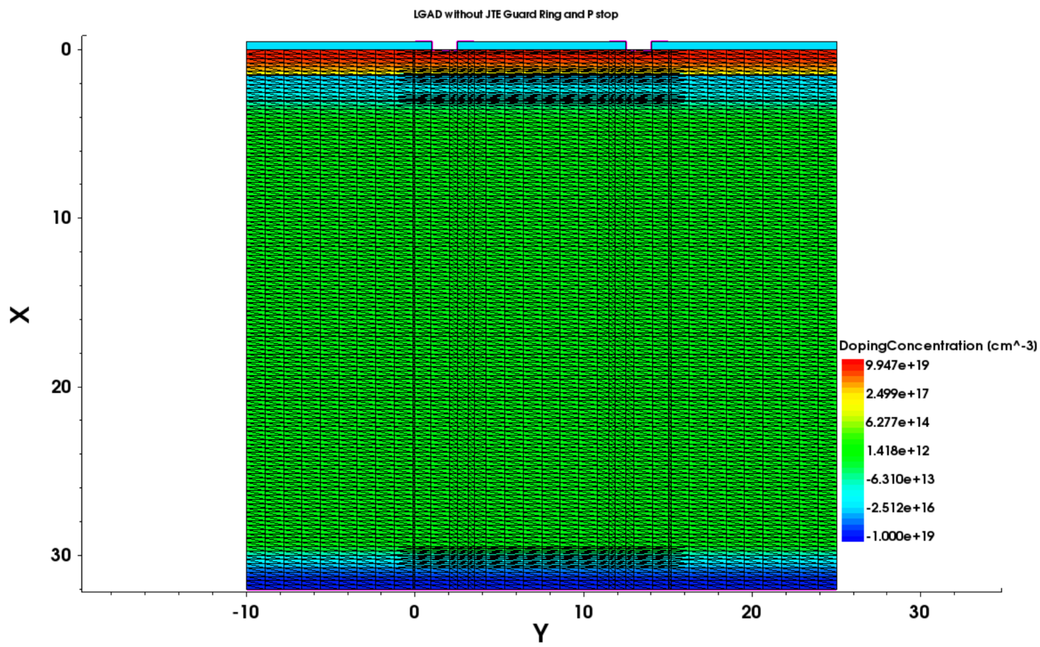

Figure 1. Structure and Mesh created for LGAD

The sdevice tool is used for the processes for the device, data received from the sde structure made will be received by sdevice where it will start simulating the process within the device. By creating variables, we can easily change different parameters for each simulation. In order to analyze and view our simulations, we use the svisual tool in TCAD Sentaurus. Using svisual, we can plot the IV Curves as well as view the structure of the LGAD, including its electric field distribution, current density distribution, doping concentration distribution, etc.

3. Results

Through the simulation of different gain layer doping, the gain layer doping concentration of 5.3e17 was chosen for further simulations. Fig 2. Shows the IV Curve simulation using different values of gain layer doping.

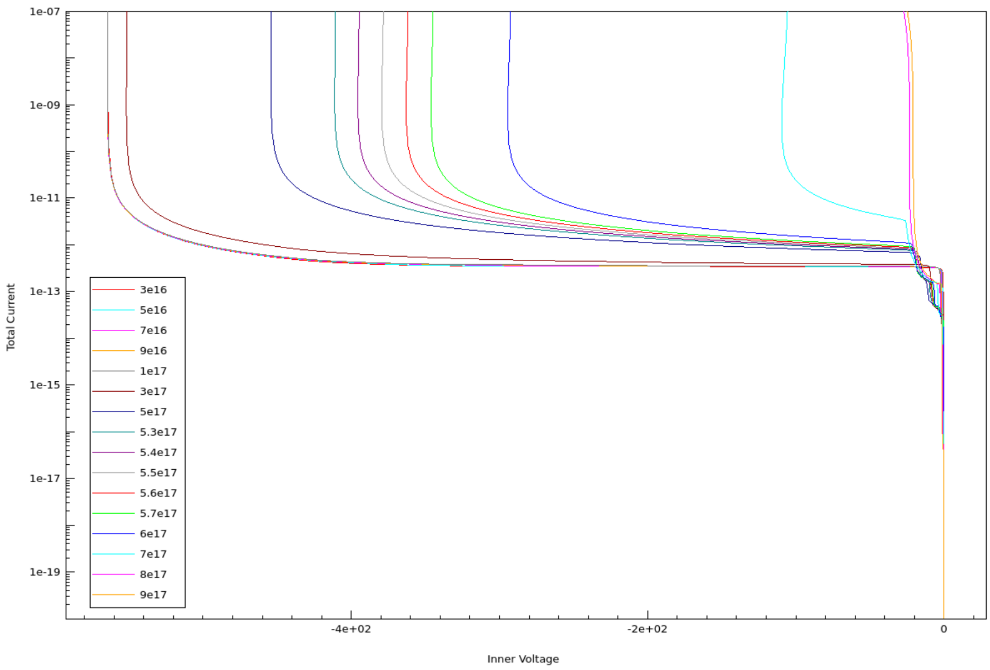

Fig 2. IV Curve with different gain layer doping

JTE Width is one of the parameters that can change the breakdown voltage. So different JTE widths were used and compared in simulations. Figure 3 shows the IV Curves at different JTE widths 5 um, 10 um, 20 um, 30 um 40 um. As we can see from the graph, it breaks down significantly earlier when JTE width is at 5 um. Therefore, JTE width of 10um was used in the final design.

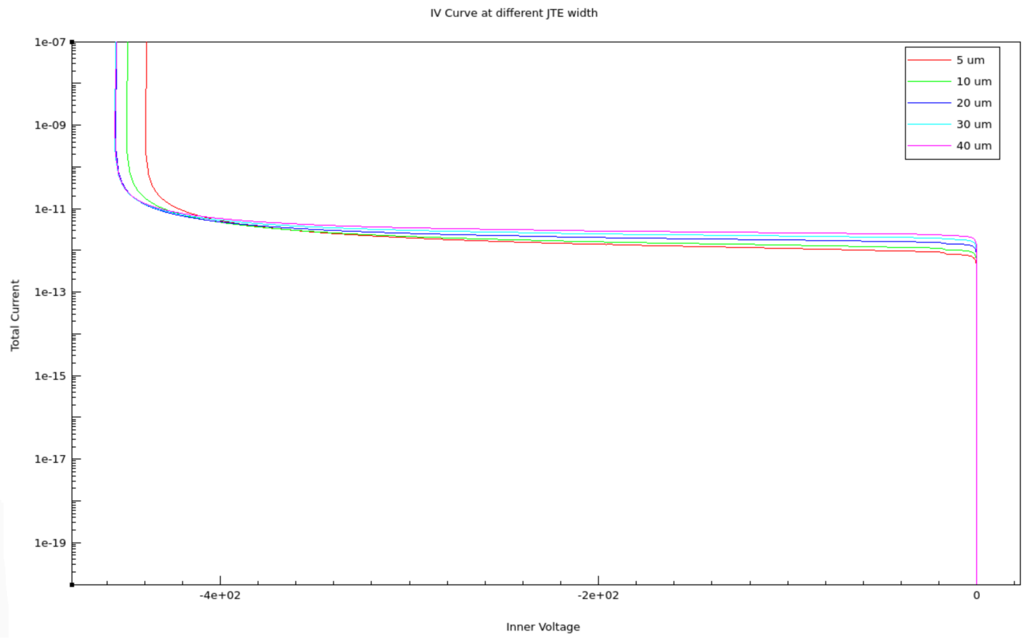

Fig 3. IV Curve for LGAD with different JTE Widths

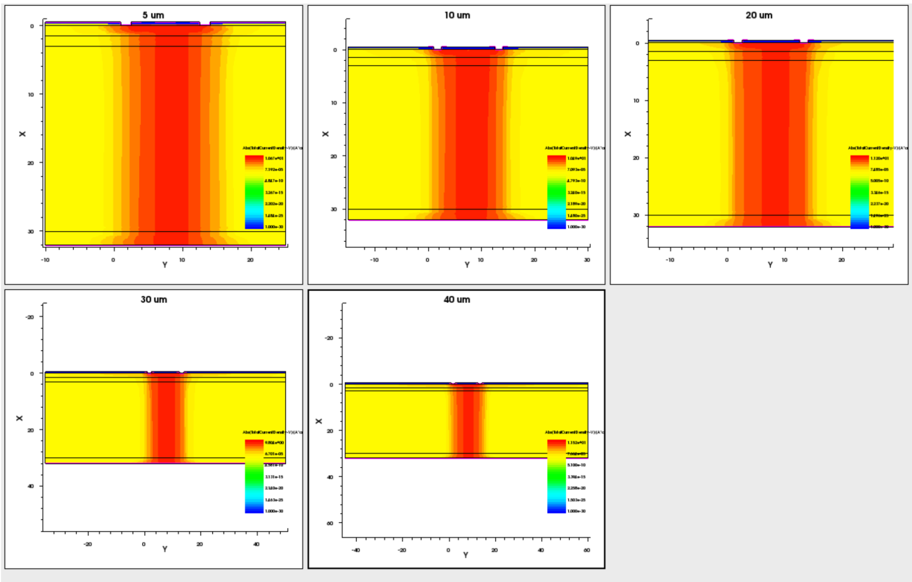

Fig 4. Current Density distribution for different JTE Widths

Figure 4 above shows the different current density distributions of the device at different JTE widths. We can observe that there is highest current density in the active region of the device, this confirms that breakdown occurs in the active area and the device works correctly.

Similar to JTE width, the JTE to P stop distance is also one of the parameters that can affect the breakdown voltage. Simulations of different JTE to P stop distances of 10 to 40 um were done. Figure 5 below shows and compares the IV Curve at different distances, as the distance of JTE and P stop decreases, it leads to an earlier breakdown. Therefore, distances of 20um or above should be used to prevent early breakdowns.

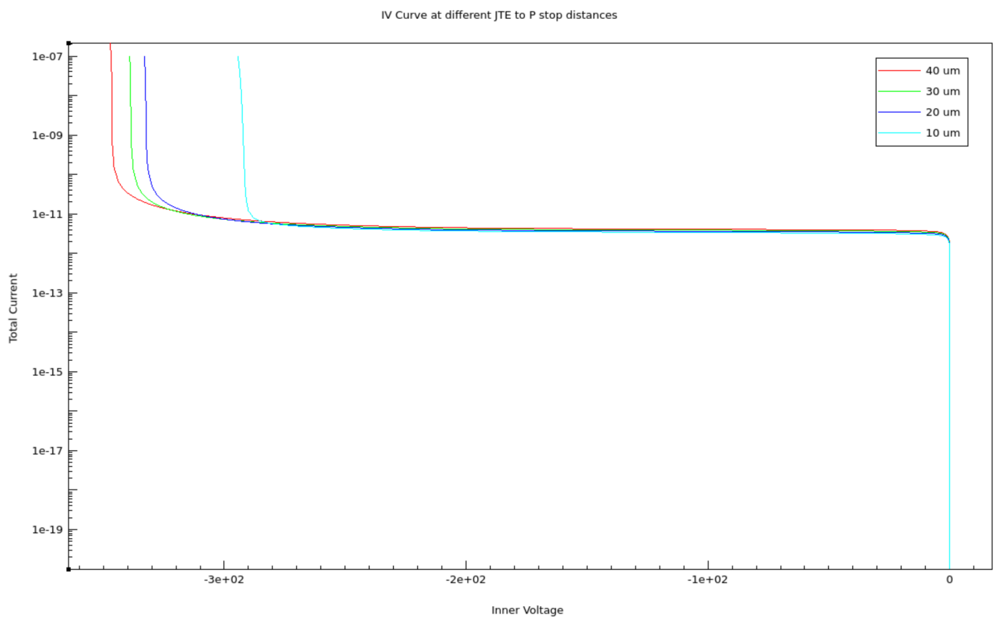

Fig 5. IV Curve at different JTE to P stop distances

4. Conclusion

TCAD sentaurus provides us with the ability to simulate devices before bringing them into the real world, it gives us insight to the design process and what results we can expect from it.Through our simulations, we can determine the best values for different parameters in order to prevent premature breakdown. The simulation of the LGAD confirms the feasibility of its use in future applications. Through the simulation, the most effective doping concentration for the gain layer was found to be 5.3e17. And through the simulation of two parameters, the JTE width and the JTE to P stop distance, it showed that JTE width should be designed to be 10 um and more, and the distance from JTE to P stop should be at least 20 um.

Due to its great timing resolution, LGAD sensors have many application prospects for the future. They can be expected to play a crucial role in next generation particle detectors as well as medical imaging technologies.

5. Reference

[1] "Design and fabrication of Low Gain Avalanche Detectors (LGAD): a TCAD simulation study" K. Wu et al 2020 JINST 15 C03008

6. Reflection

As the only member in this group, I realized how difficult it is to do everything alone. Although group projects allow for discussion and collaboration, I believe that I also gained a lot of knowledge working on this study alone. Since every single part of the project was done by myself, I was able to familiarize myself with the process of simulation for the LGAD. This study gave me insight into how difficult it is to do a simulation for any device. TCAD Sentaurus is an incredibly powerful tool and although I have been working on it for months, I have only explored a small percentage of its full potential and use.

LGAD is a very interesting device and I am grateful I had the chance to learn and perform simulations on it. And through these simulations, I was able to appreciate how complex these optical devices are and the amount of work and research that goes into them.

Lastly, I would like to thank my professor Prof. Yi-Shan Lee and the senior student James for their guidance. Through their advice and assistance, I was able to do well in this project and learn many new things on the way. The experience I gained from this study is invaluable and I believe that it will be very useful to me in the future.