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AN ANALYSIS OF D-BAND GUNN DIODE FOR MILLIMETER WAVE APPLICATION

Zaffrul Zulkarnain Aziz Masuaud, Mohd Azlishah Othman, Nadhirah Ali, Hamzah Asyrani Sulaiman and Mohamad Zoinol Abidin Abd. Aziz
Microwave Research Group, Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia, Melaka (UTeM), Durian Tunggal, Melaka, Malaysia
E-Mail: zaffrulzulkarnainaziz@gmail.com

ABSTRACT

A planar InP-based Gunn diode is designed for millimeter wave application. The SILVACO TCAD tool is utilized to generate the structure and I-V characteristic of Gunn diode. The design specification mainly focuses on varying the diameter of cathode area in three different values which are 0.8um, 1.0um and 1.2um. It can be seen that the threshold voltage and current display their powerful dependences on the 0.8um diameter of cathode area. The threshold voltage precisely at 7V alongside the current value is approximate 1.6A. In this paper, the diameter of cathode area is optimized. The results greatly propose that lower cost and high reliable InP planar Gunn diode can be utilized as single chip terahertz sources.

Keywords: InP Gunn diode, millimeter wave, SILVACO TCAD, planar Gunn diode.

INTRODUCTION

Gunn diode is additionally recognized as a transferred electron mechanism (TED) and microwave semiconductor device. It is an exceptional constituent and a form of diode utilized in high-frequency electronics. It is somewhat infrequent that it consists merely of n-doped semiconductor physical, whereas most diodes encompass of both P and N-doped regions. Practically, a Gunn diode has a span of negative differential resistance. Furthermore, Gallium Arsenide and Gallium Nitride that are materials utilized for Gunn diodes are made for frequencies up to 200GHz for GA and can grasp up to 3THz for GN (Jadhav, Kadam, Gohel, Kalamkar and Kakade).

Besides that, Gunn devices are widely used as local oscillators up to W-band (75-I 10 GHz). At these frequencies the technology and circuit design are well developed. In particular at 94 GHz, GaAs and InP Gunn devices are available with high DC to RF conversion efficiency and high RF power levels. InP is recognized to have superior characteristics compared to GaAs for power generation in the millimeter wave region. Fundamental mode operation up to 110GHz has been achieved with InP Gunn devices whereas GaAs Gunn devices are believed to operate in second harmonic mode at around 94 GHz. InP Gunn diodes have long been used as high power microwave sources in the important W-band frequency range (75-110 GHz), the key attraction being that fundamental-mode operation is relatively straightforward to achieve (unlike with GaAs). Over the last few years, increasing attention has been given to extending fundamental mode operation up to D-band frequencies (110 -170 GHz) as well as to investigating second harmonic mode operation. GaAs is a suitable material for the generation of frequency up to 70 GHz and this frequency limitation can be extended by the extraction of higher harmonics, while InP Gunn diodes operate up to 110GHz in fundamental mode. However, recent numerical studies show that the frequencies generated from diodes with aGaAs/AlGaAs structure could be expanded from 70 GHz to75 GHz-110 GHz in second-harmonic-mode operation and those generated from the InP diodes could be expanded to 480 GHz in third-harmonic-mode operation. Moreover, InP Gunn diodes demonstrated that they can bring out high RF output power levels compared with GaAs (Dunn and Kearney, 2003).

In this paper presenting a simulation result of InP planar Gunn diode with n-n+ structure and study the current voltage characteristic, alongside the varying of diameter of cathode area. The device has a notch structure which is very competent compared alongside uniform and grade doping devices, as domain will model very near to the cathode, which is illustrated by the Monte Carlo simulations theoretical. (Dunn and Kearney, 2003) In this research, the InP substrate is developed for the Gunn diode structure on above a thin layer of N-type region. It can be observed that nonlinear current voltage curve and the negative resistance region (NDR) characteristic equivalent to different dimensional Gunn diodes. The simulated current voltage curve exhibits same behaviors as being performed on diode is 0.8um, 1.0um and 1.2um diameter of cathode area with 2um width size. The features of negative differential resistance and the asymmetry current voltage curve equivalent to disparate dimensional Gunn diodes will be reviewed later.

GUNN DIODE STRUCTURE

There are three structure designed for Gunn diode with different values of diameter of cathode area. The material utilized is Indium Phosphide (InP) Gunn diode whereas it can operates at D-band frequencies (110-170GHz). The layers are in producing sequence as shown in Figure-1 whereas a InGaAs n+ layer having a doping concentration above level of 2 x 1018 cm-3, a 1.5 um deep n+ buffer having a doping concentration alongside InP at a level of 1 x 1018 cm-3, and next a 1.8 um deep InP which is active layer having a doping concentration at 1.1 x 1016

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cm-3. The thickness of substrate was varies according to frequency required which is 6.2um alongside InP at 1.3 x 1018 cm-3.

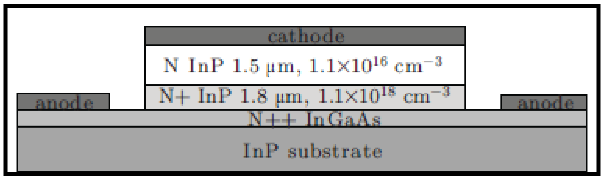

Figure-1. Schematic diagram of InP Gunn diode (Bai, Jia, Wu, Jin and Liu, 2013).

Basically, the Gunn diode is created from a single piece of n-type semiconductor material. The n-type is defined as the pentavalent impurities that had been added which are phosphorus or arsenic and antimony that contributes free electron followed by enhancing the intrinsic semiconductor conductivity. The conduction is due to the movement of negative carriers (electron) rather than positive carrier (holes) (Dunn and Kearney, 2003).

CURRENT VOLTAGE CHARACTERISTIC

Gunn diode displays specific non-linear I-V characteristics like normal diodes. The present obtained as an output from Gunn diode tends to rise alongside rising voltage, but there is a region amid the two specific voltage benefits recognized as top voltage and valley voltage amid that the present falls as the voltage is increased. This is shouted the negative resistance region because in this voltage scope the vibrant negative resistance is comprehended in words of decreased mobility and hence decreased current. The occurrence of this negative differential resistance region is clarified in pursuing points:

The net current density for Gunn diode alongside device length is composed as,

$$J = J_L + J_u \quad (1)$$

$$J = \sigma_L E + \sigma_u E \quad (2)$$

Where $\sigma = nq\mu$, and $\mu = V_d E$

$$J = qn_L \mu_L E + qn_u \mu_u E \quad (3)$$

$$J = qn_L \mu_L \frac{v}{d} + qn_u \mu_u \frac{v}{d} \quad (4)$$

Where V is the voltage has been applied, also composed as, V = ED

Most of the electrons are in lower conduction group when voltage is low:

$$n_L >> n_u \ \& \ \mu_L >> \mu_u$$

$$J = qn_L \mu_L E + qn_u \mu_u E$$

$$J = qn_L \mu_L E \quad => \quad J = qn_L \mu_L \frac{v}{d} \quad => \quad J \propto V$$

When the voltages go beyond peak value, the current rise extremely sluggishly and ways a maximum value at voltage recognized as threshold voltage (V_{th}),

$$I = JA$$

$$I = J_L A + J_u A$$

$$I = I_L + I_u$$

As voltage is identical to threshold value and outreach, current cuts due to transfer of electrons from lower conduction band to higher conduction band. On rising voltage a period comes after all electrons are in higher conduction band portion and lower conduction group is empty. At this, the current is minimum on rise in onward voltage, this minimum flowing current is recognized as valley current and correspondingly voltage provoking this current to flow is recognized as valley voltage (Vv). The Figure describes the variation of drift velocity of electrons and current flown alongside respect to requested electrical field/voltage.

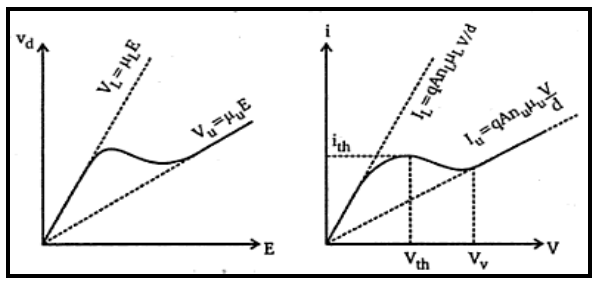

Figure-2. Current voltage curve for Gunn diode (Dinesh and Shrivastava, 2009).

$$V_{th} < V < V_V$$

$$I \approx I_u => q A n_u \mu_u \frac{v}{d}, \ (\text{hence } \mu_u < \mu_L)$$

The more rise in onward voltage induces all higher conduction band electrons to drop down to valence band. As a consequence onward current rises again. The emergence of negative differential conductivity in n-type GaAs is recognized as Gunn Effect. This region is utilized in arranging microwave oscillators and amplifiers (Dinesh and Shrivastava, 2009).

SIMULATION OF GUNN DIODE

SILVACO ATLAS tool is utilized to design the structure of Gunn diode and generate the I-V characteristic of Gunn diode. Several parameter need to be considered in early step of designing the Gunn diode structure which are the mesh parameter includes of X. MESH and Y.MESH parameter with spacing between them, region parameter, electrode parameter and doping profiles. All the parameters must be done in sequence starting from specifying the mesh, region, electrode and doping profiles.

The X. MESH parameter indicates as the width of the Gunn diode structure which is 2 microns and the Y. MESH parameters indicates as the thickness of each layer. Usually, the thickness value is corresponding to doping

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concentration value whereby it is a fixed value, but it can be varied once the I-V Characteristic generated does not meet the desired result. The spacing is used a scaling factor for the produced by the statements of X. MESH and Y. MESH. The default spacing value is 1. Thus, if the value used greater than 1, it will create a globally coarse for fast simulation but less accuracy and if the value used less than 1, it will create a globally finer for increased accuracy but slow simulation. The spacing value used in this simulation is less than 1 which is varied until no fading occurred on the Gun diode structure. Besides, there are four region parameters in Gunn diode structure that are three regions represents as Inp region and one has fixed material which is InGaAs region. The entire region is expressed in increasing order which is starting from 1 to 4. The electrode must be defined which contact a semiconductor material. Thus, there are three electrodes defined for Gunn diode structure which are both of them specified as anode and one is termed as cathode. For the doping profiles, the uniform form is used and once again the doping concentration value equivalent with the thickness of Gunn diode which is a fixed value. Notes the location parameter for the region, electrode and doping profiles were mentioned in microns employing the X. MIN, X. MAX, Y. MIN and Y. MAX (Silvaco International, 2004).

Once all the coding parameters included orderly and correctly in the software, the Gunn diode structure can be created as shown in Figure-3 indicates as the 0.8 micron diameter of cathode, Figure-4 indicates as the 1. Micron diameter of cathode area and Figure-5 indicates as the 1.8 micron diameter of cathode area. All of the Figure will be compared through the performance of the I-V Characteristics.

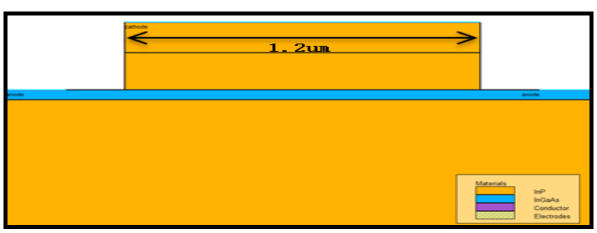

Figure-3. Structure of Gunn diode (0.8um).

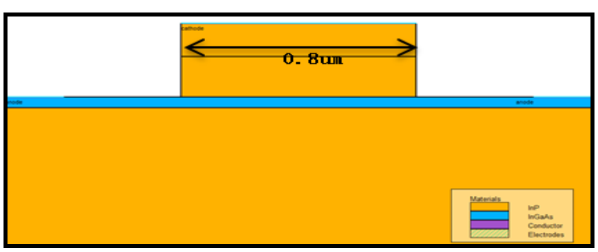

Figure-4. Structure of Gunn diode (1.0um).

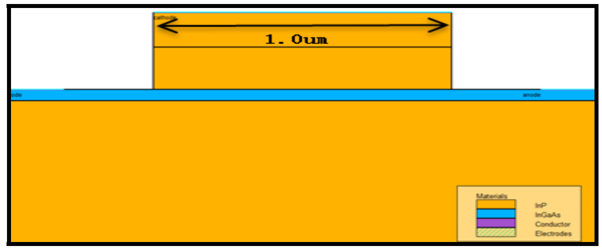

Figure-5. Structure of Gunn diode (1.2um).

It can be observed the structure designed demonstrate the diameter is become wider when the diameter used is added up to 1micron to the left side and right side. The yellow color is indicating as Indium Phosphide (InP) material and the blue color above the substrate is indicating as Indium Gallium Arsenide (InGaAs) material. The light blue color located above the top layer and InGaAs layer is cathode and anode electrode.

Once completing the structure designed of Gunn diode, the process of generating the I-V Characteristics can be begin. As usual, several parameter need to be considered to begin the simulation of I-V Characteristics which are the model and contact parameter, initial solution, method parameter and Direct Current (DC) solution.

The model used in Gunn diode simulation consists of three models which are TASCH, SRH and AUGER. The TASCH model is defined as transverse earth dependence. Merely for planar devices and needs extremely fine grid. The SRH model is termed as Shockley Read Hall where it is defined as fixed minority carrier lifetimes and ought to be utilized in most simulations. For AUGER model, it is specified as direct transition of three carriers which is vital at elevated current densities. Besides, the statement of contact is utilized to indicate the work-function of metal that represent of one or more electrodes. An electrode which is contact alongside semiconductor material is pretended by default to be ohmic. Once a work-function is specified, the electrode is termed as a Schottky contact. The electrode also is specified with a name statement whereby it is functioned as to recognize which one of the electrodes will have it features modified.

Next is implementing initial solution or termed as solve init whereby If there is no earlier solution stated, the primary guess for concentration of carrier and potential should be built from the doping profiles. This is the reasons of performing solution should be the zero bias. Notes, if the solve init syntax is no stated in the coding, ATLAS automatically classify a primary solution before the earlier statement. In order to support convergence of the primary guess, it is implemented in the mode of zero carrier solving specialized for potential.

Furthermore, the method utilized in Gunn diode simulation consists of two methods that are carrier method and newton method. The carrier method used is only specified for electron. This is because if go through the basic theory of Gunn diode. It specifies that Gunn diode is

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consists only of n doped semiconductor material whereby the conduction is due to the motion of negative carrier which is known as electrons rather than positive carrier (holes). Thus, the method specified is only one carrier is implemented for the diode. More than that, the newton method is defined as the default for drift-diffusion computations in ATLAS. There are countless calculations for that ATLAS needs that Newton's method is used. These are: DC calculations that include lumped elements; curve tracing; transient calculations; and after frequency-domain small-signal scrutiny are performed. Thus, the newton method used in this simulation is for DC calculation.

Furthermore, the finalize step is implementing the DC solution for the diode. In this solution, each of the electrode voltage is stated employing the statement of solve. Thus, in this research, the electrode voltage is not stated on solve statement, so it is assumed to be zero. Besides, for much utilization, one or more electrode sweep is currently needed. The basic stepping of DC is unsuitable and a ramped bias must be utilized. Thus, in this project, the anode voltage was ramped from 0.0V to 7.0V alongside 1.0 step with the electrode specified as anode (Silvaco International, 2004).

Once all the coding parameter needed is inserted in the software, the I-V Characteristics can be generated smoothly without any error occurred as shown in Figure-6, Figure-7 and Figure-8. The entire Figure indicates each of diameters used for cathode area which affecting the performance of Gunn diode in term of current voltage curve.

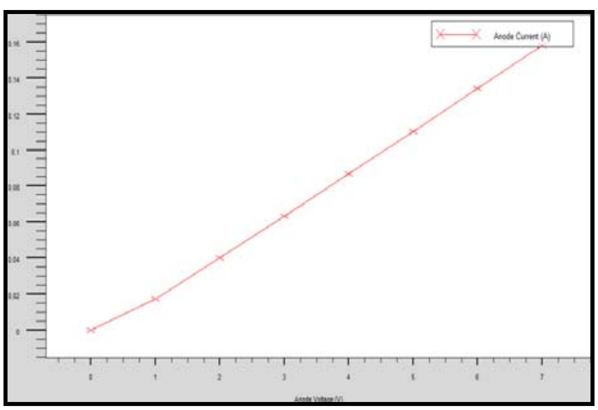

Figure-6. I-V Characteristic of Gunn diode (0.8um).

Based on Figure-6, it shows that the current is increasing when voltage is supplied from 0V until 7V. The current is approximate 0.16A with the threshold voltage at 7V.

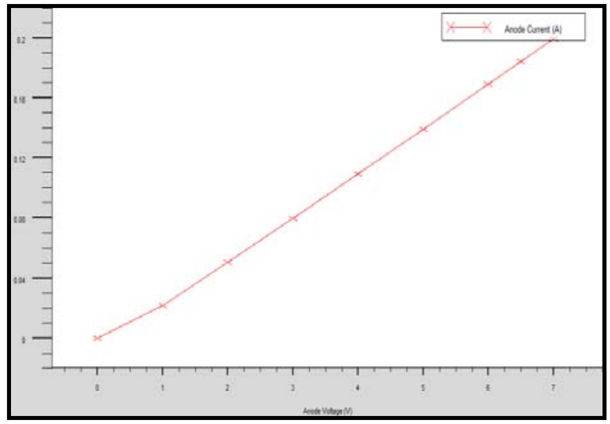

Figure-7. I-V Characteristic of Gunn diode (1.0um).

The Figure-7 above shows that the current is also increasing when then the diameter of cathode area is added up to 1.0um. It demonstrate the same view with the previous graph but a slightly change in increasing of current which is approximate 0.2A alongside the threshold voltage fixed at 7V.

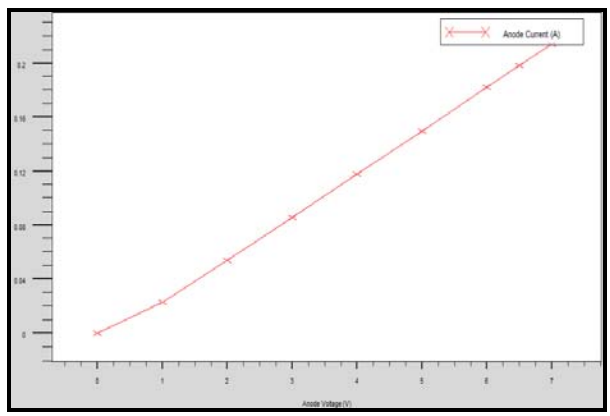

Figure-8. I-V Characteristic of Gunn diode (1.2um).

Based on Figure-8, once again the current illustrates a slightly increase compared with both previous I-V curve whereby the diameter of cathode area is being widen to 1.2um. The threshold voltage is still fixed at 7V without any changes happened on it.

In addition, to illustrate a clearly view of the I-V Characteristics for Gunn diode. The TONYPLOT overlay is utilized by combining the three graphs into one graph. Thus, the Figure-9 shows the TONYPLOT overlay for the I-V Characteristics of Gunn diode.

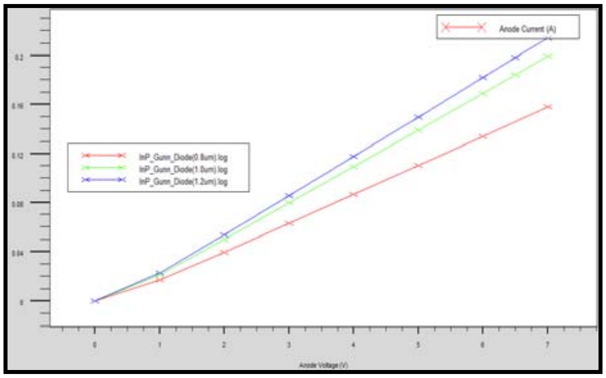

Figure-9. TONYPLOT overlay for I-V Characteristics of Gunn Diode.

According to Figure-9, it can be clearly see that the performance of the I-V curve for the three diameters used for Gunn diode cathode area. The forward voltage is applied to the anode (on the bottom of device). The electrons injected from the cathode flow to the anode through the transit region, so that current linearly increases under some voltage and the uptrend becomes a sharp decline with the voltage exceeding the threshold level. Therefore negative differential resistance can be observed, as the DC bias exceeds that level. It can be observed that the smaller diameter used corresponds to smaller current. Thus, the 0.8um diameter of cathode area shows the better performance of current due to its low current which can save cost and can be utilized for millimeter wave application.

CONCLUSIONS

At the end of this project, the objectives were achieved. The Gunn diode was successfully designed and analyze by using SILVACO TCAD tool. A planar InP-based Gunn diode was designed with a notch structure bring a higher RF power and frequency output. As the diameter of cathode area is varied, each of the diameters varied is affecting the performance of Gunn diode in term of current voltage characteristic. Thus, as a conclusion, the smaller diameter of Gunn diode corresponds to a smaller saturated current. The new low cost and high-reliable device will enable simpler monolithic microwave integrated circuits (MMICs) for a wide range of millimeter wave applications.

REFERENCES

Atlas User's Manual. 2004. Silvaco. Silvaco International, Santa Clara, California.

Bai, Y., Jia, R., Wu, D., Jin, Z., and Liu, X. 2013. The design and manufacture of a notch structure for a planar InP Gunn diode. Chinese Phys. B, 22(2), 027202.

Dinesh, and Shrivastava, V. 2009. Fundamental of Electronic Devices. p. 261. Meerut: Satyendra Rastogi "Mitra".

Dunn, G., and Kearney, M. 2003. A theoretical study of differing active region doping profiles for W-band (75–110 GHz) InP Gunn diodes. Semicond. Sci. Technol., 18(8): 794-802.

Jadhav, A., Kadam, A., Gohel, P., Kalamkar, K., and Kakade, N. Presentation on Gunn Diode. Presentation.