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Virtual Simulator

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Abstract: *This paper is based on virtual experiment approaches to Gunn diode and their vi characteristics. Virtual labs which provide remote-access to simulation-based Labs in various disciplines of Science and Engineering. In microwave and radar engineering, virtual experiments are not available. In this paper, we consider vi characteristics of Gunn diode. In this experiment without actual use of power supply we performing experiment virtually. Evaluation using web technology we introduced this experiment. Gunn devices were simulated using the Sentaurus Device software. The fabricated planar Gunn diodes are 1.3 μm long and 120 micron wide and the measured and simulated results are in excellent agreement. This experiment involving the changes in current and voltage. We further show applications and experiment actual and virtual setup.*

Keywords: Virtual Experiment

I. Introduction

1.1 Introduction of Virtual Lab

Virtual labs are interactive, digital simulations of activities that typically take place in physical laboratory settings. Virtual labs simulate the tools, equipment, tests, and procedures used in chemistry, biochemistry, physics, biology, and other disciplines that include a laboratory component in the curriculum. A key characteristic of virtual labs is their interactivity—video recordings or renderings of lab activities that cannot be manipulated by users fall outside this discussion. Similarly, physical equipment such as radio telescopes or electron microscopes that can be controlled by distant users is considered remote instrumentation rather than a virtual lab. By accurately representing the actions, reactions, and consequences of manipulating materials and equipment, virtual labs provide a way for students to participate in lab-based learning activities without the overhead of a physical lab.

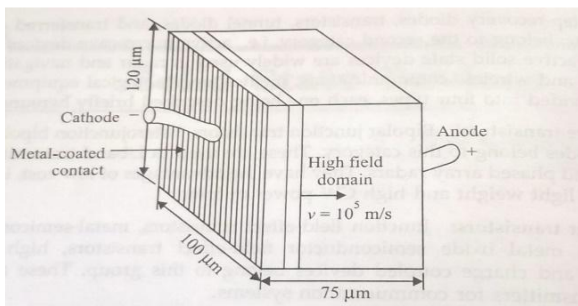
Virtual labs operate online, often embedded into an LMS. As with a physical lab, faculty members determine which lab assignments are required to support learning objectives at various points in the syllabus. Students have access to virtual representations of the equipment and supplies they would find in a physical lab. In a virtual chemistry lab, for example, students might find beakers, pipettes, cylinders, and other glassware; a collection of acids, bases, and other solutions; and Bunsen burn ; a collection of acids, bases, and other solutions; and Bunsen burners, scales, and other needed hardware. Students follow the steps of an assigned procedure and observe and record the results. Students see digital simulations of the results of their actions—or of their missteps if they make a mistake. Most virtual labs allow users to stop, start, and replay an activity. Many virtual labs integrate with a course's curriculum, recording students' progress and assigning credit toward learning goals and grading. Virtual lab applications and the content within them can be bought from vendors or developed in-house. Some vendor tools allow instructors to add or adjust the content to suit their courses, and other systems enable faculty to co-develop resources with a commercial developer. The amount of technical skill required for faculty to participate in the development or customization of virtual labs varies, depending on the tools involved.

Virtual labs allow students to participate in lab-based learning exercises without the costs and limitations of a physical lab. If an institution enrolls several hundred students in an introductory chemistry course, for example, the ability to send at least some of those students to an online lab could decrease the amount of physical lab space needed and/or significantly increase flexibility for students, given that they could do the work at their convenience. Virtual labs can provide access for Virtual labs can provide access for students in online programs or who are unable to attend physical labs due to illness or injury. Institutions in areas prone to severe weather, wildfires, or earthquakes use virtual labs to support continuity of education when such events occur, and—as was demonstrated during the COVID-19 pandemic—virtual labs can fill gaps in education at any institution due to a public-health crisis or other disruption. For some lab activities, the consequences of a mistake can be significant, and virtual labs relegate that risk to the online environment. In some ways, virtual labs can offer more functionality than a physical lab, such as the ability to include quizzes and access to additional educational resources within the simulation.

1.2 Introduction of Gun diode

A. GUNN Diodes

Gunn oscillators and amplifiers are extensively used as local oscillators and power amplifiers in radio receivers, covering the frequency range of 1 GHz to 100 GHz in which Gunn diode is a critical part. Gunn diode, basically, is an n-type slab of one of the semiconductors like GaAs, InP, InAs, InSb and CdTd. This device exhibits dynamic negative resistance, when it is biased to a potential gradient more than a certain value, known as threshold field E_{th}. This phenomenon is known as Transferred Electron Effect (TEE) or Gunn effect, in the name of J.B. Gunn (1928-2008), who was also well known as lan or lain. He was born as John Battiscombe Gunn, but only used that name in legal documents. He was a British physicist, but spent most of his time in the US. His discovery of Gunn effect led to the invention of the Gunn diode, the first inexpensive source of microwave power. Ian Gunn was a racing enthusiast and his motorcycle racing career spanned 50 years, from 1950 to 2000 in the UK and US, which included two Grands Prix, but mostly he raced in the club races.



Structure of GaAs Gunn diode carrying a high field domain.

While studying noise properties of semiconductors, Gunn observed so-called Gunn effect in thin disks of n-type GaAs and n-type InP. Herbert Kroemer a physicist pointed out in 1964 that Gunn's observations could be explained by Ridley-Watkins-Hilsum or RWH theory. Born on August 25, 1928, Kroemer worked as a professor of electrical and computer engineering at the University of California, Santa Barbara. Along with Zhores 1. Alferov, he was awarded the Nobel Prize in Physics in 2000. The Gunn effect and its relation to the RWH effect entered the monograph literature in the early 1970s.

The importance of the Gunn diode lies in the dynamic negative resistance exhibited by its characteristic, as shown in above figure. In an n-type semiconductor, the electrons drift under the application of external field. The drift velocity v_d is proportional to the field E, the proportionality constant being called mobility µ . It gives the drift velocity as $v_d=\mu E$ and the differential drift velocity as $dv_4 = \mu dE$. The relation between the drift velocity and field intensity in Gunn diodes is depicted in the graph. It can be easily noticed that the drift velocities of electrons are dependent on the field intensity. The velocity assumes the maximum value when the diode is biased to threshold value.

The peak velocities in various diodes are observed as-GaAs: 2.2, InP: 2.5, InAs: 3.6, InSb: 5.0 and CdTd: 1.5 times 10^7 cm/s. Beyond threshold, a differetial increase in potential gradient causes a differetial reduction in drift velocity, making the mobility negative. The resultant change in current density dj, a negative quantitiy, is also proportional to the differential field dE and the proportionality constant is called (differential) conductivity o It gives the current density as Dj=dE. In n-type semiconductors (and metals), where the carriers are mostly electrons, the conductivity is related to mobility through

$$\sigma = en\mu$$

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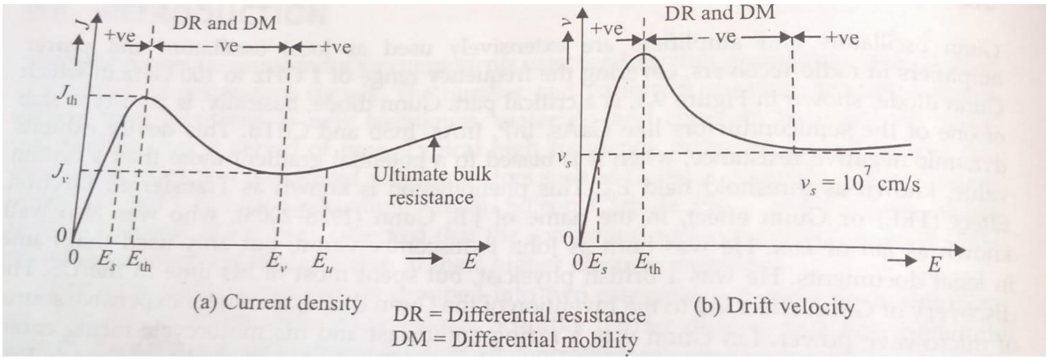


Figure: Variation of (a) Current density J and (b) Drift velocity with electric field E in a two valley semiconductor.

The constants and a usually assume positive values, but for certain n-type semiconductors, being called Gunn diodes, they assume negative values. It leads to manifestation of dynamic negative resistance when the applied field is within a certain range. In these materials,

1. When the field is less than a certain value, called threshold field E_{th}, increase in the field intensity E causes the drift velocity v_d a positive differential mobility μ. Hence, an increase in the field E causes current J to increases resulting in positive differential resistance.
2. When the field is in between threshold value E_{th}, and valley value E_v, increase in the field intensity E causes the drift velocity v_d to decrease due to the onset of TEE, resulting in the negative differential mobility μ. Hence, an increase in the field E causes current J to decrease, resulting in the negative manifestation of differential negative resistance.
3. When the field is more than E_v, increase in field E causes v_d, to increase, resulting in the positive mobility u due to the disappearance of the TEE. Hence, an increase in the field E causes current J to increase, resulting in positive differential resistance.
4. The threshold field value differs from material to material. For different materials, its values are found as-GaAs: 3.3 kV/cm, InP: 10.53 kV/cm, InAs: 1.63 kV/cm, InSb: 0.63 kV/cm CdTd: 13.03 kV/cm.
5. Once the dynamic negative resistance in a region is onset, the sample remains there until the potential gradient falls below a certain value, called sustenance field and is indicated by E_s. Note that it is less than threshold value, i.e., $E_s < E_{th}$
6. Threshold field signifies the minimum potential gradient required to initiate the dynamic negative characteristic, and sustenance field signifies the minimum potential gradient required to maintain or sustain the negative characteristic in the slab.
7. The drift velocity reaches the peak value when applied field is equal to the threshold value, i.e., $E = E_{th}$. Its value, at applied field equal to valley value, i.e., $E = E_v$, is known as sustenance velocity and is denoted by v.

At IBM in 1962, Gunn observed inconsistent experimental results in gallium arsenide and refused to accept them as noise. The cause of such results was later tracked down, ultimately leading to the discovery of Gunn effect. While Gunn recognised the importance be effect, he was not able to determine the underlying physical process. Alan Chynoweth Bell Telephone Laboratories in June 1965 showed that only a transferred electron mechanism could explain the experimental results.

The transferred electron effect is actually a field induced transfer of conduction band electrons from a high mobility lower energy satellite valley to low mobility higher energy satellite valley. The salient features of this phenomenon are mentioned below:

1. It is a bulk material property, i.e., it takes place at each and every point in the body of the material.
2. Due to this effect, the mobility of the electrons in the diode becomes negative.

When compared to the others, InP diodes exhibit better performance. In the energy band structure of Gunn diodes, there exist two satellite valleys in their conduction bands In InP diodes, however, this number is three. The peak to valley current ratio, J_{th}/J_v, in these diodes is larger because the electron transfer proceeds faster with the increasing field. As the thermal excitation of the electrons has lesser effect, InP diodes, due to larger energy separations between lower and its nearest valley, ultimately prone to lower degradation of the peak to valley current ratio. In the InAs and InSb diodes, the energy difference between the satellite valleys is more than that of the forbidden gap under normal pressures. In these diodes, therefore, the transferred electron effect can be observed only when the energy difference between satellite valleys is reduced by applying hydrostatic pressures. Gunn devices are being widely used covering 1 GHz to 100 GHz range. The upper frequency of operation is limited to 150 GHz, mainly due to their finite response time. The output power of these devices is inversely proportional to the square of the frequency. These are also associated with certain noise, which is of two types-one is AM noise normally small due to amplitude variations and the other one is FM noise, which is due to frequency deviations.

II. Experimental Setup

Actual experiments need Gunn oscillator, Gunn power supply, isolator, frequency meter, variable attenuator, detector mount, waveguide stand, VSWR meter, PIN modulator, BNC cable, Cooling fan for Gunn Oscillator. The Gunn oscillator is based on negative differential conductivity effect in bulk semi-conductors which have two conduction bands minimum separated by an energy gap (greater than thermal agitation energies). A disturbance at the cathode gives rise to high field region which travels towards the anode. When this high field domain reaches the anode, it disappears and another domain is formed at the cathode and starts moving towards anode and so on. The time requit-eu for tne uomatn to travel fron cau IOue LO anode (transit time) gives oscillation frequency. In a Gunn oscillator, the Gunn diode is placed in a resonant cavity. In this case the oscillation frequency is determined by cavity dimension rather than by diode itself.

Although Gunn oscillator can be amplitude-modulated with the bias voltage, a epnnrntp PIN modi llntnr thrnl lah PIN dindp for modi llatinn i.e. used. This the actual setup of experiment.

Test Bench: [(X-Band): 8hz to 12Ghz]

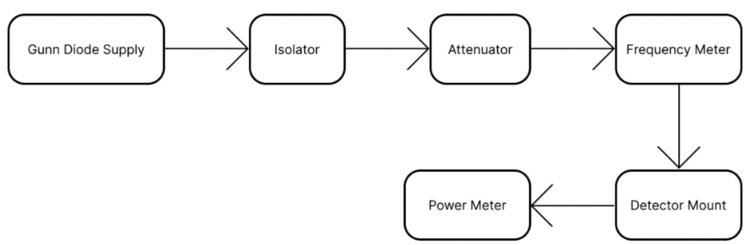


Fig: Setup of VI-Characteristics of Gunn Diode

2.1 Experiment Equipment

A. Gunn Power Supply

The Gunn power supply delivers the DC and control voltages required for the operation of the Gunn oscillator and PIN modulator and. enables the demodulated microwave signal to be quantitatively evaluated.

B. Isolater

A decontaminated unit supplied with grade A (ISO 5) or higher air quality that provides uncompromised, continuous isolation of its interior from the external environment.

C. Attenuator

A device consisting of an arrangement of resistors which reduces the strength of a radio or audio signal.

D. Frequency Meter

Device for measuring the repetitions per unit of time (customarily, a second) of a complete electromagnetic waveform.

E. Detector Mount

Detector Mount are used detect the low frequency signals with the help of the IN23 detector diode. The Detector Diode is mounted on the broad wall of the waveguide. A shorting plunger is used to tune the max power near the detector diode.

F. Power Supply

A Power Meter is one of the most useful and simple instruments to measure electrical power when no deeper analysis of the measured data is required. It measures the voltage (V) and current (A) and derives from these the most important power results

2.2 Characteristics

A. V-I Characteristics

For small forward bias voltages, the forward current keeps on increasing with voltage and attains a peak value, known as the peak current I, at some specific forward bias voltage V_p known as peak voltage. It corresponds to the maximum forward tunnelling. For further increase in the voltage, the current starts dropping and reaches a minimum value 1, known as valley current at another specific voltage, known as valley voltage V_v. With further increase in the voltage, the current starts increasing and setting in the region of positive differential resistance.

The diode exhibits infinite differential resistance at peak and valley points. In between these points, the diode offers negative differential resistance and in the remaining portion of the characteristic, the differential resistance is positive. Under reverse biased condition, the reverse current increases almost linearly with the voltage. Thus, the device acts as a resistor in this region.

B. Figure of Merit

The ratio of the peak current to the valley current, i.e., I_p/l_v, is known as the figure of merit of the diode. Its typical value is approximately equal to 3.5 for Si, 8 for Ge and 15 for GaAs tunnel diodes. Most commercially available tunnel diodes are made of Ge or GaAs. It is difficult to manufacture silicon tunnel diode with a high ratio of peak to valley current J_{th}/J_v GaAs has the highest ratio of 1/1, and largest voltage swing, $V_f - V_p = 1.0$ V.

Equivalent circuit: The equivalent circuit of tunnel diode, as shown in Figure consists of a parallel combination negative resistance $-R_n$, with junction capacitance Cin series with a series combination of lead ohmic resistance R_s, and lead inductance L Two other important parameters pertaining to tunnel diodes used in microwave amplifiers are resistive cut-off frequency and self-resonance frequency. The resistive cut-off frequency f_c, is defined as the frequency at which the real part of the input impedance of diode becomes zero. For tunnel diodes, it is given by $f_c = \frac{1}{2\pi R_n C}\sqrt{\frac{R_n}{R_s}-1}$

The self-resonance frequency f, is defined as the frequency at which the imaginary part of the input impedance is zero. For tunnel diodes, is given by

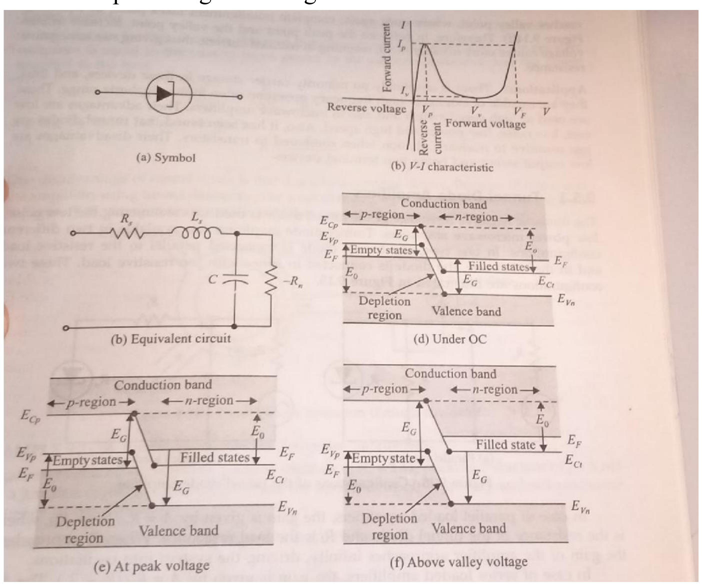
$$f_c = \frac{1}{2\pi R_n C}\sqrt{\frac{R_{nC}^2}{L_s}-1}$$

C. Energy Band Levels

The Fermi level in the tunnel diode always lies outside the forbidden energy gap. As a result of the heavy doping concentrations, on the n-side, it lies in the conduction band and on the p-side, it lies in the valence band.The contact difference of potential energy, E_o is more than the forbidden gap energy Eg, in tunnel diodes, i.e, $E_0 > E_g$. Note that in ordinary diodes, it is other way round, ie, $E_0 < E_g$. The manifestation of negative resistance in tunnel diodes can be understood with the help of energy band diagrams. In these diodes, there exist allowed empty states on p-side and completely filled states on n-side, but at different energy levels, therefore preventing the flow of electrons from filled states to empty states, resulting in no current. This situation prevails under open circuited conditions. However, with the application of forward bias voltage, the empty states and the filled states start aligning, facilitating the movement of electrons from n-side to p-side. Under these conditions, with the increase in forward bias voltage, alignment increases, resulting in the increase in current with the increase in bias voltage. It continues until the bias voltage reaches peak value, where the alignment of empty states with filled states is complete

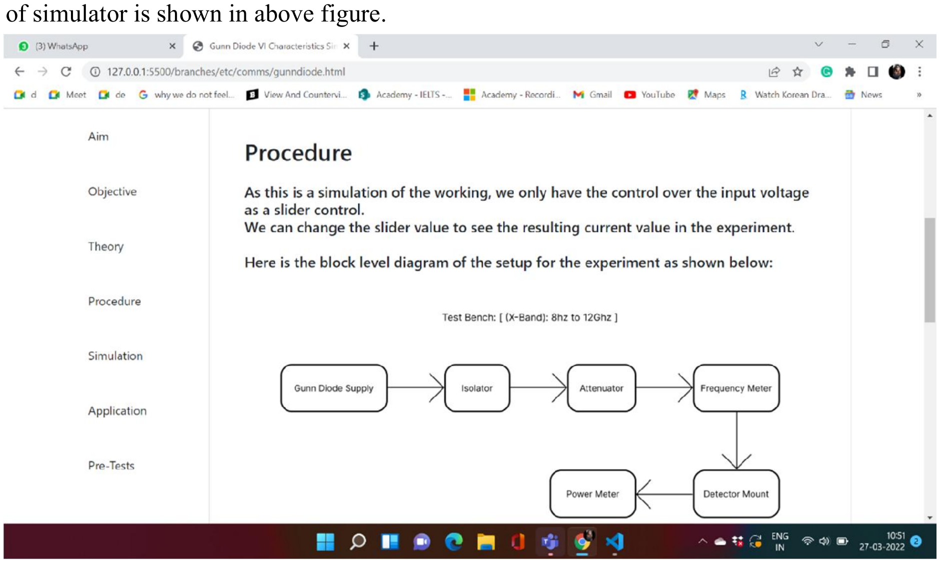
Now, with further increase in the bias voltage, the empty states and the filled states start misaligning, reducing the movement of electrons from n-side to p-side, thereby causing a reduction of current with the increase in voltage. It continues until the bias voltage reaches valley point, where once again, complete misalignment takes place, as shown in above Figure.

Therefore, in between the peak point and the valley point, increase in bas voltage causes more misalignment, resulting in reduced current, thus giving rise to negative resistance. Applications: There is absolutely no minority carrier storage in these devices, and thus, they are capable of extremely high frequency operation often in the gigahertz range. These are used as high speed switch and also in microwave amplifiers. Their advantages are low cost, low noise, low power and high speed. Also, it has been found that tunnel diodes are less sensitive to nuclear radiation when compared to transistors. Their disadvantages are low output swing and being two terminal devices.

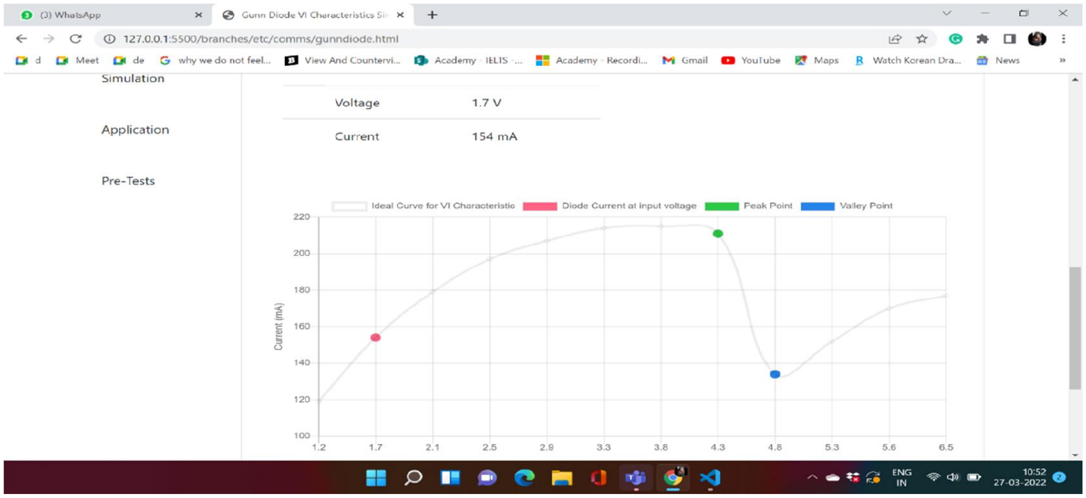


III. TEST RESULT

Virtual setup of simulator is shown in above figure.



V-I characteristics in virtual simulator is shown in above figure.



IV. Acknowledgment

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V. Conclusion

We have described the study and simulation of Gunn diode using a virtual lab.

We simulated V-I Characteristics and measured valley point and peak point of Gunn diode. This would prove very useful for student and teachers during pandemic.

This project will help to provide remote-access to simulation -based Labs in various disciplines of Science and Engineering. To enthuse students to conduct experiments by arousing their curiosity This would help them in learning basic and advanced concepts through remote experimentation.

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