Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2018, 5(5):131-138

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

The Mechanism of Thermal Stability of an Electronic Device (Diode)

Odike, Odike Chidiebere, Prof. F. B. Sigalo

Department of Physics Faculty of Science, Rivers State University, Nigeria

Abstract In this 21st century semiconductor components / devices have dominated the technology world, and have also played important roles in the development of the world technologically, however some short comings have been observed in the operation of these semiconductor devices, basically on the performance of these devices due to some inherent factors like; temperature, most especially when these devices are subjected to operate for a longer time, the temperature increases, and thereby resulting to a low performance of these devices. Experimental method was used to achieve the result of this research, as a test circuit was designed for the determination of temperature effect on the performance characteristics, application, and thermal stability of semiconductor (IN5400) diode, the test circuit was built with a 2kΩ resistor, IN5400 diode, jumper wires, project board, and multimeters and thereafter powered with (0 – 20V) power supply. The output voltages were measured across R1 and D1, and the corresponding currents for both devices were calculated with ohms law formula: (V = IR). This same procedure was used when long connecting / jumper wires were soldered together with the terminals of the diode, these connecting wires replaced the terminals of the diode in the project board, and then the diode was put into furnace, and the furnace was switched on, then the thermometer attached to the furnace was carefully monitored. The output voltage readings, both across resistor and diode were taken after every 5°C increase in the temperature of the furnace. These output readings above room temperature were taken between (35 - 65°C).

Keywords Thermal Stability, Electronic Device

1. Introduction

This research work is concerned with the determination of characteristics, application, and thermal stability of some electronics device, like; diode, when it is functioning under and above room temperature. This study will review if this component can perform stably or effectively, if it has to function under temperature that is above room temperature. This will involve the use of furnace to heat these components from 30 - 65°C, so as to know how much temperature change can affect / alter the original characteristics of this device.

The knowledge of how increase in temperature (thermal effect) on these electronics devices affects electronic devices are important because this component and other electronics devices outside the scope of this work are designed for controlling of electrical / electronic systems (circuits), be it analog or digital system. Therefore, the intelligent realization and observations on the capabilities of this device under higher temperature are necessary and will be employed in course of this research work.

Diode

Diode is an electronic device that only allows current to flow in one direction in its functional state. It has two terminals, the anode and the cathode. Current will flow through this device if only positive voltage is applied to anode and negative to cathode, although there are different types of diodes, but for the purpose of this research, the scope will be limited to IN5400 diode. This IN5400 diode is chosen for this research work because it is the most common and used for most electronic circuit.

The Semiconductor Diode

Figure 1: IN5400 Diode

Semiconductor material in its pure state is a poor conductor of electricity. However the conducting ability of a semiconductor material such as such as silicon or germanium with four valence electrons each, can be improved by adding impurity atom such as indium to the semiconductor material. The impurity atom is called dopant and the process itself is called doping. Depending on the type of impurity atom used, a P-type or an N- type semiconductor material can be produced. If pentavalent (5 valence electron) impurity atom is used, an N-type semiconductor is produced, and if a trivalent (3 valence electron) is used, a P-type semiconductor material is produced. A semiconductor in its pure state is called intrinsic semiconductor while a semiconductor material in its impure state is called extrinsic semiconductor [1].

Light Emitting Diodes (LEDs)

The light emitting diode (LED) is two terminal active electronic devices. It is a simple PN-junction diode made from semiconductor materials like Gallium Arsenide (GaAs), Gallium Phosphide (GaP), and Gallium Arsenide-Phosphide, which emits light through the recombination of electrons and holes when current is forced through the junction by forward biasing the junction in a similar way as in ordinary PN-junction diode. It is important to note that LEDs are not made from silicon or germanium because such LEDs will emit energy with greater percentage as heat with very insignificant amount of light energy [1].

Diode Application

The simplest semiconductor component, the diode, has an astonishing number of applications that are enabled by a number of practical and unique types of diodes that are vital in modern electronics.

While only two pin semiconductor devices, there are a number of applications of diodes that are vital in modern electronics. Diodes are known for only allowing current to move in one direction.

This lets a diode acts as a one-way valve, keeping signals where they need to be or routing them around components. While diodes only let current move in one direction, each type of diode acts differently, making a number of useful applications for diodes.

Some of the typical applications of diodes include:

- Rectifying a voltage, such as turning AC into DC voltages
- Isolating signals from a supply
- Voltage Reference
- Controlling the size of a signal
- Mixing signals
- Detection signals
- Lighting
- Lasers diodes

Power Conversion

One significant application of diodes is to convert AC power to DC power. A single diode or four diodes can be used to transform 110V household power to DC by forming a half-way (single diodes) or a full-wave (four diodes) rectifier. A diode does this by allowing only half of the AC waveform to travel through it. When this voltage pulse is used to charge a capacitor, the output voltage appears to be a steady DC voltage with a small voltage ripple.

Using a full wave rectifier makes this process even more efficient by routing the AC pulses so both the positive and negative halves of the input sine wave are seen as only positive pulses, effectively doubling the frequency of the input pulses to the capacitor which helps keep it charged and deliver a more stable voltage.

Diodes and capacitors can also be used to create a number of types of voltage multipliers to take a small AC voltage and multiply it to create very high voltage outputs. Both AC and DC outputs are possible using the right configuration of capacitors and diodes.

Demodulation of Signals

The most common use for diodes is to remove the negative component of an AC signal so it can be worked with easier with electronics. Since the negative portion of an AC waveform is usually identical to the positive half, very little information is effectively lost in this process. Signal demodulation is commonly used in radios as part of the filtering system to help extract the radio signal from the carrier wave.

Over-Voltage Protections

Diodes also function well as protection devices for sensitive electronic components. When used as voltage protection devices, the diodes are non-conducting under normal operating conditions but immediately short any high voltage spike to ground where it cannot harm an integrated circuit. Specialized diodes called transient voltage suppressors are designed specifically for over-voltage protection and can handle very large power spikes for short time periods, typical characteristics of a voltage spike or electric shock, which would normally damage components and shorten the life of an electronic product.

Current Steering

The basic application of diodes is to steer current and make sure it only flows in the proper direction. One area where the current steering capability of diodes is used to good effect is in switching from power from a power supply to running from a battery. When a device is plugged in and charging, for example, a cell phone or uninterruptible power supply, the device should be drawing power only from the external power supply and not the battery and while the device is plugged in the battery should be drawing power and recharging. As soon as the power source is removed, the battery should power the device so no interruption in noticed by the user, (lifewire.com/application).

This is an important area in research which serves as a bedrock to our own pathway to making contribution to knowledge, in specific terms, it is the review of what other researchers has done on what we are to embark on, how they did it, and what they achieved as a result of the method used and possibly where they published it. Radzieemska, [2] carried out a work on effect of temperature on dark current characteristics of silicon solar cells and diodes; he discovered that the formed voltage of the solar cell degrades 2mv and that in the case of diode 1mv per 1k temperature increase at constant forward current of 100 MA, i.e. for single crystalline silicon solar cell, and a silicon diode within the range of 295 -373k. This result was achieved by placing different thermal resistance on the solar cell using a thick hot copper in the dark. He therefore concluded in this his research work that protection of silicon diodes against overheating is essential during their exploitation. Emre, et al [3] carried out research on high temperature schottyky diode characteristics of bulk zink oxide (ZnO). They discovered that the ideality factor almost remains constant in the temperature range from 240 – 400k, which shows that stability of the schottky contact in this temperature range. This result was achieved by current voltage (I -V) measurement of argon indium (Agln)–zink oxide (ZnO) which was carried out at the temperature of 200 – 500k in order to understand the temperature dependence of diode characteristics. Forward bias I- V analysis results in a schottky barrier height of 0.82eV and the ideality factor of 1.55η at room temperature. The barrier height of 0.74eV and Richardson constant of 0.248$Ak^{-2}cm^{-2}$ were also calculated from Richardson plot, which shows nearly linear characteristics in the temperature range of 240 - 440k. Kang, et al [4] carried out a research on; Temperature dependence and effect of series resistance on the electrical characteristics of polycrystalline diamond metal – semiconductor diode; they discovered, between 25 – 30 degree celcius, the current-voltage (I-V) characteristics of the device show rectifying behavior with forward bias conduction limited by series resistance over the temperature range investigated, the I – V data confirmed that the conduction mechanism of diode is controlled by extrapolating the forward saturation current data, and the ideality factor was observed to decrease from 2.4 – 1.1 while apparent barrier increased linearly from 0.68 – 1.02ev in the same temperature range from 25 – 300 degree celcius. Ejderha, et al [5] carried out a work on; Effect of temperature on current capacitance and conductance –voltage characteristics of Ti/n-GaAs diode; they discovered, the fact that temperature coefficient of barrier height changes from metal to metal has been ascribed to the nature of the contact metal or metal electromagnetivity. This result was achieved through fabrication of Ti / n –GaAsschottky barrier diode by DC magnetron sputtering. The current – voltage, capacitance – voltage, and conductance - voltage characteristics of Ti / n –GaAs- diode was investigated in temperature range of 80 – 320 kelvin. The ideality factor and barrier height value was calculated from forward current – voltage characteristics. The variation of the diode parameters with the sample temperature has been attributed to the presence of the lateral in homogeneities of the barrier height. The temperature dependent capacitance – voltage characteristics was measured to calculate the barrier concentration, diffusion potential, barrier height, and temperature coefficient of the barrier sheight (-0.65meVK). Ueda, et al [6] carried out a research on; High – temperature characteristics and stability of Cu/diamond schottky diodes; they discovered, Cu/diamond schottky exhibited clear rectification up to 700 degree celcius , indicating that high temperature operation is possible using these diodes. This is thought to be due to their large schottky barrier height of approximately 1.6eV. The high temperature stability of the Cu/diamond schottky diodes was also better than that of diodes using Ag or Ni, probably because of less interfacial reaction or inter diffusion between the Cu and diamond. This result was achieved by examining and comparing the electrical stability of Cu/diamond schottky diodes and other schottky diodes using Ag and Ni electrodes. Kungen, et al [7] carried out a work on thermal stability of boron nitride/silicon p-n heterojunction diodes; they discovered, a highly rectifying p-type CBN/thick $silicon$ junction diode which shows irreversible rectification properties mainly characterized by a marked decrease in reverse current by an order of magnitude in an initial temperature ramp/down cycle. This irreversible behavior is reduced by conducting the circle twice or more. The temperature dependent properties confirm an overall increase in effective barrier heights for carrier injection and conduction by biasing at high temperatures, which consequently increases the thermal stability of the diode performance. This result was achieved by fabrication of heterojunction of p-type cubic boron nitride (CBN) and n-type silicon with sp^2-bonded BN (SP^{2BN}) interlayers under low energy ion impact by plasma –enhanced chemical vapour deposition, and their rectifications properties are studied at temperature up to 573 kelvin.

Methodology

Experimental method was used to make researches on how thermal (temperature) affects the reliability, stability, and performance characteristics of this electronic component in the circuit, electrical/electronic appliances, or even as an individual device. Earlier in this dissertation I clearly mentioned that the scope of this research was limited to only one electronic component, which is diode. This component was subjected to temperature higher than room temperature (35-65 celsuis), by the use of furnace, and then through the use of connecting wires, breadboards, and multimeters, then the output readings of the temperature increase affects were taken with multimeters.

Experimental material

- Furnace
- Multimeters
- Breadboards
- Jumper wires.

Experimental Procedures

First Approach

Bread board was made available as also the multimeters, for each of these components, as connecting/jumper wires were connected to the terminals of these components, at the same time with the help of the perforated continuous holes on the breadboard were made to be in the same potential with the connecting wires coming from the multimeters to the breadboard. At this point the components room temperature resistance values were taken, diode current (Di) and diode voltage (Dv) were also taken. Then the furnace was switched on and the diode resistance, diode current, and diode voltage (Dr, Di, Dv).

That is Dv Values were taken after every 5°c increase in furnace temperature. The readings were taken simultaneously as I understood that if the component was allowed to get cooled the virational responds to different degrees of temperature can no longer be ascertained, and it turns worse when the electronic components completely gets damaged.

Second approach

For diode forward stability test;

This circuits below were connected with the help of a breadboard, and the outputs of the circuit were measured and recorded when the diode was at room temperature and then with the help of a long connecting wire, the diode terminals were connected with the connecting wires in the same potential and the diode was put into the furnace, and the furnace was switched on, thereafter, the output readings/ results of the circuit were measured and recorded after every 5 $°c$ increase in temperature of the furnace.

Figure 2: Practical Procedure

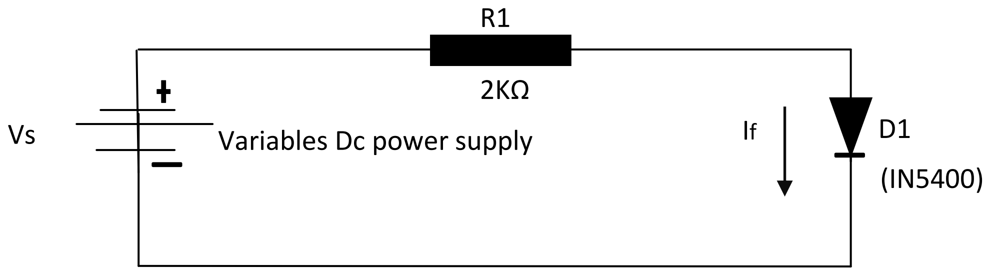

Figure 3: (Circuit connection, forward based characteristics of diode.)

Input Parameters

1. Direct current power supply of maximum voltage of 20volts.
2. Resistor of 2k ohms
3. Silicon diode of IN5400. With varying volts of (10, 15 and 20)

The output parameters: That will be measure and recorded are.

1. VR1 across the resistor R1
2. VD1 across the diode D1

Calculation of the corresponding currents,

1. IR1
2. ID1

However, these output parameters will be well recorded and presented in the next chapter.
The reverse based circuit, for IN5400

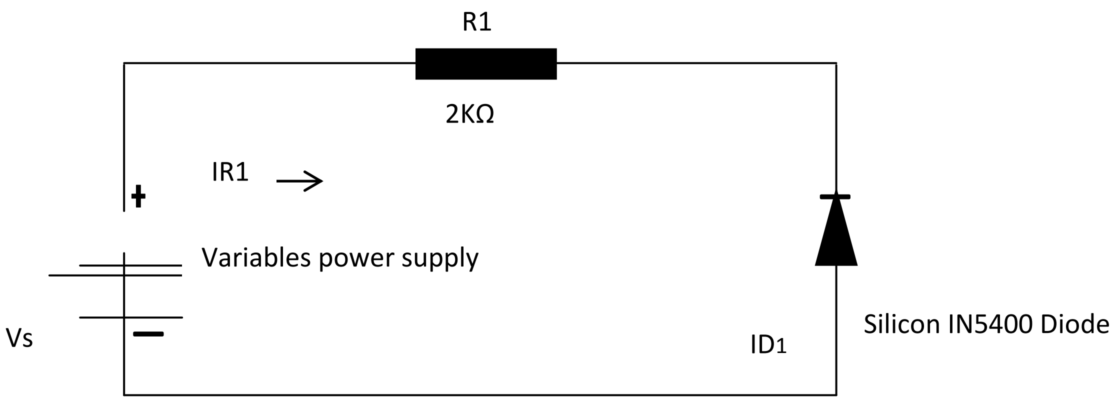

Figure 4: Circuit connection, reverse based characteristics of IN5400

Input parameters:

Direct current supply of maximum voltage of 20volts
Resistor of 2k ohms
Silicon diode of IN5400 with varying voltages of 10volts, and 20v0lts.

Output parameters measured:

VR, across R1
VD, across D1

Calculations of corresponding currents:

IR1
ID1

The results of this experiment will be recorded in chapter four, while the recommendation in chapter five.

Results (Tables and Graphs) / Discussion

The experimental circuits was designed, build / connected and measured as shown in chapter three of this dissertation therefore, this chapter of this work shall contain the results of the experimental work carried out, which shall be unfolded in tables, graphs below and the corresponding discussion of the results.

The table emanating from fig. 3 circuit connection, forward biased characteristics of diode, operating at room temperature, and varied temperature between (35- 65 degree Celsius)

Table 1: Experimental result for diode from room temperature (30°c) to 60°c, Vin = 5.5V

S/N	DATA MEASURED	TEMP.	30°C	35°C	40°C	45°C	50°C	55°C	60°C	65°C
1.	VR1: volt across R1	Temp.	7.460V	7.450V	7.400V	7.489V	7.490V	7.510V	7.510V	7.520V
2.	VD1: volt across D1	Temp	0.609V	0.599V	0.587V	0.576V	0.565V	0.553V	0.548V	0.536V
3.	IR1: calculated, $I = \frac{V}{R}$	Temp	3.370A	3.725A	3.735A	3.740A	3.745A	3.755A	3.755A	3.760A
4.	ID1: : calculated, $I = \frac{V}{R}$	Temp	0.304A	0.299A	0.294A	0.288A	0.283A	0.277A	0.274A	0.268A

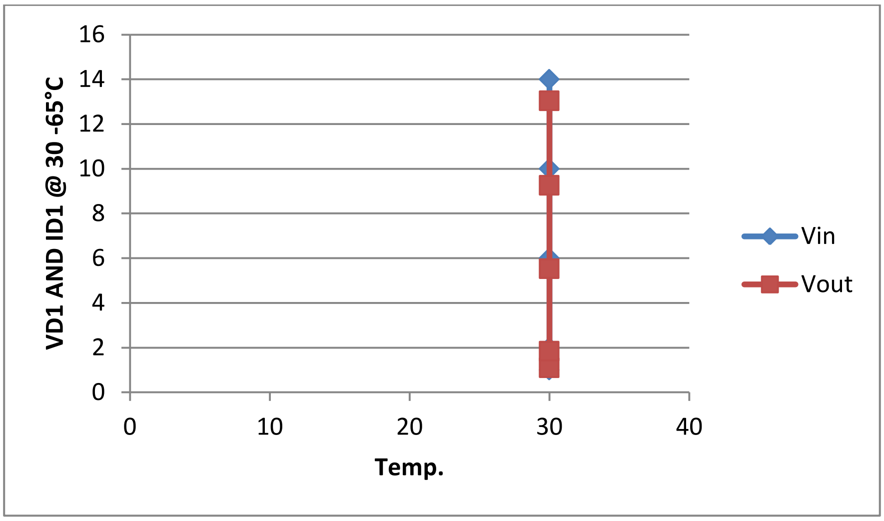

Figure 5: Experimental Graph for voltage (Vd1) and diode current (Id1) diode against Temp. between 30 – 65 °C for forward bias connection

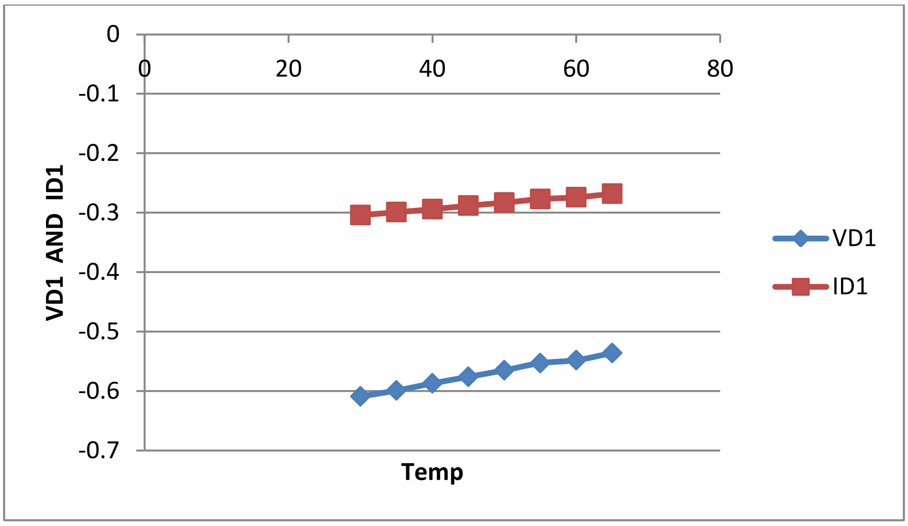

Figure 7: Experimental Graph for voltage (Vd1) and diode current (Id1) diode against Temp. between 30 – 65 °C for reverse bias connection.

Discussion of the Results

It is imperative that after performing practical / research as a scientist / researcher, that we should be able to represent our data in table / graph form, and we should also be able to write report of the outcome of our research, even to the understanding of those outside our field. The graphs which are about to be explained and discussed at this point of this dissertation, are graphs plotted from tables above in this chapter.

Fig. 5 is a graph plotted between VD1 and I D1 against temperature, in a forward bias direction, clear colours indications were made for better understanding of the graphs. Vin is represented in blue colour, while Vout is in red colour, from 30°C -35°C the input voltage (Vin) produced a higher output voltage (Vout) from the test circuit, but as the temperature of the furnace increased from 40°c -65°c, the increase in the input voltage (Vin) resulted in decrease in the output voltage (Vout).

While for Fig. 6, the graph plotted between VD1and ID1 against temperature, but in reverse bias direction, and in this case all the output voltages were all negative values, though the increase in temperature resulted in output increase of both current and voltage.

Conclusion

From the experiment conducted, and the method applied in course of the research carried out, results were achieved, and from the results that were achieved, it was observed that the achieved results were not quite different from the results and information gathered during the literature review of this dissertation. The aim of this work was to know how temperature change (temperature increase 30°C - 65°C) affects semi-conductor devices, although it was limited to only one semi-conductor component (diode). It was observed that indeed, temperature increase between the regions of 30°C - 65°C affected the components output parameters like, the output voltage, current so, conclusively the result of this dissertation work shows that the temperature increase from 30°C to 65°C affected diode output test circuit negatively.

Recommendations

1. There should be improvement in the production of semiconductor devices most especially diode and transistor, in terms of elimination of impurities like oxygen during their formation.
2. Since heat sink alone has not been able to solve the problem of infant mortality on semiconductor components, then there is need for invention of air conditional chips to further reduce increase of heat in a circuit.
3. There should be improvement of heat treatment and annealing of these semiconductor components after their formation processes.
4. Efforts should be put to ensure that commercial electronic / electrical machines functions in an air conditioned environment.

References

[1]. Owate, I. O., Enhirim, C. N., Amusan, J. A., and Ugwuanyi, P. O., (2014). Basic Instrumentation Practical Manual Two. Port Harcourt: ACOTEC Technologies.

[2]. Radziemska, E., (2006). Effect of Temperature on Dark Current Characteristics of Silicon Cells and Diodes. International Journal of Energy Research, 30 (2), Pp. 127 – 134.

[3]. Emre, G., Tuzemen, S., Bayram, K. and Coskun, C., (2007).High Temperature Scottky Diode Characteristics of Bulk ZnO. Journal of Institute of Physics, 19 (19), Pp. 1 - 20.

[4]. Kang, W. P., Davidson, J. L., Gurbuz, Y., and Kerns, D. V., (1995). Temperature dependence and effect of series resistance on the electrical characteristics of a polycrystalline diamond metal-insulator-semiconductor diode. Journal of Applied Physics, 78 (2), P. 1101.

[5]. Ederha, K., Duman, S., Nuhoglu, C., Urhan, F., and Turut, A. (2014). Effect of temperature on the current (capacitance and conductance) – voltage characteristics of $\frac{Ti}{n}$ – GaAs diode.Journal of American Institute of Physics, 116 (23), p.4101.

[6]. Ueda, K., Kawamoto, K., & Asano, H. (2014). High-temperature characteristics and stability of Cu/diamond Schottky diodes. Japanese Journal of Applied Physics, 53(4S), 04EP05.

[7]. Kungen, T., Yusein, M., Takuro, H., and Seichiro, M., (2015). Thermal Stability of Boron Nibide/Silicon p – n Hetero Junction Diodes. Journal of Applied Institute of Physics, 118 (15), P. 5102.