How Temperature Shapes Diode Performance: An Experimental Study on Rectifier, Avalanche, and Zener Diodes

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ABSTRACT

Purpose of the study: The purpose of this study is to experimentally analyze the effect of temperature on the internal resistance of rectifier, avalanche, and Zener diodes by measuring their current–voltage characteristics across different operating temperatures.

Methodology: This study employed an experimental method using two digital multimeters (Sanwa CD800a), a K-type thermocouple (Omega), a DC power supply (GW Instek GPS-3030), an aluminum container, and an electric heater. Data were recorded manually and analyzed using Microsoft Excel for I–V plotting and temperature coefficient calculations.

Main Findings: The rectifier, avalanche, and Zener diodes exhibited distinct I–V characteristics and temperature-dependent behavior. Maximum forward currents were 264.8 mA (rectifier), 299.4 mA (avalanche), and 37.25 mA (Zener). Temperature coefficients showed negative values for avalanche diodes and positive values for Zener diodes. Internal resistance increased with temperature for all diodes, with rectifier Rd ranging from 0.185 Ω to 0.2 Ω, avalanche Rd from 0.233 Ω to 0.25 Ω, and Zener Rd from 0.1 Ω to 0.125 Ω.

Novelty/Originality of this study: This study presents a novel experimental comparison of rectifier, avalanche, and Zener diodes by simultaneously evaluating internal resistance and temperature resistivity coefficients under identical thermal conditions. The results provide new empirical insights into diode-specific thermal behavior, advancing current knowledge on temperature-sensitive performance in practical electronic applications.

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1. INTRODUCTION

The development of modern electronic technology is highly dependent on understanding the characteristics of semiconductor components. Previous research has shown that temperature variations can affect the performance of semiconductor-based devices [1]-[3]. Other studies emphasize that the stability of electronic components is highly sensitive to fluctuations in operating temperature [4]-[6]. In addition, research on diode characteristics indicates that thermal effects can influence the electrical response of components [7]. Therefore, a deeper understanding of the relationship between temperature and the internal resistance of diodes is crucial.

Semiconductor diodes are fundamental components in electronic circuits that are sensitive to temperature changes. Several studies explain that the forward current of a diode increases with rising temperature due to a decrease in barrier voltage [8]-[10]. Other research reports that temperature significantly affects both forward and reverse voltage values. Additional findings also confirm that the temperature coefficient of a diode is an important parameter in precision circuit design [11]-[13]. Thus, understanding the thermal characteristics of diodes is essential for practical applications.

Internal resistance is a key parameter that determines diode performance under various operating conditions. Several studies indicate that the internal resistance of a diode is strongly influenced by temperature due to changes in charge carrier mobility [14], [15]. Other research explains that increasing temperature shifts the diode's I–V characteristics and alters its resistance value [16], [17]. Previous experimental studies have also identified a non-linear relationship between resistance and temperature in certain types of diodes [18]-[20]. Therefore, internal resistance becomes a primary focus in understanding thermal effects in diodes.

However, most previous studies have focused only on general diode characteristics without specifically examining changes in internal resistance in response to temperature variations. Some studies highlight the effect of temperature on forward current without directly measuring resistance [21], [22]. Other research places greater emphasis on thermal effects on device efficiency without separately investigating the internal resistance parameter [23]-[25]. Some studies are even limited to simulations without experimental verification [26], [27]. This indicates the existence of a research gap in experimentally based measurements of internal resistance.

Moreover, research comparing three types of diodes rectifier, avalanche, and Zener diodes in the context of internal resistance across various temperatures remains very limited. Several publications discuss only the general characteristics of rectifier diodes without examining their internal resistance behavior under extreme thermal conditions [28]-[30]. Studies on Zener diodes generally focus on voltage regulation effects rather than internal resistance [31]-[33]. Meanwhile, research on avalanche diodes largely addresses breakdown voltage and thermal runaway phenomena without an in-depth analysis of resistance. Therefore, a comparative study among these diode types is important to fill this gap.

The urgency of this research is further strengthened by the widespread application of electronic devices operating under high-temperature conditions. Previous studies have shown that increasing temperature can lead to performance degradation of diodes in power devices [34], [35]. For example, high-temperature electrothermal stressing of GaN Schottky diodes revealed progressive degradation mechanisms under elevated thermal conditions that impair device reliability and electrical performance [1], [36]. Additional research has found that increased internal resistance may reduce power conversion efficiency in electronic systems. Furthermore, changes in internal resistance under high-temperature conditions can increase the risk of component failure. Therefore, accurate experimental analysis is needed to predict diode performance in real thermal environments.

Considering the identified gaps, urgency, and limitations of previous studies, this research offers direct measurement of diode internal resistance at various temperatures using a standardized experimental approach. Previous studies have not integrated simultaneous measurements of current, voltage, and temperature across three types of diodes. Only limited research has examined the temperature resistivity coefficient in detail within a laboratory temperature range. In addition, comparative characterization among different diode types under thermal conditions has rarely been reported. Thus, this study provides a novel contribution by expanding understanding of the relationship between temperature and the internal resistance of semiconductor diodes. The purpose of this study is to experimentally analyze the effect of temperature on the internal resistance of rectifier, avalanche, and Zener diodes by measuring their current–voltage characteristics across different operating temperatures.

2. RESEARCH METHOD

The equipment used in this study included two digital multimeters, a thermocouple, a DC power supply, an aluminum container, an electric heater, and connecting cables as supporting measurement devices. The materials consisted of three types of semiconductor diodesrectifier, Zener, and avalanche diodes as well as water, which functioned as a heat transfer medium during the heating process. All of these instruments and materials were used in an integrated manner to obtain accurate data on changes in the internal resistance of the diodes with respect to temperature variations.

The data collection procedure began with a preparation stage, which included testing the functionality of the measuring instruments such as the DC power supply, digital multimeters, and thermocouple, as well as assembling the entire experimental setup. During the data acquisition stage, the internal current (Id) and internal voltage (Vd) were measured under both forward-bias and reverse-bias conditions for each type of diode at room temperature. Subsequently, the rectifier diode was placed in the aluminum container filled with water and heated using the electric heater until it reached a temperature of 85°C, as indicated by the thermocouple, under forward-bias conditions. The temperature was then gradually decreased in 5°C intervals while recording the current and voltage values until the lowest readable limit of the thermocouple was reached. The same procedure was then repeated under reverse-bias conditions. This treatment was subsequently applied to the avalanche and Zener diodes, and all measurement results were systematically recorded in a data table.

The data analysis technique in this study was conducted by first plotting the relationship between current (Id) and voltage (Vd) for each type of diode, allowing the internal resistance value to be determined from the slope of the characteristic curve. The measurement results obtained at various temperatures were then used to calculate the temperature coefficient of resistivity (Tc) by comparing changes in internal resistance with changes in temperature. All analyses were carried out systematically to obtain a quantitative description of the effect of temperature on the internal resistance of semiconductor diodes. The research workflow is presented in Figure 1 below.

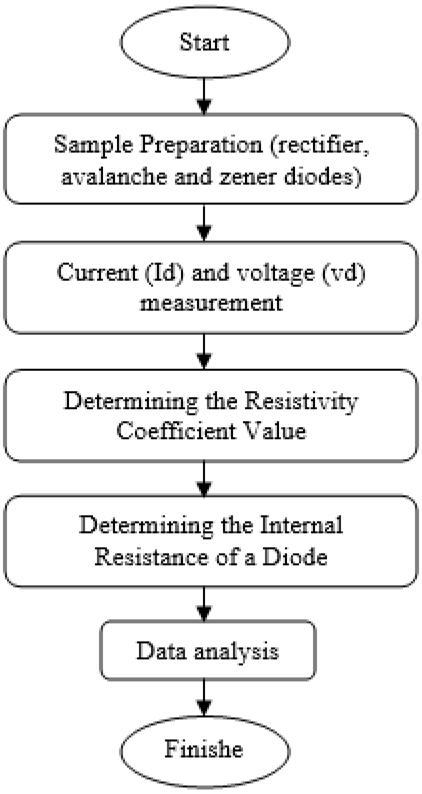

Figure 1. Research Workflow

3. RESULTS AND DISCUSSION

3.1. Before Heating

Based on the study, a table showing the relationship between current (Id) and voltage (Vd) was obtained for each diode. In this research, current (Id) and voltage (Vd) measurements were conducted on rectifier, avalanche, and Zener diodes. These three diodes serve different functions: the rectifier diode is used as a wave rectifier, while avalanche and Zener diodes are used as voltage stabilizers. In principle, avalanche and Zener diodes are similar; the primary difference lies in their Zener voltage values. The avalanche diode has a Zener voltage of 5.1 V, whereas the Zener diode has a Zener voltage of 9.1 V. The measured values of current (Id) and voltage (Vd) for the three diodes differed from one another, and each diode also exhibited different forward-bias and reverse-bias characteristics.

For the rectifier diode, under forward bias the maximum current was 264.8 mA and the maximum voltage was 0.78 V, whereas under reverse bias the maximum current was −1.3 μA and the maximum voltage was −13.9 V. For the avalanche diode, under forward bias the maximum current was 299.4 mA and the maximum voltage was 0.73 V, while under reverse bias the maximum current was 80 mA and the maximum voltage was 5.5 V. For the Zener diode, under forward bias the maximum current was 37.25 mA and the maximum voltage was 0.79 V, whereas under reverse bias the maximum current was 92.8 mA and the maximum voltage was 9.8 V.

In the forward-bias measurements of all three diodes, a source voltage (Vs) of 5 V was applied because the maximum readable forward voltage ranged between 0.6 and 0.7 V. If a source voltage higher than 5 V were used, the diode could be damaged or permanently broken.

For reverse bias, a source voltage of 15 V was applied to the rectifier and Zener diodes, as higher voltages could damage the devices. For the avalanche diode, a source voltage of 10 V was used under reverse bias to prevent breakdown. Figure 1 presents the graph of the relationship between current (Id) and voltage (Vd) for the rectifier diode.

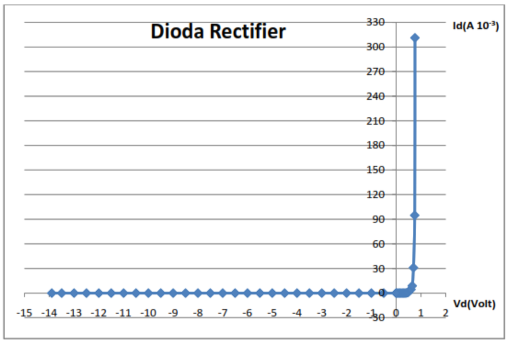

Figure 1. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Rectifier Diode

Under forward bias, no current was produced at voltages between 0.05 V and 0.3 V. The current began to increase at 0.35 V and reached 311.1 mA at 0.76 V. Under reverse bias, every change in voltage resulted in a corresponding change in current.

In forward bias, the current increases slowly at low voltages, but as the voltage approaches approximately 0.7 V, conduction-band electrons and holes accumulate near the junction in large numbers, causing the current to increase rapidly. The voltage at which the current rises sharply is called the knee voltage. For silicon diodes, the knee voltage is approximately 0.7 V, while for germanium diodes it is around 0.3 V. Beyond 0.7 V, the current increases significantly with only a small increase in voltage.

Under reverse bias, the current change is extremely small and difficult to observe on the graph. Practically, reverse current does not flow until the breakdown voltage often tens or hundreds of volts is reached, at which point the diode can no longer withstand electron flow through the depletion layer. An ideal diode behaves as a perfect conductor (zero voltage drop) under forward bias and as an insulator (zero current) under reverse bias.

Figure 2 presents the current–voltage characteristics of the avalanche diode.

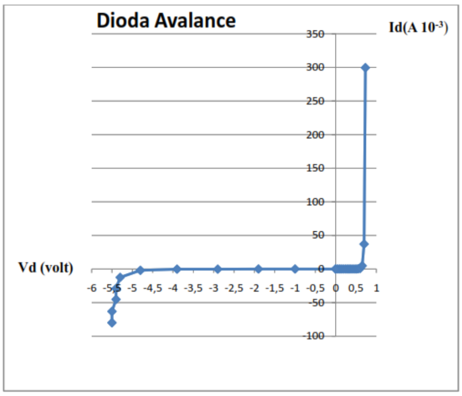

Figure 2. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Avalanche Diode

Under forward bias, no current was observed between 0.05 V and 0.45 V. The current began to increase at 0.5 V and reached 299.4 mA at 0.73 V. Under reverse bias, changes in voltage also resulted in changes in current. According to theory, when the reverse voltage of a Zener diode increases to a certain threshold, the reverse current rises sharply.

Figure 3 shows the current–voltage relationship for the Zener diode.

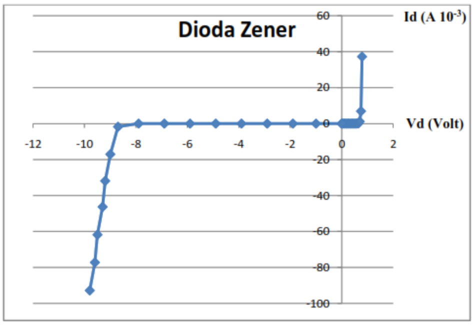

Figure 3. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Zener Diode

Under forward bias, no current was produced between 0.05 V and 0.55 V. The current began to increase at 0.6 V and reached 37.25 mA at 0.79 V. Under reverse bias, each change in voltage resulted in a corresponding change in current.

3.2. After Heating

After heating, tables of current (Id) and voltage (Vd) were obtained at various temperatures and source voltages for each diode. The heating process involved immersing each diode individually into an aluminum container filled with water and heating it using an electric heater. Each diode was heated up to 85°C, as temperatures above this limit could permanently damage the diode and result in inaccurate readings.

Once the thermocouple indicated a temperature of 85°C, measurements of current (Id) and voltage (Vd) were conducted at temperature intervals of 5°C during cooling, down to 29°C.

According to theory, excessive diode current generates excessive heat, which may damage the device. Even approaching the maximum rated temperature can accelerate degradation. Therefore, diodes are typically specified with a maximum allowable current to ensure safe operation.

Figure 4 presents the current–voltage characteristics of the rectifier diode after heating.

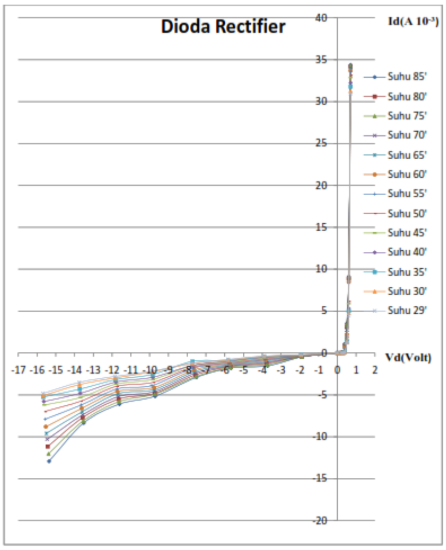

Figure 4. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Rectifier Diode After Heating

Based on Figure 4, the graph of the relationship between current (Id) and voltage (Vd) shows that for forward bias, the resulting curves are nearly identical for each temperature change, making it difficult to distinguish between current (Id) and voltage (Vd) at each temperature. This is because the data obtained from the research are nearly identical for each temperature change. Meanwhile, for reverse bias, the resulting curves clearly show the current (Id) and voltage (Vd) at each temperature change.

Based on the ideal diode curve reference, the forward bias curve should have no voltage change or a constant voltage ($\Delta v = 0$) even when the current increases. However, based on the research results, the resulting curve does not exactly match the ideal diode curve reference. However, the results obtained are close to the second approximation of the diode curve, where the current increases very rapidly after passing the diode knee voltage of 0.7 volts. Meanwhile, for reverse bias, based on the resulting curve reference, there should be no current change, or in other words, no current should flow in reverse bias ($\Delta I = 0$). However, the results obtained in the research deviate significantly from the reference because there is a change in the current value. This indicates that there is a current leakage in the rectifier diode after heating in reverse bias, because the current can pass through in reverse bias even though the voltage is only 15 volts. This shows that temperature greatly affects the characteristics of the rectifier diode. So at a certain temperature, the rectifier diode can no longer be used. Figure 5 presents a graph of the relationship between current (Id) and voltage (Vd) in the avalanche diode after heating.

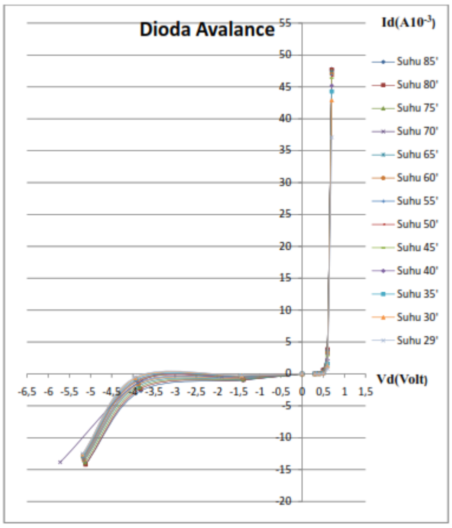

Figure 5. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Avalanche Diode After Heating

Based on the graph of the relationship between current (Id) and voltage (Vd) on an avalanche diode, the forward bias curves closely overlap at every temperature change, except at 70°C and 29°C. This is because the data obtained based on research results are nearly identical at each temperature change. Meanwhile, for reverse bias, the curves are very clear and vary at each temperature, even though they overlap.

Figure 5 shows that the graph of the relationship between current (Id) and voltage (Vd) shows that the higher the temperature on an avalanche diode, the lower the voltage. However, if the avalanche diode has exceeded its Zener voltage of 5.1 volts, the opposite occurs; the voltage (Vd) increases with increasing temperature. This indicates that an avalanche diode has a negative temperature coefficient, meaning the Zener voltage on an avalanche diode decreases with every 1°C increase. Therefore, at a certain temperature, the avalanche diode can no longer be used as a voltage stabilizer because it can affect the readings on the measuring instrument that uses the avalanche diode. Figure 6 presents a graph of the relationship between current (Id) and voltage (Vd) on a Zener diode after being heated.

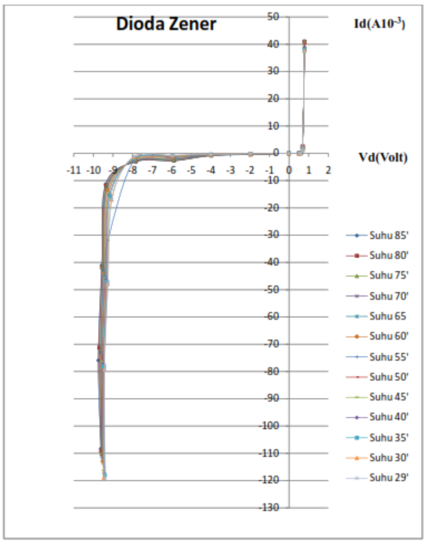

Figure 6. Graph of the Relationship Between Current (Id) and Voltage (Vd) in the Zener Diode After Heating

Based on Figure 6, the graph of the relationship between current (Id) and voltage (Vd) shows that the forward bias curves overlap significantly at all temperatures except 40°C, making it difficult to distinguish changes in current (Id) and voltage (Vd) with each temperature change. This is because the data obtained from the research results are nearly identical at each temperature change. Meanwhile, in reverse bias, the resulting curves are clearly visible and vary with each temperature change, although they overlap slightly.

Figure 6 shows that the higher the temperature, the higher the voltage value for the Zener diode. However, after the Zener diode exceeds its Zener voltage value of 9.1 volts, the opposite occurs; the voltage decreases with increasing temperature. This indicates that the Zener diode has a positive temperature coefficient, meaning the Zener voltage increases with every 1°C increase in temperature.

Zener diodes and avalanche diodes are essentially the same; the only difference is their Zener voltage. Avalanche diodes have a Zener voltage of 5.1 volts, while avalanche diodes have a Zener voltage of 9.1 volts. Both zener and avalanche diodes are designed to operate in the breakdown region. Both diodes have a sharp knee, followed by a nearly vertical current increase, meaning that when the Zener voltage is reached, the current increase will always be vertical.

For both avalanche and zener diodes, the condition for avalanche diodes is considered acceptable if their Zener voltage remains constant. A shift indicates resistance, meaning the resistance varies with temperature changes. Based on the concept of zener and avalanche diodes, the curve obtained should be constant and without a slope, and should be exactly at the Zener voltage, or there should be no voltage change, meaning the voltage will remain constant when it reaches its Zener voltage. Because the two diodes are used as reference voltages, their output voltage should remain unchanged when used as voltage stabilizers. However, the graph shows a voltage shift when the Zener diode reaches its zener point due to temperature changes. This indicates that Zener diodes have temperature limitations. Therefore, when used in certain devices, the Zener voltage will fluctuate, resulting in inaccurate readings. Based on the calculation results using the following equation for the resistivity coefficient of temperature:

$$Tc = \Delta Vz / Vz\,(T1 - T0) \times 100\% \qquad ...(1)$$

the temperature coefficient of resistivity (Tc) values for the three diodes at each source voltage were obtained. These results are presented in Table 1, which describes the relationship between temperature and the temperature coefficient of resistivity for avalanche and Zener diodes.

Table 1. Relationship Between Temperature and the Temperature Coefficient of Resistivity in Avalanche and Zener Diodes

Avalanche diode			Zener diode					
Vs(Volt)	T1(°C)	Tc(°C)	Vs(Volt)	T1(°C)	Tc(°C)	Vs(Volt)	T1(°C)	Tc(°C)
1.9	85	-0.47091	1.9	85	0.055402	9.0	70	0.084656
	75	-0.55991		65	0.099573		65	0.09009
	65	-0.69701		55	0.155945		60	0.09375
	50	-1.14833		29	4.736842		55	0.111111
	40	-2.0614	3.9	85	0.026991		50	0.116162
3.9	85	-0.04049		80	0.034517		45	0.137265
	80	-0.03945		75	0.043644		40	0.166667
	75	-0.03273		60	0.072115		35	0.222222
	70	-0.03053		50	0.11655		30	0.444444
	65	-0.02772		29	2.820513		29	0.555556
	60	-0.02404	5.9	85	0.00595	9.3	85	0.050934
	55	-0.01899		80	0.00326		80	0.051696
	50	0		75	0		75	0.05262
	45	0.015083		70	0.004036		70	0.051203
	40	0.042735		65	0.009162		65	0.049404
	35	0.10989		60	0.01589		60	0.047043
	30	0.512821		55	0.02511		55	0.043807
5.9	85	-0.05352		50	0.038521		50	0.039101
	75	-0.06131		40	0.084746		45	0.031626
	70	-0.06457		30	0.59322		40	0.026882
	65	-0.06871		29	1.186441		35	0
	60	-0.07415	7.9	85	-0.01777		30	-0.10753
	55	-0.08161		80	-0.01461		29	-0.13711
	50	-0.09245		75	-0.01347	9.5	85	0.027412
	30	-0.9322		70	-0.01206		80	0.020032

65	-0.01026	75	0.011082
60	-0.00396	70	0.00744
50	0	65	0
45	0.007446	60	-0.00651
40	0.021097	55	-0.01929
35	0.02425	50	-0.03314
30	0.253165	45	-0.06127
29	0.632911	40	-0.10417
		35	-0.20833
		30	-0.83333
		29	-1.77083

The values of the temperature coefficient of resistivity for the three diodes vary considerably; some are positive, some negative, and others equal to zero. A negative temperature coefficient indicates that with every increase in temperature, the diode voltage decreases. A positive temperature coefficient indicates that with each increase in temperature, the diode voltage also increases. Meanwhile, a zero temperature coefficient signifies that an increase in temperature does not result in any voltage change; in other words, the diode voltage remains unchanged both before and after heating.

Based on the calculated temperature coefficient of resistivity (Tc) values presented in Table 1, the results include positive, negative, and zero values. A positive Tc value indicates an increase in diode voltage as temperature rises, whereas a negative Tc value indicates a decrease in diode voltage with increasing temperature.

From the graph of the relationship between current (Id) and voltage (Vd), the internal resistance (Rd) values for the rectifier, avalanche, and Zener diodes were determined and are presented in Table 2, which shows the relationship between temperature and internal resistance.

Table 2. Table of Relationship between Temperature and Internal Resistance

Temperature	Rectifier Rd (Ω)	Avalanche Rd (Ω)	Zener Rd (Ω)
29	0.185	0.233	0.1
30	0.185	0.233	0.1
35	0.185	0.233	0.1
40	0.185	0.233	0.1
45	0.192	0.233	0.1
50	0.192	0.233	0.1
55	0.192	0.241	0.1
60	0.192	0.241	0.1
65	0.192	0.241	0.1
70	0.2	0.241	0.1
75	0.2	0.241	0.1
80	0.2	0.241	0.11
85	0.2	0.25	0.125

In rectifier diodes, based on the reference for forward bias, the Internal Resistance (Rd) value is 0 which is caused by the absence of voltage changes ($\Delta V = 0$) or the voltage is constant. While in reverse bias the internal resistance (Rd) value is infinite due to the absence of current flowing in reverse bias. However, based on the graph obtained, in forward bias there is a slope or deviation due to changes in the voltage value. This causes the forward bias rectifier diode to have an internal resistance (Rd) value, but not too large. Likewise in the avalance diode and zener diode, both diodes are shown in the graph to have a slope, so there is an Internal resistance (Rd) value. Based on the theory, the current value in the zener diode when it has reached its zener voltage, namely in the avalance diode 5.1 Volt and in the zener diode 9.1 Volt, then the increase in current will always be stable or vertical, or the resulting curve will be straight. Based on the graphs of the three diodes, it can be concluded that the internal resistance value will increase when the temperature in the diode also increases.

The results of this study demonstrate clear temperature dependence of diode electrical parameters, where internal resistance values of rectifier, avalanche, and Zener diodes vary systematically with junction temperature. Specifically, many of the diodes exhibited a decrease in dynamic resistance as temperature increased, consistent with the behavior of semiconductor charge carriers: higher thermal energy increases carrier generation and reduces effective resistance values at elevated temperatures (e.g., charge carrier concentration increases while mobility changes with temperature) as reported in recent experimental studies on PN-junction diode performance with temperature variations [1]. Moreover, the observed reduction in resistive values with increasing temperature aligns with well-established temperature effects in semiconductor devices, where forward voltage typically decreases and current increases at higher temperatures due to a reduced energy bandgap and enhanced carrier activity. This temperature dependence also parallels electrical parameter studies in Schottky diodes that show conduction mechanisms and I–V characteristics change with temperature over wide ranges, confirming that diode electrical behavior is strongly influenced by thermal conditions [37]. Additionally, literature on breakdown mechanisms in Zener and avalanche diodes indicates that the temperature coefficient of breakdown voltage can be positive or negative depending on the dominant breakdown effect, which helps explain variation trends in your Zener and avalanche diode resistance values as temperature varies. These findings support the conclusion that thermal effects play a critical role in the performance and reliability of semiconductor diodes, and highlight the importance of considering temperature dependence when designing and applying diode devices in practical circuits.

These results are consistent with previous empirical studies investigating the temperature dependence of semiconductor diode parameters. For example, Jacobs et al. [38], demonstrated that the forward voltage of silicon PN junction diodes decreases systematically with increasing temperature due to enhanced intrinsic carrier concentration and bandgap narrowing effects, while reverse leakage current increases significantly at elevated temperatures The observed temperature-dependent behavior of diode electrical parameters in this study aligns with established findings in the semiconductor literature. A classical investigation into silicon p-n junctions demonstrated that the reverse characteristics and breakdown behavior exhibit clear temperature coefficients, where Zener breakdown shows a negative temperature dependence at lower voltages while avalanche breakdown exhibits a positive temperature coefficient at higher voltages, reflecting the underlying mechanisms of tunneling and impact ionization respectively [39]. Furthermore, empirical research on gallium nitride (GaN) p-n diodes has shown that I–V characteristics including barrier heights and ideality factors vary systematically with temperature due to thermionic emission and carrier transport effects, providing evidence that temperature not only affects current magnitudes but also intrinsic diode parameter extraction [40]. Compared to these earlier studies, the present work contributes by conducting a direct comparative analysis of rectifier, Zener, and avalanche diodes under identical thermal conditions, thereby offering a clearer quantitative mapping of temperature coefficients and internal resistance changes across diverse diode types.

The novelty of this study lies in its systematic and comparative experimental analysis of temperature effects on three different types of diodes rectifier, avalanche, and Zener under identical thermal and electrical conditions, with a particular focus on the simultaneous evaluation of internal resistance (Rd) and temperature resistivity coefficient (Tc). Unlike most previous studies that typically investigate only a single diode type or emphasize breakdown voltage and I–V characteristics, this research provides a direct quantitative comparison of thermal behavior across diode categories, revealing that each diode exhibits distinct and non-linear thermal response patterns. Furthermore, this study introduces a detailed mapping of positive, negative, and zero temperature coefficients within practical operating temperature ranges (29–85°C), which has rarely been reported comprehensively in earlier literature. This integrated approach not only deepens the understanding of thermal sensitivity in semiconductor diodes but also offers new empirical evidence for selecting appropriate diode types in temperature-critical electronic applications, thereby contributing original insights to both experimental semiconductor physics and applied electronic system design.

The findings of this study have several important theoretical and practical implications. From a theoretical perspective, this research strengthens the understanding of temperature-dependent electrical behavior in semiconductor diodes, particularly by demonstrating how internal resistance (Rd) and temperature resistivity coefficient (Tc) vary differently among rectifier, avalanche, and Zener diodes. These results contribute to semiconductor device theory by providing empirical evidence that thermal effects cannot be generalized across diode types, as each device exhibits distinct thermal sensitivity patterns. From a practical perspective, the results offer valuable guidance for electronic circuit design, especially in applications that require high thermal stability, such as voltage regulation systems, power supplies, and sensor circuits. The identification of positive and negative temperature coefficients enables engineers to select the most suitable diode type based on operating temperature conditions, thereby improving circuit reliability, accuracy, and long-term performance in real-world electronic systems. This study is limited by the fact that the experiments were conducted within a restricted temperature range (29–85°C) and on a limited number of diode samples, which may not fully represent the behavior of all diode types under extreme thermal conditions.

4. CONCLUSION

Based on the analysis and discussion conducted, it can be concluded that each increase in temperature causes an increase in internal resistance in the three types of diodes, which is influenced by changes in current (Id) and voltage (Vd) values. In rectifier diodes, internal resistance increases from 0.185 Ω at 29°C to 0.2 Ω at 85°C, while in avalanche diodes it increases from 0.233 Ω to 0.25 Ω in the same temperature range. Zener diodes show an increase in internal resistance from 0.1 Ω at 29°C to 0.125 Ω at 85°C. In addition, the calculation of the temperature resistivity coefficient (Tc) value shows that the three types of diodes have different Tc values at each temperature change, which can be positive, negative, or zero. A positive Tc value indicates an increase in voltage as the temperature increases, a negative Tc indicates a decrease in voltage due to an increase in temperature, while a zero Tc indicates no change in voltage when the temperature increases. Future research should investigate the temperature-dependent characteristics of various diode types over a wider temperature range and with larger sample sizes, combined with numerical simulation, to obtain more comprehensive and generalizable results.

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