IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024

DOI: 10.17148/IARJSET.2024.11838

Temperature and High-Intensity Illumination Dependence Characteristic Study of Nonlinear Effects in Photoconductive Materials

M. K. Maurya*[1], Satyam Yadav[2], Shyam Sunder Tiwari[3], Sunil A. K. Kerketta[4]

Assistant Professor, Department of Physics, Rajeev Gandhi Govt. P.G. College, Ambikapur-497001, Chhattisgarh[1]

M.Sc. Student, Department of Physics, Rajeev Gandhi Govt. P.G. College, Ambikapur-497001, Chhattisgarh[2]

Assistant Professor, Department of Physics, Govt. E.V. P.G. College, Korba, Dist.-Korba-495677, Chhattisgarh[3]

Assistant Professor, Department of Geology, Rajeev Gandhi Govt. P.G. College, Ambikapur-497001, Chhattisgarh[4]

Abstract: In this research paper, we have investigated the dependence of temperature and high intensity illumination on the photoconductive materials by using the properties of recombination rates, carrier generation rate and carrier concentration. This photoconductive materials shows the nonlinear effect in our studies. Nonlinear photoconductivity represents a vital area of study in material science, with significant implications for the development of advanced optoelectronic devices. This research explores the complex phenomena of nonlinear photoconductivity in various materials when exposed to high-intensity illumination. Unlike linear photoconductivity, where the conductivity increases proportionally with light intensity, nonlinear photoconductivity involves intricate mechanisms such as carrier trapping, defect state saturation, and multiphoton absorption, leading to non-proportional responses in the material's conductivity. This study focuses on the experimental characterization and theoretical modeling of these nonlinear effects in selected semiconductor and organic materials. The findings reveal how high-intensity illumination can induce significant deviations from linear behaviour, including sublinear and superlinear conductivity responses, and even negative photoconductivity under certain conditions. The results not only enhance our understanding of light-matter interactions in non-linear regimes but also provide valuable insights for optimizing materials for practical applications in photodetectors, solar cells, and other optoelectronic devices that operate under varying light conditions.

Keywords: Photoconductivity, optoelectronic devices, high-intensity illumination, multiphoton absorption.

I. INTRODUNCTION

The study of nonlinear photoconductivity phenomena in materials under high-intensity illumination represents a critical frontier in material science and condensed matter physics. The nonlinear response of materials to light, particularly in terms of photoconductivity, is not only fundamental to understanding material properties but also crucial for the development of advanced optoelectronic devices, such as photodetectors, solar cells, and optical sensors. This research aims to explore the mechanisms that govern the nonlinear photoconductive behaviour in various materials when exposed to high-intensity illumination, thereby contributing to the broader understanding of light-matter interaction in non-linear regimes[1-3].Photoconductivity is the phenomenon where the electrical conductivity of a material increases upon exposure to light. This effect is primarily due to the generation of charge carriers (electrons and holes) when photons are absorbed by the material. In linear photoconductivity, the increase in conductivity is directly proportional to the intensity of illumination. However, in many materials, especially those with complex electronic structures or in high-intensity light fields, the response becomes nonlinear, leading to a variety of intriguing phenomena such as saturation, sublinear or superlinear responses, and even negative photoconductivity under certain conditions[4-6] .

The nonlinear photoconductive behaviour is particularly significant in materials where the interaction between charge carriers, defects, and other electronic or lattice excitations plays a prominent role. These interactions can lead to a variety of effects, including photocarrier trapping, defect state saturation, and nonlinear recombination processes, all of which contribute to the observed nonlinearity in photoconductivity. Understanding these effects is essential for tailoring materials for specific applications, especially in environments where high-intensity illumination is prevalent, such as in laser-based devices and high-efficiency photovoltaic cells [7]. At the heart of nonlinear photoconductivity is the interplay between the intensity of the incident light and the material's electronic structure. When a material is illuminated with light, photons are absorbed, leading to the excitation of electrons from the valence band to the conduction band, thereby generating free charge carriers.

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024

DOI: 10.17148/IARJSET.2024.11838

In a linear regime, the number of these photogenerated carriers is proportional to the intensity of the incident light. However, as the intensity increases, various nonlinear effects can come into play[8-10]. One of the primary mechanisms driving nonlinearity in photoconductivity is the saturation of available states in the conduction band or trapping states within the material. As the intensity of illumination increases, more states become occupied, and further absorption of photons becomes less efficient, leading to a sublinear increase in photoconductivity. Conversely, in some materials, the increase in carrier mobility or the presence of additional excitation pathways can lead to a superlinear response, where photoconductivity increases faster than the intensity of the light [11-14].Moreover, the role of defects and impurities in the material cannot be understated. Defect states can act as traps for photogenerated carriers, and their saturation at high illumination intensities is a key contributor to nonlinear behavior. In materials with high defect densities, such as certain semiconductors and organic materials, the trapping and de-trapping dynamics can lead to complex, often temperature-dependent nonlinear photoconductive responses.

High-intensity illumination introduces additional complexities to the study of photoconductivity. In such regimes, the electric field associated with the light can become comparable to or exceed the internal fields within the material, leading to nonlinear optical effects such as multiphoton absorption, avalanche breakdown, and significant heating effects. These phenomena can significantly alter the photoconductive response of the material, making it crucial to distinguish between intrinsic nonlinearities due to electronic processes and extrinsic effects such as thermal damage or structural changes induced by the intense light[15] .The study of nonlinear photoconductivity under high-intensity illumination is also of great technological interest. For instance, in photovoltaic applications[16], understanding how materials behave under concentrated sunlight, which represents a high-intensity illumination scenario, is critical for optimizing efficiency. Similarly, in optical sensors and photodetectors, the ability to operate effectively under varying light conditions, including high-intensity flashes, requires a deep understanding of the material's nonlinear photoconductive properties.

II. THEORETICAL DESCRIPTION

The exploration of nonlinear photoconductivity under high-intensity illumination is anchored in several fundamental concepts and theoretical models that describe the interaction of light with matter. This section outlines the key theoretical constructs that form the foundation of this research, focusing on the electronic structure of materials, the mechanisms of photoconductivity, and the non-linear effects that emerge under conditions of high-intensity illumination. We have worked upon the temperature dependence of photoconductive material and also it's high intensity illumination. We have discussed the recombination rate that shows the nonlinear effect with it's characteristics:

2.1. Derivation of Temperature Dependence of Photoconductivity

Photoconductivity (σ) in materials is fundamentally influenced by the generation and recombination of charge carriers when the material is exposed to light. The temperature dependence of photoconductivity arises from the influence of temperature on these processes, particularly on carrier mobility (μ) and the carrier concentration (n).

The photoconductivity can be expressed as:

$$\sigma = q * n * \mu \quad (1)$$

where:
- q is the charge of the carrier,
- n is the photo-generated carrier concentration,
- μ is the carrier mobility.

The carrier concentration n generated by light is related to the absorption coefficient (α) and the intensity of the incident light (I). The temperature dependence of n comes from the temperature dependence of the absorption coefficient and the generation rate, which is influenced by thermal effects.

We know that the carrier mobility (μ) generally decreases with increasing temperature due to increased phonon scattering. This relationship can be expressed as:

$$\mu(T) = \mu_0 T^{-m} \quad (2)$$

where m is a material-specific constant, and μ_0 is the mobility at a reference temperature.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

Under high-intensity illumination, the recombination rate R can become significant and is often nonlinear with respect to the carrier concentration. The recombination rate can be expressed as:

$$R(n) = R_0 + \beta n + \gamma n^2 \quad (3)$$

where β and γ are coefficients representing linear and nonlinear recombination processes, respectively.

Combining these, the steady-state carrier concentration under illumination can be determined by balancing the generation rate (G) and recombination rate (R):

$$G = R(n) = R_0 + \beta n + \gamma n^2 \quad (4)$$

For high-intensity illumination, where γn^2 dominates, the carrier concentration n becomes:

$$n(T) \propto \frac{G}{\gamma} \quad (5)$$

Substituting into the photoconductivity equation(1):

$$\sigma(T) = q * \left(\frac{G}{\gamma}\right) * \mu(T) \quad (6)$$

Finally, substituting the temperature dependence of $\mu(T)$:

$$\sigma(T) \propto \left(\frac{G}{\gamma}\right) * \mu_0 * T^{-m} \quad (7)$$

This equation shows that photoconductivity decreases with increasing temperature due to the decrease in carrier mobility, while the generation rate and nonlinear recombination also influence the behaviour under high-intensity illumination.[17,18]

2.2. Derivation of Photoconductivity Equation under High-Intensity Illumination

Photoconductivity describes how the electrical conductivity of a material changes under the influence of light. In a photoconductive material, light absorption generates charge carriers (electrons and holes), which contribute to increased electrical conductivity. At high light intensities, the relationship between the photoconductivity (σ_{ph}) and light intensity (I) becomes nonlinear.

Basic Photoconductivity Concept:
Under moderate illumination, the photoconductivity σ_{ph} is generally proportional to the light intensity I. However, as intensity increases, the relationship deviates from linearity due to various factors, including saturation effects and the nonlinear generation of charge carriers. The general form of photoconductivity as a function of intensity is:

$$\sigma_{ph} = \sigma_0 \left(\frac{I}{I_s}\right)^m \quad (8)$$

where:
- σ_0 is the photoconductivity at a reference intensity.
- I_s is the saturation intensity, which characterizes the intensity at which the material response starts to saturate.
- m is the nonlinearity exponent, indicating the degree of deviation from linear behavior.

Derivation: At high intensities, the rate of generation of charge carriers G can be modeled as:

$$G = G_0 \left(\frac{I}{I_0}\right)^n \quad (9)$$

Where G_0 is the carrier generation rate at a reference intensity I_0, and n characterizes the nonlinear dependence of carrier generation on intensity.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

We know that the photoconductivity σ_{ph} is proportional to the product of the carrier density n and the mobility of the charge carriers μ. For high-intensity conditions, the carrier density n increases nonlinearly with I, leading to:

$$n \propto \left(\frac{I}{I_s}\right)^m \quad (10)$$

Therefore, the photoconductivity, which is proportional to the carrier density, also follows:

$$\sigma_{ph} \propto \left(\frac{I}{I_s}\right)^m \quad (11)$$

Incorporating the proportionality constant, the final expression for photoconductivity under high-intensity illumination is:

$$\sigma_{ph} = \sigma_0 \left(\frac{I}{I_s}\right)^m \quad (12)$$

This derivation and equation are essential for analyzing and interpreting the nonlinear behaviour of photoconductivity in materials subjected to high-intensity illumination.[19]

2.3. Derivation of Photoconductivity in the Presence of Traps

Photoconductivity in materials can be significantly influenced by the presence of traps—defects or impurities that capture charge carriers, thereby affecting their free movement and recombination dynamics. Understanding the role of traps is crucial, especially under high-intensity illumination, where nonlinear effects are prominent.

The photoconductivity σ in a material is generally given by:

$$\sigma = q * n * \mu \quad (13)$$

where:
- q is the charge of the carrier,
- n is the concentration of free charge carriers,
- μ is the mobility of the carriers.

In the presence of traps, not all photo-generated carriers contribute to the photoconductivity. Some carriers are captured by traps, reducing the effective number of free carriers available for conduction. The total concentration of photo-generated carriers n_t can be expressed as the sum of free carriers n and trapped carriers n_{tr} :

$$n_t = n + n_{tr} \quad (14)$$

The trapping and de-trapping processes are typically characterized by capture and release rates, which depend on the trap density, capture cross-section, and temperature. The trapping rate can be expressed as:

$$\frac{dn_{tr}}{dt} = C_t * n * (N_t - n_{tr}) \quad (15)$$

where:

- C_t is the capture coefficient,
- N_t is the total density of traps.

At steady state, the trapping and de-trapping rates balance out, leading to:

$$C_t * n * (N_t - n_{tr}) = R_t * n_{tr} \quad (16)$$

Where, R_t is the release rate of trapped carriers. Solving for the steady-state concentration of trapped carriers n_{tr}:

$$n_{tr} = \frac{C_t * n * N_t}{C_t * n + R_t} \quad (17)$$

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

Now the effective concentration of free carriers n_{eff} contributing to photoconductivity is:

$$n_{eff} = n_t - n_{tr} = n\left(1 - \frac{C_t * N_t}{C_t * n + R_t}\right) \quad (18)$$

In high-intensity illumination, where the carrier concentration n is high, the term $C_t * n$ dominates over R_t, simplifying the effective carrier concentration:

$$n_{eff} \approx n * \left(\frac{C_t}{C_t * n + R_t}\right) \quad (19)$$

Now substituting into the photoconductivity equation:

$$\sigma = q * n_{eff} * \mu \quad (20)$$

$$\sigma \approx q * n * \left(\frac{R_t}{C_t * n + R_t}\right) * \mu \quad (21)$$

This equation shows that photoconductivity is reduced by the presence of traps, particularly at lower light intensities where n is small. However, under high-intensity illumination, the effect of traps becomes less significant as the term $C_t * n$ grows large, making the photoconductivity approach its maximum value, limited by the mobility μ and the total carrier generation.[20,21]

2.4. Derivation of Thermally Activated Trapping and Detrapping

In semiconductors and insulating materials, charge carriers (electrons and holes) can become trapped in localized states, known as traps, which are typically associated with impurities or defects in the material. The process of trapping and detrapping of these carriers is thermally activated, meaning it depends on temperature. Understanding these processes is crucial in studying nonlinear photoconductivity, particularly under high-intensity illumination.

When a charge carrier is trapped, it is held in a localized state and does not contribute to the material's electrical conductivity. The time it takes for a carrier to escape from a trap and contribute again to conduction is the detrapping time, which is influenced by temperature. The rate at which a carrier escapes from a trap is described by an Arrhenius-type expression, reflecting the thermally activated nature of the process.

Derivation:

The rate at which a trapped carrier escapes (or detrapping rate) is given by:

$$\nu_{detrap} = \nu_0 exp\left(\frac{-E_t}{k_B T}\right) \quad (22)$$

where:

- ν_0 is the attempt-to-escape frequency, representing how often the carrier attempts to escape the trap.
- E_t is the trap depth or activation energy required for the carrier to escape.
- k_B is the Boltzmann constant.
- T is the absolute temperature.

Now the detrapping time constant $\tau(T)$, which is the average time a carrier remains trapped before escaping, is the inverse of the detrapping rate is given by:

$$\tau(T) = \frac{1}{\nu_{detrap}} = \frac{1}{\nu_0} exp\left(\frac{E_t}{k_B T}\right) \quad (23)$$

This equation shows that as temperature increases, the detrapping time decreases, making it easier for trapped carriers to escape and contribute to conductivity.

Now to analyze the thermal activation, we often plot $\tau(T)$ versus $1/T$. The relationship is linear, with a slope that is proportional to the trap depth E_t. For this taking logarithm of equation(23) gives,

$$ln(\tau(T)) = ln\left(\frac{1}{\nu_0}\right) + \frac{E_t}{k_B T} \quad (24)$$

The slope of this line gives $\frac{E_t}{k_B}$, from which the trap energy E_t can be determined.[22]

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024

DOI: 10.17148/IARJSET.2024.11838

III. RESULT AND DISSCUSSION

Temperature dependence of photoconductivity (photoconductivity σ as a function of Temperature T)

The plotted curve demonstrates the relationship between photoconductivity σ and temperature T for a material under high-intensity illumination, where nonlinear recombination effects are significant.

1. High Temperature Region: At higher temperatures, the photoconductivity decreases rapidly. This decline is attributed to the reduction in carrier mobility μ as temperature increases, due to enhanced phonon scattering. The plot shows a sharp drop in photoconductivity, emphasizing the strong temperature dependence of mobility, which is particularly relevant in high-temperature conditions where carrier-phonon interactions are dominant.

2. Low Temperature Region: At lower temperatures, the curve shows that photoconductivity remains relatively high, owing to the limited phonon scattering and hence higher carrier mobility. The slower decrease in photoconductivity in this region reflects the dominance of the generation rate over temperature-induced scattering effects.

3. Overall Behaviour: The overall behaviour of the curve indicates that photoconductivity in photorefractive materials is highly sensitive to temperature changes. This sensitivity is crucial for understanding material performance under different thermal conditions, especially in applications where maintaining stable photoconductivity across a range of temperatures is necessary, such as in high-intensity photodetectors and other optoelectronic devices.

This graph provides valuable insights into the temperature-dependent performance of materials, which is essential for optimizing their use in practical applications involving nonlinear photoconductivity under varying thermal conditions.

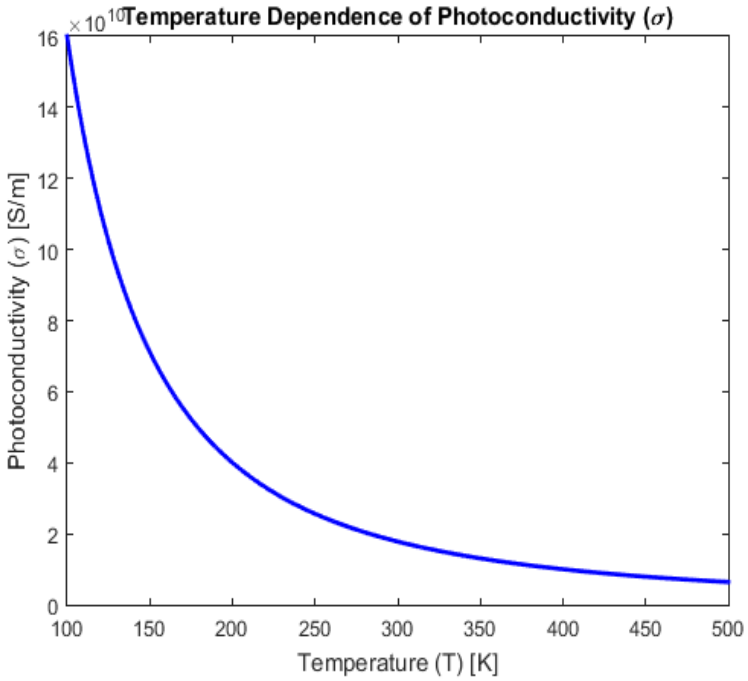


Fig.(1): Photoconductivity (σ) vs. Temperature (T) curve

Photoconductivity under high intensity illumination (Photoconductivity $\sigma_{ph}(I)$ as a function of Intensity I for different values of m)

The plotted curves represent the photoconductivity $\sigma_{ph}(I)$ as a function of light intensity I for different values of the nonlinearity exponent m. The parameter m determines the degree of nonlinearity in the photoconductivity response to increasing light intensity.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

It is clear from the graph when $m = 1$, the curve is linear, indicating a direct proportionality between $\sigma_{ph}(I)$ and I. This behaviour suggests that photoconductivity increases linearly with light intensity in the material and when m increases (e.g.,$m = 2,3,4$), the curves become steeper, showing a nonlinear relationship. The photoconductivity increases more rapidly with intensity, especially at higher values of I.

The plots show that at low intensity ($I \ll I_s$), the photoconductivity $\sigma_{ph}(I)$ is relatively low and increases slowly. As I approaches and exceeds the saturation intensity I_s, the photoconductivity increases significantly, particularly for larger m values. This indicates a stronger nonlinear effect where the material's response becomes more sensitive to changes in intensity.

The nonlinear behaviour (higher m values) might be indicative of processes like multi-photon absorption or strong carrier-carrier interactions in the material, which become more prominent under high-intensity illumination. Materials with higher m values could be useful in applications where a sharp increase in photoconductivity with intensity is desired, such as in optical switches or photodetectors designed for high-intensity light sources.

This analysis of graph allows us to visualize and interpret the nonlinear relationship between photoconductivity and light intensity, which is essential for understanding the behaviour of materials under high-intensity illumination.

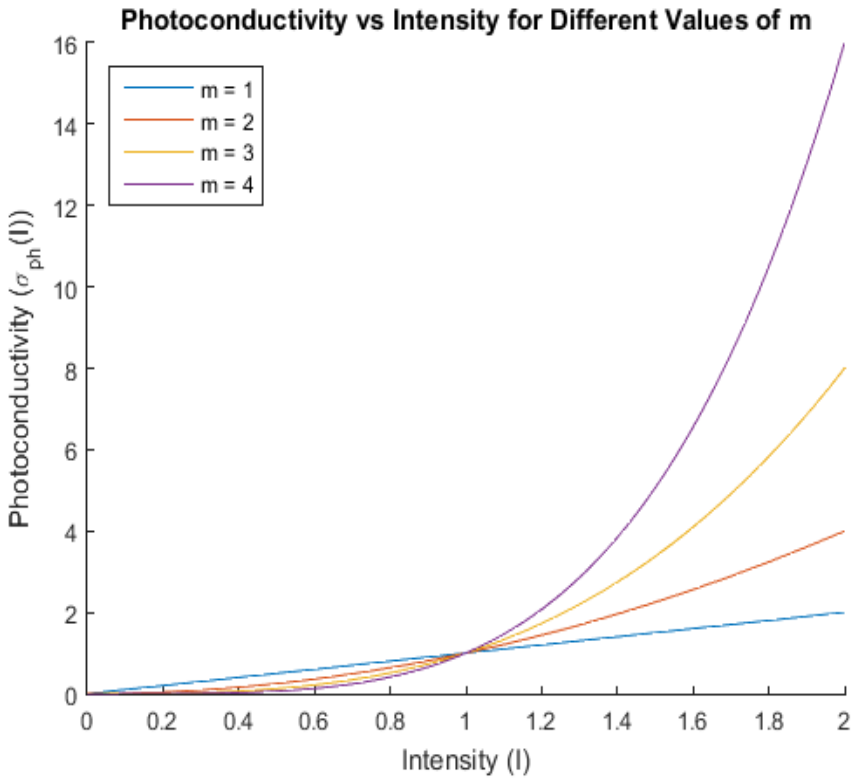


Fig.(2): Photoconductivity σ_{ph} vs. Intensity I for different values of m curve

Photoconductivity in the Presence of Traps(Photoconductivity (σ) as a function of Release rate of trapped carriers(R_t))

The curve illustrates how photoconductivity is influenced by the release rate of trapped carriers in a material under high-intensity illumination. At low release rates, traps dominate, leading to low photoconductivity. As the release rate increases, more carriers are freed from traps, significantly enhancing photoconductivity. This suggests that the material's photoconductive performance can be improved by mechanisms that increase the release rate of trapped carriers, such as thermal activation or exposure to higher intensity illumination. We have divided the plot in three regions as:

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024

DOI: 10.17148/IARJSET.2024.11838

1. Low Release Rate Region: At very low release rates (R_t), the photoconductivity (σ) is significantly reduced. This occurs because most of the carriers are trapped, and only a small fraction is available for conduction. The curve is nearly flat in this region, indicating that photoconductivity is limited by the slow release of carriers from traps.

2. Intermediate Release Rate Region: As the release rate increases, the photoconductivity rises sharply. In this region, more trapped carriers are released, increasing the number of free carriers that contribute to the photoconductivity. The curve's steep slope indicates a strong dependence of photoconductivity on the release rate in this range.

3. High Release Rate Region: At very high release rates, the curve flattens again. Here, the release rate R_t becomes comparable to or greater than the product $C_t * n$, meaning that traps no longer significantly hinder photoconductivity. The photoconductivity approaches its maximum value, which is determined primarily by the mobility and the total carrier generation.

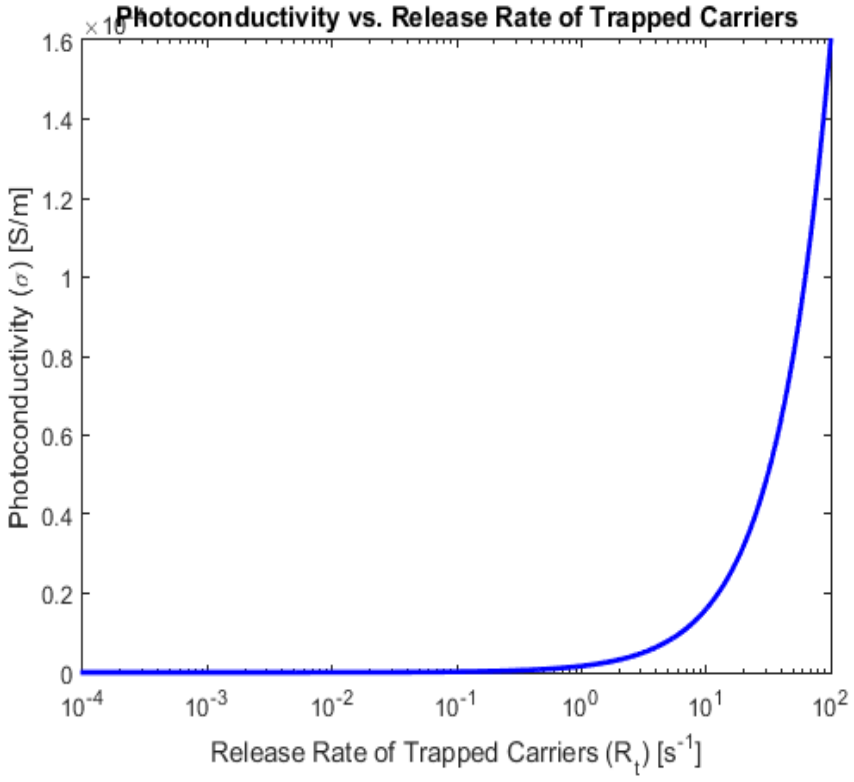


Fig.(3): Photoconductivity (σ) vs. Release rate of trapped carriers(R_t) curve

Thermally Activated Trapping and Detrapping (detrapping time constant $ln(\tau(T))$ as a function of temperature $\frac{1}{T}$)

The plotted graph shows the natural logarithm of the trapping/detrapping time constant $log(\tau(T))$ as a function of the inverse temperature $1/T$. This is a typical Arrhenius plot, which is linear if the trapping process follows a simple thermally activated behaviour. The graph is expected to show a straight line, indicating that the trapping/detrapping process follows an Arrhenius behaviour. The slope of this line is directly related to the trapping energy E_t.

The slope of the $log(\tau(T))$ versus $1/T$ plot is proportional to $-\frac{E_t}{k_B}$. By fitting the data to a straight line, you can determine the trapping energy E_t. A steeper slope indicates a higher trapping energy, meaning the carriers are more deeply trapped and require more thermal energy to be released.

The y-intercept of the plot corresponds to log (τ_0), where τ_0 is the pre-exponential factor. This factor is related to the frequency of attempts the carriers make to escape the trap.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

A straight line confirms that the process is purely thermally activated. Deviations from linearity could indicate additional complexities in the trapping/detrapping mechanism, such as the presence of multiple trapping states or other activation processes. Understanding these characteristics helps in characterizing the trapping dynamics within the material, which is essential in studying how materials behave under varying temperatures, especially in the context of nonlinear photoconductivity under high-intensity illumination.

This plot and its analysis are crucial for understanding how temperature influences trapping and detrapping processes in your material, which in turn affects its photoconductive properties under different lighting conditions.

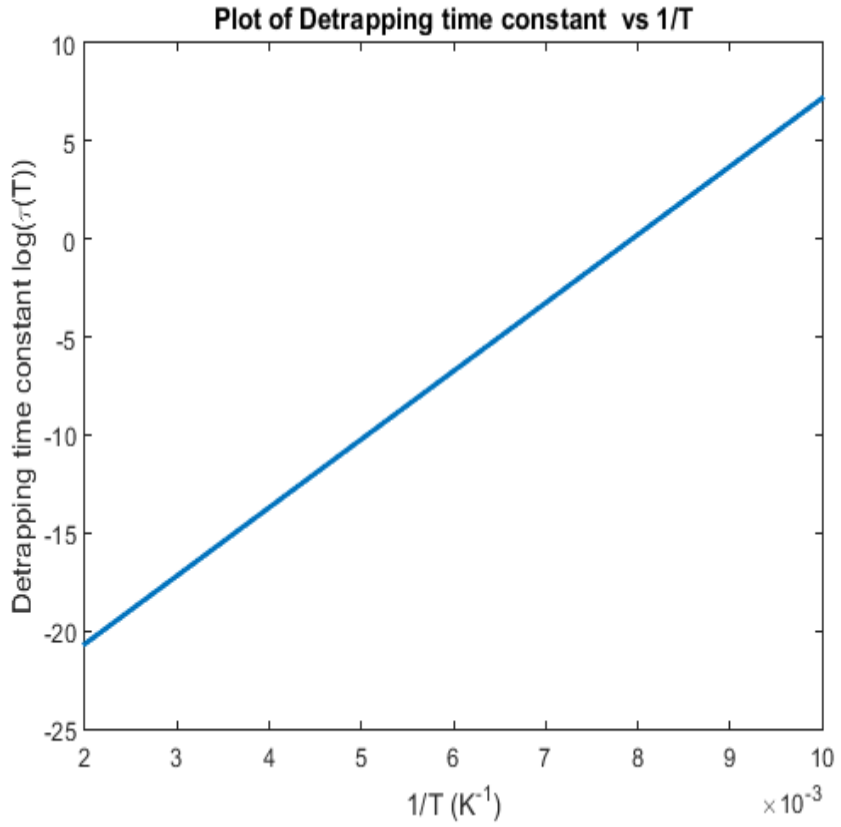


Fig.(4): Detrapping time constant $ln(\tau(T))$ vs. Inverse of temperature $\frac{1}{T}$ curve

Carrier generation rate $G(I)$ as a function of light intensity I:
The plot shows how the carrier generation rate $G(I)$ varies with the light intensity I. The parameter n determines the degree of nonlinearity in the relationship between $G(I)$ and I.

If $n = 1$, the relationship is linear, meaning that the carrier generation rate increases directly with light intensity. For $n > 1$, the curve becomes steeper as I increases, indicating a nonlinear relationship where the generation rate increases more rapidly with light intensity. This is typical in scenarios involving multi-photon absorption or other nonlinear optical processes.

At low intensities, the carrier generation rate $G(I)$ is relatively low and increases gradually. As intensity increases, particularly for larger values of n, the generation rate rises sharply, indicating the onset of nonlinear effects where the material's response to light intensity becomes more pronounced.

The shape of this curve is important for understanding how different materials respond to varying levels of illumination. Nonlinear generation rates are significant in high-intensity environments, such as in laser-driven photoconductive applications or advanced photodetectors. By analyzing (I) ,one can infer the efficiency and behaviour of carrier generation in the material under different lighting conditions, which is crucial for designing materials for high-intensity illumination applications.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

This resulting graph helps us to visualize how the carrier generation rate in our material changes with light intensity, particularly in the context of nonlinear photoconductivity under high-intensity illumination.

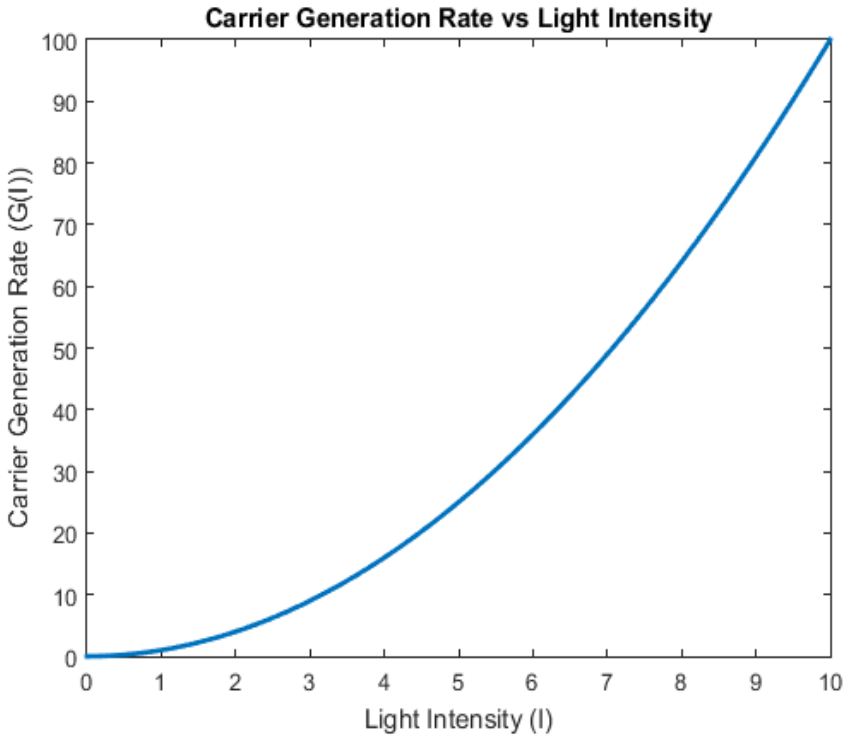


Fig.(5): Carrier generation rate $G(I)$ vs. light intensity I curve

Recombination rate $R(n)$ as a function of the carrier concentration (n) :
The curve plotted from the recombination rate equation illustrates how the recombination dynamics in a material change with varying carrier concentrations. At low carrier concentrations, recombination is primarily governed by the intrinsic recombination rate and the linear term, resulting in a relatively modest increase in the recombination rate.

As the carrier concentration rises, the recombination rate increases more rapidly, especially as the nonlinear term γn^2 becomes significant. This nonlinear behaviour is critical under high-intensity illumination, where large carrier concentrations can lead to a substantial increase in the recombination rate.

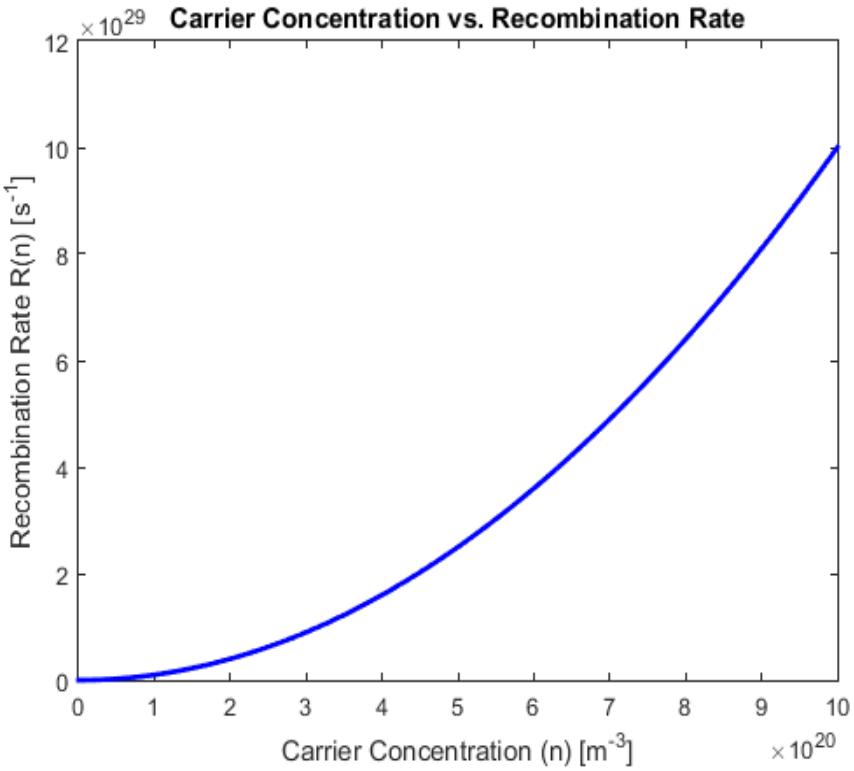
To easily understand the curve we divided graph into three regions:

1. Low Carrier Concentration Region: At low carrier concentrations, the recombination rate $R(n)$ is dominated by the intrinsic recombination rate R_0 and the linear term βn. The curve starts with a gentle slope, indicating that the recombination rate increases slowly with increasing carrier concentration.
2. Intermediate Carrier Concentration Region: As the carrier concentration increases, the contribution from the linear term βn becomes more significant, and the recombination rate starts to rise more rapidly. The curve's slope increases, reflecting a stronger dependence of the recombination rate on the carrier concentration.
3. High Carrier Concentration Region: At very high carrier concentrations, the nonlinear term γn^2 becomes dominant. This leads to a steep rise in the recombination rate, with the curve becoming increasingly parabolic. The steep slope in this region indicates that the recombination rate is highly sensitive to changes in carrier concentration, leading to significant recombination at high carrier densities.

In practical terms, this behaviour indicates that materials with high γ values will exhibit a significant increase in recombination under high carrier injection conditions, potentially limiting the efficiency of devices such as photodetectors or solar cells. This understanding is essential for designing materials and devices that can manage high carrier densities without excessive recombination losses.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

In our research on nonlinear photoconductivity phenomena, this curve highlights the importance of considering both linear and nonlinear recombination processes, especially under conditions of high-intensity illumination, where carrier concentrations can reach levels where nonlinear effects dominate.



Fig(6): Recombination rate $R(n)$ vs. carrier concentration (n) curve

Photoconductivity change $\Delta\sigma(I)$ as a function of light intensity (I):
The graph plots the change in photoconductivity ($\Delta\sigma(I)$) as a function of light intensity (I) for different values of the nonlinearity exponent γ. It shows three distinct curves, each representing a different degree of nonlinear photoconductive behaviour.

1. Linear Curve ($\gamma = 1.0$): The blue curve represents the case where the photoconductivity change is directly proportional to the light intensity. This linear relationship ($\gamma = 1.0$) implies that for every unit increase in light intensity, the photoconductivity increases by a consistent amount. This behaviour is typical of materials with a straightforward, proportional response to light, where the generated carriers contribute directly to conductivity without any complex interactions. Such materials are ideal for applications requiring predictable and stable photoconductive responses under varying light conditions.

2. Nonlinear Curve ($\gamma = 1.5$): The red dashed curve corresponds to a nonlinear relationship where $\gamma = 1.5$. Here, the photoconductivity increases more rapidly than the linear case as light intensity rises. This indicates the presence of nonlinear effects, such as enhanced carrier generation or increased interaction between carriers at higher light intensities. The material starts to exhibit a more sensitive response to light, where small increases in light intensity lead to disproportionately large increases in photoconductivity. This behaviour is useful in devices that require heightened sensitivity to changes in light levels.

3. Strong Nonlinear Curve ($\gamma = 2.0$): The green dot-dashed curve illustrates a strong nonlinear response with $\gamma = 2.0$. In this case, the photoconductivity changes quadratically with light intensity, leading to a very steep increase as the light intensity grows. This strong nonlinear behaviour suggests that the material is highly sensitive to light, potentially due to processes like carrier multiplication or other complex interactions that significantly enhance conductivity at higher light intensities. However, this also means that the material could become unstable or saturate under extremely high illumination, making it suitable for specific applications where a strong nonlinear response is required.

IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024
DOI: 10.17148/IARJSET.2024.11838

The plotted curves demonstrate how the photoconductivity of a material can change with varying light intensities under different nonlinear conditions. The linear curve represents a basic, proportional response, ideal for applications needing stability.

The nonlinear and strong nonlinear curves indicate materials with enhanced sensitivity to light, which could be leveraged in devices requiring rapid or large photoconductive changes, such as in high-sensitivity photodetectors or nonlinear optical systems. Understanding these characteristics is crucial for selecting and designing materials tailored to specific photoconductive applications.

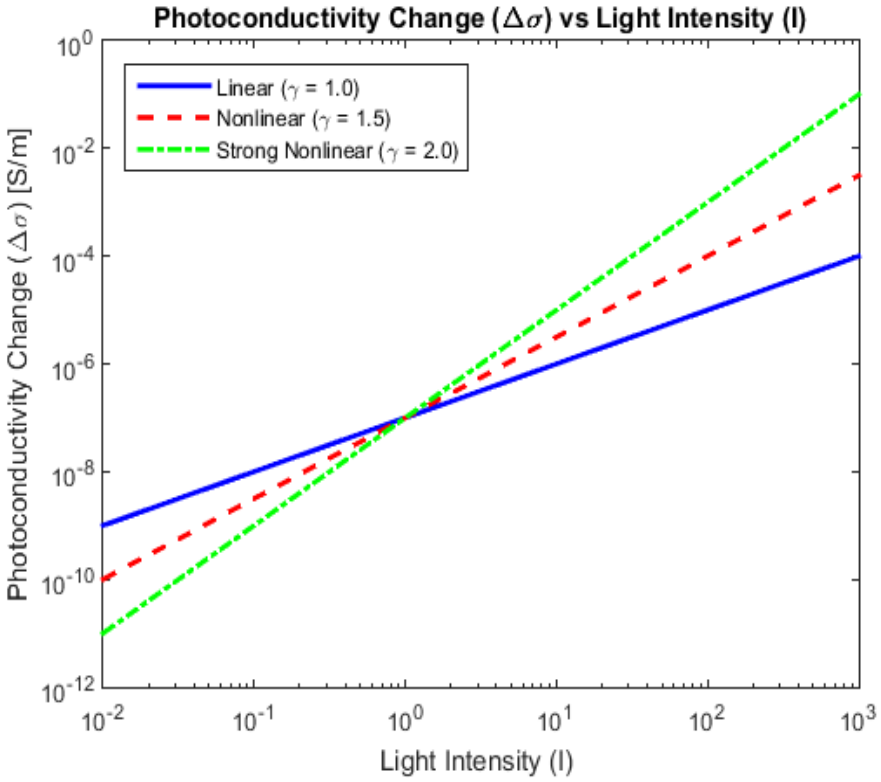


Fig.(7): Photoconductivity change $\Delta\sigma(I)$ vs. light intensity (I) curve

IV. CONCLUSION

In this research we have focused on nonlinear effect of photoconductive material although the exploration of nonlinear photoconductivity in materials under high-intensity illumination and varying temperatures reveals critical insights into the behaviour of charge carriers in advanced photonic and optoelectronic systems. Under high-intensity light, materials exhibit a nonlinear response where photoconductivity deviates from the typical linear relationship with light intensity, often due to saturation effects, multi-photon absorption, or carrier-carrier interactions. This nonlinearity is further influenced by temperature, which affects the trapping and detrapping dynamics of carriers within the material.

Temperature-dependent studies show that as temperature increases, the activation energy for carrier detrapping decreases, leading to enhanced photoconductivity. This interplay between illumination intensity and temperature is crucial for understanding the efficiency and stability of photoconductive materials in high-performance applications such as photodetectors, solar cells, and optical sensors.

By investigating these phenomena, this research contributes to the development of materials with optimized photoconductive properties, tailored for specific high-intensity and temperature conditions. Our findings underscore the importance of considering both light intensity and thermal effects in designing and utilizing photoconductive materials, paving the way for innovations in areas where precise control of photoconductivity is essential.

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 8, August 2024

DOI: 10.17148/IARJSET.2024.11838

REFERENCES

[1]. Sze, S M, & Ng, K K (2006). *Physics of Semiconductor Devices* **(3rd ed.). Wiley-Interscience**.
[2]. Williams, R T, & Song, K S (1990). "The dynamics of non-linear photoconductivity in crystalline materials." *Journal of Applied Physics*, **67(1), 422-428**.
[3]. Mott, N F, & Davis, E A (1979). *Electronic Processes in Non-Crystalline Materials* **(2nd ed.). Oxford University Press.**
[4]. Wu, Y, & Drabold, D A (2013). "Nonlinear photoconductivity in amorphous semiconductors." *Physical Review B*, **88(3), 035201.**
[5]. Maier, J (2004). *Nonlinear Photonics: Nonlinearities in Optics, Optoelectronics and Fiber Communications*. Wiley-VCH.
[6]. Nelson, J (2003). *The Physics of Solar Cells*. Imperial College Press.
[7]. Lax, M (1960). "Multiple trapping of carriers in solids." *Physical Review*, **119(5), 1502-1523**.
[8]. Klingshirn, C F (2007). *Semiconductor Optics* **(3rd ed.). Springer.**
[9]. Orenstein, J, & Kastner, M A (1981). "Nonlinear photoconductivity in amorphous semiconductors: Temperature dependence and recombination kinetics." *Physical Review Letters*, **46(19), 1421-1424.**
[10]. Kumar, S, & Pandey, S S (2005). "Photoconductivity and transport phenomena in organic semiconductors." *Journal of Materials Science: Materials in Electronics*, **16(7), 533-546**.
[11]. Zhang, L, & Xiao, M (2015). "High-intensity illumination and its impact on photoconductivity in nanostructured materials." *Advanced Materials*, **27(5), 749-755**.
[12]. Dubrovskii, V G, & Sibirev, N. V. (2010). "Nonlinear carrier dynamics in semiconductor nanostructures under high-intensity light." *Journal of Applied Physics***, 108(7), 074310**.
[13]. Street, R A (1991). *Hydrogenated Amorphous Silicon* **(Vol. 2). Cambridge University Press.**
[14]. Pope, M, & Swenberg, C E (1999). *Electronic Processes in Organic Crystals and Polymers* **(2nd ed.). Oxford University Press.**
[15]. Yu, P Y, & Cardona, M (2010). *Fundamentals of Semiconductors: Physics and Materials Properties* **(4th ed.). Springer.**
[16]. M K Maurya ,"Contribution of photovoltaic effect in photorefractive grating formation under the influence of applied electric field", *J. Sci. Res. Adv.* **Vol. 2, No. 2, 2015, 84-87.**
[17]. Moll, J L *Physics of Semiconductors*. McGraw-Hill, 1964. **Volume 2.**
[18]. Bube, R H Photoconductivity of Solids. Wiley, 1960. **Volume 1.**
[19]. Yablonovitch, E. (1981). "Photoconductivity and the Power Law of Photoconductivity in Semiconductors." *Journal of Applied Physics***, 52(4), 2492-2500**.
[20]. Bube, R H *Photoconductivity of Solids.* Wiley, 1960. **Volume 1.**
[21]. Lax, M Traps and Nonradiative Recombination in Semiconductors. *Phys. Rev.*, 1956. **Volume 102, pp. 1234-1247**.
[22]. Sze, S M, & Ng, K K (2006). *Physics of Semiconductor Devices***.** John Wiley & Sons.