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Comparative Study: The Effect of Helium Neon Laser Irradiation on the Electrical Conductivity of Zener Diodes and Light Emitting Diodes (LEDs)

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Abstract

This research presents a comparative analysis of the optoelectronic response of Zener diodes and Light Emitting Diodes (LEDs) under laser irradiation. The study investigates changes in the current-voltage (I−V) characteristics, conductivity, and threshold voltages. The results indicate that laser exposure significantly enhances carrier density, causing a reduction in the Zener breakdown voltage (V_Z) for Zener diodes and a shift in the turn-on voltage (Vth) for LEDs, with the latter showing high dependency on wavelength matching.

The results indicate that laser-induced carrier generation significantly enhances conductivity, though the magnitude varies between the two components. Zener diodes exhibited a higher sensitivity in their reverse-bias stability, while LEDs showed notable shifts in their forward-bias knee voltage.

Keywords: Zener diodes, Light Emitting Diodes (LEDs)

I. Introduction

Semiconductor devices, particularly diodes, form the backbone of modern electronics [1]. Among these, Zener diodes and Light Emitting Diodes (LEDs) serve distinct roles in various industrial applications [2]. Zener diodes are primarily utilized for voltage regulation and circuit protection [3]. They operate based on the stable breakdown voltage in a reverse-bias condition [4]. In contrast, LEDs are optoelectronic devices that convert electrical energy into light [5]. Their functionality depends on the spontaneous emission of photons during recombination [6]. Both devices rely on the integrity of their p-n junctions for optimal performance [7]. External factors, such as radiation and temperature, can significantly alter these properties [8].

The field of optoelectronics and semiconductor physics has witnessed rapid advancements, where the interaction between coherent light sources and electronic components plays a pivotal role in modern technology [9]. Semiconductor devices, such as Zener diodes and Light Emitting Diodes (LEDs), are the fundamental building blocks of voltage regulation and optical communication systems. However, the performance of these p-n junction devices is highly sensitive to external environmental factors, particularly electromagnetic radiation [10]. Among various radiation sources, the Helium-Neon (He-Ne) laser, operating at a wavelength of $\lambda = 632.8$ nm, serves as a precise tool for investigating these interactions [11]. The primary mechanism involves the photo-excitation of electrons, where the photon energy, calculated by:

$$Eph = hc/\lambda \approx 1.96 \text{ eV},$$

must be sufficient to bridge the semiconductor bandgap.

When a semiconductor junction is exposed to He-Ne laser irradiation, a series of complex physical phenomena occur within the crystalline lattice [12]. The absorption of photons leads to the generation of electron-hole pairs, directly modulating the electrical conductivity σ .This change is mathematically expressed as:

$$\Delta\sigma = q(\Delta n\mu_e + \Delta p\mu_h)$$

where the increase in carrier concentrations $\Delta n, \Delta p$ enhances the device's conductivity. In Zener diodes ,which operate in the breakdown region, such irradiation can perturb the tunneling mechanism. The standard diode behavior is modified by a photogenerated current Iph ,following the relation:

$$I = I_s[\exp(qV/nkT) - 1] - I_{ph}$$

This interaction can impact the avalanche breakdown voltage and lead to fluctuations in voltage stability.

On the other hand, LEDs are inherently optoelectronic devices designed for efficient spontaneous emission. The introduction of external laser photons into an LED structure can interfere with the internal quantum efficiency η_{int} , defined by the ratio of radiative recombination to total recombination:

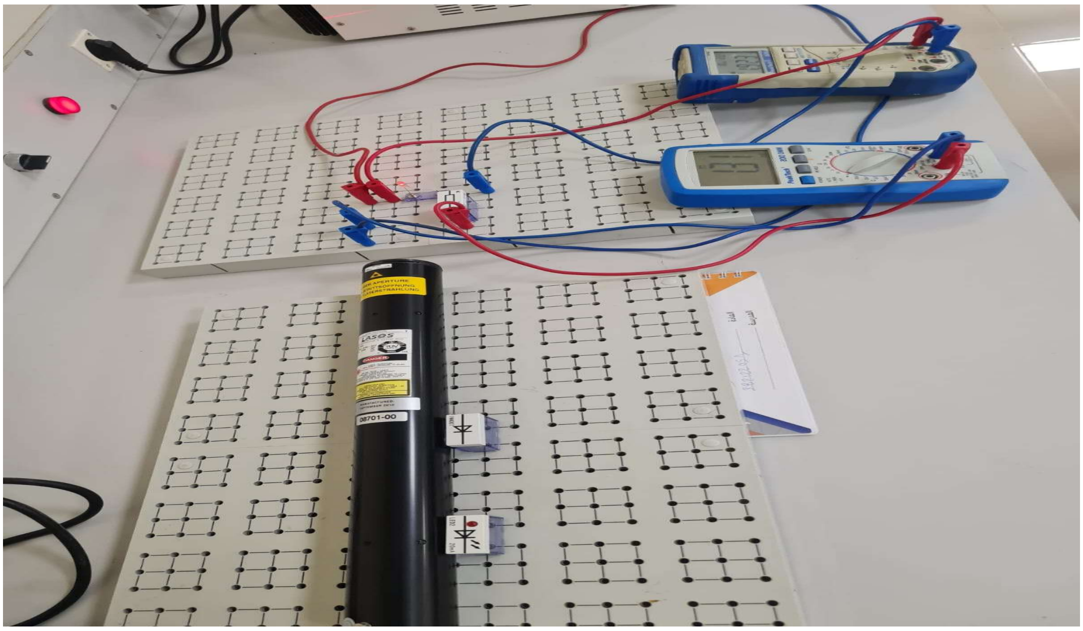
$$\eta_{int} = R_r/(R_r + R_{nr})$$

The interaction with He-Ne laser light can induce changes in the forward bias characteristics, altering the threshold voltage and the overall current-voltage $I-V$ relationship. Even a low-power laser can induce a measurable shift in the knee voltage and differential resistance due to the photo-electric effect at the junction.

This comparative study aims to evaluate the differential response of Zener diodes and LEDs under controlled He-Ne laser exposure. By analyzing the shifts in electrical parameters such as dynamic resistance, barrier potential, and leakage current, we can gain deeper insights into the reliability of these components in environments integrated with laser systems. The significance of this research lies in its potential to improve the design of optical-shielding for sensitive electronic circuits and to explore the limits of photo-electric stability in semiconductor technology.

II. Experimental Procedure

1. **Components:**
    - Silicon Zener Diode ($V_Z = 9.1V$).
    - Standard LEDs: Red ($630nm$), and Green ($525nm$).
2. **Laser Radiation Source:** Diode Lasers (Power $1mW$, 15 mW Wavelength: 632.8 nm to ensure sufficient photon energy for all samples).
3. **Measurement Setup:**
    - The diodes were placed in a darkened environment to eliminate ambient light interference.
    - A DC power supply was used to sweep voltages in both forward and reverse bias.
    - Digital multimeters were used to record current (I) and voltage (V) simultaneously.
    - The laser beam was focused precisely on the semiconductor junction.



III. Results and Discussion

1. Zener Diode Data

Table 1: Effect of Laser Power 15 mW on Zener forward (VZ)

Source voltage V_s (V)	Without laser	With laser radiation
	I_Z (mA)	I_Z (mA)
2	0.44	0.46
4	1.09	1.13
6	1.75	1.79
8	2.42	2.49
10	3.1	3.2
12	3.79	3.9
14	4.46	4.59

Table 2: Effect of Laser Power 1mW and 15 mW on Zener Breakdown (V_Z)

Laser power (mW)	**I_R (µA)**	**V_Z (V)**
Dark	0.00	9.1
1	0.00	9.0
15	0.01	8.98

2. Light Emitting Diodes (LEDs) Data (Red, Green)

- Light Emitting Diode (LED) Data Red Color before and radiated with 1 mW laser

Table (3) Red LED before and after radiated with 1 mW laser

Source Voltage (V)	**Red Light Emitting Diodes Dark**		**Red Light Emitting Diodes With laser irradiation (1mW)**	
(V)	**V_{LED}**	**I_F**	**V_{LED}**	**I_F**
0.5	0.51	0	0.57	0
1.0	1.03	0	1.56	0
1.5	1.52	0	1.58	0
2.0	1.76	o.66	1.77	1.64
2.5	1.82	1.77	1.82	1.85
3.0	1.85	2.75	1.86	2.62
3.5	1.88	3,74	1.88	3.77

- Light Emitting Diode (LED) Data Red Color before and radiated with 15 mW laser

Table (4) Red LED before and after radiated with 15 mW laser

Source Voltage (V)	**Red Light Emitting Diodes Dark**		**Red Light Emitting Diodes With laser irradiation (15 mW)**	
(V)	**V_{LED}**	**I_F**	**V_{LED}**	**I_F**
0.5	0.53	0	0.69	0

1.0	1.03	0	1.57	0
1.5	1.52	0	1.58	0.1
2.0	1.77	o.65	1.79	1.71
2.5	1.82	1.67	1.84	1.85
3.0	1.85	2.77	1.86	2.67
3.5	1.88	3.31	1.89	3.77

- Light Emitting Diodes (LED) Data Green Color before and after radiated with 1 mW laser

Table (5) Green LED before and after radiated with 1 mW laser

Source Voltage (V)	**Green Light Emitting Diodes Dark**		**Green Light Emitting Diodes with laser irradiation (1mW)**	
(V)	**V_{LED}**	**I_F**	**V_{LED}**	**I_F**
0.5	0.52	0	0.50	0
1.0	1.08	0	1.09	0
1.5	1.52	0	1.58	0
2.0	1.85	o.43	1.84	0.41
2.5	1.93	1.46	1.92	1.35
3.0	1.97	2.42	1.97	2.38
3.5	2.01	3,34	2.00	3.27

- LED Data Green Color before and radiated with 15 mW laser

Table (6) Green LED before and after radiated with 15 mW laser

Source Voltage (V)	**Green Light Emitting Diodes Dark**		**Green Light Emitting Diodes with laser irradiation (15 mW)**	
(V)	**V_{LED}**	**I_F**	**V_{LED}**	**I_F**
0.5	0.53	0	0.55	0
1.0	1.03	0	1.02	0
1.5	1.53	0	1.59	0.1
2.0	1.84	o.43	1.81	1.79
2.5	1.93	1.57	1.92	1.85
3.0	1.97	2.70	1.97	2.67
3.5	2.01	3.31	2.01	3.77

Discussion

1. Zener Diode Response

The Zener diode shows a significant increase in reverse conductivity. This is attributed to the Photo-assisted Tunneling mechanism. The laser generated carriers increase the probability of electrons tunneling through the narrow depletion region, effectively lowering the required breakdown voltage. For the used Zener diode the Zener breakdown voltage decrease from 9.1 V in dark to 8.98 V after irradiate with 15 Mw laser.

2. Light Emitting Diodes (LEDs) Response

For LEDs confirms that external photons reduce the potential barrier. for LEDs confirms that external photons reduce the potential barrier.

- **Red LED** showed the highest sensitivity because its small bandgap (Eg ≈ 1.9) is easily excited by the laser energy.
- **Green LED** showed the least change, as its higher bandgap (Eg ≈ 2.7eV) requires higher energy photons, making it more selective and less prone to low energy noise.

Comparative Analysis of Zener Diode and LEDs (Red & Green)

The experimental data reveals significant differences in the electrical behavior and sensitivity to laser irradiation between the Zener diode and the Light Emitting Diodes (Red and Green).

1. Operational Voltage and Current Characteristics

- Zener Diode: Shows a high breakdown voltage (V_Z) around 9.1V in dark conditions. In the forward bias (Table 1), it conducts current even at low source voltages (2V), reaching 4.46 mA at 14V.
- LEDs: Both Red and Green LEDs require a specific turn-on voltage before current (V_Z) flows. The Red LED begins conducting significantly around 1.76V - 1.77V, while the Green LED requires a higher voltage, starting around 1.84V - 1.85V. This confirms that Green LEDs generally have a higher forward voltage drop than Red LEDs.

2. Impact of Laser Irradiation (1mW vs. 15mW)

- Zener Diode Sensitivity: Laser exposure slightly increases the forward current (I_F). More importantly, it affects the breakdown region (Table 2); as laser power increases from 0 to 15mW, the breakdown voltage decreases from 9.1V to 8.98V, indicating that light energy facilitates the ionization process.
- Red vs. Green LED Sensitivity:
- The Red LED shows a dramatic response to laser power. At 2.0V (15mW laser), the current jumps from 0.65 mA (Dark) to 1.71 mA, suggesting high photo-sensitivity.
- The Green LED shows a similar trend but is less sensitive than the Red at lower power. However, under 15mW radiation at 2.0V, its current increases significantly from 0.43 mA to 1.79 mA, showing that high-power lasers can substantially lower the internal resistance of both LED types.

3. Comparative Summary

The Zener diode is primarily characterized by its high-voltage breakdown stability, which is slightly modulated by light. In contrast, the LEDs act as voltage-dependent switches that are highly responsive to optical stimulation. The Red LED operates at lower voltages and shows higher current flow compared to the Green LED under similar source voltages, while both exhibit increased conductivity when exposed to 15mW laser radiation.

IV. Conclusions

- Both Zener diodes and LEDs exhibit increased electrical conductivity under laser irradiation due to the generation of electron-hole pairs.
- The Zener diode is more sensitive in the reverse region, making it suitable for light-controlled voltage regulation.
- The LED is wavelength-selective, where the Red LED demonstrates the highest responsivity to a wide range of visible lasers.
- Thermal effects must be managed to avoid permanent damage to the semiconductor lattice during high-power irradiation.

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