



ISSN: 0067-2904

The Effects of Optical Power of Semiconductor Laser on the Characteristics of Si-diode in an Exposed Device

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Received: 11/8/2020

Accepted: 16/1/2021

Abstract

In this paper, we experimentally studied the effects of optical power of semiconductor laser on the electrical properties of silicon diode of an exposed device. The experimental results showed that the laser diode light of different optical powers (2, 3, and 4 mW) had effects on the silicon diode that are somewhat similar to those of thermal treatment. A shift in the current-voltage curve to the left side was also noticed, which led to a non-linear decrease of the barrier voltage of the diode by the effect of laser light. We also reveal a decrease by 344.8 nA/mW in the reverse saturation current of the silicon diode as a result of exposure to laser light. The forward resistance of the silicon diode decreased with increased incident optical power. The value of the maximum current of diode increased by 0.5 A/W with increasing the optical power incident on the diode.

Keywords: Laser diode, exposed device Si diode, I-V characteristics Si- diode.

دراسة تأثير القدرة الضوئية لليزر شبه الموصل على خصائص ثنائي السيلكون ذو النبيلة المكشوفة

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الخلاصة

تم في هذا البحث دراسة تأثير ضوء الليزر شبه الموصل على الخصائص الكهربائية لثنائي السيلكون ذو النبيلة المكشوفة. أظهرت النتائج العملية أن تأثير ضوء الليزر شبه الموصل على ثنائي السيلكون وبقدرات مختلفة (2,3,4) mW يشابه إلى حد ما التأثير الحراري على الثنائي، إذ يلاحظ حصول زحف في خصائص التيار - فولتية باتجاه اليسار مما يؤدي إلى نقصان غير خطي للجهد الحاجز للثنائي بتأثير ضوء الليزر. فيما يلاحظ أن تيار التشبع العكسي للثنائي تزداد بزيادة القدرة الضوئية الساقطة عليه وقيمة الزيادة في تيار التشبع العكسي للثنائي هي 344.8 nA/mW. أما مقاومة الثنائي الأمامية فتقل مع زيادة القدرة الضوئية الساقطة على ثنائي السيلكون. والتيار الأعظم للثنائي يزداد مع القدرة الضوئية الساقطة على الثنائي ويكون بمقدار 0.5 A/W.

1-Introduction

Laser-material interaction is the fascinating nexus where laser physics, optical physics, and materials science intersect. The range of laser-enabled applications is broad and has been exhibiting steady expansion during the last decades [1]. Diode lasers are semiconductor devices that use the p-n junction of a semiconductor diode to create light that is coherent and generally of a single wavelength. Due to the small size, low power consumption, and cost-

effective production of these devices, diode lasers have become the most common types of lasers in the world, being used in a large variety of components and fields, including electronics, communications, and medical practices [2].

The p-n junction can be prepared by doping the semiconductor with two different types of impurities (accepter and donor) to form the N-region and the P-region of p-n junction. The simplified theory of such a device, which is used to explain the transfer of current through p-n junction as a function of the voltage applied, was discovered by Schöckley [3] and is given as follows:

$$J = J_o \left[\exp \left(\frac{qV}{kT} \right) - 1 \right] \dots \dots \dots (1)$$

where J represents the density of the forward diode current, J_o is the density of saturation current, q is the electron charge, V is the voltage across the diode, k is Boltzmann constant, and T is temperature. It is known that increasing temperature of the diode shifts the characteristics of current-voltage towards the left. The p-n junction and its theory are the basic of many other electronic devices [4]. There are other types of light-emitting and laser diodes.

The laser diode has found important applications in the field of optical communication systems as a light source for transmission, which has replaced the light-emitting diode in this field [5]. Industrial laser machines differ from commercial ones because they are highly reliable on the type of laser they produce. These devices produce a laser package with individual characteristics that can be controlled in a high quality and focused accurately to reach the minimum possible spot size. This will provide very high intensity and narrow spot area that can be used for cutting and penetrating highly hardened metals or in heat treatment of materials or surfaces. This interaction of laser photon with the material can result in either a breaking of the bonds or their formation in the material, according to the treatment [6]. On the other hand, the interaction of laser light with p-n devices can change the electrical properties of the device, in a similar manner to the thermal effect. Changes in other factors of the diode, such as the working efficiency of the diode, the saturation current, the forward resistance, and the barrier voltage play an important role in the practical applications of the dual device[4].

In this paper, the effects of laser light with different optical power levels on the electrical properties of silicon p-n junction in an exposed device are studied.

2. Experimental Setup

The experimental arrangement shown in Figure 1 was used to study the effects of laser light on silicon p-n junction in an exposed device. The laser diode used is a US- commercial semiconductor lasers that gives a wavelength of 650nm and a maximum power up to 5mW. The optical power emitted was controlled by the injected current of the laser and measured by the UK- Scientific Optical Power Meter [7], which measures light powers up to 20mW. This laser was installed on an x-y-z micro-position to adjust the match between the laser spot and the exposed dual device.

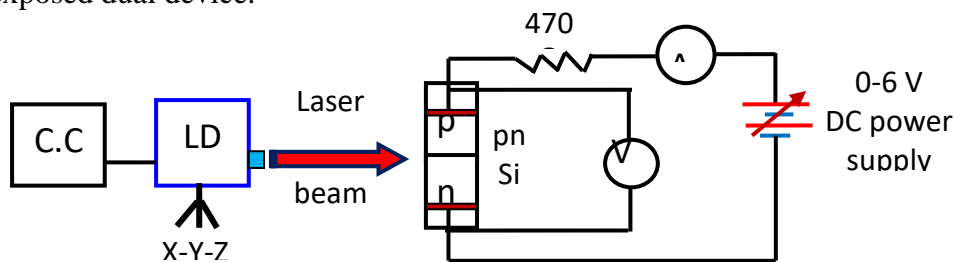


Figure 1-The experimental setup to study the effects of laser light on the electrical properties of silicon p-n junction in an exposed device.

A constant current control (C.C) source (with a regular change) with an accuracy of $\pm 0.01\text{mA}$ was used to control the injection current of the semiconductor laser and thus control the optical power emitted from it, with values of (0, 2, 3, 5mW), according to the operating current. A digital meter for both current and voltage was used to measure the diode's (I-V) characteristics.

3- Results and discussion

Figure 2 shows the current-voltage characteristics of the exposed diodes with different values of the optical power of laser beam (0, 2, 3, 5mW) falling on the Si-diode, with the same exposure time of 8 min and the same distance from the laser. In this figure, we observe that the shape of the diode's properties (I-V) is shifting to the left, that is, to the lower barrier voltage. We also notice the increase in the maximum current reached.

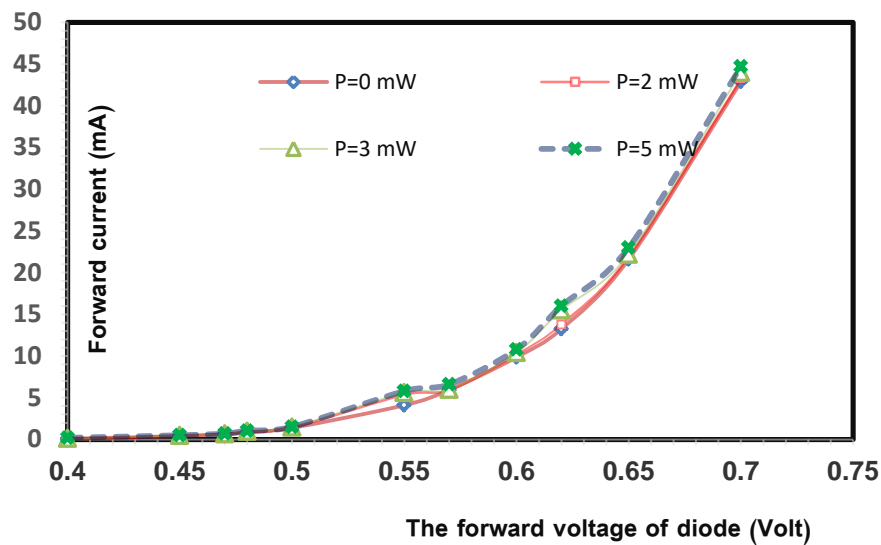


Figure 2-Effect of laser optical power on I-V characteristics of Si-diode

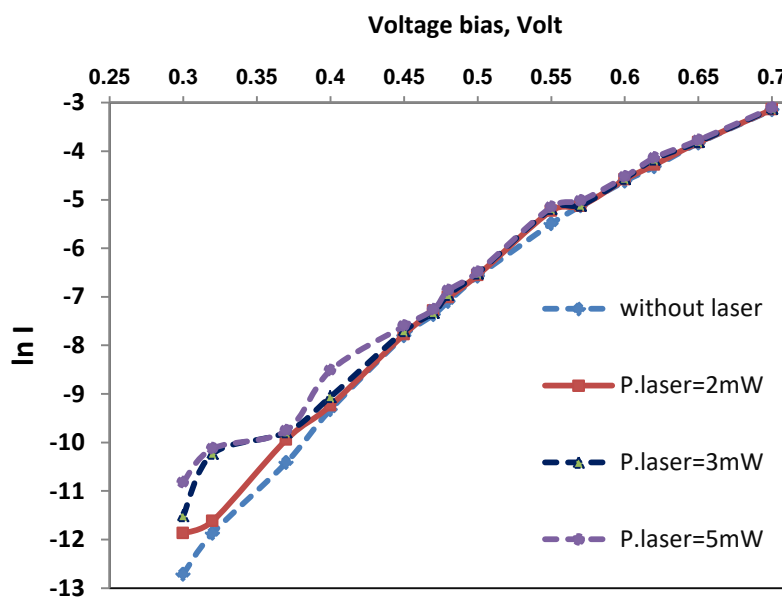


Figure 4-Extraction of (n) values and the reverse saturation current of Si-diode with the effect of incidence power laser on the diode.

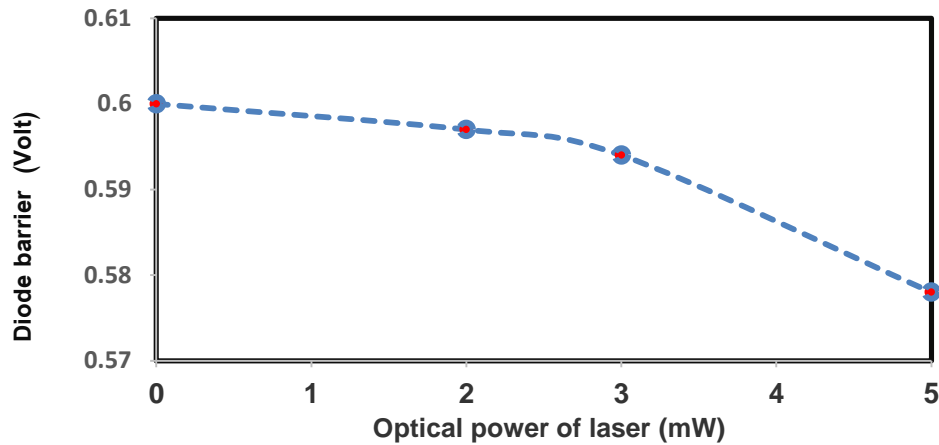


Figure 3-The relationship between the incident laser power and the diode barrier voltage

The level of barrier voltage was found for each of the incident light power values of the semiconductor laser. Figure 3 illustrates this relationship between the barrier voltage of the diode and the optical power of semiconductor laser. It is noticed that the voltage is exponentially decreased with increasing incidence optical power on the diode. The reason for that was the generation of charge carriers in the junction area of the diode that contribute to the equilibrium at a lower barrier voltage, which is similar to the effect of temperature on the barrier diode voltage [6]. The operating current of the semiconductor laser was about $1.1I_{th}$, where I_{th} represents the threshold current of the semiconductor laser and is equal to 13mA, this value is the best value for operating laser diodes [8, 9].

The saturation reverse current of Si-diode (I_o) can be found by a drawn relationship between $\ln I$ and V , as illustrated in Figure 4, and from the intersection extension curve with the $\ln I$ axis, I_o can be

Figure 5 shows the variation in the reverse saturation current I_o due to the incidence of the optical power on it, where an increase in I_o is observed when increasing the optical power of the laser and the increase can be considered linear. The reason for this is the generation of minority carriers in the regions p and n due to the intensity of the light incident on the diode. The amount of change in I_o with optical power of laser was found to be: $\frac{\Delta I_o}{\Delta P} = 344.8 \text{ nA/mW}$, and this increase in the reverse saturation current is relatively large.

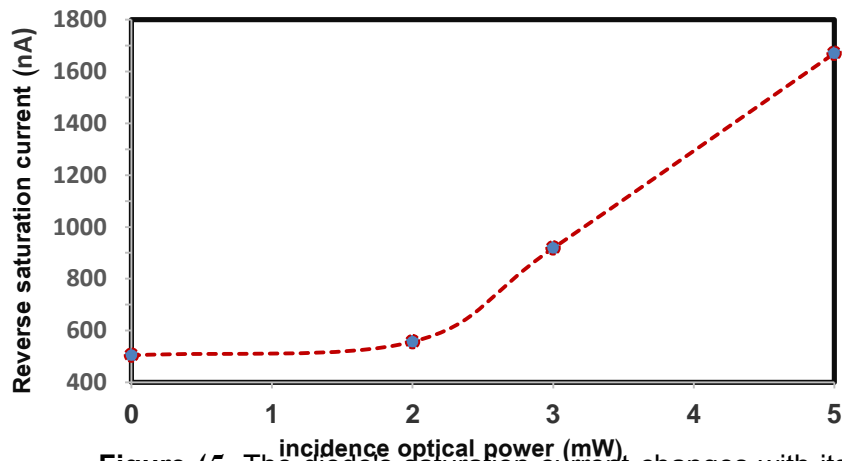


Figure (5)–The diode’s saturation current changes with its incidence optical power

As for the ideality factor (n), the value was increased by the effect of the incident optical power, due to the departure from an ideal state caused by the minority carrier generation and the thermal effect of the incident light falling on diode. Figure 6 shows this relationship, where the values of n range between 2.5 and 3.5 in an incident light power range of 5-6 mW.

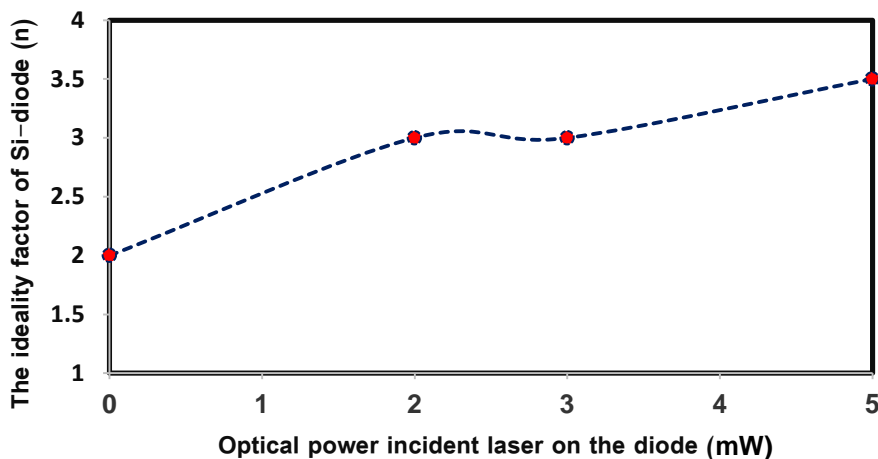


Figure 6- Effect of incidence optical power on the ideality factor of Si-diode

Figure 7 illustrates the relationship between the forward resistance R_f of the exposed Si-diode device and the incident optical power of semiconductor laser. It is generally observed that there is a non-linear increase in the forward resistance of the diode with the increase in the optical power falling on the diode. A slight decrease (2.4 - 2.5 Ω) at the forward resistance was observed when the optical power of the laser increased from 2mW to 3mW. The reason for this is a slight increase in the change in current, due to an increase in the optical power, in exchange for a slight decrease in the change in voltage, which caused an increase in the forward resistance in this region.

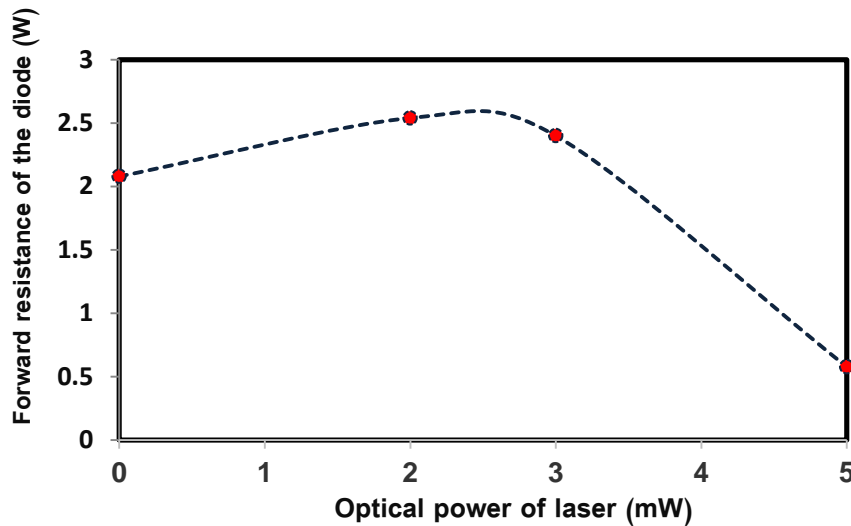


Figure 7-Effect of incidence optical power on the forward resistance R_f of the Si-diode

Finally, from Figure 8, which represents the relationship between the I_{max} of the Si-diode and the incidence optical power on the diode, it is noticed that the value of the maximum current passing through the exposed diode was increased as a result of the presence of the laser light. The amount of the increase in the maximum current is $\frac{\Delta I_{max}}{\Delta P} = 0.5 \text{ A/W}$. The reason for increasing the maximum current is the increased generation of carriers in the convergence region of the exposed Si-diode.

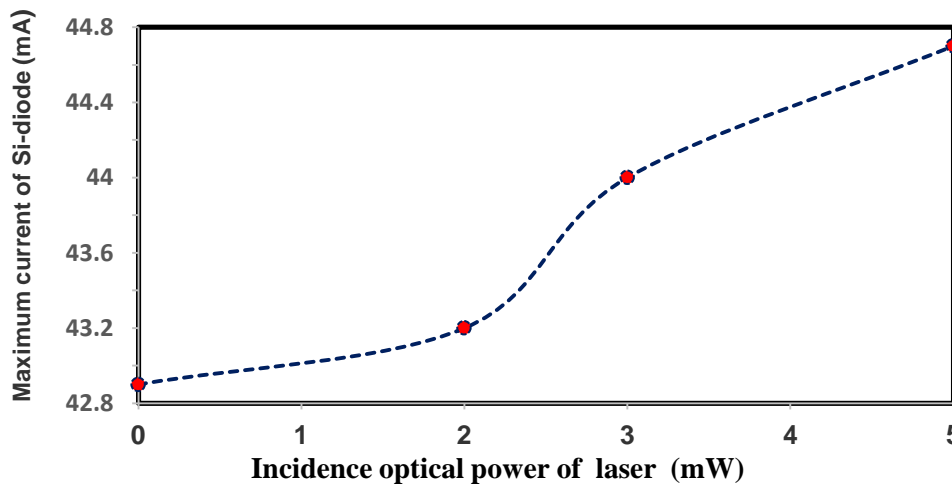


Figure 8- Effect of the laser optical power on the maximum current of Si-diode.

4- Conclusions

results showed that the effect of the semiconductor laser light on the exposed p-n diode is very similar to the thermal effect. Moreover, a shift in the (I-V) characteristics of the Si-diode to the left was noticed, which indicates that there is no change in the characteristics, but the change is reflected in the diode barrier voltage. The diode barrier voltage decreased non-

linearly with increasing incident optical power, indicating that the thermal diode of the laser light on the diode is silicon.

The I_o increased with increasing incident optical power and the magnitude of the increase was 344.8 nA/mW. We also noticed a decrease in the forward resistance of the silicon diode with the increase in the optical power. The ideality factor (n) for a Si-diode increased with the increase in the incident of optical power of semiconductor laser.

The maximum value of the current I_{max} passing in the diode increased with the increase of the optical power, and this increase was equal to 0.5 A/W.

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