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Responsivity of Silicon Photodiodes Light & Dark Current under Influence of Different Magnetic Flux Intensity and Temperature

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ABSTRACT

Responsivity of silicon photodiodes was measured for different values of temperatures and magnetic field in light and darkens. Group of silicon photodiodes was studied. The surface layer of these diodes was a thin metal silicide surface layer. As the temperature decreases the increase in current is consistent the theoretical relation. These results are particularly important for the measurement of current in extreme cooling. One has studied the effect of cooling on the photodiodes current in the presence of a magnetic field. A recognized change has been observed. The current is observed to increase as the magnetic flux density increase, which is again is conformity with the theoretical relation.

Introduction

Photodiodes are devices which emit light when exposed to light. They are widely used as indicators or as information carriers through optical fibers. They are affected by many environmental factors which can affect its performance directly [1, 2, 3, and 4]. In hot countries like Sudan the investigation of the effect the temperature is very important [5, 6]. The sun magnetic storm effect which has a direct impact on telecommunication is expected to affect photodiode performance too [7, 8]. Thus it is important to study the effect of temperature and magnetic field on the performance of a photodiode and try to explain it on a theoretical basis or in comparison with other studies. This will provide us with information which can be utilized to improve the efficiency of photodiodes and their mode of operation.

In this work section two is devoted to the theoretical background while section three is concerned with the experimental part. The two sections comprise materials and methods. The discussion and conclusions are exhibited in sections four and five respectively.

Ambient temperature variations greatly affect photodiode sensitivity and dark current. The cause of this is variation in the light absorption coefficient which is temperature related. Photodiodes are basically reverse biased diodes with optical windows that allow like to shine on the PN junction [9, 10]. Like any diode, the leakage current (otherwise known as a photodiodes 'dark' current) increases exponentially with temperature in accordance to William Shockley's idea diode equation [11, 12]. The other effect in a photo diode is the probability of a photon of a certain energy allowing an electron to cross the PN junction. This is known as the quantum efficiency of the photodiode. Because increasing temperatures increase the vibration of the silicon atoms, making them easier to be knocked loose by a photon. Thus the quantum efficiency of a photodiode will increase with temperature.

Theoretical Analysis

All photodiode characteristics are affected by changes in temperature as well as the magnetic field. They include shunt resistance, dark current, breakdown voltage, Responsivity and to a lesser extent other parameters such as junction capacitance. There are two major currents in a photodiode contributing to dark current and shunt resistance. Diffusion current is the dominating factor in a

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photovoltaic (unbiased) mode of operation, which determines the shunt resistance [13, 14]. It varies as the square of the temperature. In photoconductive mode (reverse biased), however, the drift current

Becomes the dominant current (dark current) and varies directly with temperature. Thus, the change in temperature affects the photo detector more in photovoltaic mode than in photoconductive mode of operation.

In photoconductive mode the dark current may approximately double for every 10 ºC increase change in temperature. And in photovoltaic mode, shunt resistance may approximately double for every 6 ºC decrease in temperature [15, 16]. The exact change is dependent on additional parameters such as the applied reverse bias, the resistivity of the substrate as well as the thickness of the substrate.

For small active area devices, by definition breakdown voltage is defined as the voltage at which the dark current becomes 10μA. Since dark current increases with temperature, therefore, breakdown voltage has decreased similarly with increase in temperature.

The current I is related to the applied voltage V, and the temperature T according to the relation [17]:

$$I = I_0\left(e^{\frac{eV}{kT}} - 1\right) \tag{1}$$

When a photodiode is exposed to light current I_L is generated, thus:

$$I = I_0\left(e^{\frac{eV}{kT}} - 1\right) - I_L \tag{2}$$

According to the laws of statistical physics the current is related to the energy E gained by the free carriers. i.e.:

$$I = I_0\left(e^{\frac{E}{kT}} - 1\right) + I_L \tag{3}$$

When a magnetic field of flux density B affects the electron of velocity v is given by:

$$E = BevL + eV$$

Thus:

$$I = I_0\left(e^{\frac{BevL+eV}{kT}} - 1\right) + I_L \tag{4}$$

For dark room:

$$I = I_0\left(e^{\frac{BevL+eV}{kT}} - 1\right) \tag{5}$$

When the magnetic field and the potential are weak [18]:

$$x = \frac{BevL + eV}{kT} \ll 1 \tag{6}$$

In this case:

$$I = I_0(1 + x - 1) + I_L = I_0 x - I_L$$

$$I = I_0\left(\frac{BevL + eV}{kT}\right) + I_L \tag{7}$$

When the operation takes place in a dark room [19]:

$$I = I_0\left(\frac{evLB}{kT}\right)+\frac{eI_0V}{kT} \tag{8}$$

The theoretical relations between (I) versus (T) and (I) versus (B) according to equations (4), (5), (7) and (8) are given by [20, 21]:

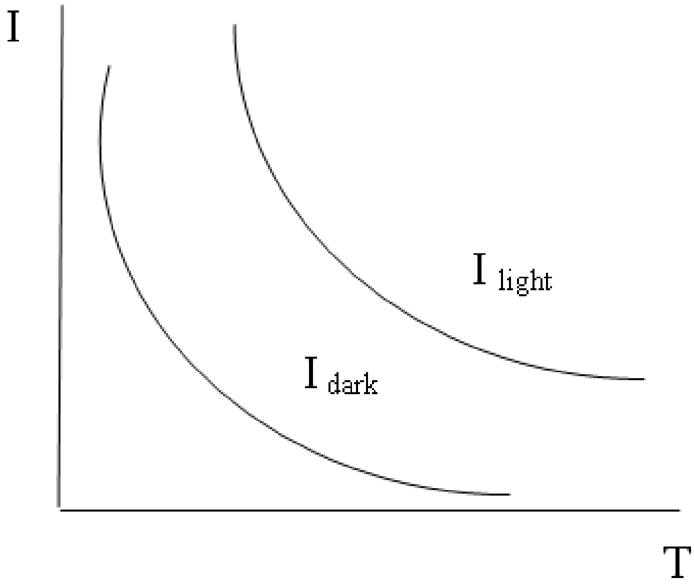

Fig (1) I versus T according to equations (4) and (5)

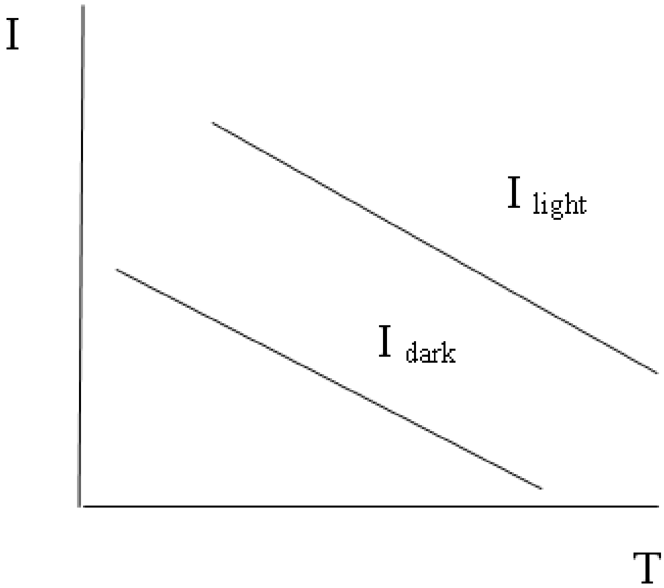

Fig (2) I versus T according to equations (7) and (8)

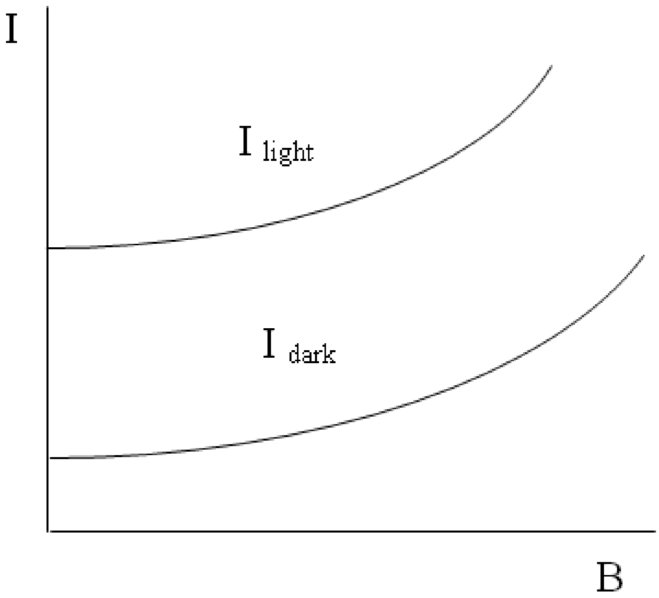

Fig (3) I versus B according to equations (4) and (5)

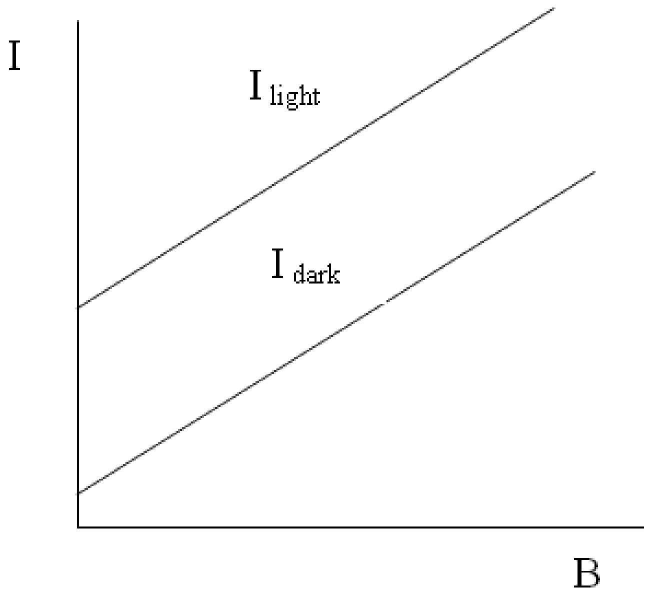

Fig (4) I versus B according to equations (7) and (8)

Experimental Procedure

In these experiments the effect of temperature and magnetic field on photo voltage were studied. The settlement of the experiment was as follows:

Apparatus: - Different photodiodes

- Magnetic sensor specifications: Leybold Didactic GmbH, 220-240V, Sensor length 8.9cm.

-Powerful magnet specifications: two coils of 10,000 turns and 5A current.

-Sealed lead acid rechargeable battery “SUNCA”, 9V.

-Digital multimeter, Voltage range: 200mV—1000V Current range: 200mA--200µA

-Thermometer range: -10ºC--50ºC.

- Beaker and ice cubes.

-Connecting wires.

Method: Part One: the diode is placed in the beaker containing water of normal temperature (35ºC); the magnetic flux is exposed vertical on the photo diode, at a fixed value of **9.87mT**, then the ice cubes are added, reading of voltage and current were taking for different values of temperatures in both light and darkens.

Part two: The same settings are used but different values of magnetic intensity and repeating the same steps.

3.1 Results: Table (1) S2: Current and voltage variations due to temperature change in dark and light-Magnetic flux intensity = 9.87 mT

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	I_{light} - $I_{darkness}$
308	9.38	1.062	9.00	1.019	0.043
303	9.39	1.063	9.11	1.019	0.044
298	9.41	1.065	9.17	1.039	0.026
293	9.43	1.068	9.20	1.042	0.026
288	9.45	1.070	9.22	1.044	0.026
283	9.48	1.074	9.24	1.046	0.028
280	9.50	1.080	9.26	1.049	0.031
273	9.53	1.081	9.88	1.051	0.03

In light **In darkness**

Table (1.1) S2: Current and voltage variation with respect to magnetic flux density change in light and dark.

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Magnetic flux density (mT)	I_{light} - $I_{darkness}$
308	9.38	1.062	9.20	1.042	39.7	0.02
303	9.20	1.042	9.16	1.037	31.00	0.005
298	9.17	1.039	9.11	1.037	30.60	0.002
293	9.09	1.029	8.89	1.007	30.51	0.022
288	8.01	0.907	8.80	0.997	20.66	-0.09
283	8.00	0.906	8.76	0.992	20.76	-0.086
280	7.44	0.843	8.68	0.983	19.96	-0.14
273	6.96	0.788	8.60	0.974	19.50	-0.186

In light **In darkness**

Table (2)Z1: Current and voltage variation due to temperature change in light and dark-Magnetic flux intensity = 9.87 mT

Temp.(K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	I_{light} - $I_{darkness}$
308	10.79	0.863	10.00	0.72	0.143
303	10.85	0.868	10.11	0.729	0.139
298	10.87	0.870	10.14	0.731	0.139
293	10.92	0.874	10.16	0.733	0.141
288	10.95	0.876	10.18	0.734	0.142
283	10.96	0.877	10.20	0.736	0.141
280	10.98	0.878	10.21	0.737	0.141

273	10.99	0.879	10.23	0.738	0.141

In light In darkness

Table (2.1) Z1: Current and voltage variation with respect to magnetic flux density and temperature change in light and dark.

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Magnetic flux density (mT)	$I_{light} - I_{darkness}$
308	10.79	0.863	10.00	0.8	39.7	0.063
303	10.62	0.850	9.88	0.790	31.00	0.06
298	10.51	0.841	9.80	0.784	30.60	0.057
293	10.48	0.838	9.73	0.778	30.51	0.06
288	10.40	0.832	9.71	0.777	20.66	0.055
283	10.38	0.830	9.68	0.774	20.76	0.056
280	10.27	0.822	9.65	0.772	19.96	0.05
273	10.20	0.816	9.60	0.768	19.50	0.048

In light In darkness

Table (3) S1: Current and voltage variation due to temperature change in light and dark- Magnetic flux intensity = 9.87 mT

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	$I_{light} - I_{darkness}$
308	11.88	1.224	10.92	1.126	0.098
303	11.90	1.227	10.94	1.128	0.099
298	11.92	1.229	10.97	1.131	0.098
293	11.93	1.230	10.99	1.133	0.097
288	11.94	1.231	11.00	1.134	0.097
283	11.95	1.232	11.17	1.152	0.08
280	11.96	1.233	11.18	1.153	0.08
273	11.98	1.235	11.20	1.155	0.08

In light In darkness

Table (3.1)S1: Current and voltage variation with respect to magnetic flux density and temperature change in light and dark.

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Magnetic flux density (mT)	$I_{light} - I_{darkness}$
308	11.88	1.225	10.92	1.126	39.7	0.099
303	11.70	1.206	10.90	1.124	31.00	0.082
298	11.64	1.2	10.87	1.121	30.60	0.079
293	11.50	1.186	10.81	1.114	30.51	0.072
288	11.48	1.184	10.80	1.113	20.66	0.071
283	11.43	1.178	10.71	1.104	20.76	0.074
280	11.40	1.175	10.68	1.01	19.96	0.165
273	11.38	1.173	10.64	1.097	19.50	0.076

In light In darkness

Table (4)P1: Current and voltage variation due to temperature change in light and dark. Magnetic flux intensity = 9.87 mT

Temp.(K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	I_{light} - $I_{darkness}$
308	10.55	0.933	9.89	0.874	0.059
303	10.57	0.935	9.91	0.876	0.059
298	10.60	0.937	9.94	0.879	0.058
293	10.64	0.941	9.96	0.881	0.06
288	10.69	0.945	9.99	0.883	0.062
283	10.72	0.948	10.11	0.894	0.054
280	10.75	0.950	10.14	0.897	0.053
273	10.77	0.952	10.16	0.898	0.054
	In light		In darkness		

Table (4.1) P1: Current and voltage variation with respect to magnetic flux density and temperature change in light and dark.

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Magnetic flux intensity (mT)	I_{light} - $I_{darkness}$
308	10.55	0.933	9.89	0.874	39.7	0.059
303	10.43	0.935	9.80	0.866	31.00	0.069
298	10.40	0.937	9.73	0.860	30.60	0.077
293	10.38	0.941	9.69	0.857	30.51	0.084
288	10.30	0.945	9.66	0.854	20.66	0.091
283	10.27	0.948	9.45	0.836	20.76	0.112
280	10.18	0.950	9.41	0.832	19.96	0.118
273	10.09	0.952	9.39	0.830	19.50	0.122
	In light		In darkness			

Table (5)K2S: Current and voltage variation due to temperature change in light and dark. Magnetic flux intensity = 9.87 mT

Temp.(K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	I_{light} - $I_{darkness}$
308	8.89	1.009	8.00	0.908	0.101
303	8.93	1.014	8.11	0.921	0.093
298	8.95	1.016	8.17	0.931	0.085
293	8.97	1.018	8.20	0.934	0.084
288	8.98	1.019	8.23	0.934	0.085
283	8.99	1.020	8.27	0.039	0.981
280	9.11	1.034	8.30	0.942	0.092
273	9.15	1.039	8.39	0.952	0.087
	In light		In darkness		

Table (5.1)K2S: : Current and voltage variation with respect to magnetic flux density and temperature change in light and dark.

Temp. (K)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Magnetic flux intensity (mT)	I_{light} - $I_{darkness}$
308	8.89	1.009	8.00	0.908	39.7	0.101
303	8.77	0.995	7.91	0.898	31.00	0.097
298	8.70	0.988	7.89	0.896	30.60	0.092
293	8.67	0.982	7.81	0.886	30.51	0.096
288	8.61	0.977	7.77	0.882	20.66	0.095
283	8.59	0.975	7.69	0.873	20.76	0.102
280	8.53	0.968	7.57	0.859	19.96	0.109
273	8.48	0.963	7.49	0.850	19.50	0.113

In light **In darkness**

Discussion:

The empirical relations in tables (1.1), (2.1), (3.1), (4.1), (5.1) Shows that the temperature affect the current (I). These relations show that the temperature increase decreases the current. Comparing these tables with the theoretical relations in figures (1, 2, 3 and 4). It is clear that the empirical relations and theoretical relations are in conformity with each other.

In view of the empirical relations in tables (1.1), (2.1), (3.1), (4.1), (5.1) it is clear that the current is affected by the magnetic field. Where the current (I) increases as the magnetic flux density (B) increases. These empirical relations are displayed in equations (7) and (8) which are displayed graphically in figures (3 and4).

Conclusion:

It is clear from the experiments that temperature and magnetic field affected the performance of photodiodes. These effects are in conformity with theoretical relations who relate current to temperature and magnetic field. This means that to improve the photodiode performance it is important to decrease temperature, thus on needs air cooler. The effect of the sun and earth magnetic field can be utilized to increase performance by reorienting photodiode till maximum current is obtained.

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