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Modeling of Radiation Induced Damage and Thermal Effects on Avalanche Photodiodes Properties

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Abstract - Radiation-induced damage in Avalanche Photodiode (APD) was shown to result from the dark current and a change of the effective doping concentration occurring within the photodiodes. In this paper a model to reveals the effect of ionizing radiation, temperature and the reverse bias voltage on the optical properties of APDs is built by using Vissim environment. This proposed model provides a mean to control the properties of APD in thermal radiation environments. Detectivity, noise equivalent power, excess noise factor and normalized detectivity are modeled. The temperature effects are combined with radiation effects to formulate a rigours treatment for the APD behavior. The results are validated against published experimental work in temperature case and show good agreement.

Keywords – Avalanche Photodiode, Neutron Radiation, Dark Current, Thermal Effects, Detectivity.

I. INTRODUCTION

Optoelectronic components have become important elements in modern electronic systems due to the many intrinsic advantages of optical signal transfer, especially the large available bandwidths, high immunity to electromagnetic interference, and light weight [1]-[6]. Among of these components is the photodiode which when is exposed to the effects of light, then the photon energy is used to break the covalent bond releasing electrons and creating a hole in the process. If the generation of electrons and holes occurred in the depletion area, then the existing electric field removes them from that area before they get a chance to recombine. As a result, the reverse current (photocurrent) occurs. Photocurrent grows in proportion to the intensity of light. For larger values of reverse bias voltage photocurrent does not depend on the applied voltage but is practically constant. The number of generated electron-hole pairs increases only with the increasing of the light intensity [7]. Moreover the designer has three basic detector choices - the silicon PIN detector, the silicon avalanche photodiode (APD) and the photomultiplier tube (PMT) [8]. However at best, a pin diode can generate only one electron-hole pair per incident photon and therefore a pre-amplifier is needed for low light level detection. This limitation can be overcome by using (APDs) [2]. On the other hand many military and space applications require the use of APDs that continue to operate during and after exposure to a wide variety of ionizing-radiation environments [5], [6]. In addition when the new photodetector prototypes have been used the main problem is caused by the neutron radiation [9]. Furthermore neutron irradiation is believed to cause large clusters of disorder (defects) in the crystal lattice. In addition this results in an increase in the photodiode dark (leakage) current and therefore a larger background noise level. The other important permanent damage effect is a change of the effective doping concentration (Neff) that will modify the avalanche gain behavior of the APD. Such defects could also act as trapping centers and cause a change of APD parameters such as the change collection efficiency and quantum efficiency and a reduction in optical sensitivity [5], [10]-[13]. Thus, it is important to know the properties of the APDs in the irradiation environment, and how we can optimize these properties in order to improve APDs characteristics. Consequently, we are concerned with radiation effects on dark current, excess noise factor that enables us to calculate the humiliation that occurs in APDs performance under irradiation environment. In addition, it allows improving the Detectivity, NEP, contributes in achieving maximum usage of the communication system bandwidth, and to control APDs properties in radiation environments. The arising effects of radiation induced damage are decisive in designing high-bit-rate optical communication systems. This work is done by using VisSim environment. VisSim is a visual block diagram language for simulation of dynamical systems and model based design of embedded systems. It uses a graphical data flow paradigm to implement dynamic systems based on differential equation.

This paper is organized as follows: Section II presents the basic assumptions and modeling of radiation induced damage, section III describes the model results. However section IV is devoted to conclusion.

II. BASIC ASSUMPTIONS AND MODELING OF RADIATION INDUCED DAMAGE

The radiation sensitivity of avalanche photodiode shows up as interference by radiation-induced dark current and a change of the effective doping concentration (N_{eff}). In this model two Avalanche photodiodes were used, one of effective thickness =140μm and the other is equal to 120μm and the photodiodes are assumed to overfill the fiber so that all mode groups are received. The cross sectional areas diameters of the two devices are 0.8 and 0.5 mm. Operating wavelength of the optical sources used for transmitting data is 850 nm. To illustrate the optical responses of avalanche photodiode in radiation environment, the effect of the neutron radiation on the properties of avalanche photodiodes such as Detectivity and Noise Equivalent Power has been studied under different thermal condition. Consequently we should reveal the harmful neutron radiation effect that has two main contributions to the dark current of an APD. The first of these is the surface dark current, generated at or near of the perimeter of the junction. This current occurs outside the multiplying region, and is therefore not multiplied. The second contribution to the dark current is bulk current, generated within the junction region, and in an APD this current component undergoes multiplication. Thus we have [8].

$$I_D = I_{DS} + \mathrm{M} I_{DB} \quad (1)$$

Where I_D, I_{DS}, I_{DB}, and M are a the total dark current, the unmultiplied surface component of the dark current, the multiplied component of the dark current, and multiplication factor (gain) respectively. Moreover the dark current resulted from neutron effect can be also obtained as [14].

$$I_{Dark}neutron \cong I_{Dark}gamma - I_{Dark}proton = \mathrm{M} I_{DB} \quad (2)$$

Therefore equation (1) can be simplified as follows:

$$I_D = I_{DS} + I_{Dark}neutron \quad (3)$$

However, under neutron fluence Φ the dark current is a volume effect, so usually the increase in the dark current I_{Dark} neutron is written as follows [9].

$$I_{Dark}neutron = \alpha v \Phi \quad (4)$$

where v, α are the volume of the detector, and a parameter which has been measured by different groups, and its value is ranging between α = (10-13)10^{-17}A/cm. In the case of Avalanche Photodiodes, the volume which is relevant for the generation of the bulk current is the area times the effective thickness of the detector [9].

$$v = A_d \times \mathrm{T_E} \quad (5)$$

herefore equation (3) can be rewritten as follows:

$$I_D = I_{DS} + \alpha v \Phi \quad (6)$$

In addition values of avalanche parameters of a photodiode at a given operating voltage (at the fixed λ and T) determine about a signal to noise ratio, a noise equivalent power (NEP) and resulting from it detectivity D or D^*. In correctly processed photodiode structures, their noise is of shot nature. The dependencies of total noise and dark noise on gain are given below [15].

$$I_N = \left[\left(2q\left[I_{ph} + I_{DB}\right]\mathrm{M}^2 F(\mathrm{M}) + I_{DS}\right)B\right]^{1/2} \quad (7)$$

$$I_N = \left[\left(2q I_{DB}\mathrm{M}^2 F(\mathrm{M}) + I_{DS}\right)B\right]^{1/2} \quad (8)$$

Substituting from equations (2), and (4) in to equation (8). The following equation can be obtained

$$I_N = \left[\left(2q\alpha v\Phi \mathrm{M} F(\mathrm{M}) + I_{DS}\right)B\right]^{1/2} \quad (9)$$

Where B is the system bandwidth, however the excess noise factor is a function of the carrier ionization ratio, k, where k is usually defined as the ratio of hole to electron ionization probabilities (k < 1). The excess noise factor may be calculated using the model developed my McIntyre which considers the statistical nature of avalanche multiplication. Thus the excess noise factor is given by [8]

$$F(\mathrm{M}) = K_{EFF}\mathrm{M} + \left[1 - K_{EFF}\right]\left(2 - \frac{1}{\mathrm{M}}\right) \quad (10)$$

Where K_{EFF} is the effective k-factor for an APD, Moreover based on equation (9) the noise equivalent power and detectivity can be calculated as follows [15]

The amount of optical power incident on the surface of a photodetector that produces a signal at the output of the detector just equal to the noise generated internally by the detector is the noise equivalent power (NEP). This is usually the minimum detectable signal level. On the other hand when we compare the detectors in terms of their detecting ability (that is, in terms of the minimum detectable incident power) the best detector is the one with the lowest NEP.

$$NEP = \frac{\left[I_N / B^{\frac{1}{2}}\right]}{S_0 \mathrm{M}} \quad (11)$$

However noise equivalent power (NEP) cannot be used as the only measure of a detector's relative performance, but rather detector detectivity at a specific wavelength and bandwidth should be used to determine the optimum detector type for a given application, so if we take the reciprocal of the NEP, we can define the detectivity. The higher the value of the detectivity, the better the detector. The detectivity (D) is given by the following equation [8].

$$D = \frac{S_0 \mathrm{M}}{\left[I_N / B^{\frac{1}{2}}\right]} = \frac{1}{NEP} \quad (12)$$

Nevertheless the NEP—and hence the value of detectivity—depends on the area of the detector. This makes it difficult to compare the intrinsic properties of two different types of detectors. To remove this dependence, we use another term, called D^* (detectivity normalized to the unit of detector area 1 cm^2) to rate photodetectors. D^* is given by the following equation:

$$D^* = \frac{S_0 \mathrm{M} A_d}{\left[I_N / B^{\frac{1}{2}}\right]} = \frac{A_d}{NEP} \quad (13)$$

Where A_d is the detector area. Moreover a substantial characteristic for an avalanche photodiode is dependence of a multiplication factor (M) on its reverse bias voltage. Therefore an empirical relationship is given by [16].

$$\mathrm{M}(V, \Phi, \mathrm{T}) = \frac{\mathrm{H}}{V_b + \left[0.18(300 - \mathrm{T})\right] - V_R} \quad (14)$$

Where V_b, V_R, T are the breakdown voltage, and the reverse bias voltage, and ambient temperature respectively. In addition an approximate universal expression of the breakdown voltage for all semiconductors studied can be given as follows [17].

$$V_b = a\left[\frac{E_g}{1.1eV}\right]^{3/2}\left[\frac{N_{eff}}{10^{16}cm^{-3}}\right]^{-3/4} \quad (15)$$

Where E_g, N_{eff} are the bandgab energy of silicon, and the effective doping concentration respectively. Furthermore, defects generated during irradiation cause changes in the effective doping concentration which are macroscopically modeled as a function of the radiation particle fluence, Φ given by [17].

$$N_{eff} = 1.53 \times 10^{15} \exp\left[-1.139 \times 10^{-15}\Phi\right] \quad (16)$$

III. RESULTS AND DISCUSSION

We have demonstrated the optical response of APDs in thermal irradiation environment. We illuminate the effect of those environments on the optical signal detecting by APDs and how we can reduce the neutron effect in those devices. The results showed that the key to reducing thermal radiation effect is minimizing the active device volume and increasing device initial sensitivity or by selecting the materials that have lower ionization ratio. Moreover reducing the frequency band will contribute in improving detectivity and noise equivalent power. Furthermore optimizations of the device fabrication processes have resulted in significantly better electrical characteristics while maintaining good optical properties. The reference values of these parameters are shown in Table 1. These values of the calculations are taken from [15-17].

Table 1 Operating parameters values used in our proposal model.

Symbol	Operating parameter	Value
Φ	Radiation Fluence	$1x10^{11}$ n/cm^2-$5x10^{12}$ n/cm^2
T	Ambient Temperature	300 K- 400 K
P	Incident Power	1 nW - 10 nW
B	Bandwidth	1 MHz – 2 MHz
λ	incidence light wavelength	800 nm – 1100 nm
S_0	Detector initial sensitivity	0.5 A/W – 0.75 A/W
Eg	energy gap of silicon	1.15 eV

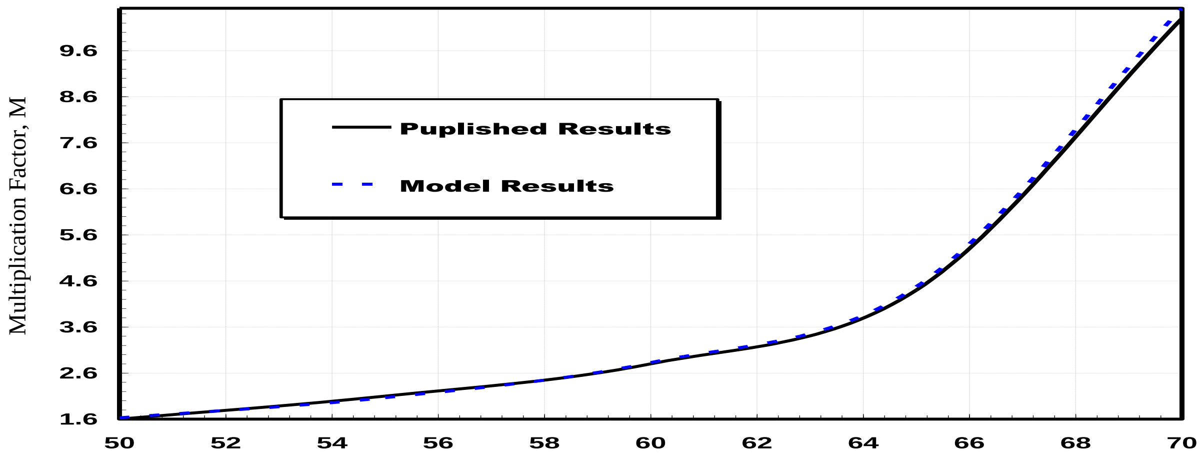


Fig.1. Variations of the multiplication factor (M) against reverse bias voltage (V_R) with T=300K, P=10nW, B=1MHz, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4.5 KΩ

In figure (1) the typical computed values for the Multiplication Factor (M) against reverse bias voltage (V_R) under thermal effect, and experimental values are represented in the above figure that shows a good agreement between the resulted curve and published experimental curve.

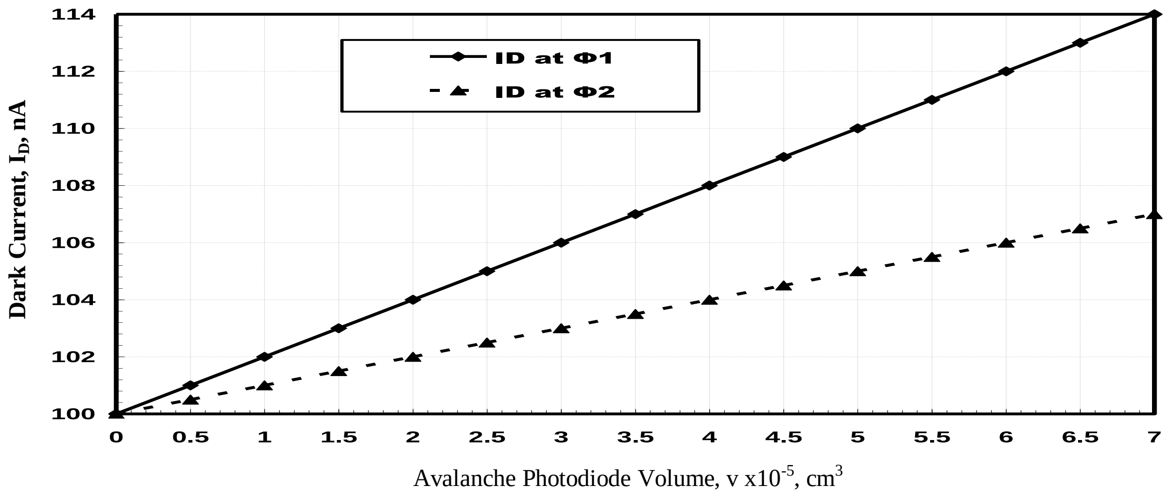


Fig.2. Variations of the dark current (I_D) against avalanche photodiode volume (v) at different radiation fluencies where ($\Phi_1=2x10^{11}$ n/cm^2, $\Phi_2=1x10^{11}$ n/cm^2) (Φ) with T=320K, P=10nW, B=1MHz, and λ=850nm

Figure (2) reveals the relation between the dark current (I_D) and the device volume (v); from the figure it is apparent that the dark current increase as the device volume increase. Moreover the induced dark current is increases as the neutron fluence increase. This result can be attributed to the creation of the defects in the silicon lattice which are responsible for the increase of the dark current is a volume effect, so usually the using of APD that has large volume will contribute in increasing of dark current I_D increment than APD that has small device volume. Moreover By minimizing the active device volume, the magnitude of the radiation induced signal current can be reduced. Relatively short minority carrier diffusion lengths also decrease the number of ionizing-radiation induced minority carriers that contribute to the device current [5]. Furthermore Care must be taken not to make the active region thickness too narrow or the minority carrier diffusion length too small or the desired optically generated minority carriers will not contribute to the device current and the optical responsivity will be suboptimal [5].

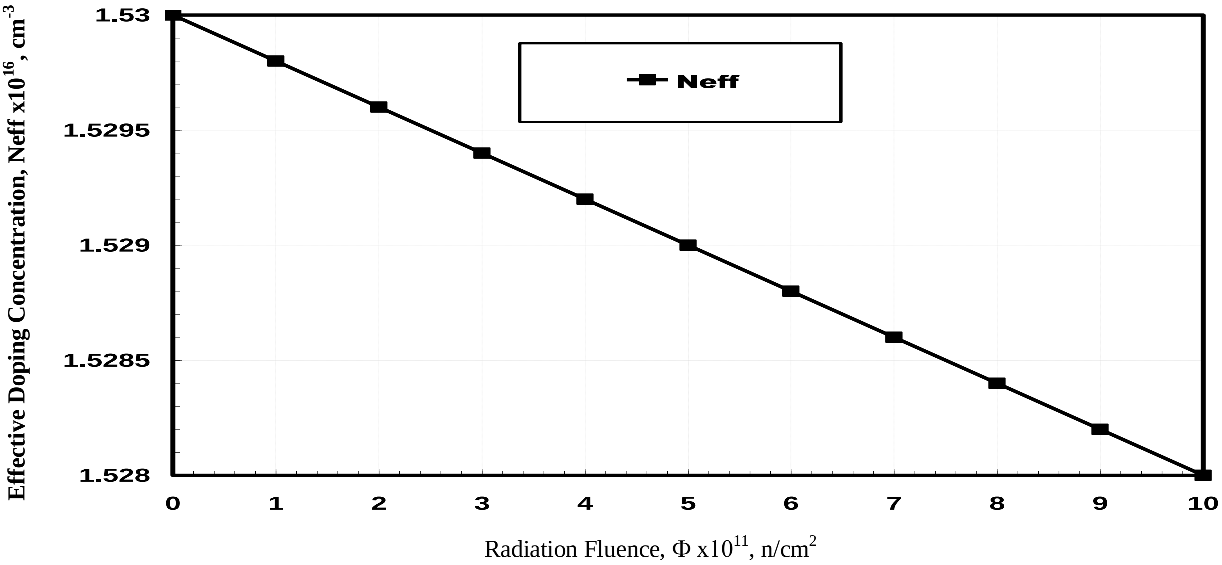


Fig.3. Variations of the effective doping concentration (Neff) against radiation fluence (Φ) with T=320K, P=10nW, B=1MHz, λ=850nm, and R_L=4 KΩ.

Figure (3) reveals the relation between the radiation fluence and effective carrier concentration. Results show decreasing of effective carrier concentration with increase radiation fluence. Therefore an important permanent damage effect of neutron radiation is a change of the effective doping concentration (N_{eff}) that will modify the avalanche gain behavior of the APD and cause a change of APD parameters such as the change collection efficiency and quantum efficiency and a reduction in optical sensitivity

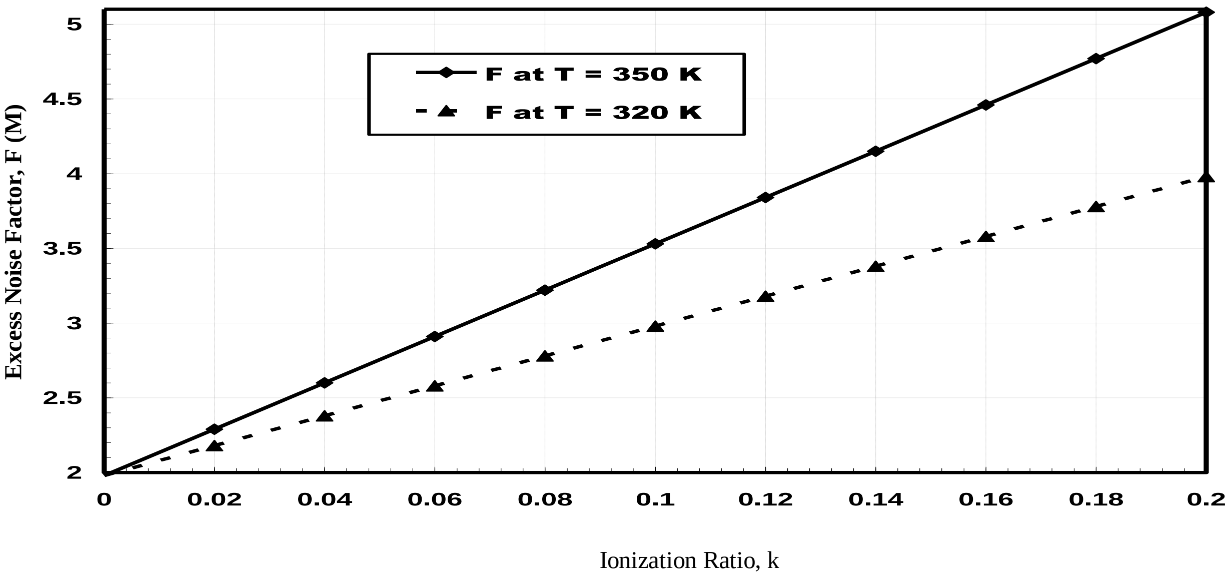


Fig.4. Variations of the excess noise factor (F) against ionization ratio (k) at different temperatures (T) with P=10nW, B=1MHz, Φ=1x10[11] n/cm[2], λ=850nm, and R_L=4 KΩ.

Figure (4) reveals the relation between the excess noise factor F (M) and the ionization ratio (k); from the figure it is apparent that the excess noise factor increase with increasing the temperature and ionization ratio. This result can be attributed to; all avalanche photodiodes generate excess noise due to the statistical nature of the avalanche process [8]. In addition these avalanche process statistics generate current fluctuations these fluctuations increases with the temperature, and

APD performance is degraded by an excess noise factor (F) compared to a PIN especially at higher temperatures [8]. Furthermore the excess noise factor is a function of the carrier ionization ratio, k, where k is usually defined as the ratio of hole to electron ionization probabilities [8]. Therefore the lower the values of k the lower the excess noise factor [8].

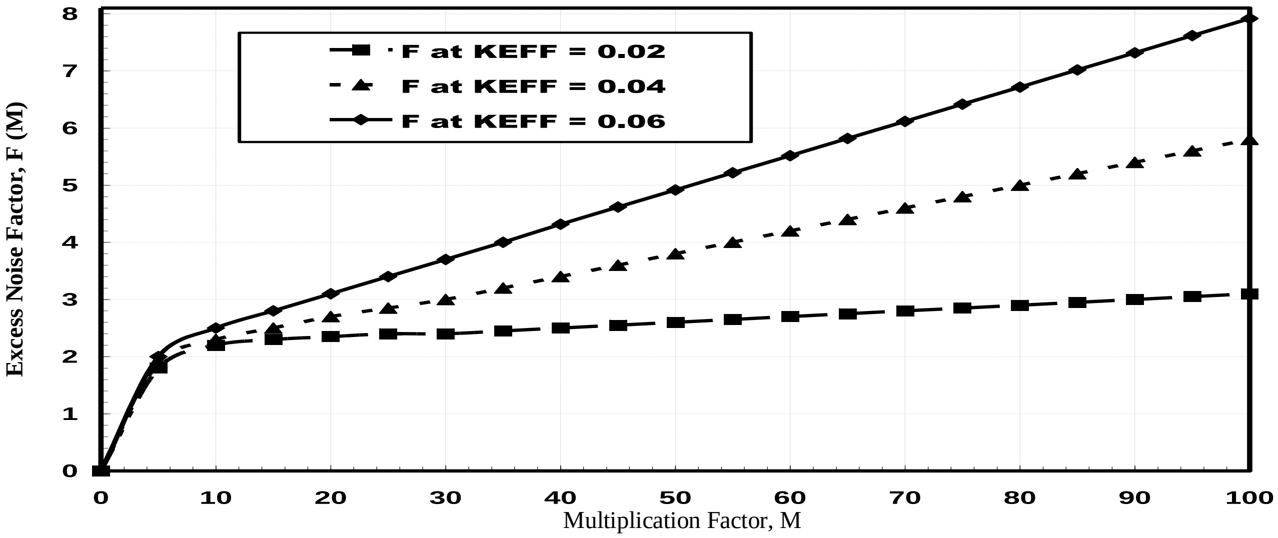
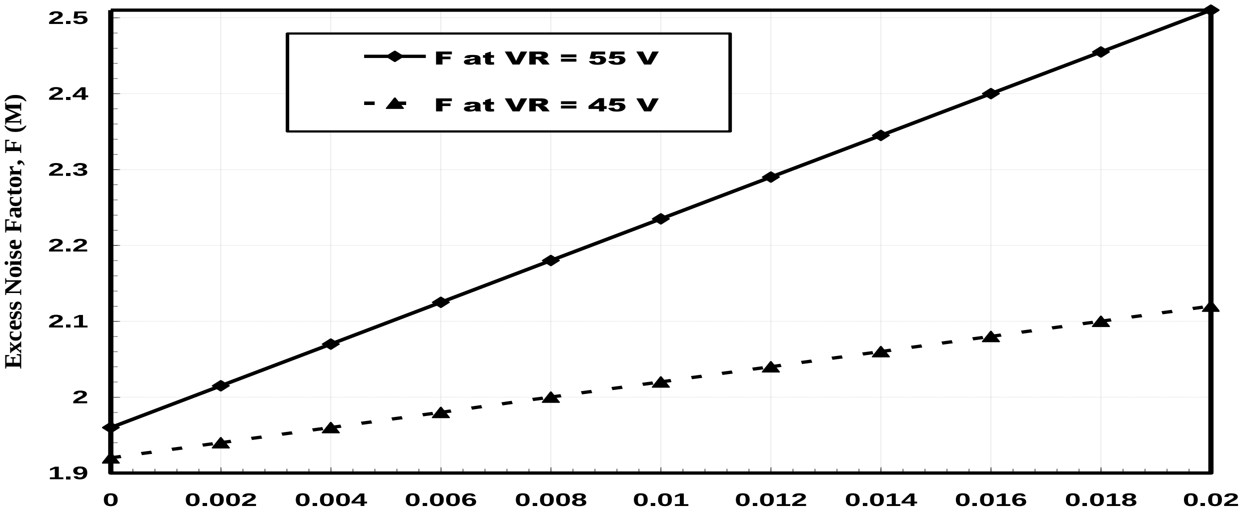


Fig.5. Variations of the excess noise factor (F) against multiplication factor (M) at different effective k-factor with T=320K, P=10nW, B=1MHz, $\Phi=1\times10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (5) reveals the relation between the excess noise factor F (M) and the multiplication factor (M); from the figure it is apparent that the excess noise factor increase with increasing multiplication factor. This result can be accredited to the fact that all avalanche photodiodes generate excess noise due to the statistical nature of the avalanche process [8]. Therefore, higher multiplication factor results in higher excess noise factor. Moreover the excess noise factor is a function of the carrier ionization ratio, k, where k is usually defined as the ratio of hole to electron ionization probabilities [8]. Therefore the lower the values of k and M; the lower the excess noise factor [8].



Ionization Ratio, k

Fig.6. Variations of the excess noise factor (F) against ionization ratio (k) at different reverse bias voltage (V_R) with T=320K, P=10nW, B=1MHz, $\Phi=1\times10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (6) reveals the relation between the excess noise factor F (M) and the ionization ratio (k) at different reverse bias voltage; from the figure the excess noise factor increase with increasing reverse voltage. This result can be credited to higher reverse bias voltage results in higher multiplication factor [16]. However the avalanche gain causes an increase in excess noise. Therefore the excess noise factor increases with increase reverses bias voltage.

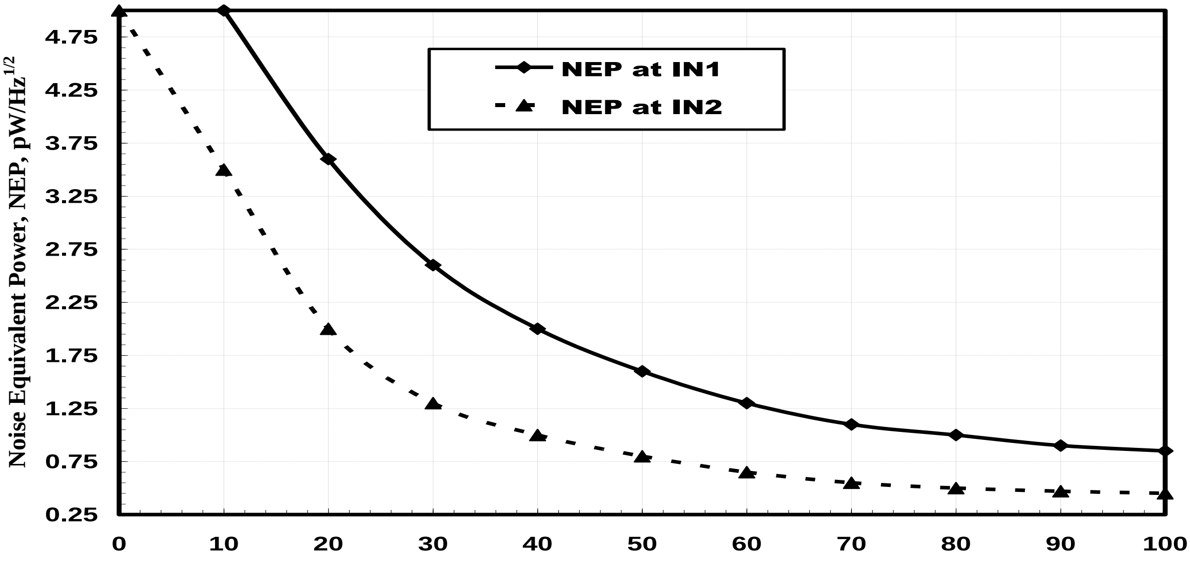


Fig.7. Variations of the noise equivalent power (NEP) against multiplication factor (M) at different Noise current (I_N) where (I_{N1}= 0.4 pA/$Hz^{1/2}$, I_{N2}= 0.2 pA/$Hz^{1/2}$) with T=320K, P=10nW, B=1MHz, Φ=1x10^{11} n/cm^2, λ=850nm, and R_L=4 KΩ.

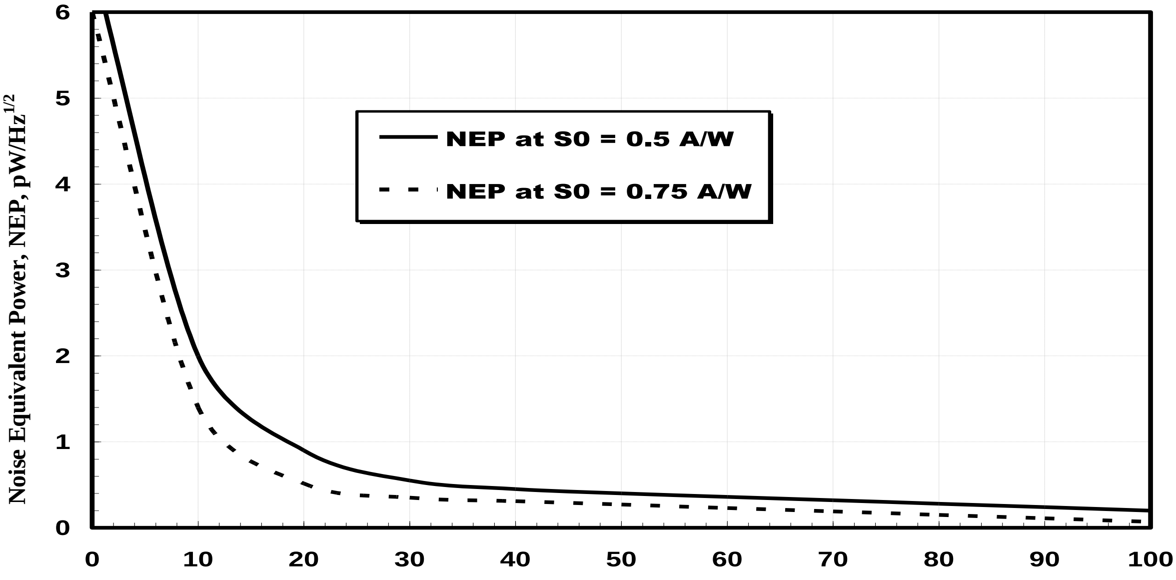


Fig.8. Variations of the Noise Equivalent Power (NEP) against Multiplication factor (M) at different Initial sensitivity (S0) with T=320K, P=10nW, B=1MHz, Φ=1x1011 n/cm2, λ=850nm, and RL=4 KΩ.

Figure (7), (8) reveals the relation between noise equivalent power and the multiplication factor. In addition based on the definition of NEP that is the amount of optical power incident on the surface of a photodetector that produces a signal at the output of the detector just equal to the noise generated internally by the detector. This is usually the minimum detectable signal level. On the other hand a mechanism of internal gain causes significant increases in a signal current generated in a detector and improves the signal to noise ratio [16]. So that NEP reduces with increasing the multiplication factor. Furthermore in figure (7) since noise currents which proportional to the square root of leakage currents determine the minimum detection levels [16]. Therefore NEP value decreases with lower noise current. However in figure (14) since NEP represents the minimum detectable signal level so, increasing device initial sensitivity results in decrease the noise equivalent power.

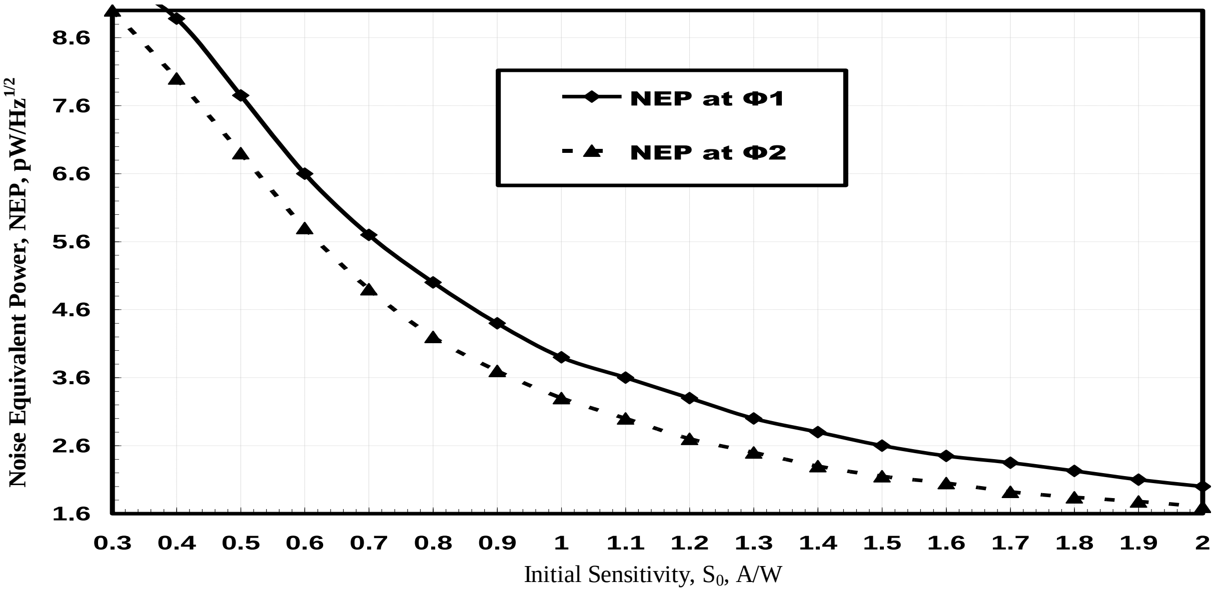


Fig.9. Variations of the noise equivalent power (NEP) against initial sensitivity (S_0) at different radiation fluencies (Φ) where (Φ_1= 5x10^{12} n/cm^2, Φ_2= 1x10^{11} n/cm^2) with P=10nW, B=1MHz, T=320K, λ=850nm, and R_L=4 KΩ.

Figure (9) reveals the relation between the noise equivalent power (NEP) and the Initial sensitivity (S_0) at different radiation fluencies, from the figure, noise equivalent power decrease with increasing device initial sensitivity, since NEP represents the minimum detectable signal level. However neutron irradiation is believed to cause large clusters of disorder in the crystal lattice due to the relatively large energy transfer associated with neutron scattering. These disorder clusters in the crystal lattice create generation sites in the depletion region of the semiconductor junction. This causes an increase in the depletion layer generation recombination current. This results in an increase in the photodiode dark (leakage) current and therefore a larger background noise level [5]. Furthermore this tends to raise the minimum power level of detectable optical signals. So this leads to NEP increment [6].

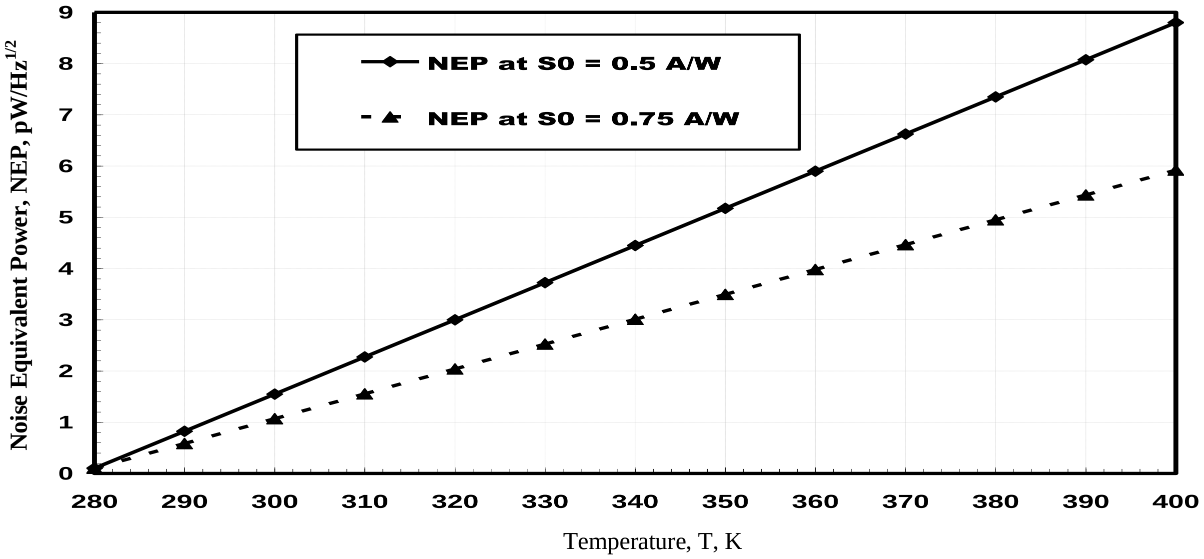


Fig.10. Variations of the noise equivalent power (NEP) against temperature (T) at different initial sensitivity (S_0) with P=10nW, B=1MHz, Φ=1x1011 n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (10) reveals the relation between the noise equivalent power (NEP) and temperature at different initial sensitivity (S_0), from the figure; noise equivalent power increase with increasing temperature. This result can be ascribed to neutron irradiation which causes large clusters of disorder in the crystal lattice due to the relatively large energy transfer associated with neutron scattering. This results in an increase in the photodiode dark (leakage) current and therefore a larger background noise level [5]. Moreover rise temperatures by 10^0C can double the reaction rates that take place during/after irradiation [24]. Therefore this duplication of defects created throughout the optically active volume tends also to increase the photodiode dark (leakage) current and noise level and as a result raise the minimum power level of detectable optical signals. So this leads to increase NEP [6].

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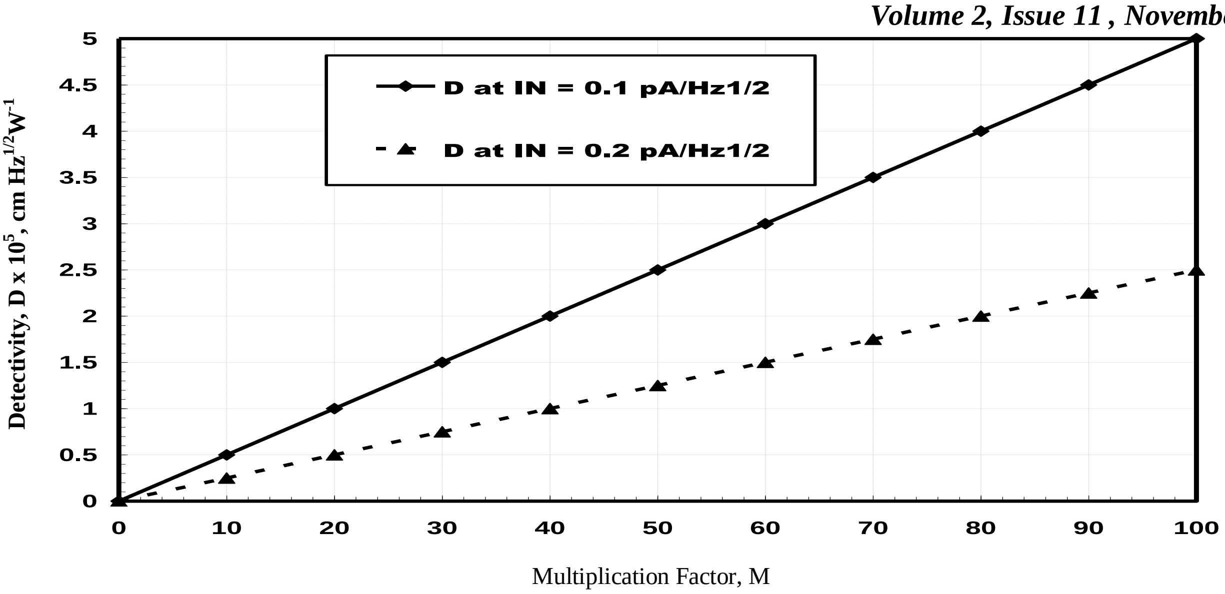

Fig.11. Variations of the detectivity (D) against multiplication factor (M) at different bandwidths (B) with T=320K, P=10nW, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (11) reveals the relation between detectivity (D) and the multiplication factor (M); from the figure it is apparent that the detectivity increase with increasing the multiplication factor. This result can be attributed to a mechanism of internal gain which causes significant increases in a signal current generated in a detector and improves the signal to noise ratio [16]. Consequently lowering the minimum power level of detectable optical signals and hence the detectivity increase. However an increase in dark current raising the minimum power level of detectable optical signals and increasing the noise [12]. For this reason detctivity decrease with increase the noise current.

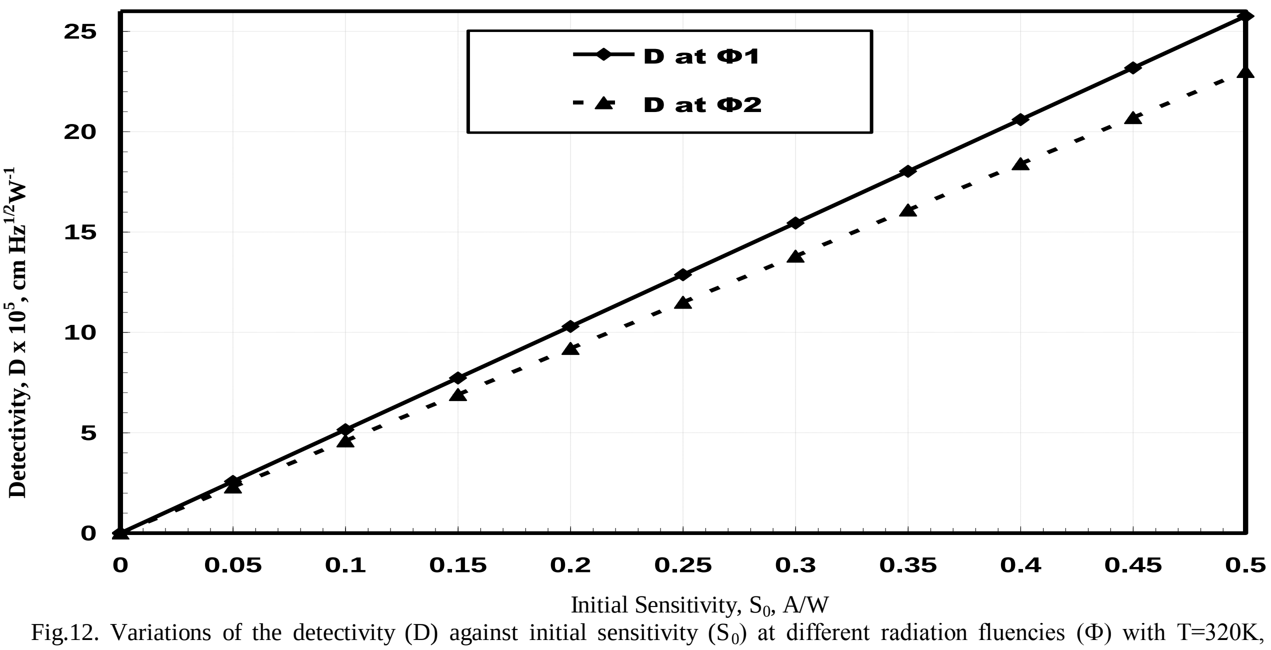

Fig.12. Variations of the detectivity (D) against initial sensitivity (S_0) at different radiation fluencies (Φ) with T=320K, P=10nW, B=1MHz, λ=850nm, and RL=4 KΩ.

Figure (12) reveals the relation between detectivity (D) and the initial sensitivity (S0) at different radiation fluencies (Φ); from the figure it is apparent that the detectivity increase with increasing the initial sensitivity and decreases at high neutron fluencies. This result can be ascribed to neutron radiation causes large clusters of disorder in the crystal lattice due to the relatively large energy transfer associated with neutron scattering. These disorder clusters in the crystal lattice create generation sites in the depletion region of the semiconductor junction. This results in an increase in the photodiode dark (leakage) current and therefore a larger background noise level [5]. Moreover the internally generated noise of a photodiode is one of the main factors affecting the minimum optical power an optical detector can sense. This limitation determines the lower limit on the incident optical power before signal to noise ratios is unacceptable and error rates become too large [5]. Therefore dectivity decreases at high neutron fluencies. However increasing device initial sensitivity improves the minimum optical power an optical detector can sense. Thus detectivity increase by increases initial sensitivity.

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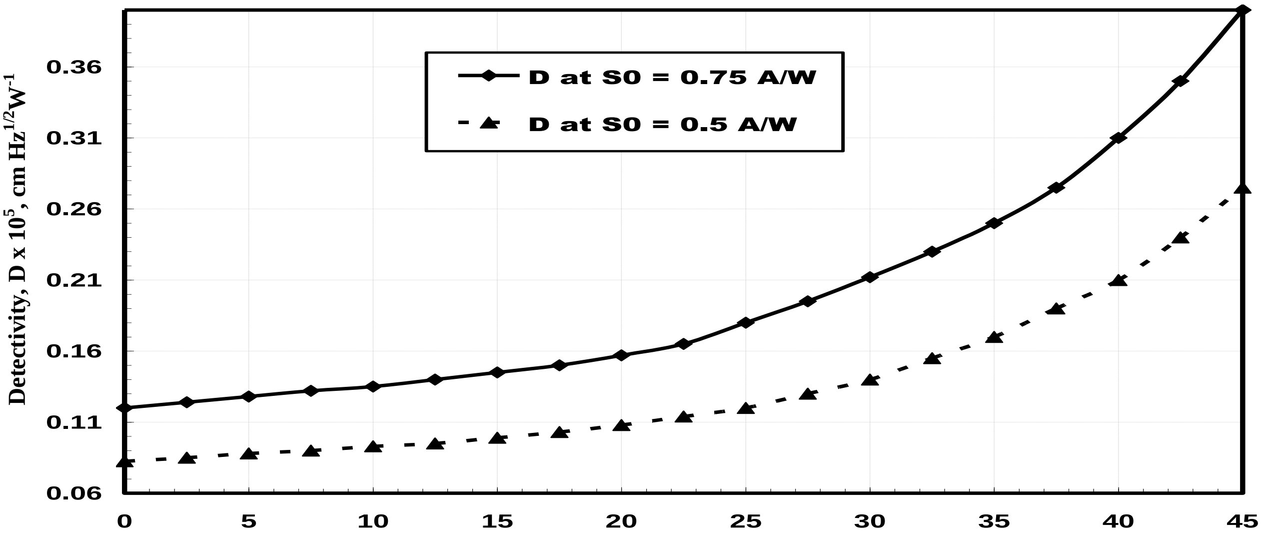

Fig.13. Variations of the detectivity (D) against reverse bias voltage (V_R) at different initial sensitivity (S_0) with P=10nW, B=1MHz, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (13) reveals the relation between detectivity (D) and the Reverse bias voltage (V_R) at different initial sensitivity (S_0); from the figure it is apparent that the detectivity increase with increasing reverse bias voltage. For the reason that reverse bias voltage results in increasing multiplication factor which causes significant increases in a signal current generated in a detector and improves the signal to noise ratio [16]. Furthermore this result in reducing the minimum power level of detectable optical signals [12]. Consequently detectivity will increase.

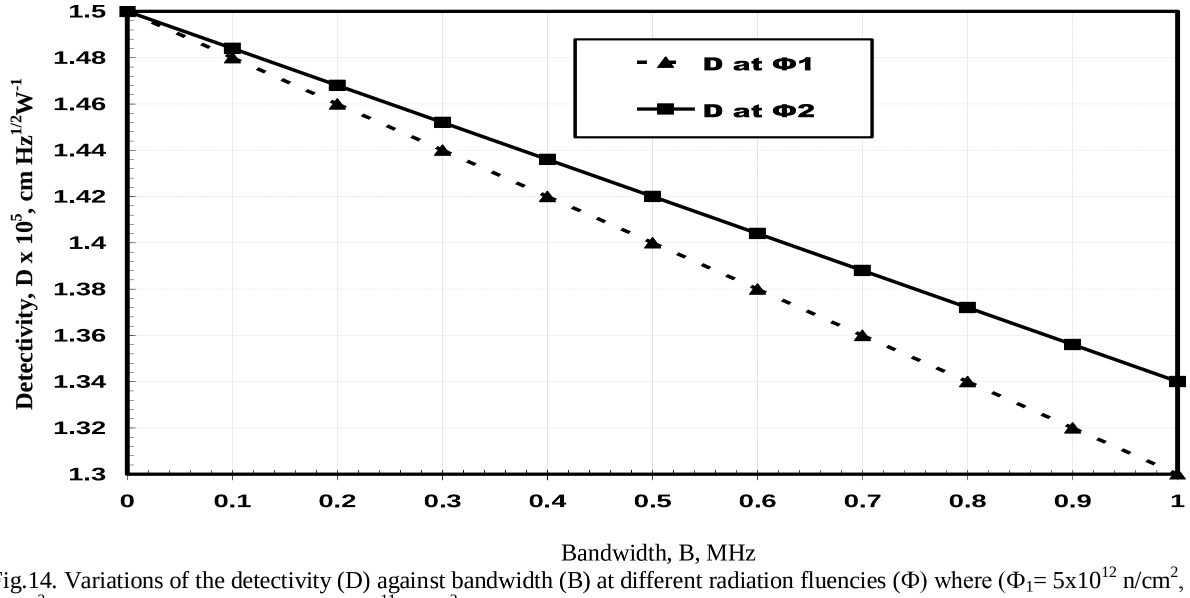

Fig.14. Variations of the detectivity (D) against bandwidth (B) at different radiation fluencies (Φ) where (Φ_1= 5x10^{12} n/cm^2, Φ_2= 1x10^{11} n/cm^2) with P=10nW, T=320K, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (14) reveals the relation between detectivity (D) and the bandwidth (B) at different radiation fluencies (Φ); from the figure it is apparent that the detectivity decrease with increasing bandwidth. This result can be endorsed to while impact ionization can increase the APDs detectivity it still limits their bandwidth at high M because of the long multiplication chains, which takes time to build up and die away. This accompanying increase in response time with M results in a roughly constant gain bandwidth product [2]. While increasing the avalanche gain the detectivity increase it causes both, an increase in the noise originated from the dark current and in the quantum noise this restricts the bandwidth [16].

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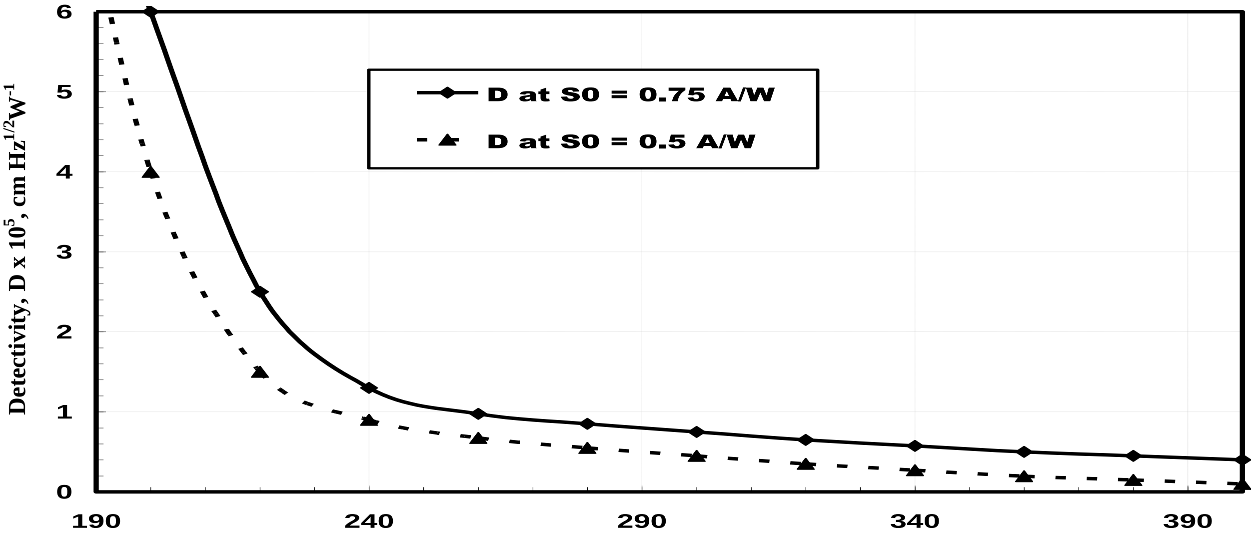


Fig.15. Variations of the detectivity (D) against temperature (T) at different initial sensitivity (S_0) with P=10nW, B=1MHz, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (15) reveals the relation between detectivity (D) and the temperature (T) at different initial sensitivity (S_0); from the figure it is apparent that the detectivity decrease with increasing temperature. For the reason that rises in 10^0C can double the reaction rates that take place during/after irradiation [24]. Therefore this duplication of defects created throughout the optically active volume tends to decrease the overall collection of optically generated minority carriers by reducing the minority carrier diffusion length and increase the dark current [23]. Moreover the avalanche process statistics generate current fluctuations these fluctuations increases with the temperature [16]. As a result this will raise the minimum optical power an optical detector can sense and reduce device detectivity [5].

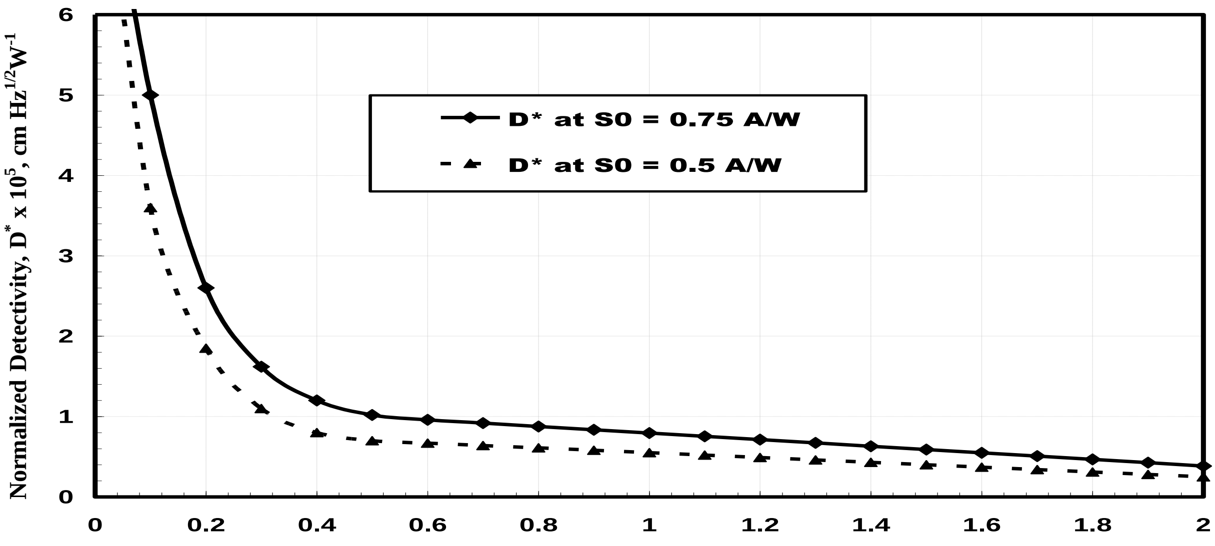
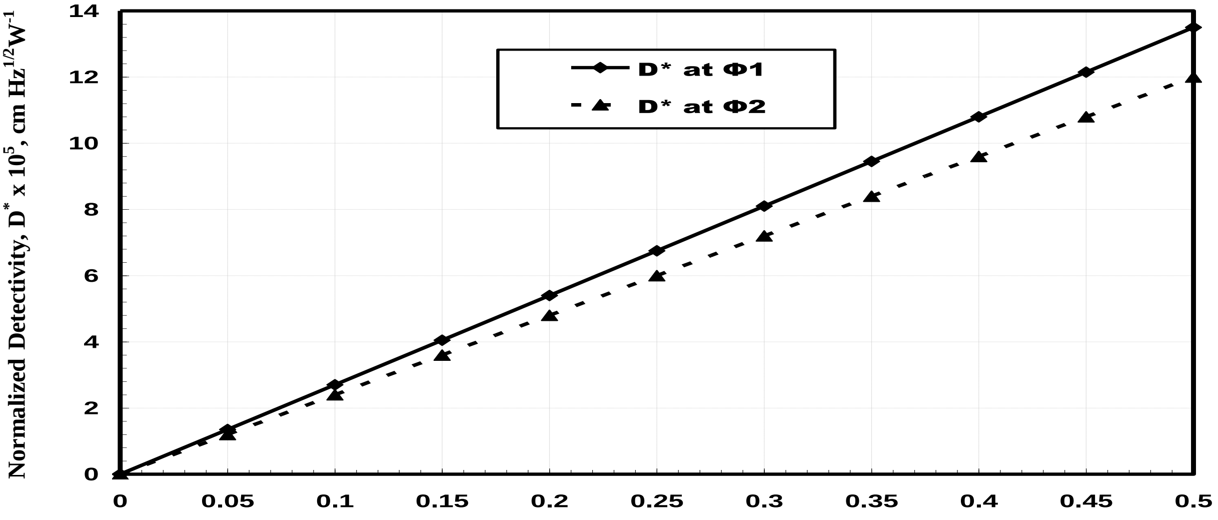


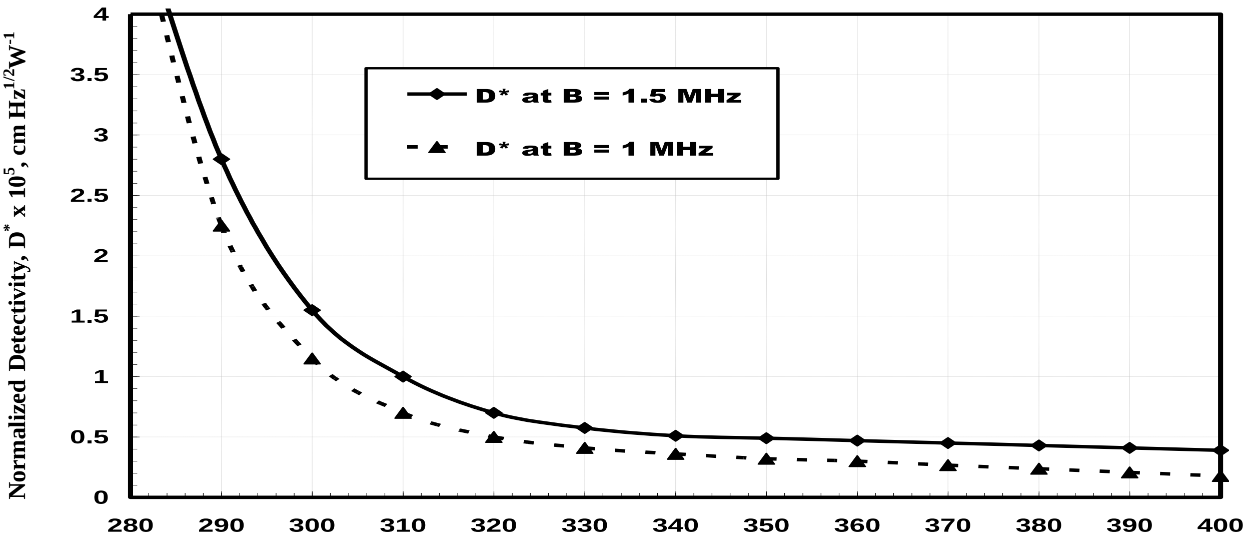
Fig.16. Variations of the normalized detectivity (D^*) against noise current (I_N) at different Initial sensitivity (S_0) with T=320K, P=10nW, B=1MHz, $\Phi=1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (16) reveals the relation between normalized detectivity (D^*) and the Noise current (I_N); from the figure it is apparent that the normalized detectivity decrease with both increasing noise current and decrease the initial sensitivity. This result can be attributed to increasing the noise current will reduce signal to noise ratio and tends to impose a lower bound on the minimum detectable optical signal for a given signal to noise ratio [6]. Therefore higher noise current results in lower normalized detectivity. Moreover decrease the initial sensitivity result in raising the minimum power level of detectable optical signals [12], hence the normalized detectivity decrease.



Initial Sensitivity, S_0, A/W
Fig.17. Variations of the normalized detectivity (D*) against Initial sensitivity (S0) at different radiation fluencies where ($\Phi 1 = 1x10^{11}$ n/cm^2, $\Phi 2 = 2x10^{11}$ n/cm^2) (Φ) with P=10nW, B=1MHz, T=320 K, λ=850nm, and R_L=4 KΩ.

Figure (17) reveals the relation between normalized detectivity (D*) and the initial sensitivity (S_0) at different radiation fluencies (Φ); from the figure it is apparent that the normalized detectivity increase with increasing the initial sensitivity and decreases at high neutron fluencies. This result can be ascribed to radiation damage occurs when incident particles transfer sufficient energy to a material to displace host atoms or to cause ionization. In semiconductor APD displacement damage introduces defect states into the band-gap that can act as generation recombination centers. In these APD generation of charge at the defects causes an increase in dark current, raising the minimum power level of detectable optical signals and increasing the noise [12]. Therefore normalized dectivity decreases at high neutron fluencies.



Temperature, T, K
Fig.18. Variations of the normalized detectivity (D*) against at temperature (T) at different Bandwidth (B) with P=10nW, B $\Phi = 1x10^{11}$ n/cm^2, λ=850nm, and R_L=4 KΩ.

Figure (18) reveals the relation between normalized detectivity (D^*) and the temperature (T) at different bandwidth (B); from the figure it is apparent that the normalized detectivity decrease with decrease bandwidth and increasing temperature. For the reason that rises in 10^0C can double the reaction rates that take place during/after irradiation [24]. Therefore this duplication of defects created throughout the optically active volume tends to decrease the overall collection of optically generated minority carriers by reducing the minority carrier diffusion length and increase the dark current and this increase noise level [23]. Moreover the avalanche process statistics generate current fluctuations these fluctuations increases with the temperature [16]. As a result this will raise the minimum optical power an optical detector can sense and reduce normalized detectivity [5].

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IV. CONCLUSION

In this paper a block diagram model treating the radiation induced damage is proposed to provide a mean to control the optical properties of APDs in thermal radiation environments. The proposed treatment can be used to improve the detectivity and noise equivalent power as well as the normalized detectivity. A model is built using VisSim environment. The obtained results show that the key to reducing thermal radiation effect is minimizing the active device volume and selecting the devices that have higher initial sensitivity. Moreover reducing the frequency band will contribute in improving detectivity and noise equivalent power. Furthermore this can be achieved by selecting the materials that have lower ionization ratio through the fabrication process. These results are significant for many applications in which noise currents which proportional to the square root of leakage currents determine the minimum detection levels. The results are validated against published experimental work in temperature case and show good agreement**.**

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