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An Accurate Model for Vertical Cavity Surface Emitting Laser Performance under Radiation and Thermal Effects

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Abstract*— Radiation induced degradation in Vertical Cavity Surface Emitting Laser (VCSELs) performance was shown to result from the radiation-induced crystal defects act as non-radiative recombination centers, decreasing the minority carrier lifetime and the fraction of radiative recombinations. In this paper a model to reveals the effect of ionizing radiation and ambient temperature on the performance of VCSELs is built by using Vissim environment. This proposed model provides a mean to control the properties of VCSELs when they are selected to operate in thermal radiation environments. Efficiency, threshold current, and device temperature change are modeled. The ambient temperature effects are combined with temperature change due to physical properties of the device itself under radiation effects to formulate a rigours treatment for the VCSELs behavior. The results are validated against published experimental work and show good agreement.

***Index Term* – Vertical Cavity Surface Emitting Laser, Neutron Radiation, Thermal Effects, Efficiency, and threshold current.**

I. INTRODUCTION

The rapid explosion of information has created ever increasing demands for data bandwidth. Optical fiber communication now dominates long-haul and metropolitan telecommunication networks, and it has made many in-roads into data-communication networks in campus and high-performance computing environments. However, traditional electrical signaling is still used for many tele- and data-communication links at the edge of these networks where data rates are still modest. But, even here optical techniques are beginning to look more attractive as the optical component cost becomes more competitive and the bandwidth demands increase [1]-[2]. Moreover optics is progressively replacing many electrical links, from networks to eventually even chip-to-chip and on-chip interconnects within computers. Low-cost, power-efficient, high-speed optical sources are one of the main keys to enable this transition. Vertical-Cavity Surface Emitting Lasers (VCSELs) are inherently suitable for optical data transmission for various reasons. Their small volume fundamentally implies that low power consumption and high-speed operation can be realized simultaneously. Due to surface emission, VCSELs can produce a more circular output beam with less divergence, can easily be fabricated in arrays, and can support on-wafer testing, high modulation bandwidth and high efficiency. All these lead to a significant reduction of the testing and packaging costs and make them suitable candidates for short-range optical communications and optical interconnects [1], [3]-[9]. Furthermore the numerous advantages of this component make the VCSEL technology competitive face to the Edge Emitter Laser (EEL) and the Light Emitting Diode (LED) [10]. In addition as a consequence of their advantages, VCSELs have been studied as elements of a variety of systems, including multichannel optical links, smart pixel systems, optoelectronic switches, WDM applications, optical storage, and laser printing [6]-[7]. However may be the most important characteristic of VCSELs is its strong thermal dependent behavior. Because of the poor heat dissipation and the large resistance introduced by their distributed Bragg reflectors (DBRs), a typical VCSEL undergoes relatively severe heating, and consequently can exhibit strong thermally dependent behavior [6], [11]. Furthermore optical fiber communication advantages have recently led them to be widely used in high-radiation environments, which include reactors and the space environments. Therefore the radiation sources influence the VCSELs properties can be neutrons, gamma, or X-rays, or a wide range of charged particles including electrons, protons, and heavy nuclei [12]. As well the exposure of every solid material to ionizing radiations produces changes in the microstructural properties of the material, which in turn affects the optical, electrical and other physical properties of the material [13]. On the other hand the oldest material system is AlGaAs-GaAs, used for wavelengths between 0.65 and 0.85 μm. Alloys of AlGaAs are lattice matched with GaAs to about 0.1 %, allowing a wide range of compositions to be used [14]. Furthermore the degradation of GaAs LEDs and VCSELs by irradiation is due to displacement damage (bulk damage) which is caused by elastic or inelastic interactions of incident particles with atoms in the semiconductor lattice, by recoiling nuclei and by secondary particles or fragments produced in inelastic nuclear reactions [15]. Although progress toward ionizing radiation tolerant optoelectronic devices has been made, further work is required to expand the operational environment of fiber optic data links.

Thus, it is essential to be acquainted with the thermal radiation influences on VCSELs properties in the radiation environment, and how we can optimize these properties in order to improve VCSELs characteristics. Consequently, we are concerned with radiation effects on device efficiency, resonance frequency, and rise time that enable us to calculate the degradation that occurs in VCSELs performance under irradiation environment. In addition this will contributes in achieving maximum usage of the communication system bandwidth, and to control VCSELs properties when they selected to operate in radiation fields. The arising effects of radiation induced damage are decisive in designing high-bit-rate optical communication systems. The motivation of this work comes from the need to examine the competence of these devices for exploitation in the neutron irradiation environmental applications and tests. 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 performance degradation, section III describes the model results. However section IV is devoted to conclusion.

II. BASIC ASSUMPTIONS AND MODELING OF RADIATION INDUCED PERFORMANCE DEGRADATION

Vertical-Cavity Surface Emitting Lasers (VCSELs) have already shown very good performance in various applications than the Edge Emitter Laser (EEL) and the Light Emitting Diode (LED). However, their performance is degraded drastically when they are operated in radiation environments. This degradation can be attributed to radiation-induced crystal defects act as non-radiative recombination centers, decreasing the minority carrier lifetime and the fraction of radiative recombinations. Furthermore radiation results in an increase in the threshold current and the reduction of device efficiency. In this model we have study the thermal effect that outcome from the ambient temperature combined with the heat that results from the device it self, in addition to the effect of ionizing radiation on the performance characteristics of the vertical cavity surface emitting lasers (VCSELs) over wide range of the affecting parameters. The dominant mechanism, by which displacement damage causes a degradation of LEDs or VCSELs that is radiation-induced crystal defects act as non-radiative recombination centers, decreasing the minority carrier lifetime and the fraction of radiative recombinations. Assuming the densities n_i of the different types of defects present in the diode junction at a given time to be proportional to the fluence ψ, the minority carrier lifetime τ may be written as [4],[16]:

$$\frac{1}{\tau} = \frac{1}{\tau_0} + K\psi \qquad (1)$$

Where τ_0, and K are the pre-irradiation minority carrier lifetime, and radiation damage constant respectively. If we assume that the total current through the LED junction is dominated by either the diffusion or the recombination current, the relative light output P_e/P_{e0} at a constant operating current is approximately related by a power law to the ratio of the minority carrier lifetimes before and after irradiation [4].

$$\left(\frac{P_e}{P_{e0}}\right)^{\varepsilon} = \frac{\tau}{\tau_0} \qquad (2)$$

Where $\varepsilon \geq 2/3$ for a linear graded pn junction in the limit of a total current dominated by the diffusion current (i.e. for an injection efficiency $\eta_{inj} \approx 100\%$). Moreover the power forward current of VCSEL device under thermal irradiation effect can be represented by the following equation [14]

$$P_e(I, T_a, \psi) = P_e(I, T_a)G(\psi) \qquad (3)$$

Where P_e (I, T_a) is the emitted power as a function of ambient temperature (T_a), which can be obtained from the following nonlinear thermal relations [14]

$$P_e(I, T_a) = A_0 + A_1 I + A_2 I^2 \text{ (m watt)} \qquad (4)$$

Where the set of parameters (A_0, A_1, A_2) are polynomial functions of ambient temperature T_a.

$$A_0 = 0.73 - 0.00169T_a + 0.000345T_a^2 \qquad (5)$$

$$A_1 = 2.5 - 0.0072T_a + 0.0002T_a^2 \qquad (6)$$

$$A_2 = -7.3 - 0.002T_a + 0.000065T_a^2 \qquad (7)$$

However $G(\psi)$ is a function of the irradiation fluence ψ, can be expressed as follows [14]

$$G(\psi) = 1 + \delta_1\psi + \delta_2\psi^2 \qquad (8)$$

Where the set of the coefficients of $\delta_1 = 0.0005$, $\delta_2 = -0.001$. However, by considering physical effects which are intrinsic to a VCSEL's behavior. Such as, due to their poor heat dissipation and the large resistance introduced by their DBR's, typical VCSEL's undergo relatively severe heating, and consequently can exhibit strong thermally dependent behavior, including thermal lensing, temperature dependent threshold current, and output power rollover [5]. Moreover thermal leakage of carriers out of the active region has a severe impact on device performance. As the device temperature increases, the bandgap of a VCSEL's active layer shrinks. Eventually, the high temperature no longer allow the active layer to adequately confine carriers, and leakage current becomes a dominant influence on the VCSEL's operation. The leakage current can be modeled as a function of temperature [5]

$$I_L(T) = \sum_{i=1}^{n} a_i T^{i-1} \qquad (9)$$

Where a_i are constants. On the other hand the power dissipated as heat can be expressed as [5]

$$\Delta P = VI - P_e \qquad (10)$$

Where V, I, and P_e are the input voltage, input current, and optical output power respectively. Furthermore the temperature can be described via a thermal rate equation that accounts for the transient temperature increase as a result of heat dissipation as [11]

$$T = T_a + \Delta T = T_a + R_{th}\Delta P - \tau_{th}\frac{dT}{dt} \qquad (11)$$

Where T_a, R_{th}, and τ_{th} is the environment temperature, the VCSEL's thermal impedance (which relates the change in device temperature to the power dissipated as heat), the thermal time constant which is necessary to account for the nonzero response time of the device temperature. However the VCSEL's thermal impedance can be expressed by the following relation [17]

$$R_{th} = \frac{\Delta T}{\Delta P} \qquad (12)$$

Additionally by substituting from equation (10) into (12) the following equation can be obtained

$$\Delta T = \Delta P R_{th} = R_{th}(VI - P_e) \qquad (13)$$

Where I, V, and P_e is laser input current, voltage, and optical emitted power respectively. Furthermore a quantity of practical interest is the slope of the P–I curve for I > I_{th}; it is called the slope efficiency and is defined as [18]

$$\frac{dP_e}{dI}=\frac{\hbar w}{2q}\eta_d \qquad (14)$$

Where η_d is called the differential quantum efficiency, as it is a measure of the efficiency with which light output increases with an increase in the injected current, it can be calculated from the following equation [18]

$$P_e=\frac{\hbar w}{2q}\eta_d\left(I-I_{th}\right) \qquad (15)$$

Where I_{th} is the threshold current which defined as the minimum pump power needed to begin laser action and can be calculated from the following equation [19]

$$I_{th}=\frac{q}{\tau_n}\left(N_{pt}+\frac{1}{g_{po}\tau_p}\right) \qquad (16)$$

Where N_{pt}, τ_p, τ_n, q, and g_{po} is the carrier number at transparency, the photon lifetime, the carrier lifetime, electron charge, and the gain slope constant respectively. On the other hand the external quantum efficiency η_{ext} can be defined as [18], η_{ext}= (Photon emission rate/ Electron injection rate), which can be represented by the following equation :

$$\eta_{ext}=\frac{2q}{\hbar w}\frac{P_e}{I} \qquad (17)$$

Furthermore η_{ext} and η_d are found to be related by [18]:

$$\eta_{ext}=\eta_d\left(1-\frac{I_{th}}{I}\right) \qquad (18)$$

However $\eta_{ext} < \eta_d$ but becomes nearly the same for I >> I_{th}. Similar to the case of LEDs, the total quantum efficiency (or wall-plug efficiency) can be defined as [18]:

$$\eta_{tot}=\frac{2P_e}{VI} \qquad (19)$$

Where V is the applied voltage. Moreover the total quantum efficiency η_{tot} is related to η_{ext} as [18]:

$$\eta_{tot}=\frac{\hbar w}{qV}\eta_{ext}\approx\frac{E_g}{qV}\eta_{ext} \qquad (20)$$

Where E_g is the bandgap energy. Furthermore the total quantum efficiency η_{tot} is related to the power dissipated ΔP by the following equation [17]:

$$\Delta P=VI\left(1-\eta_{tot}\right) \qquad (21)$$

Where V and I are input voltage and current respectively.

III. Simulation Results and performance Evaluation

The model has been demonstrated the harmful radiation damage on the optical performance degradation of VCSELs. We illuminate the effect of those environments on the differential quantum efficiency, external efficiency, and total efficiency of VCSELs and how we can reduce the neutron effect in those devices. In addition this model provide a method to calculate the performance degradation results from device physical properties such as the poor heat dissipation and the large resistance introduced by their distributed Bragg reflectors combined with the effect of the ambient temperature under radiation effects. The results showed that the key to reducing thermal radiation effect would expect in increasing the derive current and reduce the device thermal impedance. These results are considerable in designing optoelectronic systems, requiring immunity to the permanent and transient effects of thermal ionizing-irradiation. The values of these operating parameters are shown in Table 1.

Table 1 Operating parameters used in our proposal model [14, 18-20]

Symbol	Operating parameter	Value
Φ	Radiation Fluence	$1x10^{14}$ n/cm^2-$5x10^{14}$ n/cm^2
Ta	Ambient Temperature	300 K - 400 K
P_e	Emitted Power	1 nW - 10 nW
τ_p	Photon Lifetime	2.28 psec
I	Device Input Current	2.5 mA – 50 mA
τ_n	Carrier Lifetime	$2.094x10^{-10}$ sec
Eg	Energy gap of AlGaAs	1.424 eV
τ_{th}	Thermal Time Constant	1 µsec
q	Electron Charge	$1.602x10^{-19}$ C
R_{th}	Device Thermal Impedance	2 KΩ - 5 KΩ

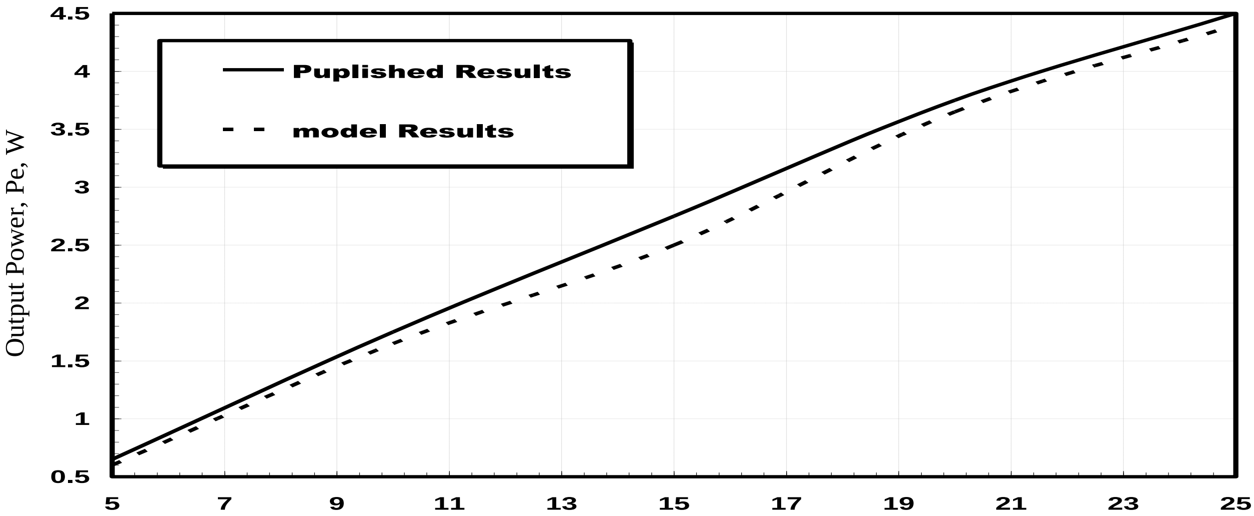

Fig.1. Variations of the output power (P_e) against input current (I) at ψ=$1x10^{14}$ n/cm^2, T= 300 K and R_{th}=2.6 KΩ.

In Fig. (1) the typical computed values for the Phase diagram under the irradiation environment effect, and experimental values are represented in the above figure that shows a good agreement between the resulted curve and published experimental curve. Based on the above model and the series of the operating parameters variations of the [differential quantum efficiency, external efficiency, total efficiency, threshold current, change of device temperature, power dissipation, and device transient temperature increase] against the variations of a set of effects [irradiation fluence Φ, ambient temperature T_a, input current I, and device thermal impedance] are displayed in the series of Figs. (2-19):

i. Figs. (2-7) have assured that as radiation fluence increases, these results in decreasing differential quantum efficiency, external efficiency, and total efficiency of VCSEL device, this degradation can be attributed to radiation induced crystal defects act as non-radiative recombination centers, decreasing the minority carrier lifetime and the fraction of radiative recombinations. These results illustrate the harmful effects of the neutrons irradiation on the performance characteristics of these devices.

ii. However as indicated in Figs. (2-4), as the drive current increases, this leads to increase of output device power [14], [11], consequently this will improve the device efficiencies [18].

iii. On the other hand Figs. (5-7) illustrate that as ambient temperature increases, these results in decreasing differential quantum efficiency, external efficiency, and total efficiency of VCSEL device, this degradation can be attributed to as the temperature increases, the bandgap of a VCSEL’s active layer shrinks. Eventually, the high temperature no longer allow the active layer to adequately confine carriers, and leakage current becomes a dominant influence on the VCSEL’s operation [5].

iv. Figs. (8-10) have indicated that as the drive current increases, this improve the device efficiencies even if in case of ambient temperature increment, this improvement can be attributed to as the drive current increases, this leads to increase of output device power, and then to increase the device efficiencies

v. Figs. (11-12) have guaranteed that as radiation fluence increases, these results in increasing threshold current of VCSEL device, this increment can be attributed to radiation damage that occurs when incident particles transfer sufficient energy to a material to displace host atoms or to cause ionisation. In semiconductor lasers diodes, we have found that the effects of displacement damage are more important than ionisation damage. Displacement damage introduces defect states into the band-gap that can act as generation recombination canters. In semiconductor lasers, recombination at these defects competes with band-to-band radiative transitions for the injected carriers, resulting in higher threshold currents. Above threshold, the stimulated recombination lifetime is much shorter than the lifetime associated with recombination at defects. The laser slope efficiency is therefore relatively unaffected by displacement damage, until high fluences are reached [21].

vi. Furthermore as indicated in Fig. (11), if all the devices received the same fluence, it is found that the damage effects are greater in the lower biased lasers. This result can be attributed to the fact that the degradation of GaAs LEDs and VCSELs by irradiation is due to displacement damage (bulk damage) which is caused by elastic or inelastic interactions of incident particles with atoms in the semiconductor lattice, by recoiling nuclei and by secondary particles or fragments produced in inelastic nuclear reactions [15]. Initially generated Ga and As vacancies and interstitials, leading both to vacancy-interstitial recombination (and thus to annealing of the damage occurred during the irradiation period since the threshold increase is roughly linear with fluence) and to the formation of more stable defect clusters like, e.g. antisite defects and vacancy-impurity complexes. These processes depend on the operating conditions of the diodes during and after irradiation, in particular on the forward current through the diode junction, since electron-hole recombination at a defect may increase its mobility and lead to further annealing (injection annealing) [5]. So that electrical bias decreases the radiation induced threshold increase [21].

vii. Moreover Fig. (12), illustrates that as ambient temperature increases, this results in increase the threshold current, The strong thermal dependence of a VCSEL is caused by a number of mechanisms such as Auger recombination, optical loss, temperature-dependent gain and carrier leakage. The exponential increase in the threshold current with temperature can be understood from equation (16). The carrier lifetime τ_n is generally N (number of electrons) dependent because of Auger recombination and decreases with N as N^2. The rate of Auger recombination increases exponentially with temperature and is responsible for the temperature sensitivity of VCSELs lasers [11].

x. Figs. (13-14) have definite that as radiation fluence increases, this results in increase change of device temperature, this effect can be ascribed to the actuality that the nuclear thermal radiation will be absorbed, reflected and transmitted in varying degrees, according to the physical properties of the materials on which it falls. The portion which is absorbed will cause a rise in temperature, the magnitude of which depends on the rate at which the thermal pulse deposits energy into the material, and the rate at which the heated layer of material loses energy through conduction, radiation and convection [22]. In addition because of the poor heat dissipation and the large resistance introduced by their distributed Bragg reflectors (DBRs), a typical VCSEL undergoes relatively severe heating, and consequently can exhibit strong thermally dependent behavior [6], [11], particularly under radiation exposure.

ix. In addition Fig. (13), illustrates that as the device thermal impedance decrease, this results in decrease change of device temperature. This result can be attributed to the thermal impedance relates temperature change to the heat power dissipation, thus lower thermal impedance value results in decrease power dissipation and consequently the heat from it, in the same time decrease change of device temperature.

xi. As well Fig. (14), illustrates that as the device input current increase, this results in decrease change of device temperature, this effect can be attributed to increasing electrical bias decreases the radiation induced damage[21] due to injection annealing [5].

xii. Figs. (15-16) have definite that as radiation fluence increases, this results in increase power dissipation, this effect can be attributed to by combining equations (1) and (2), we obtain the following relation:

$$\left(\frac{P_{e0}}{P_e}\right)^{\varepsilon} = \frac{\tau_0}{\tau} = 1 + \tau_0 K \psi \tag{22}$$

Which shows that a degradation of the minority carrier lifetime τ, and thus of the light output, is expected if the product $\tau_0 K\psi$ becomes significant compared to 1. Since for VCSELs the minority carrier lifetime in the lasing regime is dominated by stimulated emission, it is much smaller than for LEDs and higher fluences are required to produce a substantial change of τ_0/τ. Below the lasing threshold, however, the minority carrier lifetime is determined by spontaneous emission as in the case of LEDs. Therefore, the presence of radiation-induced non-radiative recombination centers decreases the light yield [4], consequently from equation (10) this effect increase the power dissipation. In addition the lasing threshold current of VCSELs is expected to increase after irradiation, while the conversion efficiency above threshold does not change substantially.

xiii. As well Fig. (15), illustrates that as the device input current increase, this results in decrease power dissipation, this effect can be attributed to increasing electrical bias decreases the radiation induced damage[21] due to injection annealing [5]. Therefore higher currents are required to enter the lasing regime [4] to improve output power and thus decrease power dissipation.

xiv. In addition Fig. (16), illustrates that as the ambient temperature increase, this results in increase power dissipation, this effect can be attributed to rises in 10^0C can double the reaction rates that take place during/after irradiation [23]. Therefore, the duplication of radiation-induced non-radiative recombination centers created throughout the lasing regime tends to lower output power and thus increase power dissipation.

xv. Figs. (17-18) have assured that as radiation fluence increases, these results in increase device transient temperature, this effect can be certified to the fact that the nuclear thermal radiation will be absorbed, reflected and transmitted in varying degrees, according to the physical properties of the materials on which it falls. The portion which is absorbed will cause a rise in temperature, the magnitude of which depends on the rate at which the thermal pulse deposits energy into the material, and the rate at which the heated layer of material loses energy through conduction, radiation and convection [22]. In addition radiation-induced non-radiative recombination centers decreases the output light, which consequently increase the power dissipation which dissipated as heat, this will cause a rise in temperature due to the poor heat dissipation which are intrinsic to a VCSEL's behavior, also as the ambient temperature increase, this results in active region temperature increase. All these effects result in increase device transient temperature [5].

xiv. In addition Fig. (17), illustrates that as the device thermal impedance decrease, this results in decrease device transient temperature. This result can be attributed to the thermal impedance relates temperature change to the heat power dissipation, thus lower thermal impedance value results in decrease power dissipation and consequently the heat from it, in the same time decrease change of device temperature, which results in decrease device transient temperature.

xvi. As well Fig. (18), illustrates that as the device input current increase, this results in decrease device transient temperature increment, this effect can be attributed to increasing input current decreases the radiation induced damage[21], results in increase output power and in the same time decrease power dissipation which dissipated as heat, consequently this results in decrease device transient temperature increment.

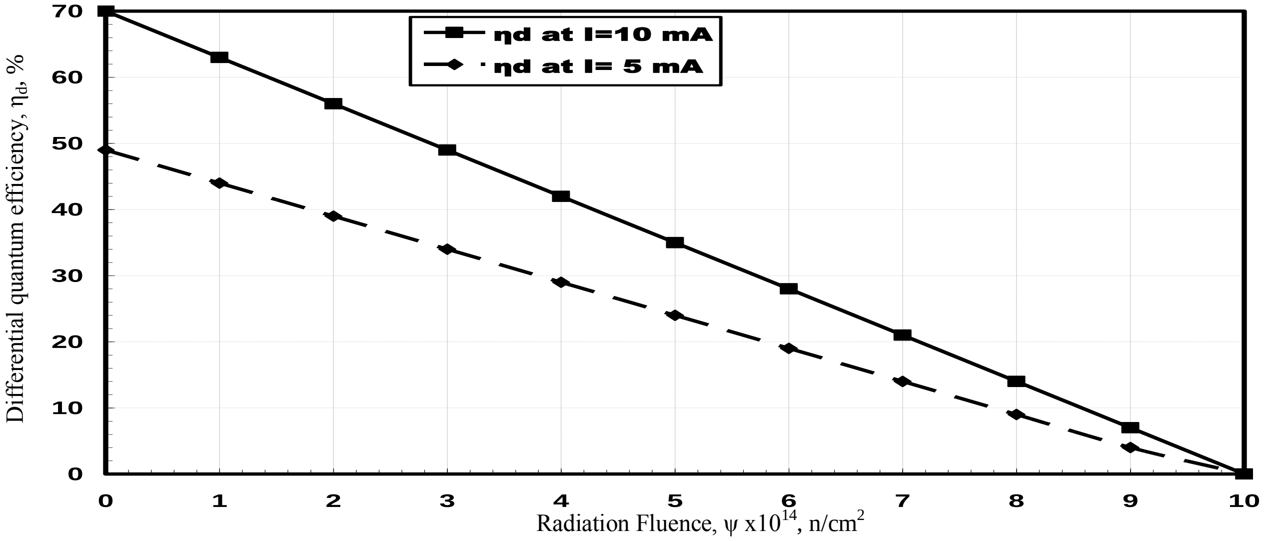

Fig. 2. Variations of the differential quantum efficiency (η_d) against radiation fluence (ψ) at different input current (I) with T_a=300K, and R_{th}=2.6 KΩ.

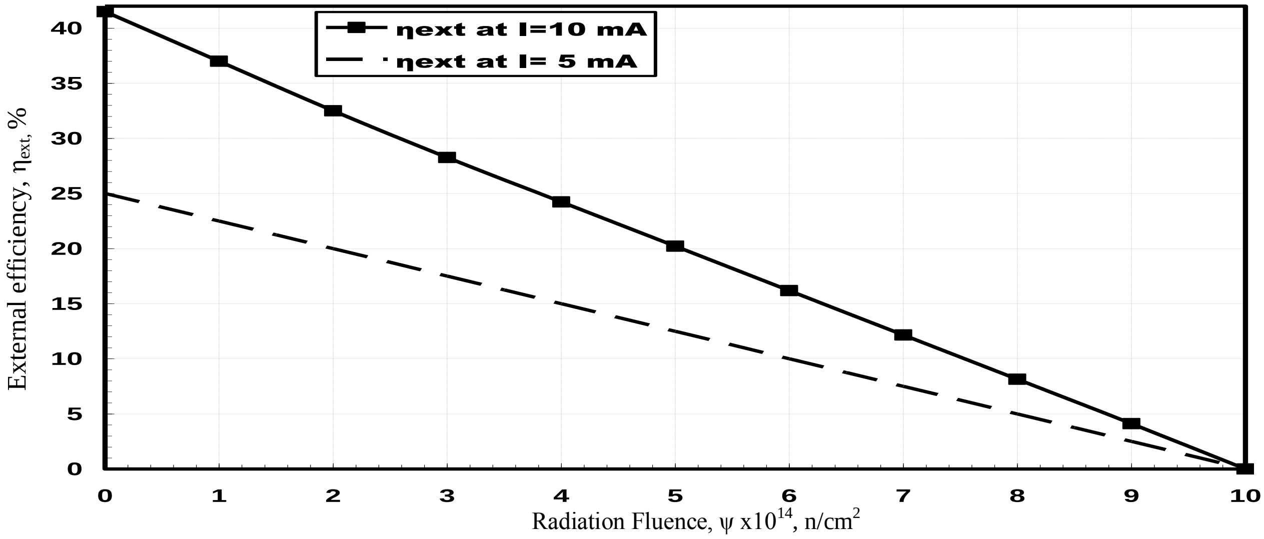

Fig.3. Variations of the external efficiency (η_{ext}) against radiation fluence (ψ) at different input current (I) with T_a=300K, and R_{th}=2.6 KΩ.

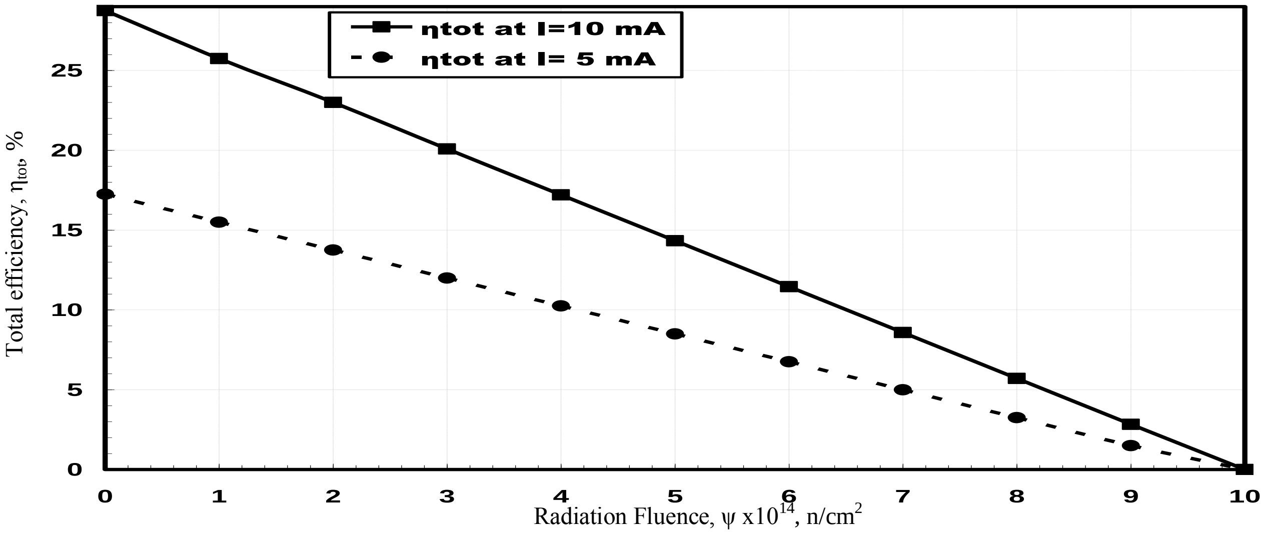

Fig.4. Variations of the total efficiency (η_{tot}) against radiation fluence (ψ) at different input current (I) with T_a=300K, and R_{th}=2.6 KΩ.

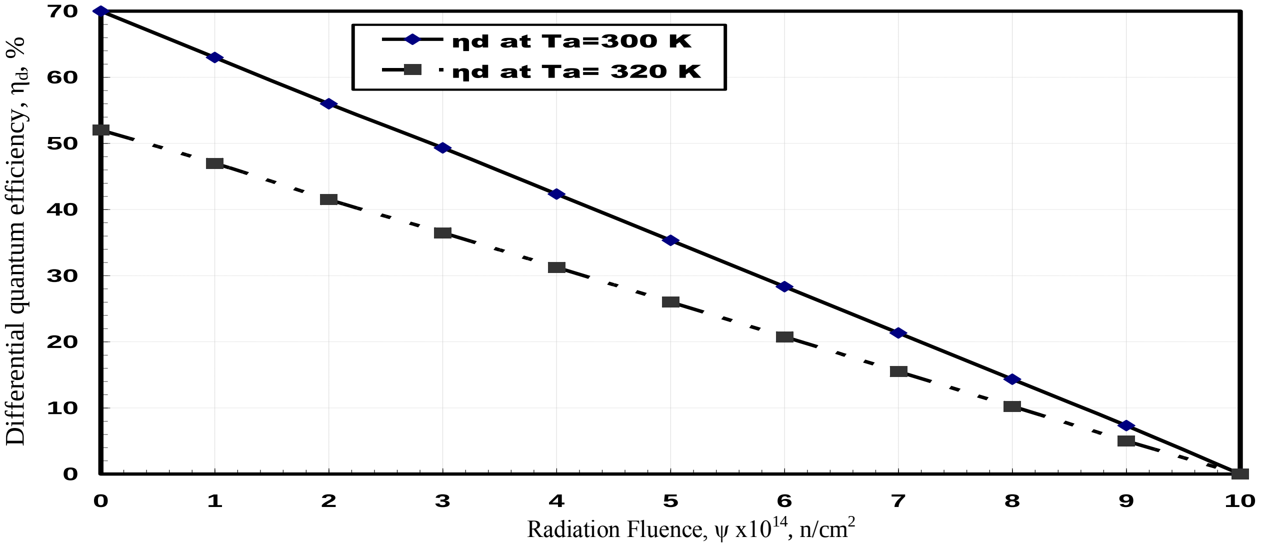

Fig.5. Variations of the differential quantum efficiency (η_d) against radiation fluence (ψ) at different ambient temperature (T_a) with I=10 mA, and R_{th}=2.6 KΩ.

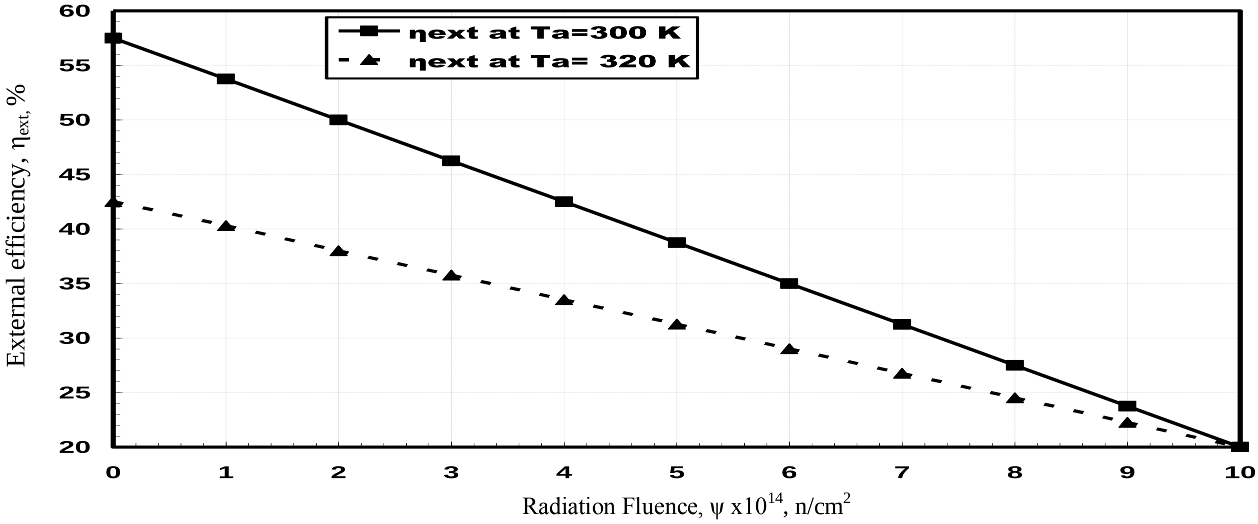

Fig.6. Variations of the external efficiency (η_{ext}) against radiation fluence (ψ) at different ambient temperature (T_a) with I=10 mA, and R_{th}=2.6 KΩ.

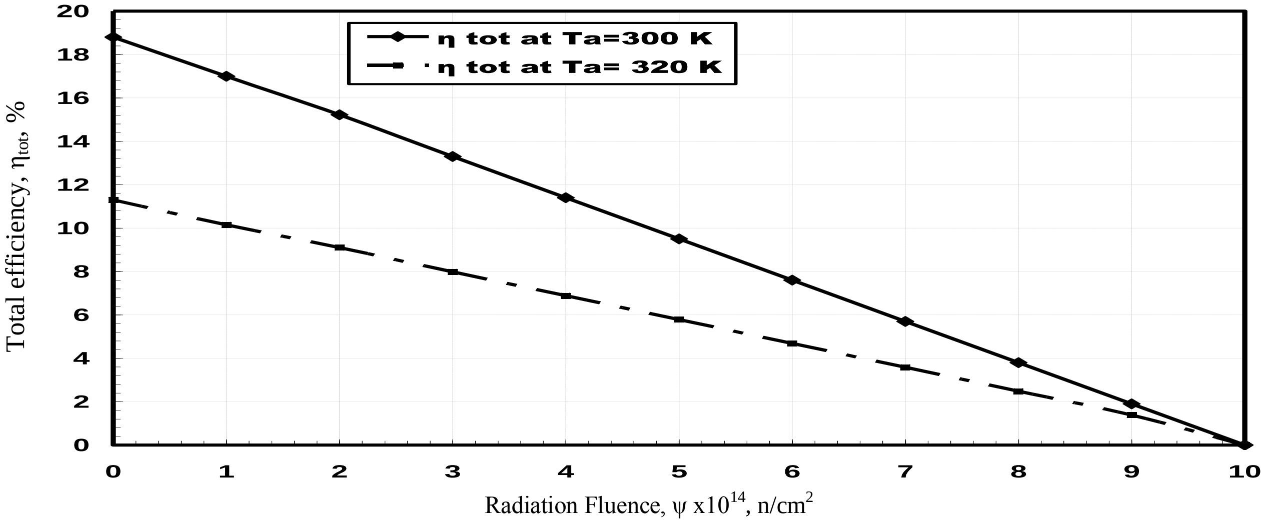

Fig.7. Variations of the total efficiency (η_{tot}) against radiation fluence (ψ) at different ambient temperature (T_a) with I=10 mA, and R_{th}=2.6 KΩ.

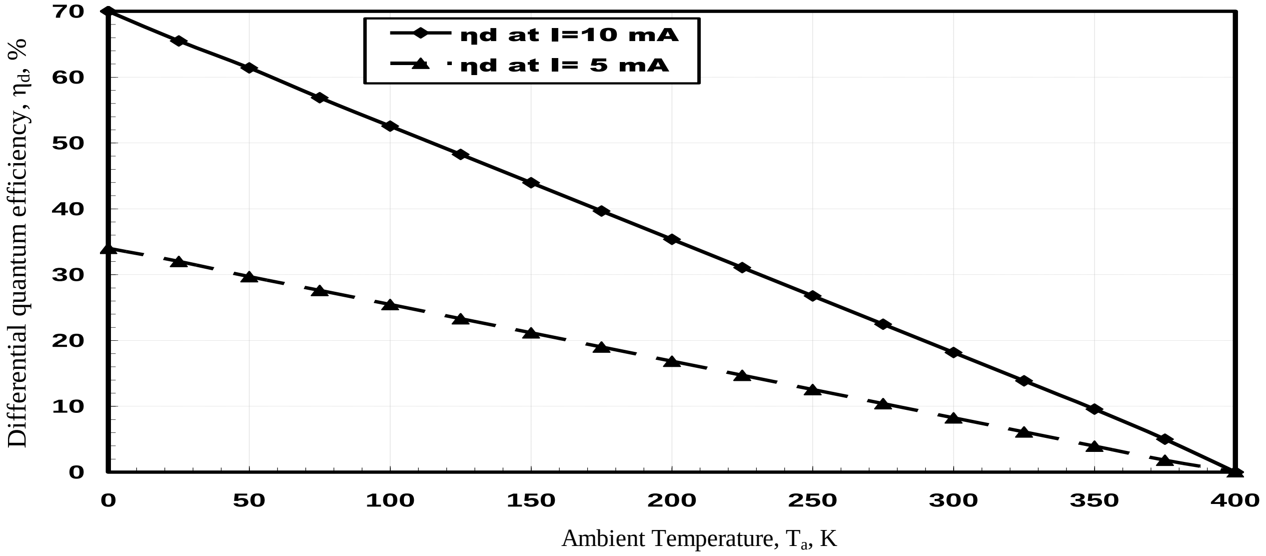

Fig.8. Variations of the differential quantum efficiency (η_d) against ambient temperature (T_a) at different input current (I) with $\psi=1x10^{14}$ n/cm^2, and R_{th}=2.6 KΩ.

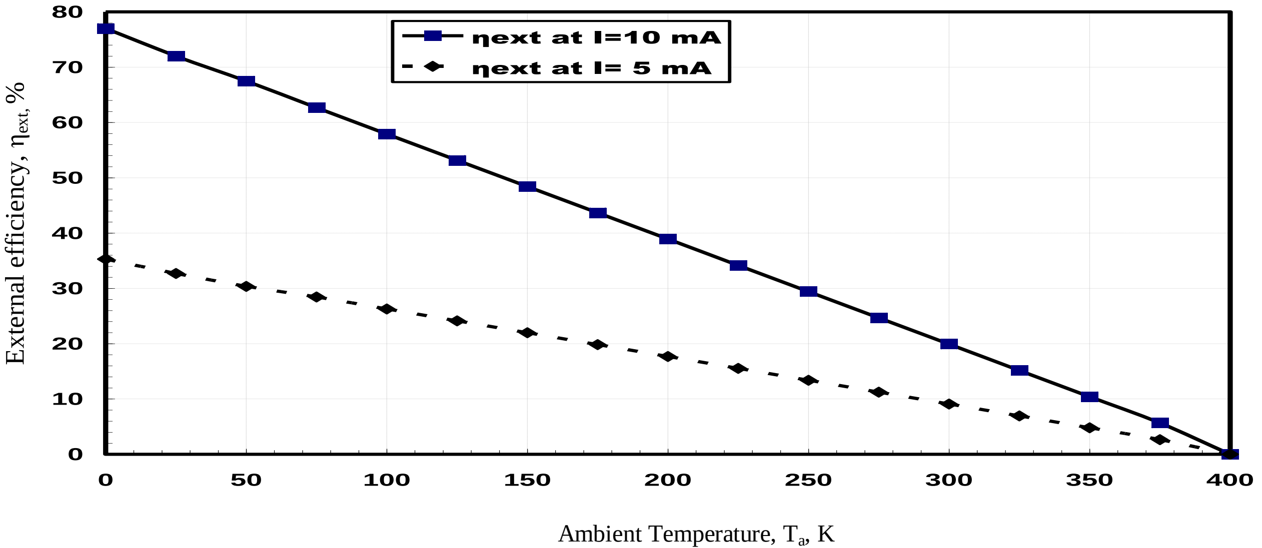

Fig.9. Variations of the external efficiency (η_{ext}) against ambient temperature (T_a) at different input current (I) with $\psi=1x10^{14}$ n/cm^2, and R_{th}=2.6 KΩ.

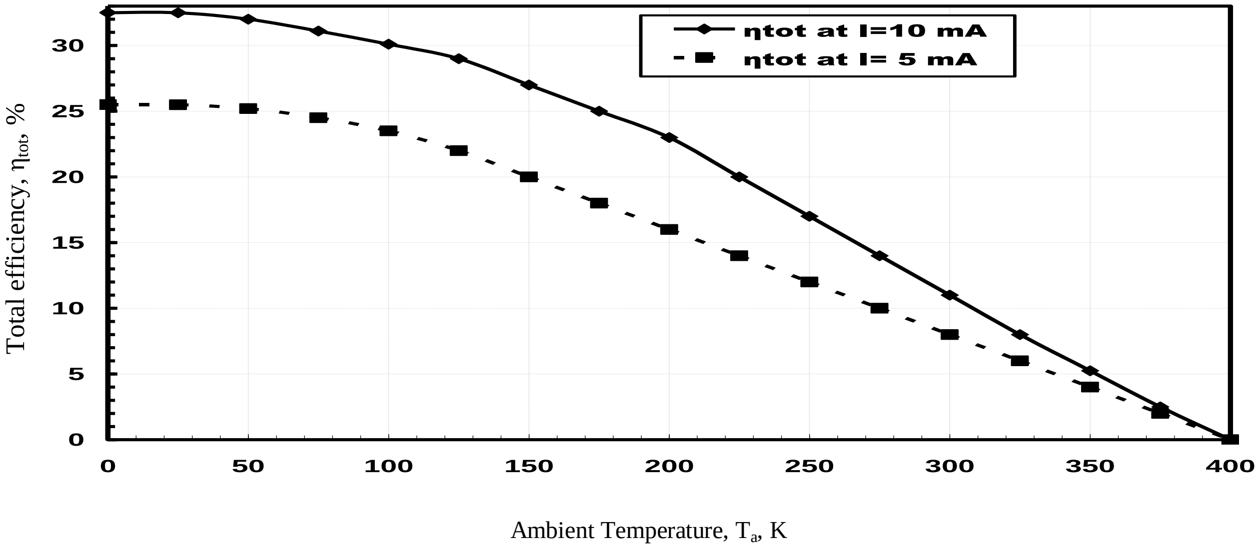

Fig.10. Variations of the total efficiency (η_{tot}) against ambient temperature (K) at different input current (I) with $\psi=1x10^{14}$ n/cm^2, and R_{th}=2.6 KΩ.

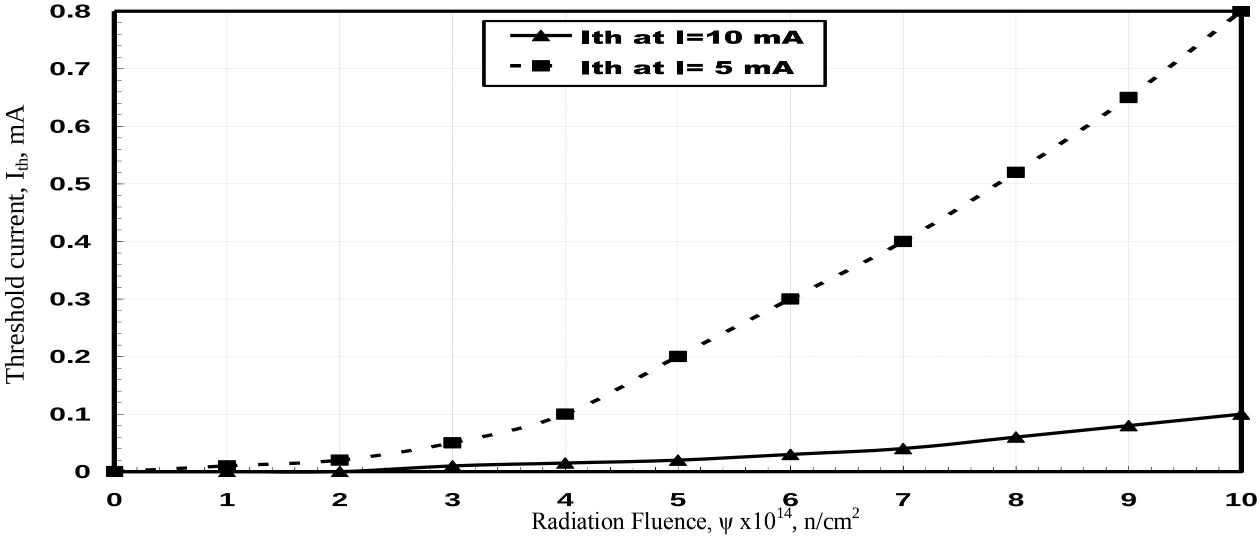

Fig.11. Variations of the threshold current I_{th} against radiation fluence (ψ) at different input current (I) with T_a=300K, and R_{th}=2.6 KΩ.

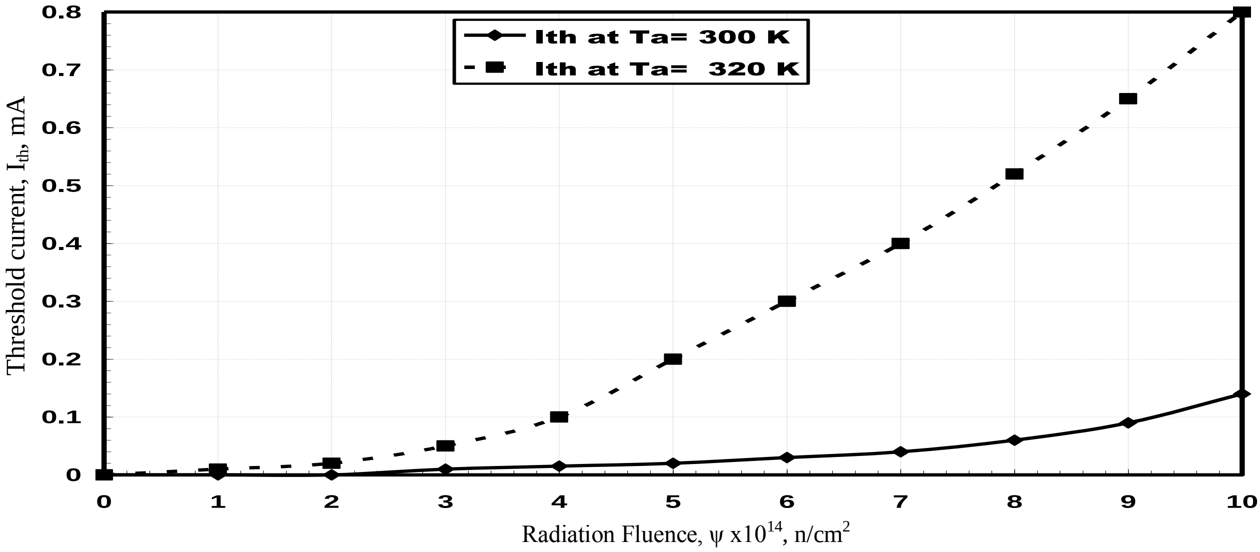

Fig.12. Variations of the threshold current I_{th} against radiation fluence (ψ) at different ambient temperature (T_a) with I=10 mA, and R_{th}=2.6 KΩ.

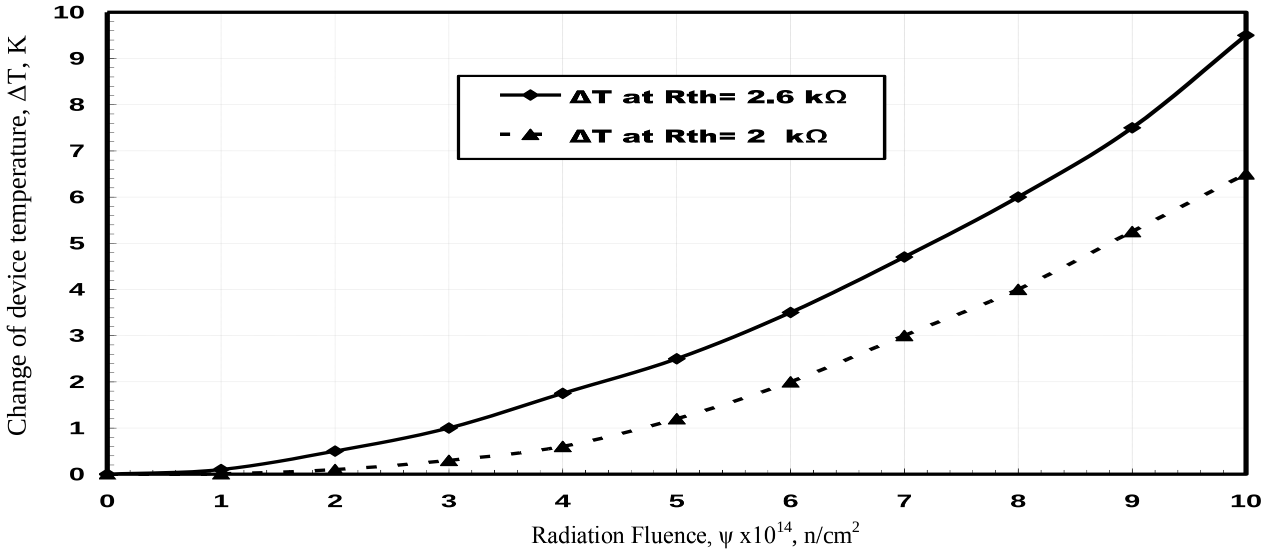

Fig.13. Variations of the change of device temperature (ΔT) against radiation fluence (ψ) at different device thermal impedance R_{th} with Ta =300 K, and I=10 mA.

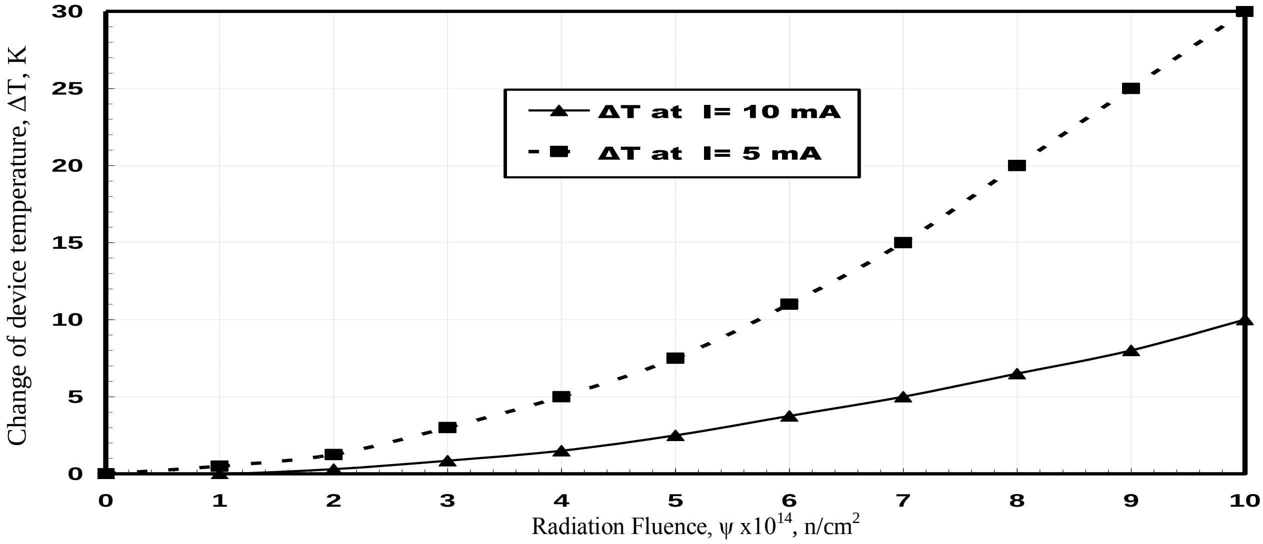

Fig.14. Variations of the change of device temperature (ΔT) against radiation fluence (ψ) at different input current (I) with T_a =300K, and R_{th}=2.6 KΩ.

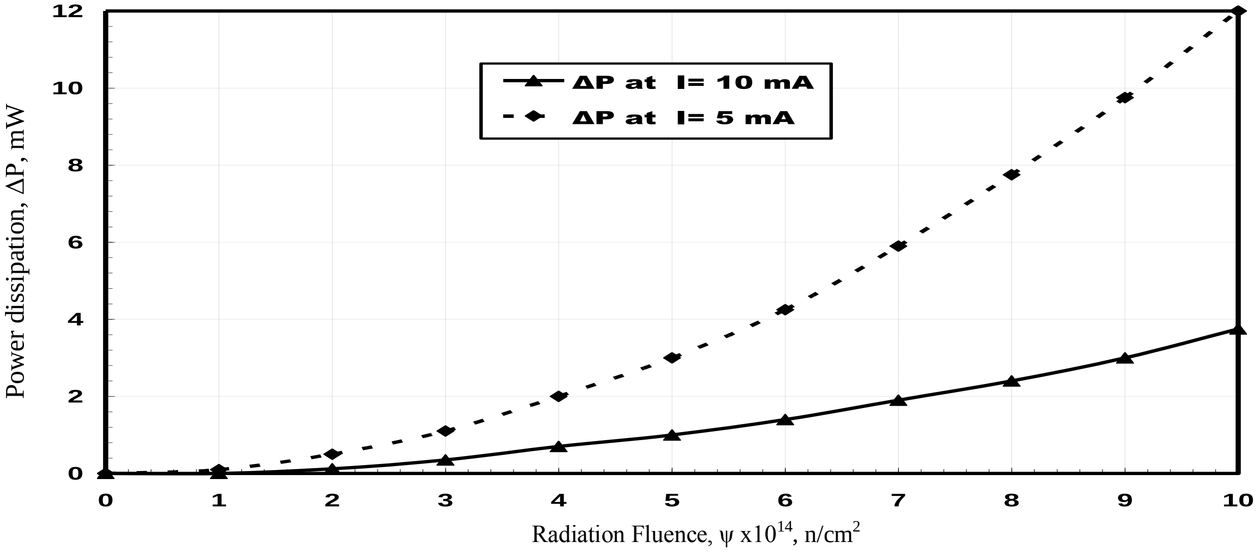

Fig.15. Variations of the power dissipation (ΔP) against radiation fluence (ψ) at different input current (I) with T_a =300K, and R_{th}=2.6 KΩ.

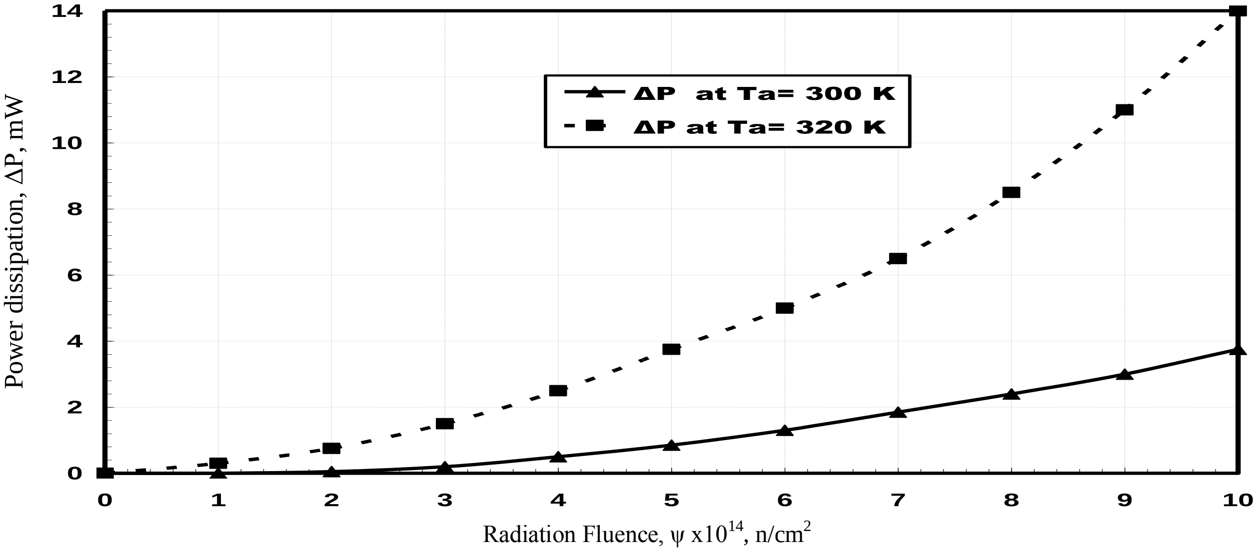

Fig.16. Variations of the power dissipation (ΔP) against radiation fluence (ψ) at different ambient temperature with I = 10 mA, and R_{th}=2.6 KΩ.

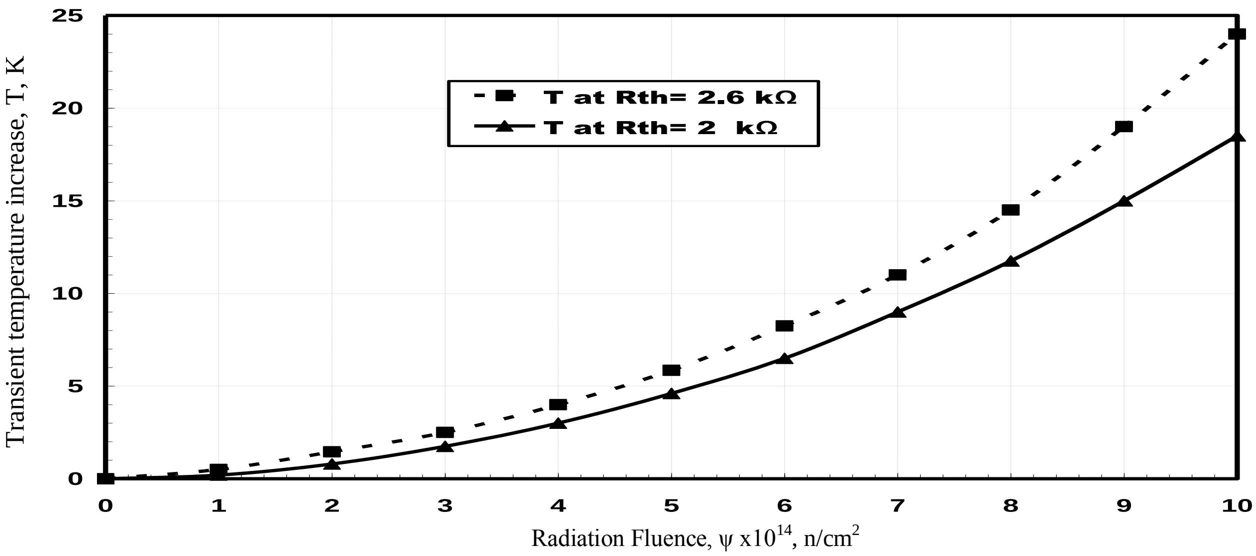

Fig.17. Variations of the transient temperature increase (T) against radiation fluence (ψ) at different device thermal impedance R_{th} with T_a =300 K, and I=10 mA.

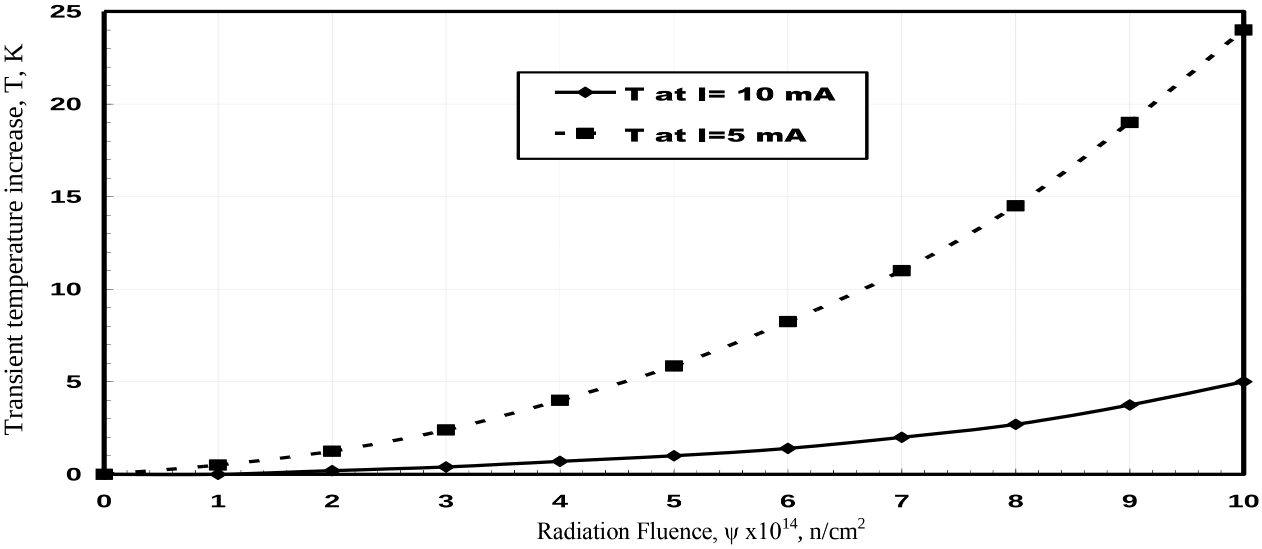

Fig.18. Variations of the transient temperature increase (T) against radiation fluence (ψ) at different input current (I) with T_a =300K, and R_{th}=2.6 KΩ.

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 VCSELs in thermal radiation environments. The proposed treatment can be used to improve the efficiency, and signal to noise ratio when VCSELs are selected to operate in these environments. A model is built using VisSim environment. The results showed that the key to reducing thermal radiation effect would expect in increase input current and choice the device that has lower thermal impedance. These results are significant in designing optoelectronic systems, requiring immunity to the permanent and transient effects of thermal ionizing-radiation. The results are validated against the published experimental work and good agreement is observed.

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