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Full Length Research Paper

Transient behavior and transmission bit rates analysis of optoelectronic integrated devices laser diode (LD) and light emitting diode (LED) under amplification and ionizing irradiation environments

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This paper has proposed the device that is composed of a hetrojunction phototransistor (HPT) and a laser diode (LD). The expressions describing the transient response of the output. The rise time, and the output derivative are derived. The effect of the various device parameters on the transient response is outlined. The results show that the transient response of these types of devices is strongly dependent on the optical feedback inside the device and it is found that the device works in two different modes, which are: amplification, for small optical feedback coefficient. Switching, for high optical feedback coefficient. The transient behavior of the integrated device is investigated by considering: i) the frequency response of a phototransistor and a light-emitting diode, and ii) the optical feedback inside the devices. The analytical expressions describing the transient response of the integrated device are derived, and the rise times in both the amplification and the switching modes also are calculated in order to calculate the transmission bit rates depend on non return to zero (NRZ) and return to zero (RZ) coding formats in both amplification and switching modes. By increasing the optical feedback, the rise time in the amplification mode is increased along with an increasing output, while that in the switching mode can be reduced effectively with a saturated output.

Key words: Dynamic characteristics, amplification and switching modes, heterojunction phototransistor (HPT), and irradiation environments.

INTRODUCTION

A tremendous effort has been focused on fabrication, modeling, and analysis of the performance of optoelectronic integrated devices (OEID). One type of OEIDs is a light amplifying optical switch (LAOS). A light amplifying optical switch consists of a heterojunction phototransistor (HPT) that is vertically integrated with a light emitting diode (LED) or LD. The input light is shone on the phototransistor, and is converted into current that passes through the LED or LD. When the current in the LED or LD is greater than the threshold current, the LED or LD will emit light. Part of this light is fed back to the phototransistor. This feedback is referred to as optical feedback (Feld et al., 1991; Vahid et al., 1997) showed that, based on the value of the optical feedback, the device can operate in one of two modes. For a small feedback coefficient the device operates in an amplification mode, where the output light varies linearly with the input light. For large values of the feedback coefficient, the device operates in a switching mode. In this mode the light jumps abruptly from a low state to a high one when the input light exceeds a specific threshold value. In their work they assumed constant feedback that is independent of frequency and currents. Based on this assumption, they modelled the optical switch as a linear device in a form of block diagram, and they drive the expression for both optical gain and rise

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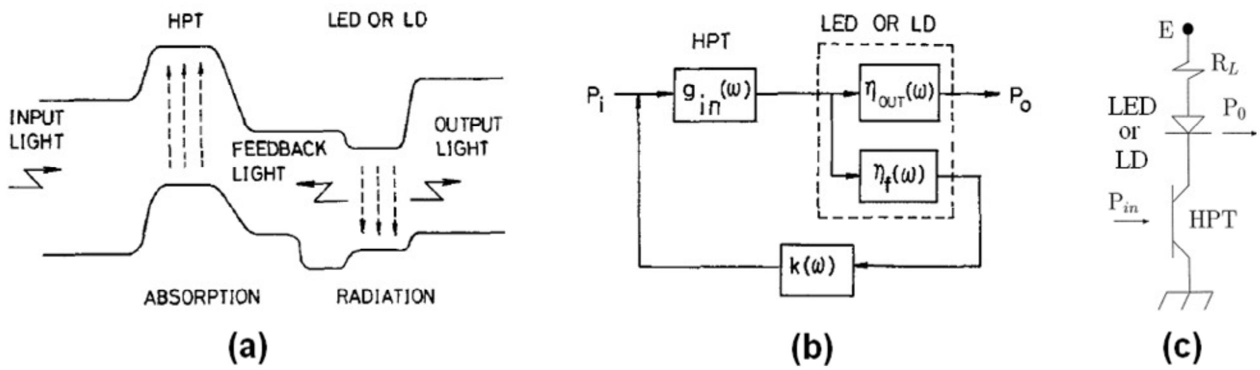

Figure 1. a) Energy band diagram of OEID. b) Block diagram of OEID with optical feedback. c) Circuit diagram of the OEID.

time of the optical switch. The constant feedback assumption is acceptable if the source light device is LED but in if the source devise is LD the feedback coefficient is not a constant. (Noda et al., 1992) reported that the feedback coefficient is not a constant but rather a linear function of the current (Chand et al., 1985; Noda et al., 1992) has found that the optical feedback coefficient is a nonlinear function, but their work based on the effect of the LED on the equivalent circuit is neglected. This is due to the fact that the cutoff frequency of the LED is higher than the cutoff frequency of the HBT (Milano et al., 1982). The feedback mechanisms, the early effect, and the HPT gain nonlinearity, are considered in the analysis of both amplification and switching modes.

OPTICAL SOURCES PRE-IRRADIATION ANALYSIS

LED pre-irradiation analysis

The block diagram of the OEID with optical feedback, which is considered as a linear system, is shown in Figure 1, and the frequency response of the optical gain G (ω) of the OEID can be expressed as Sze et al. (1981a):

$$G(\omega) = \frac{g_{in}(\omega)\eta_{out}(\omega)}{1 - k(\omega)g_{in}(\omega)\eta_f(\omega)} \tag{1}$$

Where $g_{in}(\omega)$ denotes the conversion gain of the HPT, $\eta_{out}(\omega)$ the external quantum efficiency of the LED. $\eta_f(\omega)$ the internal quantum efficiency of the LED or LD for the feedback light, and $k(\omega)$ the ratio of the photons which reach the HPT to those emitted by the LED or LD inside the OEID. The frequency response of conversion gain of the HPT is (Ghardi, 1968):

$$g_{in}(\omega) = \frac{g_0}{1 + j\omega/\omega_\beta} \tag{2}$$

Where $g_o = \beta_0 \eta h_0$ denotes the conversion gain of the HPT at low-frequency regime, and $\beta_0 = I_c/I_p$ and $\eta h_0 = (I_p/q)/(P_{in}/hv_{in})$ are the current gain and the quantum efficiency of the HPT in the low frequency regime, respectively, I_p and I_c, are the primary photocurrent and the output current, respectively; P_{in} and hv_{in}; are the power and the photon energy of the input light; and ω_B is the beta cutoff frequency. Since the time constant for the generation of the primary photocurrent is negligible compared to that for the current amplification (Ghardi, 1968) the quantum efficiency $\eta h(\omega)$ of the HPT was approximated to be independent of frequency, that is,, $\eta h(\omega) = \eta h_0$. The frequency response of an LED can be expressed as Roy and Chakrabarti (1987) and Ghardi (1968):

$$\eta_{\underset{out}{LED}}(\omega) = \frac{\eta_{out0}}{1 + j\omega/\omega_1} \tag{3}$$

Where $\eta_{out0} \propto \tau / \tau_r$, denotes the quantum efficiency for the spontaneous emission in the low-frequency regime; τ and τ_r, are the lifetimes for the whole and radiative recombination processes, respectively; ω_1 is the cutoff frequency of the LED; and ω_1^{-1} is the same order of the magnitude as τ. The frequency response of the optical feedback can be examined. Since the distance between the integrated HPT and LED is on the order of pm, the delay time caused by the light transmission from the LED to the HPT is in the order of a femtosecond and can be neglected compared to the delays caused by the HPT and the LED. Within the regime of the frequency response of the HPT, the optical feedback is assumed independent of the frequency as Harth et al.(1976):

$$K(\omega) = K_0 \tag{4}$$

The value of k_0 is $0 \le k_0 \le 1$, which is determined by the geometrical arrangement of the HPT and LED, and by the overlap of the spectrum responses of the HPT and the LED.

The frequency response of the OEID can thus be expressed as Suzuki et al. (1985):

Table 1. Dependence of λ_1 and λ_2 on the optical feedback (f).

$k_0 g_0 \eta_{f0}$ **=0**	**0<** $k_0 g_0 \eta_{f0}$ **>1**	$k_0 g_0 \eta_{f0}$ **=1**	$k_0 g_0 \eta_{f0}$ **>1**
λ1=-ωβ λ2=-ω1	−ωβ <λ1<0 −(ωβ+ω1) <λ2<-ω1	λ1=0 λ2=−(ωβ+ω1)	λ1>0 λ2<−(ωβ+ω1)

$$G(\omega)=\frac{\dfrac{g_0\eta_{out0}}{(1+j\omega/\omega_\beta)(1+j\omega/\omega_1)}}{1-\dfrac{k_0 g_0\eta_{f0}}{(1+j\omega/\omega_\beta)(1+j\omega/\omega_1)}} \quad (5)$$

Where η_{out0} denotes the quantum efficiency for the output, and η_{f0} the feedback light at low-frequency regime. When the input light, P_{in} is assumed as a step function in time, the Laplace transform of the output light can be obtained from Equation 5 as Uomi et al. (1986):

$$g_{in}(s)=\frac{g_0\omega_\beta}{s+\omega_\beta} \quad (6)$$

$$\underset{LED}{\eta_{out}}(s)=\frac{\eta_0\omega_1}{s+\omega_1} \quad (7)$$

$$\eta_f(s)=\frac{\eta_{f0}\omega_1}{1+\omega_1} \quad (8)$$

$$G(s)=\frac{g_{in}(s)\eta_{out}(s)}{1-g_{in}k(s)\eta_f(s)} \quad (9)$$

Then $p_{out}(s)=\dfrac{\psi p_{in}}{s}G(s)=\dfrac{g_0\eta_0\omega_\beta\omega_1\psi p_{in}}{s(s+\lambda_1)(s-\lambda_2)}$ (10)

Where $\psi = v_{out}/v_{in}$ and v_{out} and v_{in} are the frequencies of the output and input lights, respectively, and

$$\underset{LED}{\lambda_{1,2}}=\frac{-(\omega_\beta+\omega_1)\pm\sqrt{(\omega_\beta+\omega_1)^2-4(1-k_0 g_0\eta_{f0})\omega_\beta\omega_1}}{2} \quad (11)$$

The dependence of λ_1 and λ_2 on the optical feedback is listed in Table 1. From the characteristics of HPT and LED reported (Scavennec et al., 1983) $\omega_B = 10^8$ Hz, $\omega_1 = 10^{10}$ Hz, and $g_0\eta_0$= 100 are used in the calculation in Equation 12.

LD pre-irradiation analysis

The generalized harmonic response transfer function of VCSELD's in the S-domain (Sasaki et al., 1988) is:

$$\underset{LD}{\eta_{out}}(s)=\frac{\omega_n^2}{S^2-BS+\omega_n^2} \quad (12)$$

Where ω_n is the device natural frequency, B is the damping coefficient, and the laplase transform is a recent form as:

$$\underset{LD}{\eta_{out}}(s)=\frac{\omega_n^2}{(S-B/2)^2+\omega_n^2-B^4/4} \quad (13)$$

Therefore the simplified the second order of the LD transfer function to first order, to equal the external quantum efficiency of LED, We must consider the feedback coefficient as a linear function of the output current in case LD instead of a constant coefficient as in LED, according this consideration (Noda and Sasaki, 1993):

$$\underset{LD}{\eta_{out}}(s)=\underset{LD}{\eta_{out}}(s)=\frac{\eta_0\omega_1}{s+\omega_1} \quad (14)$$

And $K(s)=cI+K_0$ (15)

Where c and k_0 are constants and $0\le k_0\le 1$. From the block diagram shown in Figure 1. b, one can represent the current in the following form (Sasaki and Kuzuhara, 1981):

$$I=\frac{[q/(h\nu)_{in}]g_{in}P_{in}}{1-g_{in}\eta_{out}K(s)} \quad (16)$$

Substituting the value of I of Equation 15 into 16 and rearranging the terms, the following relation for K(s) can be derived:

$$K^2(s)-ak(s)+b=0 \quad (17)$$

Where $a=K_0+\dfrac{1}{g_{in}\eta_{out}}$ (18)

And $b=\dfrac{K_0}{g_{in}\eta_{out}}+\dfrac{qp_{in}c}{(h\nu)_{in}\eta_{out}}$ (19)

Substituting Equations (6), (7), (8) into (9), G(s) can be expressed as follows (Beneking et al., 1981):

$$G(s)=\frac{g_0\eta_0\omega_\beta\omega_1}{(s+\omega_\beta)(s+\omega_1)-k(s)g_0\eta_{f0}\omega_\beta\omega_1} \quad (20)$$

And from Equation (3)

$$k(s)=\frac{1}{2}(a\pm\sqrt{a^2-4b}) \quad (21)$$

Where a^2-4b is a fourth degree polynomial in s(say $p_4(s)$) Substituting Equation (21) into (20) yields:

$$G(s)=\frac{g_0\eta_0\omega_\beta\omega_1}{(1-\eta_{f0}/2\eta_0)(s+\omega_\beta)(s+\omega_1)-(\eta_{f0}/2\eta_0)k_0g_0\eta_0\omega_\beta\omega_1-(\pm\eta_{f0}/2\eta_0)\sqrt{p_4(s)}} \quad (22)$$

The value of $p_4(s)$. along any subinterval dictates the following case:

p(s)≥0 then $(p_4(s))^{0.5}$ can always be fit, accurately, to a second degree polynomial, that can be written in the following form (Takeda et al., 1989):

$$\sqrt{p_4(s)}=(s-\alpha_1)(s-\alpha_2) \quad (23)$$

Substituting Equation 23 into 22 gives:

$$G(s)=\frac{g_0\eta_0\omega_\beta\omega_1}{p_2(s)} \quad (24)$$

Where

$$p_2(s)=b_2s^2+b_1s+b_0 \quad (25)$$

$$b_0=\left(1-\frac{\eta_{f0}}{2\eta_0}\right)\omega_\beta\omega_1-\frac{\eta_{f0}}{2\eta_0}(k_0g_0\eta_0\omega_\beta\omega\pm\alpha_1\alpha_2) \quad (26)$$

$$b_1=\left(1-\frac{\eta_{f0}}{2\eta_0}\right)(\omega_\beta+\omega_1)\pm\frac{\eta_{f0}}{2\eta_0}(\alpha_1+\alpha_2) \quad (27)$$

$$b_2=1-(1\pm1)\left(\frac{\eta_{f0}}{2\eta_0}\right) \quad (28)$$

The coefficients of $p_2(s)$ are all real numbers even if $\alpha_1$and α_2 are complex conjugate. The roots of $p_2(s)$ are (Mutsuda et al., 1990a):

$$\lambda_{\substack{1,2\\LD}}=-\frac{b_1}{2b_2}\pm\frac{\sqrt{b_1^2-4b_2b_0}}{2b_2} \quad (29)$$

It should be noted that for practical values of the parameters in Equations 25 to 28, one of the two roots is either a negative real number or a complex number with negative real part. The inverse Laplace transformation of $P_{out}(s)$ is (Mutsuda et al., 1990b):

$$p_{out}(t)=\frac{g_0\eta_0\omega_\beta\omega_1\psi p_{in}}{\lambda_1\lambda_2(\lambda_1-\lambda_2)}\left[(\lambda_1-\lambda_2)+\lambda_2e^{\lambda_1t}-\lambda_1e^{\lambda_2t}\right] \quad (30)$$

If the two roots λ_1 and λ_2 are negative real numbers, the device is in an amplification mode. Whereas if at least one of the two roots is a positive real number then the device is in a switching mode.

OPTICAL SOURCES RISE TIME ANALYSIS

The rise time of the OEID (the time needed for the OEID optical gain to reach 90% of its final state), can be expressed as Sasakiet al., (1984):

$$T=\int_{p_{out}(t_i)}^{0.9\,p_{out}(t_f)}\frac{dp_{out}}{V} \quad (31)$$

Where

$$V=\frac{dp_{out}(t)}{dt} \quad (32)$$

Because the real part of λ_1 is negative, the term exp (λ_1t) in Equation 30 can be neglected and therefore the output light power $P_0(t)$ and the rise time are approximated, respectively with:

$$p_{out}(t)=\frac{g_0\eta_0\omega_\beta\omega_1\psi p_{in}}{\lambda_1\lambda_2(\lambda_1-\lambda_2)}\left[(\lambda_1-\lambda_2)-\lambda_1e^{\lambda_2t}\right] \quad (33)$$

$$T=\int_{p_{out}(t_i)}^{0.9p_{out}(t_f)}\frac{dp_{out}}{\lambda_2\left(p_{out}-\frac{g_0\eta_0\omega_\beta\omega_1\psi p_{in}}{\lambda_1\lambda_2}\right)} \quad (34)$$

The output light power at the initial state $P_{out}(t_i)$ is (Zhu et al., 1995):

$$p_{out}(t_i)=p_{out}(0)=-\frac{g_0\eta_0\omega_\beta\omega_1\psi p_{in}}{\lambda_1(\lambda_1-\lambda_2)} \quad (35)$$

Similarly, the output power at the final state $P_0(t_f)$ (in the amplification mode) is given by:

$$p_{out}(t_f)=p_{out}(\infty)=\frac{g_0\eta_0\omega_\beta\omega_1\gamma p_{in}}{\lambda_1\lambda_2} \quad (36)$$

In the switching mode, the output light power at the final state $P_0(t_f)$ is determined from the external circuit of the device in Figure 1. c) as Zebda and Omar, (1994):

$$p_{0Max} = \frac{(h\nu)_{in}\eta_0 E}{qP_{in}R_L} \quad (37)$$

Where E, R_L, and $(h\nu)$ in are the bias voltage, load resistance, and the photon energy of the input light, respectively. Using the above given values of the output light power at the initial and final states, and using Equation 30, the rise time in the amplification mode can be written.

LED rise time analysis

Since the cutoff frequency of the LED, ω_1 is higher than that of the HPT ω_β the relations $\lambda_1 > \lambda_2$ and $|\lambda_1| < |\lambda_2|$ were used to derive the Equation 33 When $k_0 g_0 \eta_{f0}$<1, Eq. 11 can be approximately written as λ_1 = -(1 - $k_0 g_0 \eta_{f0}$)ω_β and $\lambda_2 = -\omega_1$. Thus, Equation 33 becomes (Amadi et al., 1997):

$$p_{out}(t) = \frac{g_0\eta_0\psi p_{in}}{1 - k_0 g_0 \eta_{f0}}\left[1 - \exp\left[-(1 - k_0 g_0 \eta_{f0})\omega_\beta t\right]\right] \quad (38)$$

The transient response of the OEID for 0 < $k_0 g_0 \eta_{f0}$ < 1 (Ahmadi and Sheikhi, 1998; Sheikhi et al., 2000). It can be seen that the output light of the OEID approaches a definite value (Tucker and David, 1983).

$$p_{out}(t) = \frac{g_0\eta_0\psi p_{in}}{1 - k_0 g_0 \eta_{f0}} \quad (39)$$

Proportional to the input light. The transient response of the OEID with $k_0 g_0 \eta_{f0}$> 1 is indicated in Zory (1993). When $k_0 g_0 \eta_{f0}$ > 1, we have $\lambda_1 > 0$. As shown in Equation 33, the output of the OEID increases exponentially with time, which corresponds to the jump in the switching mode. In the case of 1 < $k_0 g_0 \eta_{f0}$ < 3, we have λ_1 ~ ($k_0 g_0 \eta_{f0}$ - l)ω_β, and thus Equation 33 can be simplified as (Ming et al., 1992).

$$p_{out}(t) = \frac{g_0\eta_0\psi p_{in}}{k_0 g_0 \eta_{f0} - 1}\left[\exp\left[(k_0 g_0 \eta_{f0} - 1)\omega_\beta t\right] - 1\right] \quad (40)$$

When $k_0 g_0 \eta_{f0}$ = 1, the transient response of the OEID can be obtained from the inverse Laplace transforms as:

$$p_{out}(t) = \frac{g_0\eta_0\psi p_{in}\omega_\beta}{\omega_1}\left[\omega_1 t - 1 + \exp(\omega_1 t)\right] \quad (41)$$

For t > 1/ω_1 Eq.40 can be simplified as (Campbell et al., 1982):

$$p_{out}(t) = g_0\eta_0\psi p_{in}\omega_\beta t \quad (42)$$

By using Equations 31, 32 and 33, the rise time of the OEID for $k_0 g_0 \eta_{f0}$≠1 can be given by (Ghisoni et al., 1987):

$$T_{LED} = \frac{1}{\lambda_{1_{LED}}}\ln\left[\frac{g_0\eta_0 - 0.9\frac{P_{out}}{\psi P_{in}}(1 - k_0 g_0 \eta_{f0})}{g_0\eta_0}\right] \quad (43)$$

When $k_0 g_0 \eta_{f0}$ < 1, the rise time in the amplification mode can be obtained as (Sze, 1981b).

$$T_{a_{LED}} = \frac{\ln 10}{(1 - k_0 g_0 \eta_{f0})\omega_\beta} \quad (44)$$

When $k_0 g_0 \eta_{f0}$ > 1, the rise time in the switching mode can be obtained as:

$$T_{s_{LED}} = \frac{1}{(k_0 g_0 \eta_{f0} - 1)\omega_\beta}\ln\left[\frac{g_0\eta_0 + 0.9\frac{P_{out}}{\psi P_{in}}(k_0 g_0 \eta_{f0} - 1)}{g_0\eta_0}\right] \quad (45)$$

In the case of 1 < $k_0 g_0 \eta_{f0}$ < 3 the rise time in the switching mode for $k_0 g_0 \eta_{f0}$=1 can be obtained from Equations (31) and (42) as (Lengyel et al., 1990):

$$T_{s_{LED}} = \frac{0.9\frac{P_{out}}{\psi P_{in}}}{g_0\eta_0\omega_\beta} \quad (46)$$

LD rise time analysis

The rise time in the amplification mode can be written as (Bastard et al., 1983).

$$T_{a_{\mathrm{LD}}} = \frac{1}{\lambda_{2_{\mathrm{LD}}}}\ln\left[0.1\left(1 - \frac{\lambda_{2_{\mathrm{LD}}}}{\lambda_{1_{\mathrm{LD}}}}\right)\right] \quad (47)$$

The rise time in the switching mode is (Miller et., 1986; Noda et al., 1995).

$$T_{s_{LD}} = \frac{1}{\lambda_2} \ln\left[\frac{0.9 P_{0Max} \lambda_{1_{LD}} \lambda_{2_{LD}} - g_0 \eta_0 \omega_\beta \omega_1 \psi p_{in} (\lambda_{1_{LD}} - \lambda_{2_{LD}})}{\lambda_{1_{LD}} g_0 \eta_0 \omega_\beta \omega_1 \psi p_{in}} \right] \quad (48)$$

POST RADIATION EFFECT CHARACTERISTICS

Here, the irradiation effect on the performance of OEID is studied based on replacing all parameters in the above equations, which are considered to be pre-irradiation parameters by the equivalent post-irradiation parameters that include the radiation factors. The minority carrier life time parameter to is sensitive to irradiation flux, and hence all factors include this parameter, such as (g_0, η_0 ,ω_1) are sensitive to irradiation flux. In the literature, various authors have reported on the effects of neutron irradiation on the degradation behavior of light-emitting diodes (Abd El-Naser et al., 2011e).The most important radiation-sensitive parameter for LED operation is the minority carrier lifetime τ_0. The physical mechanism responsible for radiation-induced degradation of the light output from an LED is that nonradiative recombination centers are introduced which compete with radiative centers for excess carriers resulting in a reduction in minority carrier lifetime. The total lifetime can be written as:

$$\frac{1}{\tau_0} = \frac{1}{\tau_{0R}} + \frac{1}{\tau_{0NR}} \quad (49)$$

Where τ_0 is the pre-irradiation value of lifetime and τ_{0R} and τ_{0NR} are pre-irradiation values of lifetime associated with radiative and nonradiative recombination processes, respectively. It is the reduction in τ_{0NR} which is primarily responsible for the reduction in total lifetime. A variety of recombination centers can act as sites for nonradiative recombination. If these centers are introduced during exposure to a radiation fluence, Φ(n cm^{-2}), at a rate determined by a damage constant, K(cm^2 n-s^{-1}), then one can express the reduction in minority carrier lifetime and diffusion length to the post-irradiation values of τ after and l□$_{after}$ as related to the pre-irradiation l|$_{after}$ before and l|$_{before}$ in the following manner (Abd El-Naser et al., 2011a).

$$\frac{\tau_{before}}{\tau_{after}} = 1 + \tau_{before} K \phi \quad (50)$$

$$\frac{l_{before}^2}{l_{after}^2} = 1 + l_{before}^2 K \phi \quad (51)$$

Where l|$_{after}$, the post-irradiation diffusion length; l|$_{before}$, the pre- irradiation diffusion length; K, the minority carrier diffusion length damage constant (depends on target material, type of radiation, injection level, and temperature); and Φ, the radiation fluence. As regards the HPT, it is often convenient to express the transistor damage as a gain damage factor, K_b. Thus,

$$\frac{1}{\beta_{after}} - \frac{1}{\beta_{before}} = \Delta(1/\beta) = K_b \phi \quad (52)$$

$$\frac{1}{h_{FE}} = \frac{1}{h_{FE0}} + K_b \phi \quad (53)$$

Gain after a given irradiation as related to gain before irradiation can be calculated as

$$\beta_{after} = \frac{\beta_{before}}{1 + \beta_0 K_b \phi} \quad (54)$$

A simple relation between K_b and K is derived as (Luo et al., 2006).

$$\beta_{after} = \frac{\beta_{before}}{1 + \beta_0 K_b \phi} \quad (55)$$

where ω_T is the gain band width product of HPT, $\omega_T = \beta_0 \omega_\beta$. Diminution of carrier concentration in n semiconductors. Lattice defects can catch electrons and the effective doping of n-semiconductors decrease. The law is:

$$n_{eff} = N_D \exp(-\phi / 2k) \quad (56)$$

N to P inversion: This event happens when the electron concentration decrease so much that it becomes lower than the hole concentration. The generated light output L behaves in an analogous manner as:

$$L = L_s \exp(qV / kT) \quad (57)$$

Where L_s is the pre-exponential factor for the externally-emitted photon rate. Considering this, and solving the continuity equation for the injected minority carrier lifetime, a relationship between light output L and minority carrier lifetime □ can be derived as (Abd El-Naser et al., 2011b).

$$L = C\sqrt{\tau} \exp(qV / kT) \quad (58)$$

Where C is a constant containing parameters which do not depend on τ or T. For constant current operation, and assuming that current flow is dominated by carrier diffusion, the total current is given by (Darabi et al., 2006).

$$I = \frac{C_1}{\tau}\exp(qV / kT) \tag{59}$$

Where C_1 is a constant. Using Equations (55) and (56), one can write:

$$L = C_2 I \tau^{3/2} \tag{60}$$

Where C_2 is another constant. Using Equations (52) and (57), one can show that:

$$\frac{\tau_0}{\tau} = \left(\frac{L_0}{L}\right)^{\frac{2}{3}} = 1 + \tau_0 k\phi \tag{61}$$

Taking the log of the above expression yields:

$$\log\left[\left(\frac{L_0}{L}\right)^{\frac{2}{3}} - 1\right] = \log \tau_0 k + \log \phi \tag{62}$$

Where τ_0 and L_0 are the pre-irradiation values of lifetime and light output, respectively. This equation holds for linear-graded junctions provided that the current is dominated by diffusion. On the other hand, if the current is dominated by recombination in the space-charge region, then the expression for total current I is given by (Eladl, 2009).

$$I = \left(\frac{c_5}{\tau}\right)\exp(qV / 2kT) \tag{63}$$

where C_5 is a constant. Using Equations (55) and (61), one gets:

$$\log\left[\left(\frac{L_0}{L}\right)^{\frac{2}{5}} - 1\right] = \log \tau_0 k + \log \phi \tag{64}$$

The product of initial lifetime and damage factor $\tau_0 K$ which is of interest and the set of the model constants (C_1-C_5) are listed in (El_Mashade, 2004).

TRANSMISSION BIT RATES WITH DIFFERENT CODING FORMATS

The transmission data rate that the system can support non return to zero (NRZ) coding as the following (Abd El-Naser et al., 2011c).

$$B_{R(NRZ)} = \frac{0.7}{T_s}\ , \tag{65}$$

Also the transmission data rate that the system can support return to zero (RZ) coding as the following (Abd El-Naser et al., 2011d).

$$B_{R(RZ)} = \frac{0.35}{T_s}\ , \tag{66}$$

SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In the present paper, we have investigated the transient response of the output photons flux, the rise time, and the output derivative. The effect of the various device parameters on the transient response is outlined. As well as the device under consideration can be changed from switching mode to the amplification mode, if the fractions of trapped photons exceed a specified value. The model has been investigated under the assumed set of the operating parameters listed as: ω_B = $l0^8$ Hz, ω_1 = $l0^{10}$ Hz, and $g_0\eta_0$= 100, 900 ≤G_s, optical switching gain≤2000, 0.65 ≤$\eta_{0(LED)}$, quantum efficiency ≤0.8, 0.75 ≤$\eta_{0(LD)}$, quantum efficiency ≤0.9, P_{in}=0.3 Watt, 0 ≤f, optical feedback≤10, and 2x10^{14} ≤φ, irradiation fluence, n/cm^2≤50x10^{14}. Based on the assumed set of the operating parameters listed above and the series of the equations analysis in our basic model, the following facts are assured:

(1) Figures 2 and 3 have assured that as optical feedback increases, this results in increasing of device rise time for both laser diode and light emitting diode devices in amplification mode. But in the case of switching mode, the device rise time is decreased. Moreover, we have observed that switching mode has presented lower device rise time than amplification mode.
(2) Figures 4 to 7 have indicated that as optical feedback increases, this results in decreasing of device transmission bit rates for both laser diode and light emitting diode devices in amplification mode. But in the case of switching mode, the device transmission bit rate is increased. As well as switching mode has presented higher transmission bit rates than amplification mode for both devices under study for both NRZ and RZ coding formats.
(2) Figure 8 has demonstrated that as optical switching gain increases, this leads to increase in device rise time for both devices under study. We have observed that laser diode devices have presented lower rise time at the same optical switching gain compared to light emitting diode devices.
(4) Figures 9 and 10 have assured that as irradiation fluences increase, this results in increasing of rise time for both devices under study in both switching and amplification modes. Light emitting diode devices have presented higher rise time compared to laser diode devices at the same amount of irradiation doses.
(5) Figures 11 to 14 have assured that as irradiation

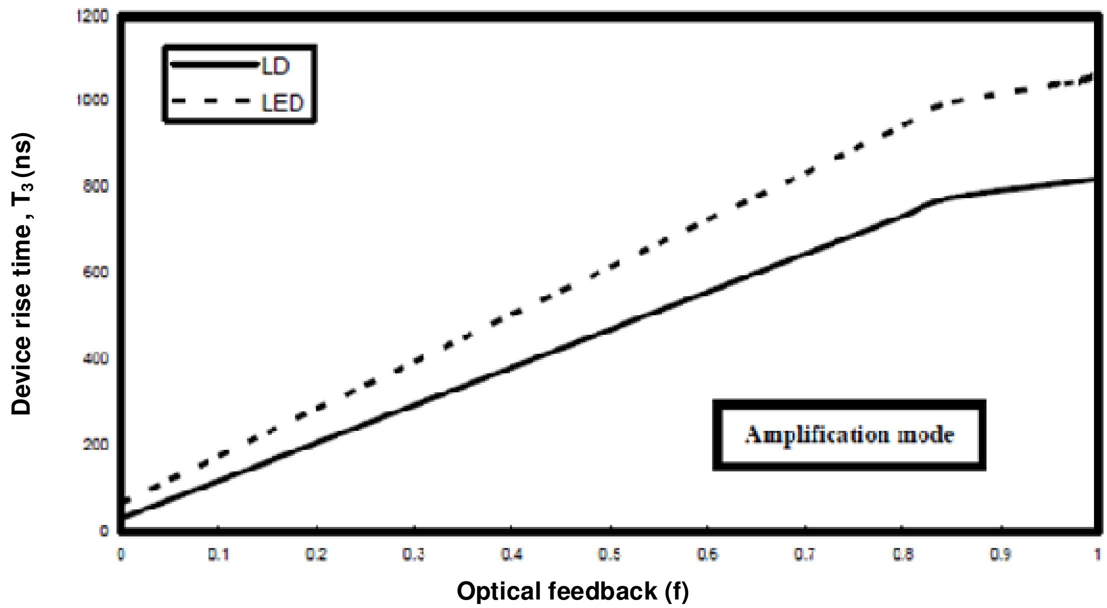

Figure 2. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

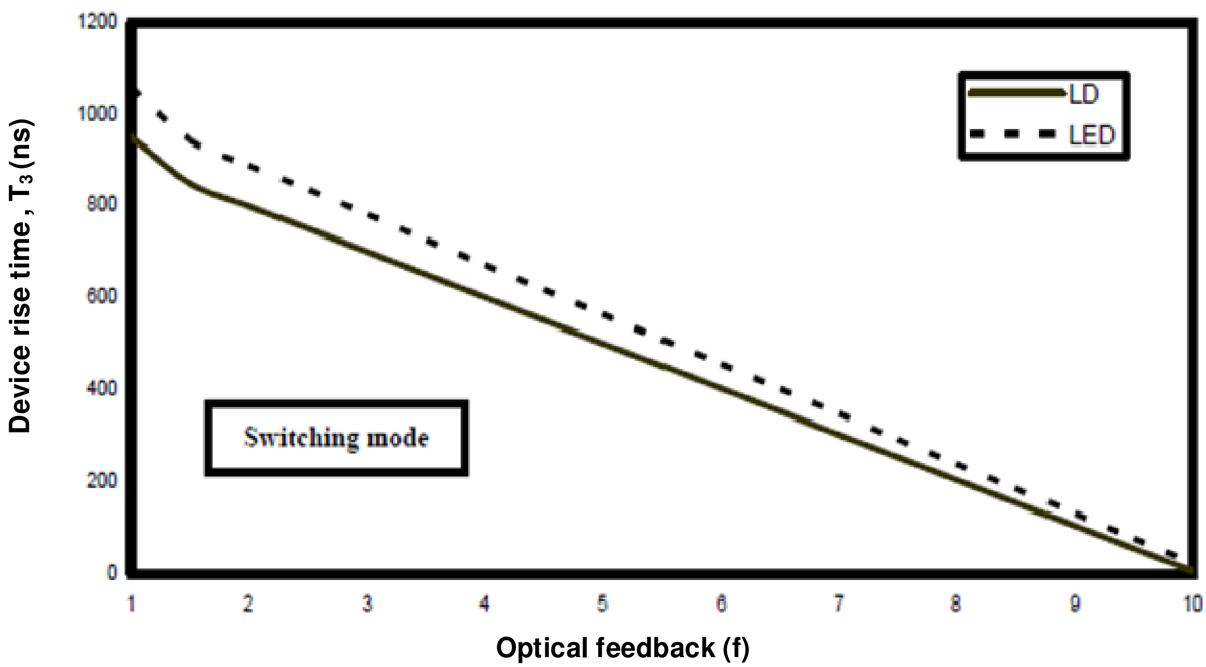

Figure 3. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

fluences increase, this results in decreasing of transmission bit rates for both devices under study in both switching and amplification modes. As well as light emitting diode devices have presented lower transmission bit rates compared to laser diode devices at the same amount of irradiation doses for both RZ and NRZ coding formats.

Conclusions

In summary, we have deeply investigated the dynamic

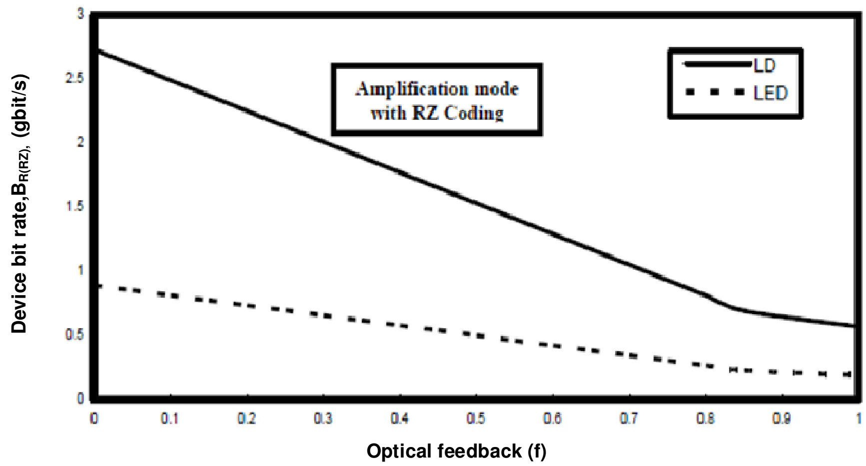

Figure 4. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

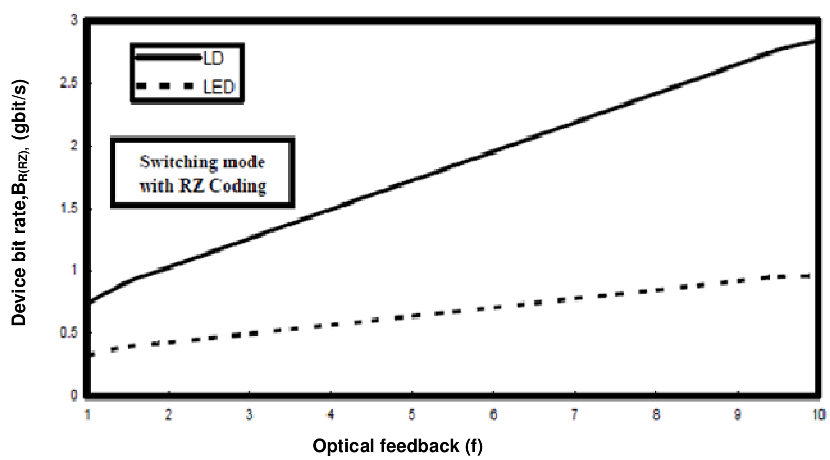

Figure 5. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

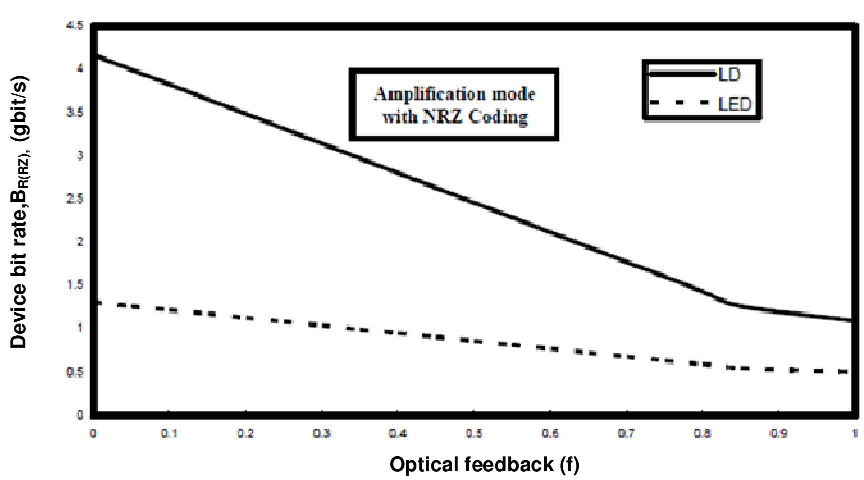

Figure 6. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

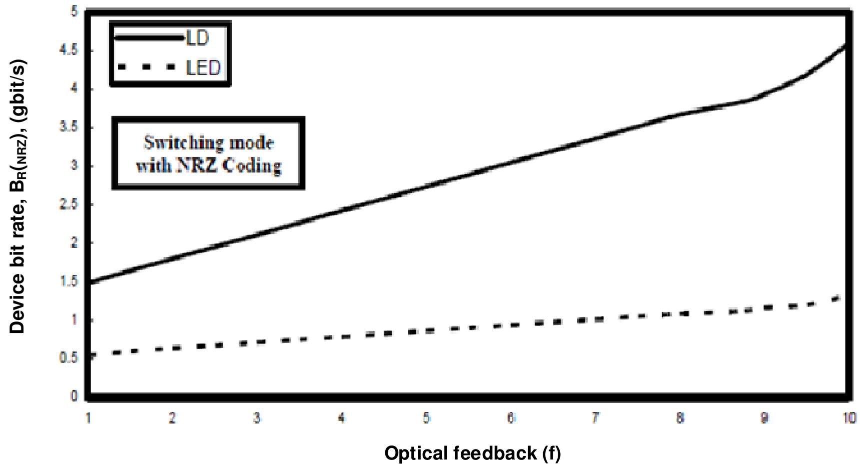

Figure 7. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

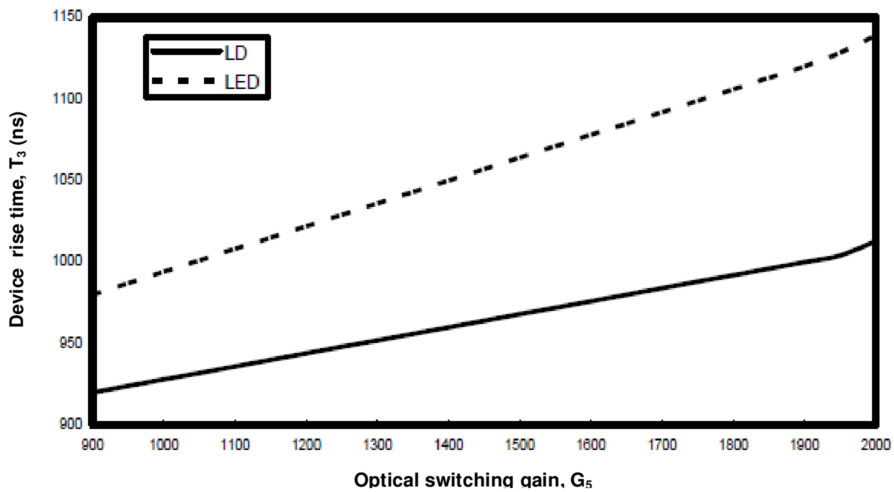

Figure 8. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

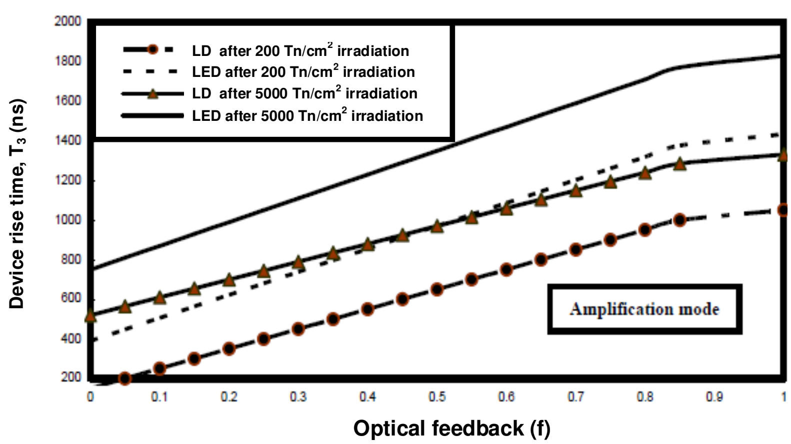

Figure 9. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

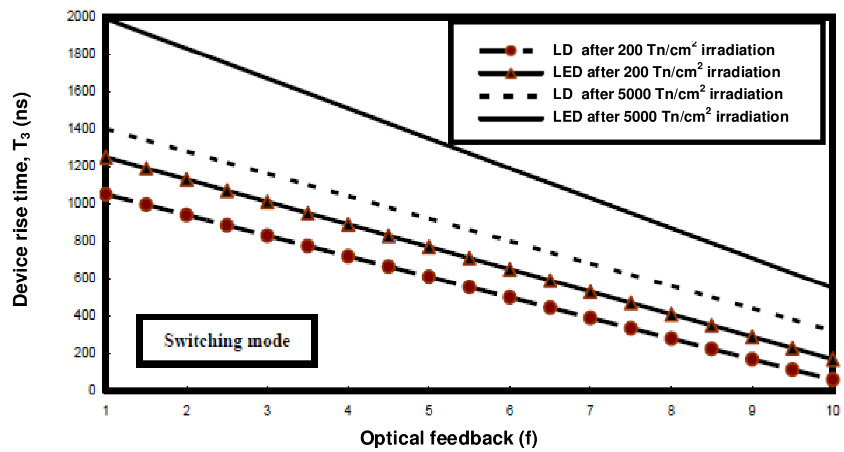

Figure 10. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

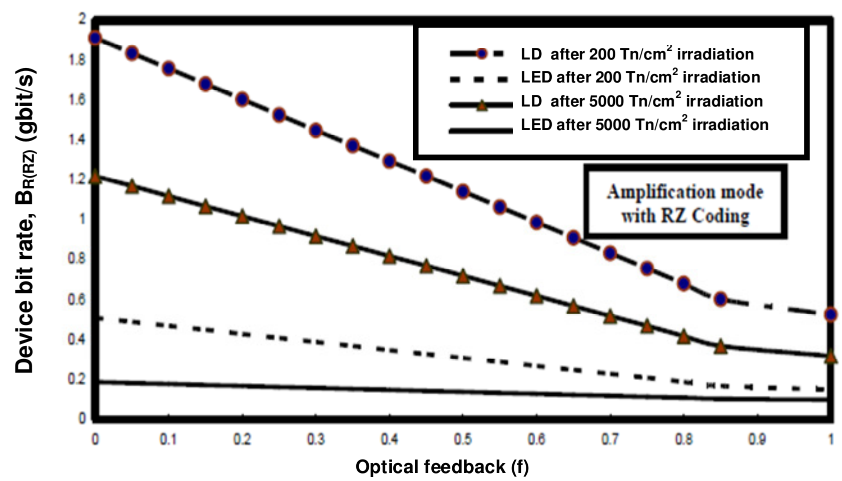

Figure 11. Variations of the device rise time against optical feedback at the assumed set of the operating parameters

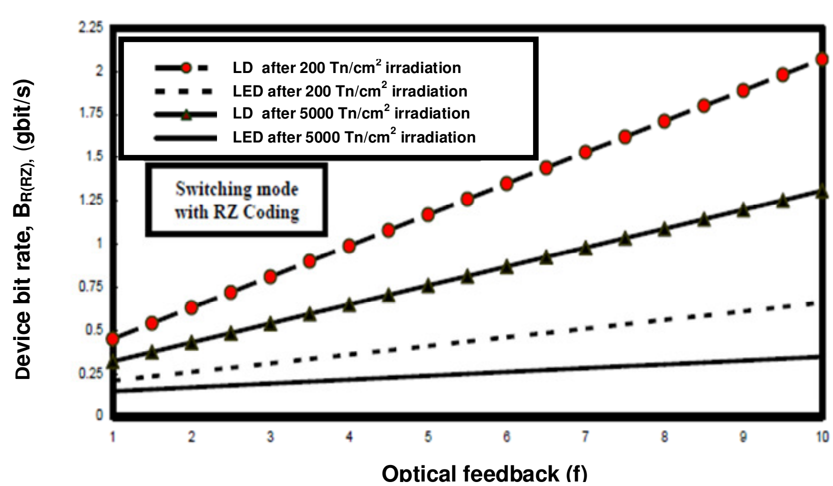

Figure 12. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

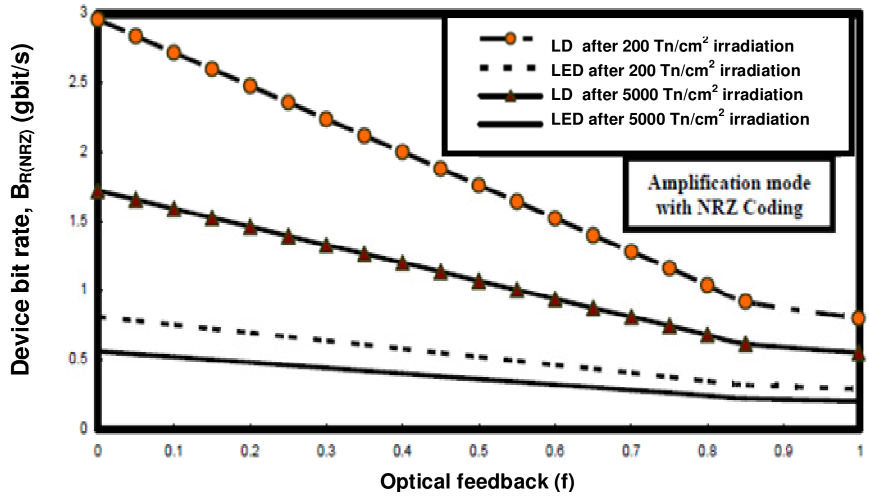

Figure 13. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

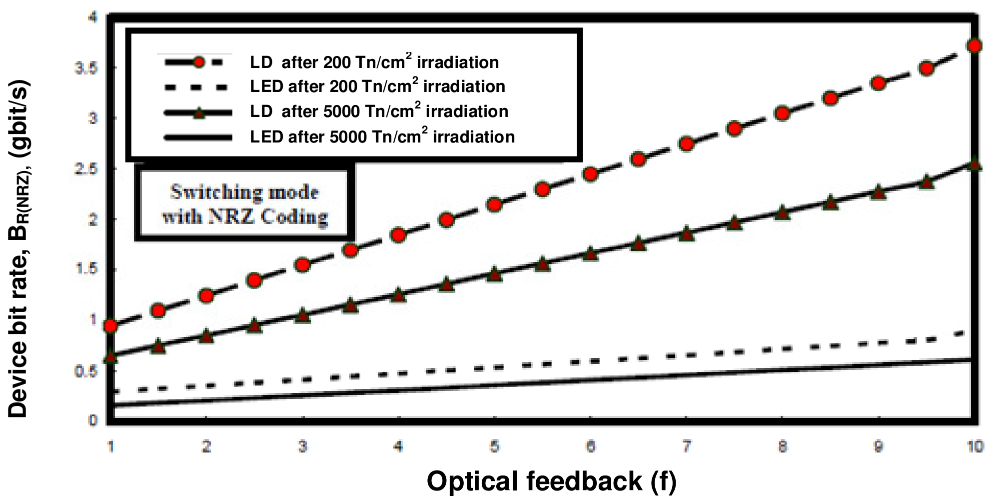

Figure 14. Variations of the device rise time against optical feedback at the assumed set of the operating parameters.

characteristics and time transient performance for optoelectronic integrated devices within amplification and switching modes and in different irradiation doses using different coding formats. As well as we have taken into account the rise time and transmission bit rate analysis for both LD and LED devices as a guide of the best device performance. It is evident that the increased optical feedback, this results in the decreased rise time and the increased transmission bit rates for both devices under study in amplification mode, but the increased optical feedback in the switching mode, this results in the decreased device rise time and then the increased device transmission bit rates within using RZ and NRZ coding formats. It is theoretically found that switching mode has presented lower rise time and higher transmission bit rates compared to amplification mode under the same operating conditions. A s well as we have presented the effects of different irradiation doses on LD and LED devices in both switching and amplification modes. It is evident that the increased irradiation doses, this leads to the increased rise time and the decreased transmission bit rates for both devices under study in both switching and amplification modes.

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