مجلة جامعة تشرين للدراسات والبحوث العلمية _ سلسلة العلوم الأساسية المجلد (25) العدد (15)2003
Tishreen University Journal for Studies and Scientific Research- Basic Science Series Vol (25) No (15) 2003

مقاومة الثنائيات الليزيرية GaAs/GaAlAs من نوع فكسل (VCSELs) للإشعاعات

الدكتور جبور جبّور*
الدكتور م. زازوي**
ج. ك. بورغوان
و. جيرارد

(قبل للنشر في 2003/12/8)

□ الملخّص □

تم تعريض ثنائيات (ديودات) ليزيرية من نوع (VCSELs) مصنوعة من GaAs/GaAlAs، حيث تعتمد في تركيبها على الآبار (الحفر) الكوانتية ، لسلسة من الإشعاعات الإلكترونية، وذلك لمعرفة مدى مقاومتها لهذه الإشعاعات عند استخدامها في التطبيقات الفضائية (على سبيل المثال في الأقمار الاصطناعية والمركبات الفضائية). إن طاقة هذه الإشعاعات كانت 1 ميغا إلكترون فولط (1MeV). لقد تم قياس تغير التيار بتابعية الكمون (الجهد) المطبق على هذه الثنائيات (I-V)، وشدة الضوء الصادر عن هذه الثنائيات بتابعية التيار (Light intensity-I) وذلك قبل وبعد تعرض هذه الثنائيات للإشعاعات. لقد تبين أن تيار العتبة هو أهم مقدار يتغير نتجية زيادة مقدار جرعة الإشعاعات التي تتعرض لها هذه الثنائيات. ولاحظنا أن السبب الأساسي في تلف هذه الثنائيات يتمثل بتغير تيار العتبة الذي سببه تولد مراكز إعادة ارتباط. إن هذه الدراسة سمحت بفهم آلية عمل هذا النوع من الثنائيات، وتم استنتاج أن هذه الثنائيات أكثر مقاومة للإشعاعات وأكثر فعالية (خاصة بالنسبة لتيار الإصدار الضوئي) من الثنائيات الكلاسيكية (التي لا تعتمد في تركيبها على الآبار الكوانتية). وأيضاً، فإن هذه الدراسة تسمح بالتوقع والتنبؤ بنسبة تلف أي نوع من العناصر الإلكترونية التي تعتمد في تركيبها على الآبار الكوانتية، في حال تعرضها لإشعاعات كالإلكترونات والبروتونات.

<u>ملاحظة:</u> أُنجرز هذا البحث في مخبر:* Laboratoire des Milieux Désordonnés et Hétérogènes *التابع لجامعة باريس السادسة – جامعة بيير وماري كوري – باريس – فرنسا (2003).

---

* أستاذ في قسم الفيزياء – كلية العلوم – جامعة تشرين – اللاذقية – سورية.
** أستاذ في قسم الفيزياء – كلية العلوم والتقنيات – جامعة المحمدية – المحمدية، المملكة المغربية.

I. INTRODUCTION

Owing to the wide field of applications of Vertical Cavity Surface Emitting Lasers (VCSEL) arriving on the market, the knowledge of their behaviour in various kinds of environments is necessary. In particular, because photonic systems are well suited to space applications, it is important to be able to predict their degradation when submitted to particle irradiations (electrons and protons) encountered during a space mission.

The aim of this communication is to describe the way by which the degradation of a VCSEL, and more generally of a Laser Emitting Detectors (LEDs) or a Laser, based on quantum well structures, can be predicted. Taking, as typical device, a VCSEL containing several GaAs quantum wells, we shall study its degradation. We shall determine the rate of degradation of the emitted light and of the threshold voltage for the case where the well(s) is (are) made of GaAs. We shall show that the degradation obtained for an irradiation with 1 MeV electrons can be easy extended to protons and to variable energies.

This study will allow to understand why quantum well structures based Lasers or LEDs are more radiation resistante than those which use a classical junction as active layer. It will also allow to predict simply the degradation induced by proton and (or) electron irradiations for any device based on such structures.

Studies describing proton irradiation effects on quantum well lasers [1-6] already exist. However, these studies describe the results of the irradiation without presenting the physical basis on which the degradation lies, from which the modeling of this degradation can be made.

II. EXPERIMENTAL

We consider a typical structure in which the injected carriers recombine in a region made of 3 GaAs quantum wells, is located between GaAlAs barriers. The selected device is a VCSEL emitting a 840 nm, in which the emitting surface is 2´ 10^{-5} cm^2. The total GaAs well thickness is 42 nm. Since the typical current of injection is 10^{-2} A, the injection density is 500 $A.cm^{-2}$. The density of electrons injected in the wells, to recombine per second, is therefore : 7.4×10^{26} $cm^{-3}.s^{-1}$. The irradiation is performed with the device unpolarized in order to prevent eventual annealing induced by carrier injection of the defect produced [7].

The injected carriers recombine radiatively and via non radiative recombination centers. The density of carriers recombining through the non radiative channel is:

$$\mathbf{J_{nr} = qn/t_0} \qquad \mathbf{(1)}$$

where n is the electron concentration in the well, t_0 the lifetime associated with the recombination and N_0 the non radiative centers characterized by a capture cross section s_0 [7, 8, 9] :

$$\mathbf{t_0 = (N_0 s_0 v)^{-1}} \qquad \mathbf{(2)}$$

(v is the thermal carrier velocity, 10^7 $cm.s^{-1}$ at room temperature). In epitaxial GaAs, the concentration of non radiative centers is low and the associated lifetime t_0 is of the order of 10^2 ns [7, 8, 9].

As to the recombination through the radiative channel, it can be written:

$$\mathbf{J_r = qBn^2} \qquad \mathbf{(3)}$$

with $B = 7.2 \times 10^{-10}$ $cm^{-3}s^{-1}$ for GaAs.

Thus, knowing the total density J of the injected carriers:

$$\mathbf{J = J_r + J_{nr}} \qquad \mathbf{(4)}$$

it is possible to extract n (10^{18} cm^{-3}) and, hence, to determine the fractions of the carriers which recombine through each channel. The ratio R between non radiative and radiative recombination (before irradiation, i.e. for a fluence $\varphi = 0$) is:

$$\mathbf{R(0) = J_{nr}(0)/J_r(0) \approx 10^{-2}} \qquad \mathbf{(5)}$$

Irradiation introduces defects, some of them act as non radiative recombination centers. The concentration N of these non radiative defects is:

$$\mathbf{N = k\varphi} \qquad \mathbf{(6)}$$

(k is the so-called defect introduction rate). These defects are characterized by a minority carrier capture cross section σ. Therefore τ_0 becomes τ as the following:

$$\tau^{-1} = \tau_0^{-1} + k\varphi\sigma v \qquad \mathbf{(7)}$$

and J_{nr} can be written:

$$\mathbf{J_{nr}(\varphi) = J_{nr}(0) + qnk\sigma v\varphi} \qquad \mathbf{(8)}$$

Since the ratio R is being small and if it remains small after irradiation, the changes induced by an irradiation can be treated as a first order perturbation: one should expect the effect of an irradiation to be linear with φ.

III. IRRADIATION EFFECTS

We have monitored the changes in the current-voltage I(V) and in the emitted light $\Phi(I)$ characteristics versus the fluence φ of irradiation with 1 MeV electrons. This energy is chosen because it is used as a standard to compare irradiation effects with different particules and for different energies in case of space applications. The irradiation is performed in vacuum with a scanned beam, through the quartz window of the laser. The electron energy is adapted to account for the energy loss in this window. The irradiation fluence has been chosen to induce small but detectable effects, and to remain in the range of the fluences encountered in space.

The log I versus V characteristics exhibits a linear region whose slope is equal to kT/q at 300 °K, but which has nothing to do with the diffusion regime of a standard junction (this slope does not vary with the temperature T). As shown in fig. 1, the changes introduced by the irradiation are minor, justifying a first order treatment. But they are well recognized when using a linear plot (see fig. 2).

The emitted light f is chopped and measured with a lock-in, using a Si detector. The changes induced in f by the irradiation are given in fig. 3. Again, it is verified that the decrease of the emitted light, for a given constant current density J, varies linearly versus fluence (fig. 4). This decrease does not depend on the J value which is chosen in the saturation region and can be characterized by the coefficient a_1 such that :

$$f/f_0 = \mathbf{1} - a_1 j \qquad \mathbf{(9)}$$

with a_1 = 1.5´ 10^{-18} cm^2.

From the extrapolation of the light intensity versus injecting current at various fluences (fig. 3) we can derive the threshold value J_{th} for lasing (see fig. 5). As we can see, the J_{th} varies linearly versus fluence (fig. 5). This increase can be expressed by the coefficient a_2 such that:

$$\mathbf{J_{th}/ J_{th}(0) = 1} + a_2 j \qquad \mathbf{(10)}$$

with a_2 = 3.6´ 10^{-18} cm^2.

Also, from extrapolation of the log I (V) plot, we can derive the threshold value V_{th} for lasing corresponding to J_{th} value. The variation of this quantity versus the irradiation fluence is given in fig. 6.

IV. DISCUSSION

The light intensity f varies as $J_r(j)$ which is given by expression (4), when R remaining small enough :

$$\mathbf{J_r(j)/J = 1 - qnkj\, s v/J} \qquad \mathbf{(11)}$$

as soon as $J_{nr}(0) < qnkj\, s v$. Hence, at constant current J, the emitted light decreases [10] with the rate:

$$\mathbf{a_1 = qnks v/J} \qquad \mathbf{(12)}$$

The value of a_1 obtained experimentally allows to derive the value of ks » 10^{-16} cm, where n is assumed to remain constant, i.e. in the approximation where R is small.

The threshold density J_{th} is a constant, given by (11) in which $J_r(j)$ is replaced by J_{th}. Hence, the injection density $J(j)$ corresponding to J_{th}, derived from:

$$\mathbf{J_{th}/J(j) = 1 - a_1 j} \qquad \mathbf{(13)}$$

is therefore:

$$\mathbf{J(j) = J_{th}\,(1 + a_1 j)} \qquad \mathbf{(14)}$$

The slope found experimentally (a_2), is slightly higher than a_1 ($a_2 = 2.4\, a_1$), difference which can be accounted by the approximation made in the derivation of expression (14) and in the experimental accurancy.

IV. SIMULATION OF DEGRADATION. ELECTRON - PROTON EQUIVALENCE

We have determined the parameter $k\sigma$ which allows to deduce quantitatively, for a 1 MeV electron irradiation, the variation of ϕ and V_{th} (or J_{th}) versus the fluence φ .

The parameter σ is characteristic of the defect created and does not vary with the electron energy E. It is the introduction rate k(E) which is energy dependent and can be easily calculated [7, 8, 9].

Hence, from the value of $k(1\mathrm{MeV})\sigma$ it is possible to derive $k(E)\sigma$ for any energy E and thus the increase of the parameter $k(S)\sigma$ equivalent induced by any energy distribution S(E):

$$k(S) = k(1\mathrm{MeV})\int_S \frac{k(E)}{k(1\mathrm{MeV})}dE \qquad \textbf{(15)}$$

since the degradation is given by the coefficient α directely related to $k(S)\sigma$.

The same procedure can be used to derive the degradation induced by proton irradiation when the equivalence between proton and electron degradation is known. The way to derive the electron-proton equivalence is the following. It is first based on the demonstration, which will be developped elsewhere, that the defects produced by proton irradiation are identical to the ones produced by electron irradiation. Indeed, the nature of the defects resulting from the energy transmitted into atomic collisions by an incident particle do not depend on the particle itself. The difference between electron and proton irradiation is in the spatial distribution of the induced defects. As we shall develop, the spatial distribution of proton induced defect is such that, in case of an omnidirectional irradiation, the defects can be in practice considered as randomly distributed like in case of electron irradiation. Indeed, they are separated by an average distance such that they can be considered as isolated, as in the case of electron irradiation.

In case of proton irradiation the introduction rate k is unknown. However, we know that it is proportional to the energy transmitted into atomic collisions, the so-called NIEL for non ionizing energy loss (the ionizing energy loss is being the energy dissipated into electronic excitations).

Let $E_{nl}(E)$ be the nuclear energy loss per unit length of path for a proton of energy E. The corresponding introduction rate of defects is:

$$\mathbf{k(E) = E_{nl}(E)/E_a} \qquad \textbf{(16)}$$

where E_a is the average energy necessary to created a defect. According to [11] the threshold energy for atomic diplacement is of the order of 20 eV in GaAs, and approximatively 1/10 of the created defects are non radiative recombination centers. We then expect $E_a \approx 200$ eV. As illustration, consider a 40 MeV proton. The NEIL, i.e. the nuclear energy loss is $E_{nl} = 3.07 \times 10^4$ eV.cm^{-1}, according to the evaluation made with the program SRIM [12]. We therefore expect that this proton creates about ~150 defects cm^{1}.

We can directly measure the electron-proton equivalence by comparing the degradation induced by protons and electrons in the same device, the VCSEL used in this work for instance since their degradation provide directly the parameter $k\sigma$.

Proton irradiations have been performed at constant fluence (10^{13}cm^{-2}) for various energies. The energies considered (30 to 60 MeV) are such that the protons are not stopped inside the active region of the device and thus create a defect distribution equivalent to that of an omnidirectional irradiation.

The results, shown in fig. 7, give the relative variation of the threshold current Δ versus the NIEL (or E_{nl}), translated from the variation of J_{th} versus the proton energy given in ref. [13].

The slope of the curve, 2.3×10^{-19} eV^{-1}cm, gives the degradation Δ per proton which transmit 1 keV.cm^{-1} in an atomic collision: Δ(1keV.cm^{-1}) = 2.3×10^{-16}. The same magnitude of the degradation can be obtained with φ_e electrons of 1MeV, for which: Δ(1keV) = $\alpha_1\varphi_e$. Thus, the electron fluence φ_e equivalent to the above proton:

$$\boldsymbol{\varphi_e = 2.3\times 10^{-16}/3.6\times 10^{-18} \approx 64\ \mathrm{cm}^{-2}.}$$

This value is reasonable in view of the qualitative arguments considered above. Indeed a flux of 64 cm^{-2}, 1MeV electrons creates about 6 defects.cm^{-3} ($k \sim 0.1$ cm^{-1}). On the other hand one proton 1000 eV.cm^{-2} creates approximatively 1000/200 = 5 defects.cm^{-3}.

Thus, a proton characterized by a NEIL of $E_{nl} = 10^3$ eV.cm^{-1} is equivalent to a flux of 64 cm^{-2} 1MeV electrons.

IV. CONCLUSION

We have studied the degradation of a Vertical Cavity Surface Emitting Lasers (VCSEL) induced by irradiation. We have shown that this degradation can be accounted by simple arguments and we demonstrate that these arguments can be generalyzed to any device based on quantum wells. We have determined the value of the parameter which characterize this degradation in case where the wells are made of GaAs. This study allows to model the degradation induced by any electron distribution. It has been extended to the case of proton irradiation and we have shown how the equivalence between proton and electron irradiation can be obtained. Finally, it is remain to demonstrate that this equivalence is general, i.e. applies to any type of device and to extend it to low energy protons i.e. protons which stop in the active area of the device.

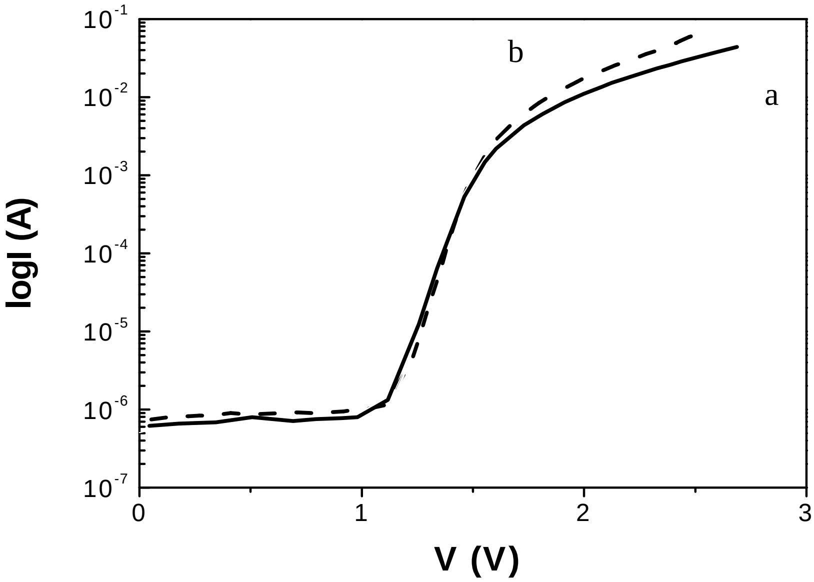

Fig.1. Logarithm current-voltage plot of the characteristics versus fluence of 1 MeV electrons. Only the (a) irradiaded with 1´ 10^{17} electrons cm^{-2}, and (b) unirradiated characteristics are presented.

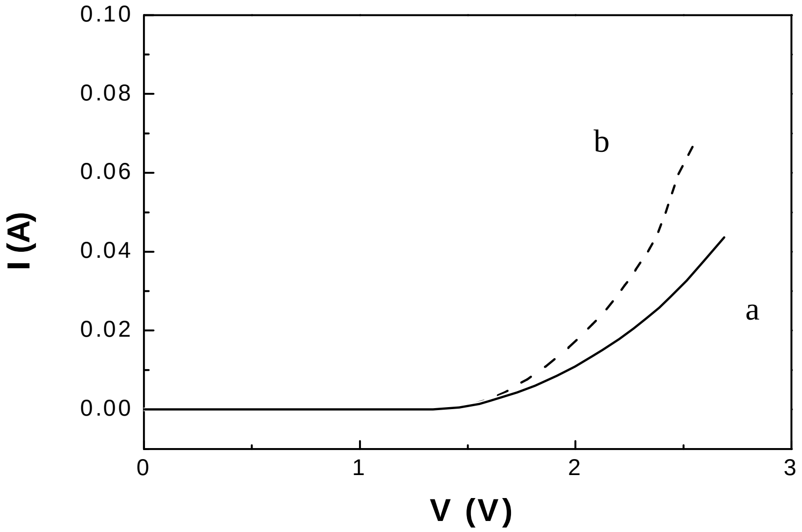

Fig.2. Linear plot of the current-voltage characteristics versus fluence of 1 MeV electrons. Only the (a) irradiaded with 1´ 10^{17} electrons cm^{-2}, (b) unirradiated characteristics are presented.

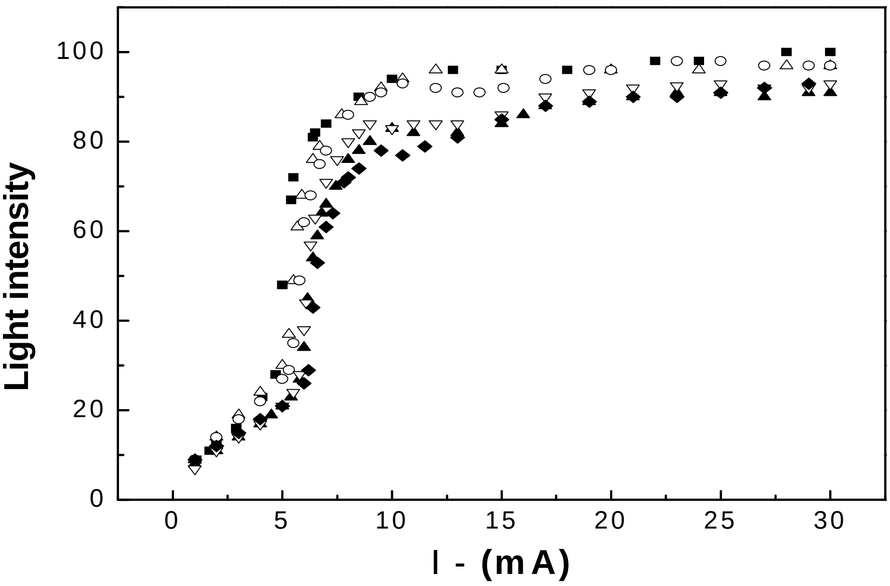

Fig.3. Variation of the light intensity in relative unit versus injecting current for variation fluences (10^{16}xcm^{-2}): ¾ (0), D(2), • (4), p (6), s (8), ¨ (10).

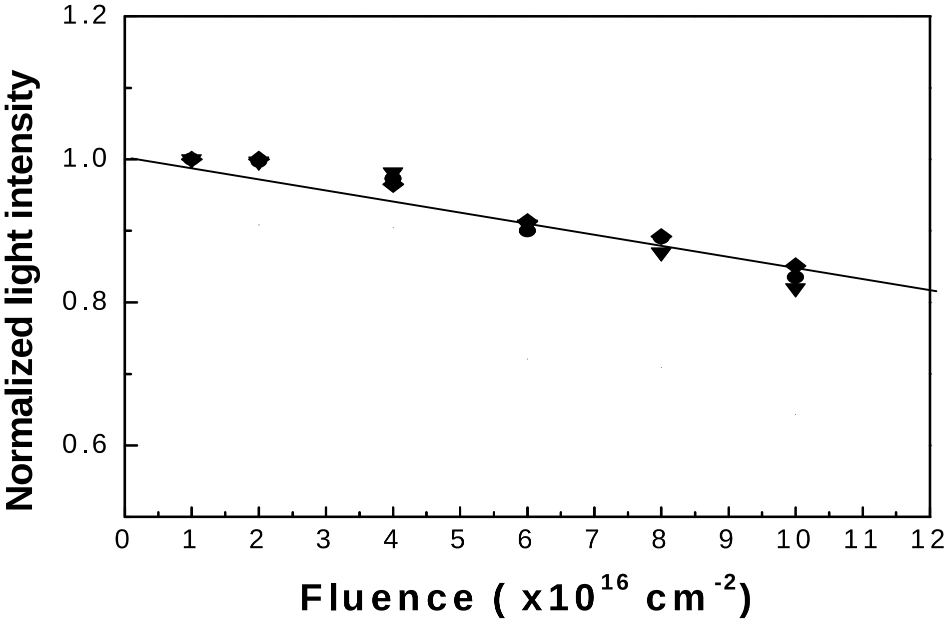

Fig.4. Normalized light intensity variations in versus electron irradiation fluence measured for J equal to 8.5 (,), 10 (–), 15 (¾) mA.

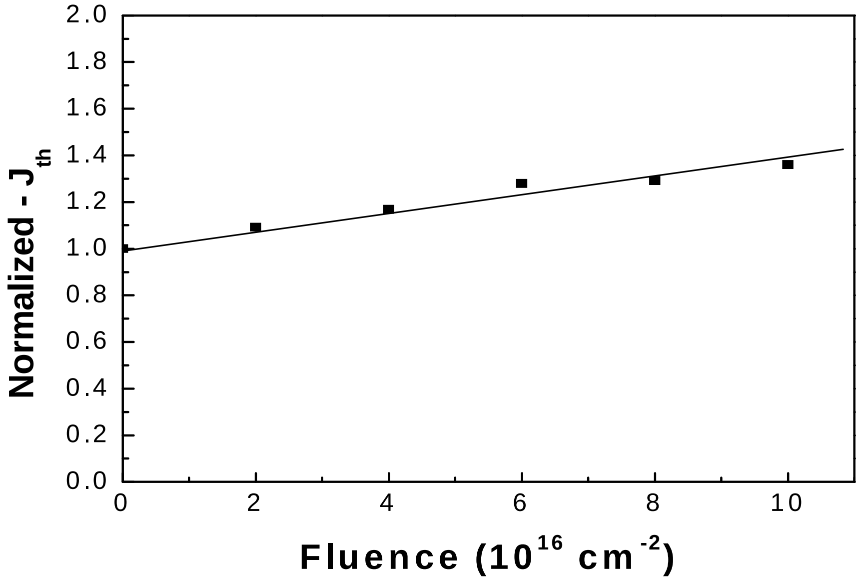

Fig.5. Normalized threshold current versus electron irradiation fluence.

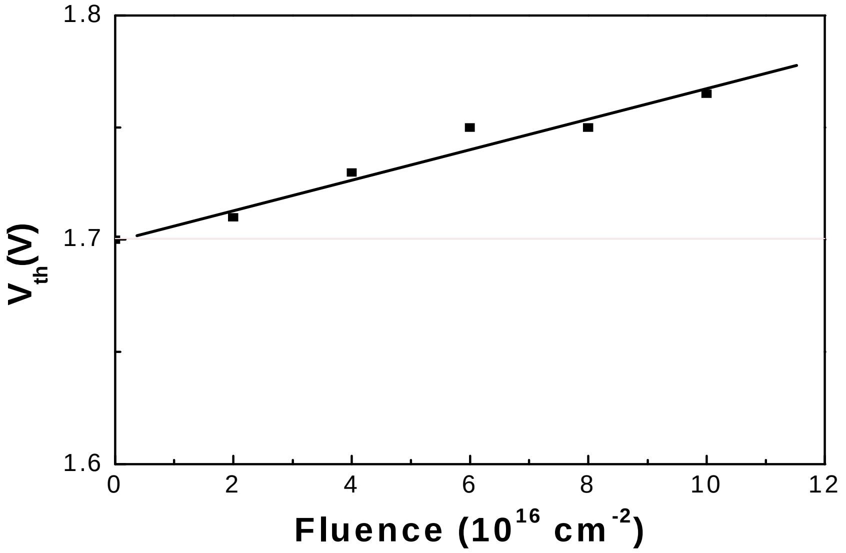

Fig.6. Normalized threshold voltage versus electron irradiation fluence.

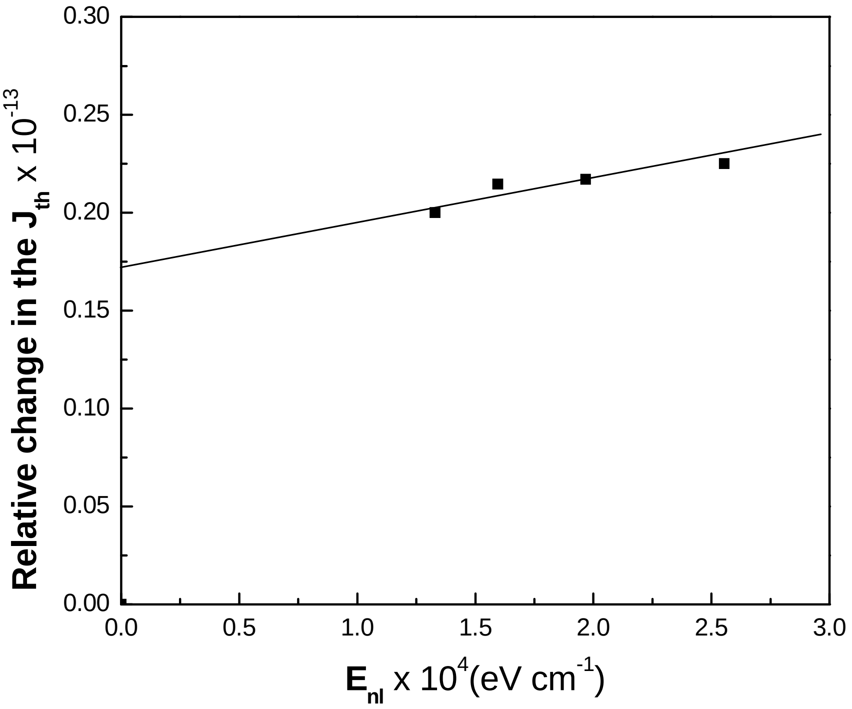

Fig.7. Relative change in the threshold current versus the nuclear energy loss by protons.

REFERENCES :

……………………………

[1] B. D. Evans, H. E. Hager, and B. W. Hughlock, IEEE Trans. Nucl. Sci. 40, 1645 (1993).

[2] H. Schöne, R. F. Carson, A. H. Paxton, and E. W. Taylor, IEEE Photon. Technol. Let. RTL-9, 1552 (1997).

[3] A. H. Paxton, R. F. Carson, H. Schöne, E. W. Taylor, K. D. Choquette, H. Q. Hou, K. L. Lear, and M. E. Warren, IEEE Trans. Nucl. Sci. 44, 1893 (1997).

[4] E. W. Taylor, A. H. Paxton, H. Schöne, R. F. Carson, J. Bristow, J. A. Lehman, M.K. Hibbs-Brenner, R. A. Morgan, and T. Marta, IEEE Trans. Nucl. Sci. 45, 1514 (1998).

[5] C. E. Barnes, J. R. Schwank, G. M. Swift, M. G. Armendariz, A. Johnston, S. Guertin, G. L. Hash, and K. D. Choquette, RADECS 2000 (Louvain-la-Neuve, Belgium, September 2000).

[6] A. H. Johnston, T. F. Miyahira, and B. G. Rax, IEEE Trans. Nucl. Sci. 48, 1764 (2001).

[7] J. C. Bourgoin, and M. Zazoui, Semicond. Sci. Technol. 17, 453 (2002).

[8] M. Zazoui, M. Mbarki, A. Zin Aldin, J. C. Bourgoin, O. Gilard, and G. Strobl, J. Appl. Phys. 93, 5080 (2003).

[9] J. C. Bourgoin, and N. De Angelis, Semicond. Sci. Technol. 16, 497 (2001).

[10] Proc. 3rd World Conference on Photovoltaic Energy Conversion, May 2003, Osaka (Japan).

[11] D. Stievenard, and J. C. Bourgoin, J. Appl. Phys. 59, 743 (1986).

[12] James F. Ziegler, Electronic mail/ Zeigler@SRIM.org, 1201 Dixona Drive, Edgewater, MD, 21037, USA, Website: www.SRIM.org.

[13] P. Le Metayer, O. Gilard, R. Germanicus, D. Campillo, F. Ledu, J. Cazes, W. Falo, and C. Chatry, IEEE Trans. Nucl. Sci., in press.

///

مجلة جامعة تشرين للدراسات والبحوث العلمية _ سلسلة العلوم الأساسية المجلد (25) العدد (15)2003
Tishreen University Journal for Studies and Scientific Research- Basic Science Series Vol (25) No (15) 2003

Computing The Induced Radiation Activities For Calcium (The Main Constituent Of Bone) And Some Other Trace Elements Activated By 14-Mev Neutrons

Dr. Aida Abboud [*]
Dr. Ahmed Yehia [**]
Amal Assem [**]

(Accepted 19/6/2003)

☐ ABSTRACT ☐

The induced activities per gm per unit flux, of the trace elements in bone such as Calcium, Fe, Cu, Zn, Sr, Ba, and Pb have been computed by using 14-MeV neutrons induced primary reaction cross-sections. These cross-sections are calculated using the computer code EXIFON which is based on an analytical model for statistical multistep direct and multistep compound nucleus reactions. The agreement between the computed cross-sections and the available experimental data is fairly good.

The induced beta or gamma activities for the (n,p) and (n,α) reactions for the isotopes of the prementioned elements with half-life-times of residual nuclei ranging from few seconds to several hundreds of years, per gm per unit neutron flux have been computed.

---

[*] Professor, Nucl. Res. Center, Atomic Energy Authority, Cairo, Egypt
[**] Temporary Assistant Researcher, Nucl. Res. Center, Atomic Energy Authority, Cairo, Egypt