Environmental and Radiation (α and β particles) Effect on (J-V) characteristics of abruptly p^+n and n^+p Junction Films

تأثير المحيط وجسيمات ألف وبيتا على خواص كثافة تيار – فولتية لأغشية مفارق الجرمانيوم n^+p و p^+n المطعمة تطعيما ثقيلا

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Abstract

The heavily aluminum and arsenic doped germanium films were prepared using thermal co-evaporation process to deposit abrupt p^+n and n^+p junction films with (4 and 0.5wt%) concentration. The prepared films were exposed to circumstance and natural radionuclide (Ra^{226}) emitted alpha and (Sr^{90}) emitted beta particles after heat treatment with various dosages .The J-V characteristics refer to shifting in both forward and reverse bias and lead to change in bulk resistivity, threshold voltages, damage coefficient, saturation current density, breakdown voltage, resistivity variation and damage percentages. It was observed that the damage coefficient and saturation current density decrease, but increasing in bulk resistivity and breakdown voltage after every stage of exposed radiation.

Keywords: thin film, doping, semiconductors, environment, beta particle, alpha particle, thermal evaporation, abrupt p-n junction.

الخلاصة :-

طعمت أغشية الجرمانيوم بالالمنيوم والزرنيخ تطعيما ثقيلا باستخدام عملية التبخير الحراري المشترك لترسيب أغشية المفارق p^+n وn^+p بالنسب الوزنية 4% و0.5% .عرضت النماذج للمصدر المشع aR^{226} الذي يبعث جسيمات ألفا والمصدر المشع rS^{90} بعد المعالجة الحرارية . درست خواص كثافة التيار – فولتية في الانحيازين الأمامي والعكسي للنماذج المرسبة ،ولقد بينت النتائج حدوث تغيير في المقاومية الحجمية ،فولتية العتبة، كثافة التيار المشبع، انهيار الفولتية ،انخفاض في معامل الضرر والتغير في النسب المئوية للاضرار بعد كل مرحلة من التعرض للمحيط واشعاع ألفا وبيتا.

1.Introduction

The germanium atom substitutes with an arsenic or aluminum atom by covalent bonds formed[1]. Arsenic atom have low negativity, it forms double electronic bond with almost right angle [2]. The most fifth doping elements go to substitutional sites in networks of material, such that the displaced germanium transfers to the free surface [3]. Small quantity of impurities has large effect on electrical characteristic [4]. (Hu, 1987) supposed clustering four arsenic atoms which formed tetragonal at interstitial natural position of silicon lattice [5]. The clustering vacancy defect and impurity atom probability occur under stress especially heavily doped [3]. (Flangan & Klontz, 1968) studied effect of radiation in n-type more than p-type because of defect production at low temperature [6]. The tracks result from radiation, lead to disturbing regions at thin specimen, while thick samples could be recombination of atoms[7]. The cross section of secondary defects is non-proportional to impurity concentration, which describe in term of free migration of primary defect[8]. The impurities with larger diameter occupy to extension regions, surrounded by dislocations. (Gurtis & Cravtord, 1961) [9] found that the data of doped Ge with As at range (150-240^{O}C) agreement in characteristic of some data taken from irradiated germanium by electron accomplish with (Brown). (Mora *et al.*, 1972) [10] studied the effect of neutrons on electrical

properties of heavily doped ((1-8)*$10^{18}$$cm^{-3}$) (p-type) of GaAs. (Inshino & Matsuatani, 1977) [11] are irradiated small rectangular wafers of heavily doped germanium with arsenic or antimony to form n-type by fast neutron of doses (2-5)*10^{14} n/cm^2. (Mch Hardy & Fitzgerald, 1985) [12] presented research about the effect of different electronic irradiation intensities on the calcogenates (Si, Se, Te) films with arsenice and germanium covered with silver. (Srivastava *et al.*, 1986) [13] prepared germanium film using thermal evaporation vacuum techniques on glass substrate at room temperature. (Fuknoka, Noboru *et al.*, 1992) [14] measured the value of single crystal germanium resistivity after neutron irradiation. (Al-Bassam F.A., 1996) [15] prepared amorphous pure and doped germanium films by thermal co-evaporation process and irradiated with alpha and beta particles and observed shifting in (J-V) characteristics. (O.V. Aleksandrov *et al.*, 1999) [16] studied the influence of electrically inactive impurities such as carbon, oxygen, nitrogen and fluorine on the formation of donor centers in silicon layers implanted with erbium. (S.A. Shevchenk, 1999)(17) studied influence of annealing on the dislocation-related electrical conductivity of Ge n-type single crystals with donor conc. of (3*$10^{12}$$cm^{-3}$) was formed at(760 ^{o}C) to strains. (M. Oszwaldonski *et al.*, 2001) [18] studied the structural properties of InSbBi and InSbAsBi thin films prepared by flash-evaporation method using a mixture of powders. The electrical sheet conductivity and dominated the recombination current due to the generation and trapping center [19]. (Faisal A.M. *et al.*, 2004) [20] studied irradiated pure and doped amorphous germanium films with antimony. It showed that d.c. conductivity of n-type film increase with gamma radiation. (Faisal A.M., 2001) [21] deposited p-GeAl (0.1wt%) films by thermal co-evaporation and irradiation with fluency alpha and beta up to 10^9 particle/cm^2, moreover to atmospheric exposure. (Faisal A.M., 2004) [22] prepared lightly As doped Ge films (0.1 wt) and irradiated with alpha particle emitted from (Ra^{226}).The aim of the project is to obtain the (J-V) characteristics of p^+n and n^+p junctions before and after exposed to alpha and beta particles in addition to environment and derive a new damage coefficient equations related to variation in current density and voltage of the films.

2.Theoretical Calculations

When beta particles have entered into thin films with certain solid angle, some electrical changes appear as result of defects, depending on the energy of particles and type of film. To compute the flux of radiation (particle/cm^2.sec), we used the equation [23]:

$$\phi = \frac{\text{no. of particle/sec}}{\Omega A_s} \qquad (1)$$

where A_s (cm^2) the source area, and Ω is the solid angle that can be calculated from the equation [24] :

$$\Omega = \frac{1}{2}\left(1 - \frac{d}{\sqrt{d^2 + R_d{}^2}}\right) \qquad (2)$$

So R_d (cm) is the radius of the exposed, d (cm) is the distance between the source and exposed area. The resistivity $(\Omega \cdot cm)$ is given by [3]:

$$\rho = \frac{\Delta V}{\Delta J}\left(\frac{1}{l}\right) \qquad (3)$$

Such as l is the length of the film. The equation to find the damage coefficient (D) (Amp/cm) is [25]:

$$\frac{\Delta I}{V} = D.\phi \qquad (4)$$

Where V (cm^3) is the volume of the exposed area, ΔI is the variation in current.

The maximum range R_{max}. (Material independent) of beta particle can be computed from empirical formula given by Katz and Penfold [26]:

$$R_{\max}.\rho(gm/cm^2)=\begin{cases}0.412E_{\beta}^{1.265-0.0954\ln E_{\beta}}, E_{\beta}\langle 2.5MeV\\ 0.530E_{\beta}-0.106, E_{\beta}\rangle 2.5MeV\end{cases} \quad (5)$$

Where E_{β} is the maximum beta energy in MeV. The thickness (t_d) of the material gives a generic quantifier which various absorbers can be compared [26] :

$$t_d(gm/cm^2)=\rho(gm/cm^3)\times t \ (cm) \quad (6)$$

Also by Appling the Bragg-Kleeman rule for one material [23]:

$$\frac{R_1}{R_2}=\frac{\rho_1}{\rho_2}\cdot\frac{\sqrt{A_1}}{\sqrt{A_2}} \quad (7)$$

Where ρ_i and A_i are the density and atomic weight respectively and R_i is the distance of particle in material, then effective atomic weight was found from the equation [23]:

$$A_{eff.}=\sum_{i=1}^{L}\frac{w_i}{\sqrt{A_i}} \quad (8)$$

Where L is the no. of elements and w_i is the concentration of element.

The effective atomic number and atomic weight of alpha particle effect is given by[23]:

$$Z_{eff.}=\Sigma W_i Z_i \quad (9)$$

From equation (3) and (4) produce:

$$D_V=\frac{|V_2-V_1|}{\phi l^2\rho} \quad (10)$$

Where $V=Al$, $\Delta J=\Delta I/A$

From Boltzmann equation[27]:

$$J=J_S(e^{\frac{V}{\eta V_T}}-1) \quad (11)$$

Such that $V_T=kT/q$, $\eta=1$ for germanium, derive eq.(11) with respect to V produce:

$$\frac{dJ}{dV}=\frac{J_S e^{\frac{V}{V_T}}}{V_T}$$

$$C=\frac{J+J_S}{V_T} \quad (12)$$

Where $C(\Omega.cm^2)^{-1}$ represents the conductance of p-n junction also:

$$\sigma_v=\left(\frac{J+J_S}{V_T}\right)\left(\frac{l}{wt}\right) \quad (13)$$

Where σ_v is the bulk conductivity of the film $(\Omega.cm^3)^{-1}$..

From eq.(11):

$$\Delta J=\Delta J_S\left(e^{\frac{V}{V_T}}-1\right) \quad (14)$$

Substitute eq.(4) in eq.(14) and if :

$e^{\frac{V}{V_T}} \rangle\rangle 1$ and $V \rangle\rangle V_T$

$$D_J = (J_{S2} - J_{S1}) \frac{e^{\frac{V}{V_T}}}{\phi l} \quad (15)$$

It can be produced the damage equation in terms of hyperbolic function[28]:

$$\cosh v = \frac{e^{v} + e^{-v}}{2} \quad (16)$$

By analyzing produce:

$$e^{2v} - 2e^{v} \cosh v + 1 = 0$$

$$e^{v} = \cosh v \pm \sqrt{\cosh^2 v - 1}$$

But

$$\cosh^2 v - \sinh^2 v = 1$$

$$e^{\frac{V}{V_T}} = \cosh(\frac{V}{V_T}) \pm \sinh(\frac{V}{V_T}) \quad (17)$$

Equation (15) becomes:

$$D_J = (\frac{J_{S2} - J_{S1}}{\phi l})(\cosh(\frac{V}{V_T}) \pm \sinh(\frac{V}{V_T}) \quad (18)$$

This equation represents the damage coefficient of p-n junction film in the case of current density variation before and after exposure to nuclear radiation.

In the case the current density and voltage are changed; equation (14) becomes:

$$\Delta J = J_{S2} e^{\frac{V_2}{V_T}} - J_{S1} e^{\frac{V_1}{V_T}} \quad (19)$$

Connect between equations (15) and (17) produce:

$$D_V = \frac{1}{l\phi} \{ J_{S2} \left(\cosh(\frac{V_2}{V_T}) \pm \sinh(\frac{V_2}{V_T}) \right) - J_{S1} \left(\cosh(\frac{V_1}{V_T}) \pm \sinh(\frac{V_1}{V_T}) \right) \} \quad (20)$$

This equation represents the damage coefficient in the case of the current density and voltage variation of p-n junctions.

3.Experimental details:

The films were deposited on hot glass substrate (100^{o} C) by means of (Edward's system) using thermal co-evaporation technique from two separate source for the host (Ge, 96wt%,99.5wt%) and dopant (Al,4%wt,As,0.5% wt for $p^{+}n$)(As,4%wt,Al,0.5% wt for $n^{+}p$) materials under vacuum system around (10^{-6} torr). The rate of deposition was about (6A^{o}/sec). The heat treatment was about (393K) for (30min.) by using digital thermometer $(\pm 5K)$. The thickness of the film was (350 ± 10)nm and aluminum ohmic contact on the film was made prior to exposure to radiation as electrodes. The films were mounted on two sides at (0.2, 0.4 cm) distances and exposed to particle radiation at (300K) with(Ra^{226}) source emitted alpha particle its activity is (10^{-6}mCi) and (Sr^{90}) source emmited beta particle its activity($5*10^{-3}$mCi for three period times respectively . The other specimens of abruptly $p^{+}n$ and $n^{+}p$ junctions exposed to environment. Measurements of d.c. electrical resistivity were preformed on three thin film specimens of well-characterized homogeneity. The rate of count activity of the source was obtained by using silicon surface barrier-layer detector and scintillation (NaITI) detector. The samples were carefully kept in

a glass chamber evacuated to (0.1) torr pressure.The measurement of the film thickness can be estimated by equation [9]:

$$t = \frac{m}{2\pi r^2 \rho \cdot r^2} \qquad (21)$$

Where m (gm) and ρ (gm/cm^3) are the mass and density of materials. r(cm) is the distance between the source and the glass substrate.

4.Results and Discussion

For high concentration doping germanium with aluminum(4,0.5 wt%) and arsenic (o.5,4wt %) to form abruptly p^+n and n^+p junctions respectively. It causes shifting in J-V characteristic as result of alpha and beta particles and environment exposures.

4-1 *Effect of atmospheric exposure on abrupt p^+n film*

From Fig.(1a,b) curves, it was observed that the saturation current values has low decrease as result to exposed to radiation, while the break down voltage is a little increasing as shown in table (1).Also the bulk resistivity increase in both biases as shown in table (2). The shifting in (J-V) characteristic in the first stage is greater and so constant in the final. The bulk resistivity variation percentage is (23.9%) in forward and (30.9%) in reverse as shown in table (3).Table (4) indicates the damage percentages with (20.0%) in forward and (26.7%) in reverse after 6 days of exposure. These variations occur because of atmospheric factors that occur perturbation in equilibrium of donor and acceptor density carriers, permit to oxidation film and leads to increasing of oxygen contents in p^+ and n sides. However the connections of (Ge-Al) and (Ge-As) contains oxygen atoms, lead to retard to passing current in the film.

4-2 *Effect of alpha particles on abrupt p^+n films*

Fig. (2a,b) shows varying in (J-V) characteristic after every stage of exposed to radiation. The threshold voltage values increase after exposure to alpha particles, moreover the volume resistivity and the resistivity variation percentage to (150.5%) for forward and (90.5%) for reverse bias, but get decreases in saturation current densities because the point defects (vacancies) have generated continuously until reach saturation defect state, moreover to atmospheric exposure. The data is described in table (3),(4),(5).The damage coefficient decreases after every stage of exposure. The non-linear of ohmic (J-V) characteristics is attributed to jumping the voltage values or raise resistance at these values. These are because of amorphouzation, unsteady and inhomogenity of the film. These produce a disordered zones and cascades of clusters. This means that the sites of host and impurity atoms are in dispersion positions due to preparation factors.

4-3 *Effect of beta particles on abrupt p^+n films*

Fig. (3a,b) indicates to decreasing in J_s and V_z after first stages of exposure and increasing in bulk resistivity in forward and reverse biases even reach 97.7% and (41.3%) after the third stage of exposure more the atmospheric exposure by (10.4%) and (73.8%) values. The factor values described in tables (1),(4),(5),(6). This because of defect generation after exposure as result to displaced impurity atom or the host atom on two sides of junction. The partial destroy of potential barrier that is occurred lead to change in resistivity values at second and third stages and hence the film becomes stable for long duration time. The creation of vacancy defects in amorphous structure leads to decreasing donor levels, which trapped donor centers that means decreasing of carrier's contribution. The occurrence irregular atomic displacements as result to beta particles increase dangling bonds and then more the amorphouzation. The increasing dangling bonds is weaken the transitions from covalent band to conduction band.

4-4 *Effect of atmospheric exposure on abrupt n^+p film*

Fig. (4a,b) Indicates a large shifting in (J-V) characteristic as a result of sensitive film to atmosphere. The oxidation phenomena of n-type that contain a high density of arsenic atom .Table (1)describes a decreasing in saturation current density and increasing in break down voltages. Also

bulk resistivity increase with values (64.3%) and (81.5%) in both forward and reverse biases as shown in table (2). The damage percent increases with (44.4%) and (53.6%) in two basis as shown in tables(3) and (4).These variation occur because of unstable of arsenic atom and can be easily oxidized. Also a weak connection of arsenic and germanium atoms.

4-5 *Effect of alpha particles on abrupt n^+p films*

Fig.(5a,b) shows a high shifing in (J-V) characteristic obtained as a result to particle effect at barrier region. This leads to decreasing in current density and increase in bulk voltage as shown in table (1). The bulk resistivity after third stage of exposure show an increase in both biases with (190.0%) and (229.3%) respectively as shown in tables (2) and (3).The damage coefficients is relatively high in the first stage of exposure of (10^{-11}Amp./cm) order, and decrease after the final stage of exposure. These change in values because of defect generation in p ,n^+ and depletion layer of the junction, lead to occurring capture of electron produce by n^+ type. The heavy incident particle create collisions and vacancies or holes. The absorption converts at least a portion of energy from the alpha particles into electron-hole pairs for collection by the one p-n junction in the layer of semiconductor material[29].

4-6 *Effect of beta particles on abrupt n^+p films*

Fig.(6a,b) shows the shifting in (J-V) characteristic especially in forward bais. The saturation current density decrease and bulk resistivity ,break down voltage increase as shown in tables (1),(2).The values of resistivity variation and damage percentages are (85.5%) and (88.9%) ,(49.7%) and (51.9%)for forward and reverse baises as shown in tables(3) and(4).These variation are occur because of the capture of beta particles from n^+ -side . Some beta particles are penetrate out side the film after some defect created interior the film.

5.Conclusions

From the result of the project we can be produce:

1-It is observed that the abruptly doped p-n junction film have effects on (J-V) characteristics before exposed to environment, alpha and beta radiation.

2-The shifting in forward bias is more than reverse bias in p^+n and n^+p and effect of alpha is more than beta .

3-The abruptly p^+n junction film is the best to make devices.

4-The resistivity and damge percentage change little after the third stage of exposure.

5-The saturation current density decreases and break down voltage increase as result to exposure.

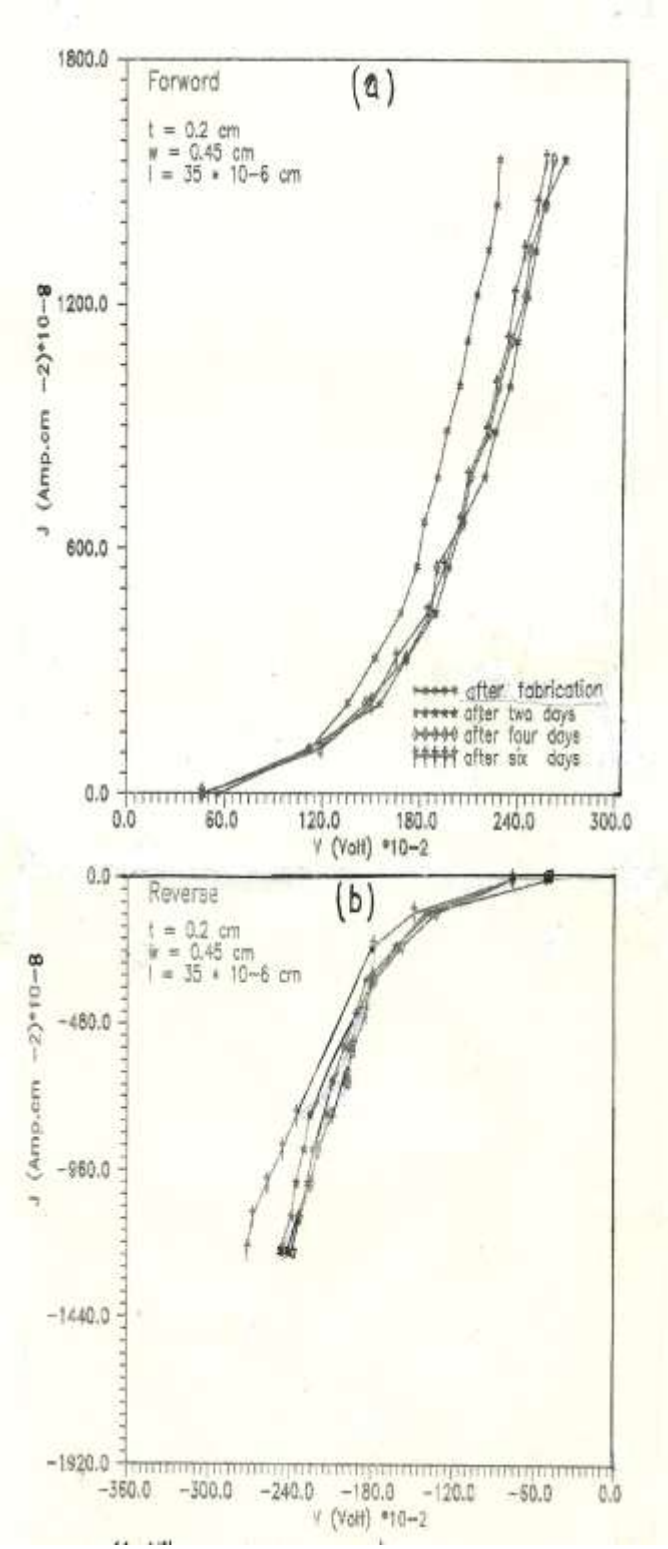


Fig.1 J-V characteristic of T.F. p^+n junction (A.E)

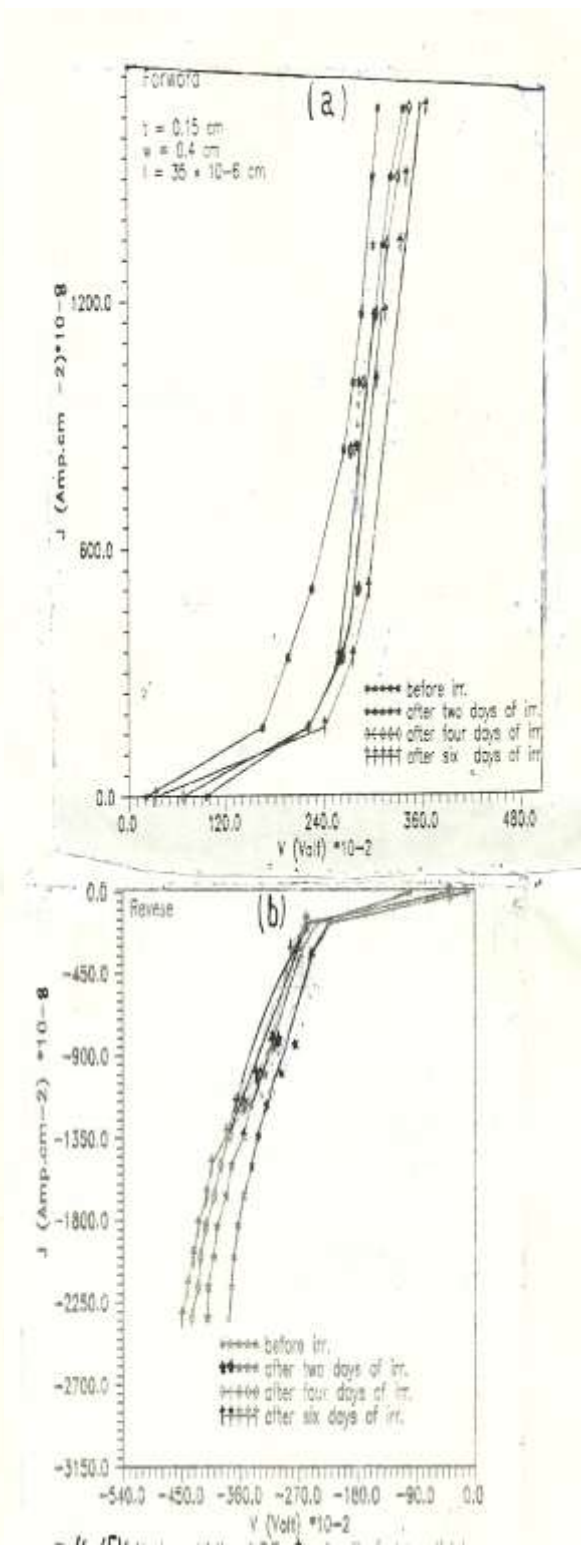
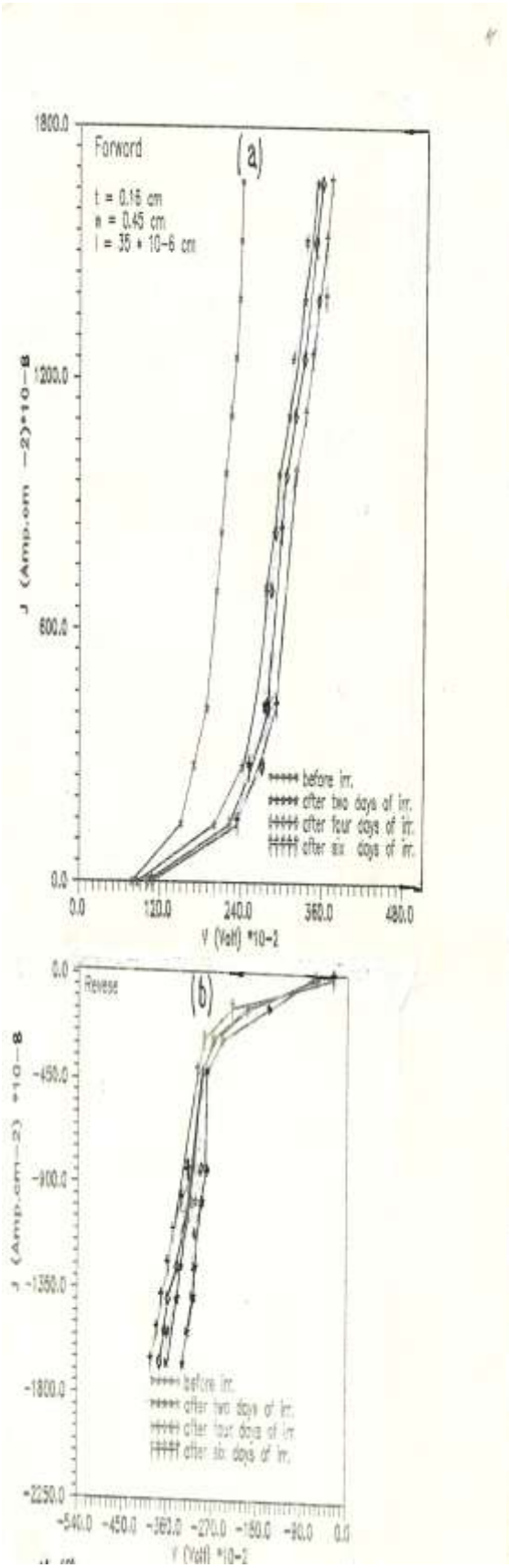


Fig.2 J-V characteristic of T.F. p^+n junction (α-particle)



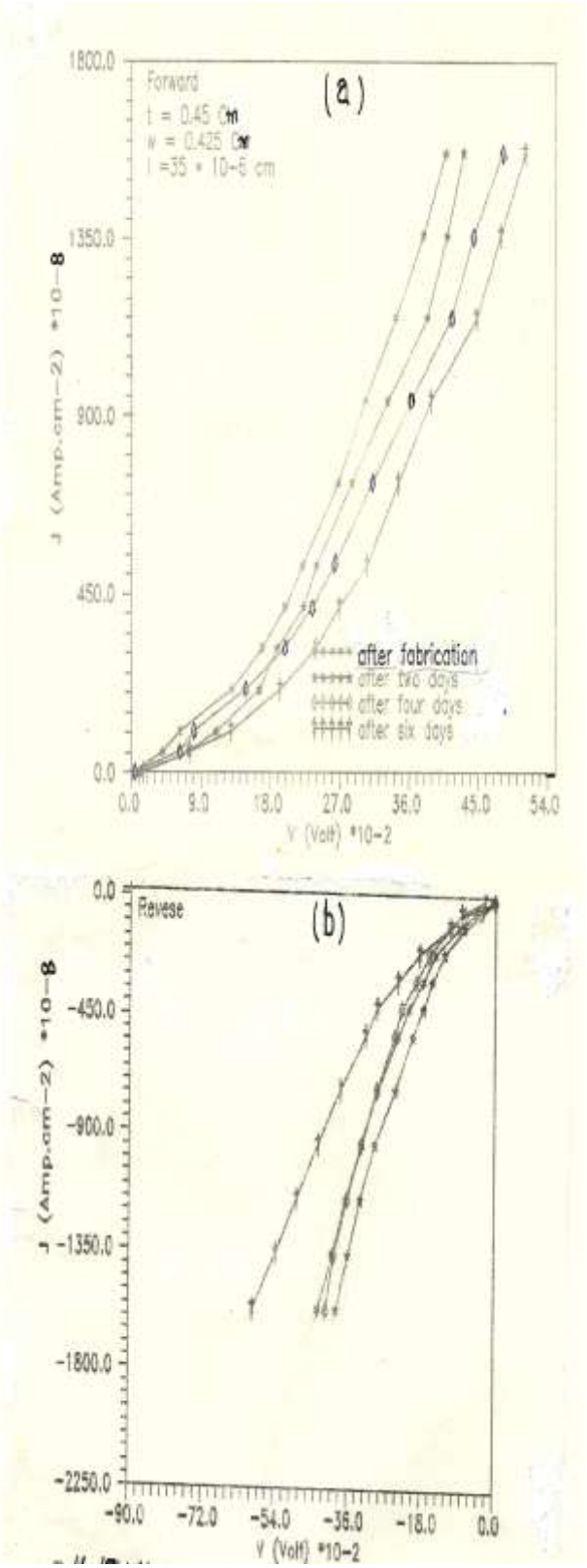


Fig.3 J-V characteristic of T.F. $p^{+}n$ junction (β-particle) Fig.4 J-V characteristic of T.F $n^{+}p$ junction (A.E.)

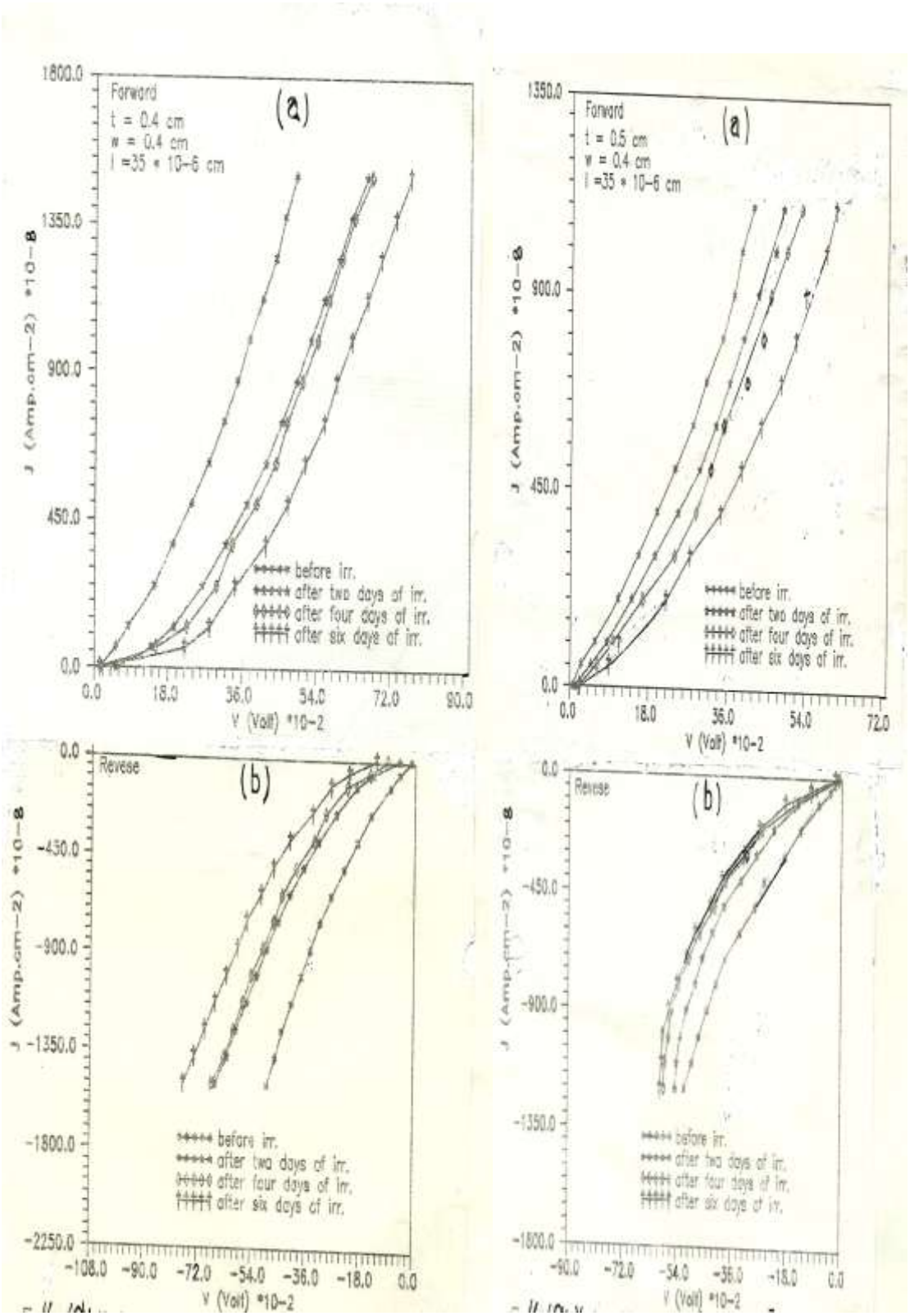


Fig.5 J-V characteristic of T.F. n^+ p junction (α-particle) Fig.6 J-V characteristic of T.F. n^+ p junction (β-particle)

Table(1) saturation current density and break down of abruptly p^+n and n^+p junctions

Exposure type	Junction	p^+n		n^+p	
	E.T.(days)	J_s*10^{-6} ($Amp.cm^{-2}$)	V_z(Volt)	J_s*10^{-6} ($Amp.cm^{-2}$)	V_z(Volt)
A.E.	0 2 4 6	1.45 1.15 1.20 1.20	2.80 2.97 2.74 3.00	2.25 2.00 1.90 1.85	0.54 0.45 0.48 0.69
Alpha&A.E.	0 2 4 6	1.52 1.50 1.15 1.25	3.70 4.10 4.30 4.50	2.20 1.75 1.30 1.15	0.57 0.75 0.77 0.86
Beta &A.E.	0 2 4 6	1.51 2.00 1.50 1.40	3.70 3.90 4.00 4.20	2.23 1.90 1.80 1.50	0.56 0.57 0.59 0.60

Table(2) Bulk resistivity of abruptly p^+n and n^+p junction films

Exposure type	Junction	p^+n		n^+p	
	E.T.(days)	F $*10^6$	R$*10^6$	F$*10^6$	R$*10^6$
A.E.	0 2 4 6	1.568 1.758 1.774 1.944	2.272 2.560 2.298 2.974	0.423 0.488 0.566 0.695	0.514 0.656 0.716 0.933
Alpha &A.E.	0 2 4 6	1.514 2.571 3.370 3.792	2.274 2.884 3.889 4.333	0.431 0.795 0.890 1.250	0.508 1.007 1.126 1.673
Beta &A.E.	0 2 4 6	1.579 2.022 2.579 3.121	2.294 2.407 2.974 3.241	0.434 0.532 0.611 0.805	0.507 0.711 0.820 0.958

Table(3) resistivity variation percent $((\rho - \rho_o)/\rho_o\%)$ of abruptly p^+n and n^+p junction films after 6 days of exposure.

Exposure type	p^+n		n^+p	
	F	R	F	R
A.E. Alpha &A.E. Beta&A.E.	23.9 150.5 97.7	30.0 90.5 41.3	64.3 190.0 85.5	81.5 229.3 88.9

Table(4) damage percent $((J-J_o)/J_o\%)$ of abruptly p^+n and n^+p junction films

junction		p^+n		n^+p	
Exposure type	E.T.(days)	F	R	F	R
A.E.	2	8.0	6.7	18.9	25.0
	4	10.0	16.7	27.8	32.1
	6	20.0	26.7	44.4	53.6
Alpha &A.E.	2	48.2	27.2	50.9	56.7
	4	60.6	46.6	53.6	58.3
	6	67.6	56.3	69.1	75.0
Beta&A.E.	2	29.2	18.8	19.4	33.3
	4	43.3	31.3	31.5	44.4
	6	55.8	37.5	49.7	51.9
Alpha	2	40.2	20.5	37.0	31.7
	4	50.6	39.9	25.8	26.2
	6	47.6	29.6	24.7	21.4
Beta	2	21.2	12.1	5.5	8.3
	4	33.3	24.6	3.7	12.3
	6	35.8	10.8	5.3	+1.7

Table(5) Damage coefficient $*10^{-11}$ Amp./cm of abruptly p^+n and n^+p junction films

Exposure type	Junction	p^+n		n^+p	
	E.T.(days)	F $*10^6$	R$*10^6$	F$*10^6$	R$*10^6$
Alpha	2	11.590	3.958	15.830	14.417
	4	7.279	3.392	8.339	7.421
	6	5.418	2.733	7.161	6.361
Beta	2	1.085	0.465	0.992	1.394
	4	0.806	0.387	0.806	0.929
	6	0.692	0.309	0.826	0.728

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