Surface Recombination Velocity of the LPE Grown P ($Al_{.86}$ $Ga_{.l4}$ As) -P (GaAs)-N (GaAs) Solar Cells

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Abstract:-

Photolumincsccncc (PL) measurements were earried out on Liquid-phase epitaxy (LPE) grown P($A1_{.86}Ga_{.14}$As)-P(GaAS)-N(GaAs) solar cells in the temperature range 10-350K.By the PL measurements analysis and using a simple theoretical model, we evaluate the surface recombination velocity at the GaAs p-n junction surface as a function of temperature.

Our results indicate that surface recombination is not playing an important role in the heterojunction device , and show that the surface recombination velocity at the (GaAs) p-n junction surface is proportional to Exp (-Ea/KT) with activation energies Ea of 3.5 meV to 13 meV in the temperature range studied.

Introduction:-

The attempt to improve the performance of solar cells, by increasing their spectral response and power conversion efficiency, has been the aim of several papers and interesting proposals in the last few years.

However, as early as 1980 the use of Alx GaA-x As GaAs as a semiconductor material in solar cell structures had been widely recognized as one of the best ways to achieve high solar energy conversion-efficiency.

Knowledge of the recombination parameters is thus of great important to the device performance and hence to the process designer. In particular , an accurate method to measure the surface recombination velocity (S) is extremely important *in* the above semiconductors .which are promising and already widely used materials in optoelectronic devices.

The purpose of this paper is to analyse the photoluminescence (PL) measurements of the P (AI.86 Ga.uAs)-P (GaAS)- N(GaAs) solar cells using a simple theoretical model to evaluate the surface recombination velocity at the GaAs surface, which is the greatest cause of low collection efficiency.

Experimental Details:-

A series of heavily Be-doped p-type AlxGai.x As GaAs layers with Al composition x~0.86 and at different thickness were grown on n-type GaAs substrates by using the liquid phase epitaxy techniques (LPE).

Tne substrates were (100) oriented and doped with SI to a carrier concentration of 1.3 E17 to 1.9 E18 cm . The growth temperature was 700 C. The grown layers were about 0.5 \i m thick as determined by a Ball Lapapparatus [1]. Free carrier concentration in the grown layers (~2E17 to 1 2E18 cm 3) was determined from Van der Pauw measurements [2].(Be) atoms diffuses into the n-type substrates during the growth cycle, resulting in a p-n junction located within the substrate This junction will operate as the active photovoltaic junction. [Full details of the apparatus used for preparation of samples for this work can be found in ref. 3 .]. Photoluminescence (PL) measurements at different temperature (10-300 K) were carried out on four sample (LP1 ,LP2,LP3,LP4) by using an evacuable liquid He cryostat. An automatic heating control system with direct readout of sample temperature between 10 and 300 K with +1" K accuracy. Due to the high Al composition (x) in the window layer (giving indirect gap material) and the small layer thickness only the GaAs PL signals were obtained. The techniques used to obtain the spectra have been fully described in ref (4) The properties of the samples used in this study are shown in Table (1) .

Theory

The A).ae Ga uAs - GaAs solar cell is excited with light of photon energy less than the band gap of the Al.8e Ga.uAs layer so that the incident radiation penetrates the wide -bandgap Alx Gai.x As top layer and is absorbed in the p-type GaAs active layer. Electron-hole pairs are created in excess of their equilibrium numbers at/or near the surface of the p-type GaAs layer and they may diffuse further into the bulk of the sample before recombining with the emission of a photon (i.e., radiatively) or in a processes which do not result in external photon emission (i.e. , nonradiatively).

However, consideration of the factors that influence the observed external emission in the case of Alx Gai_x As GaAs structure suggest that most of the large difference in the PL emission intensities between the "coated"(i.e., Alx Gat* As *f* GaAs structure) and" uncoated " by the solid-solution layer (i.e., GaAs) can be ascribed to differences in surface properties [5]. The analysis was performed by Williams and Chapman |6] for a homogenous semi-infinite solid with the photoexcited carries being generated by radiation incident on the surface. The diffusion of the excess minority carriers (electrons) of concentration n is obtained by solution of continuity equation :-

$$D_n\nabla^2 n-\left(\frac{n}{\tau}\right)+ge^{-\alpha x}=0 \quad \text{................(1)}$$

Where D_n is the electron diffusion coefficient, QC is the absorption coefficient for the incident exciting radiation , *t* is the total life time , x is the normal distance from the surface ,and g is the net generation rate of free carries .The appropriate boundary conditions are :-

$$D_n \nabla^2 n = S_n$$

At x=0

And

n=0 at x=∞

Where S is the surface recombination velocity the subject to these particular boundary conditions is the solution to this differential equation

$$n = \frac{gL_n^2}{D_n}\left(1-\alpha^2 L_n^2\right)^{-1}\left[e^{-\alpha x} - \left(\frac{\alpha + \left(\frac{S}{D_n}\right)}{L_n^{-1} + \left(\frac{S}{D_n}\right)}\right)e^{-x/L_n}\right] \text{.........................}(2)$$

The total radiative recombination rate inside the sample (i.e., the luminescence intensity l_c-due to radiative recombination of mechanism i escaping the surface) is determined by n(x),the life timeTi for this recombination mechanism , the absorption coefficient ß for this *luminescence* ,the *detector efficiency* and solid-angle *factor* ,and an *internal reflection* coefficient r:-

$$I_i = \varepsilon_i r \int_0^\infty \frac{n}{\tau_i} e^{(-\beta i x)} dx \qquad (photons/cm^2.\text{sec}) \quad \text{……………..}(3)$$

By carrying out the integration using the value of n from equation (2) and the small signal approximation thattri is a constant gives :

$$I_i = \frac{\varepsilon_i r}{\tau_i}\,\frac{g}{D_n}\,\frac{(S/D_n + L_n^{-1} + \alpha + \beta)}{(S/D_n + L_n^{-1})(\alpha + \beta_i)(\alpha + L_n^{-1})(\beta_i + L_n^{-1})} \text{………}(4)$$

which can be applied to each of several radiative recombination processes which occur simultaneously.
The above expression contains factors which are the same for the coated and uncoated samples,such as £ i.r.g.andti for a given experimental arrangement. Hence the ratio of the PL emission intensities of P-type GaAs layer with coated and uncoated surfaces *(y\Uti)* is of the form:-

$$\frac{I_c}{I_{uc}} = \frac{(1 + \frac{\alpha + \beta}{S_c D_n^{-1} + L_n^{-1}})}{(1 + \frac{\alpha + \beta}{S_{uc} D_n^{-1} + L_n^{-1}})} \text{………………..}(5)$$

here , *oc* is the obsorption coefficient of GaAs at the wavelength of the exciting

radiation (oc~10^6 cm-^{1} [7]) and /is the self-absorption coefficient of the luminescence signal, which is very small (~/0^2 cm-^{1}). *Neglecting the value of* S_c D_n-^{1} compared with L_n"^{1},reflecting the fact that the recombination velocity at the Al* Gai_$_x$ As - GaAs heterojunction is small(~10^2cm/sec)[8],the above expression can be further approximated, and the following expression for S_{uc} on p-type GaAs is obtained when l_c/l_{uc} is much less than α L_n.-

$$S_{uc} = \frac{D_n}{L_n}(\frac{I_c}{I_{uc}} - 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The diffusion coefficient D_n is related to the mobility u. $_n$ of the minority carriers

through the Einstein relation (qD_n=(in KT).Hence ,S_{uc}can be evaluated from :-

$$S_{uc} \approx \frac{\mu_n KT}{qL_n}(\frac{I_c}{I_{uc}} - 1) \quad \ldots\ldots\ldots.(7)$$

Where q is the electronic charge ,K is the Boltzmann constant ,T is the temperature in °K.

Results and discussion :-

To avoid the change in the recombination mechanism which could be caused by the temperature increase above about 140 °K , and the bandgap shrinkage caused by the *temperature* increase above 140 °K *which* make the *exciting light* absorbed in the upper Al_x Ga1-X As layer and hence the P-type GaAs layer is no longer excited with constant excitation density, We consider in the following calculation only the temperature below 140 K.In addition, we assume for the calculation that the continuous decrease of the PL emission intensity of the Al_xGaj.$_x$ As-GaAs solar cells with temperature is mainly due to the enhanced participation of nonradiative recombination process at the results Al_x Ga-1$_x$ As-GaAs, interface . In order to extract S_{uc} values from the results ,it is necessary to make *sweeping assumptions on* the transport *parameters and thier temperature* dependence. For simplicity we assume that the electron diffusion length L_n in eqn.(7) has temperature-independent value of 10 fx $_m$, which is typical for a direct -gap semiconductor like GaAs (9].AIthough the measured mobilities in p-type GaAs at P ~1 X 10^{18}cm-^{3} obtained by Hall measurement show some variation within this *temperature range* , we assume a constant value of 5000 cm^2/v.sec for our calculation [10]The value of S_{uc} at different temperature calculated in this way are given in the arrhenius plot of figures (1,*2,3,4)The straight line* indicates that for the layer investigated here (S_{uc})is proportional to exp (-Ea/KT) with an activation energy Ea of 3.5meV to 13meV. The observed temperature dependence of Suc is similar to that of the capture cross section of most bulk kilters as obtained from DLTS [11],which has been attributed to *multi*- phonon *processes,and to that of interface recombination centers as obtained from the* measurements of the internal quantum efficiency of AlXGa1-XAs heterostructures [12} The resulting values of the surface recombination velocity S_{uc} (~1.5 X10^4 cm/sec at 10 °K to ~8.5 X 10^6 cm/sec at 140 °K)for the samples studied agree well with the value reported in the literature [8,13]

conclusion :-

The AI.86 Ga.14As window layer is transparent to photons with energies up to about 2.8 eV at low temperature This *high energy transparency in the spectral response was* used to determine approximate values for the surface recombination velocity (S_{uc})at the GaAs p-n junction surface as a function of temperature .For each of the four solar cells investigated ,this significant step in the determination of the recombination parameters in the $Al_x Gai_{-x}$ As *solar ceils* has been taken by *using* a simple theoretical model *allowing* the quantitative description of the diffusion and recombination processes and of the quantum efficiency of the Al_x $Ga1_{-x}$ As-Ga As solar cells as a function of temperature The comparison of the temperature *dependence* of the experimentally observed luminescence intensities when the $Al_x Gai\_{x}$ As window layer is in place ,and from the GaAs emitter (i.e.. Al_x Ga1-X As window layer removed) , allows a simple determination of the surface recombination velocity at the GaAs P-N junction surface . These investigation and the *theoretical model* .which has been applied for the first time to a set of Al_xGa1-X As-GaAs

solar cells provide insight into the understanding of the mechanism of carrier diffusion and recombination through the cell .which depends on a variety of material parameters and on excitation conditions .Also .the concept of surface passivation by a bandgap transition has been demonstrated and

incorporated into current GaAs cells .The beneficial effects of these layers have a dominant influence on the high overall PL emission intensity and hence on the overall performance of the cell, and our results have shown that indeed the major cause of increased coll output was the passivation of surface states at the Al_x Ga1-X As-GaAs interface.

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Table (1)

$Al_x Ga_{1-x} As / Ga As$ material properties.

Sample no.	Al comp. (x)	$Al_x Ga_{1-x} As$ layer thick. (µm)	$Al_x Ga_{1-x} As$ dopant and type	$Al_x Ga_{1-x} As$ Plcc	Ga As emitter layer	Ga As substrate
LP1	0.86	0.51	Be - P	2 E17	Be-1E18-P	Si-1.6 E17-n
LP2	0.86	0.58	Be - P	1.2 E18	Be-1E18-P	Si-1.9 E18-n
LP3	0.86	0.55	Be - P	1.1 E18	Be-1E18-P	Si-1.9 E18-n
LP4	0.86	0.57	Be - P	1.3 E18	Be-1.5E18-P	Si-1.4 E17-n

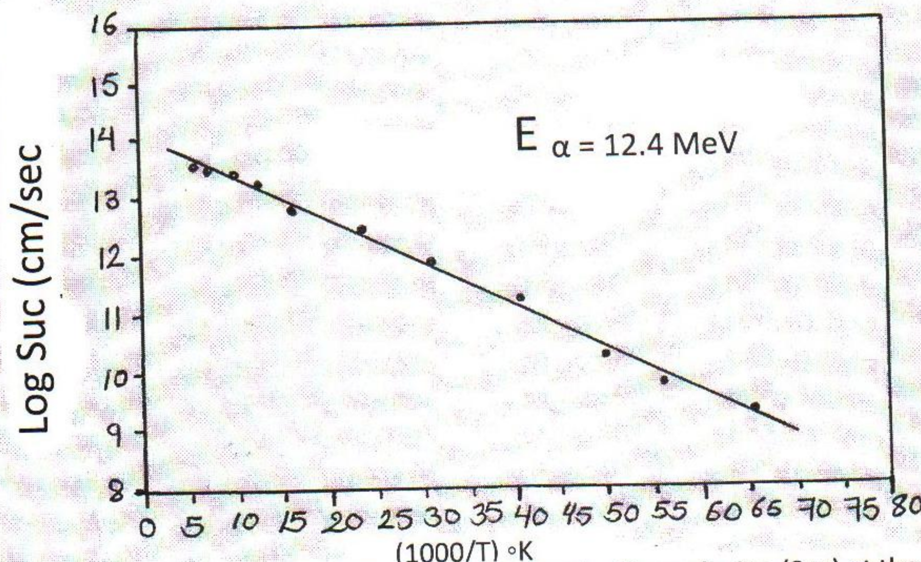


Fig.(1): Arrhenius plot of the surface recombination velocity .(Suc) at the GaAs p-n junction surface of sample LP1.

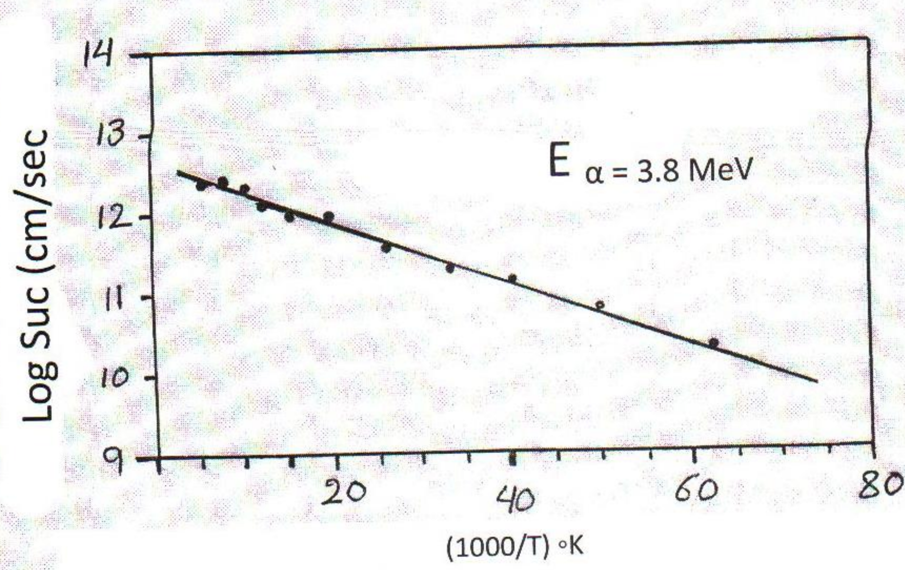
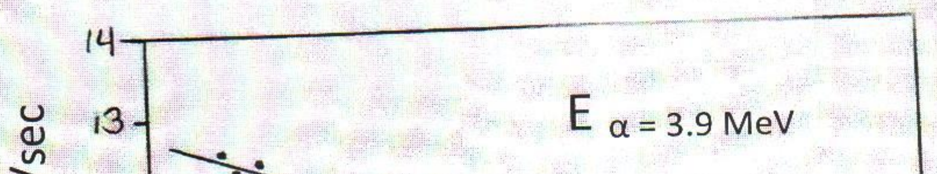


Fig.(2): Arrhenius plot of the surface recombination velocity .(Suc) at the GaAs p-n junction surface of sample LP2.



AL-Qadisiya Journal For Science Vol .17 No.2 Year 2012

A.K.Farhood ISSN-1997-4290

دراسة تأثير سرعة الالتحام السطحية في الخلايا الشمسية من نوع المحضرة بطريقة النمو من الحالة السائلة *($Al_{.86}$ $Ga_{.14}$ As)-P (GaAs)-N (GaAs)*

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قسم الفيزياء

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خلاصة :-

في هذه الدراسة تم اجراء قياسات ضوئية (Photoluminescence measurements) على مجموعة من الخلايا الشمسية التي تم نموها بطريقة النمو من الحالة السائلة (LPE) وكانت بتركيب (P($Al_{.86}$ Ga. $_{14}$ As)-(P(GaAs)-N(GaAs) وفي مدى درجات حرارة تراوح بين 10K الى 350K . بأستخدام طريقة القياسات الضوئية هذه (PL measurements) ونموذج نظري للحسابات ، تم ايجاد سرعة التحام حاملات الشحنة السطحية في وسطح وصلة الـ(p-n) بدلالة درجة الحرارة .

لقد بينت النتائج ان سرعة الالتحام لاتلعب دوراً مهماً في هذا النوع من الاجهزة كذلك بينت ان سرعة الالتحام عند الاتصال (p-n) يتناسب مع {(Exp (-Ea/kT) } وبطاقة تنشيط (Ea) تراوحت بين (35Mev) الى (13MeV) في مدى درجات الحرارة المذكورة.