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RESEARCH ARTICLE

MINORITY CARRIER'S DENSITY AND RECOMBINATION VELOCITY AT THE BACK FACE OF N+PP+ SILICON SOLAR CELL: EFFECTS OF DOPING RATE AND TEMPERATURE

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Abstract

In this article, we have established the expressions of the density of minority charge carriersand the recombination velocity at the back face of our sample.The effects of the base doping rate combined with the effects of temperature on the latter have been the subject of our study.Thus, we followed the evolution of the density of minority charge carriers and of the recombination velocity at the back face as a function of the thickness of the base for different base doping rate and for different values of the temperature.

Introduction:-

To obtain photovoltaic cells, it is necessary to manufacture what physicists call " P-N Junctions" by doping silicon [1]. By definition, doping is the addition of impurities to a pure semiconductor. It is an effective way to increase the conductivity of a pure semiconductor material in the same way as the contribution of temperature.There are different doping mechanisms: thermal diffusion, ion implantation and growth by epitaxy.

We start from the following articles and the conclusions that can be extracted from them:

1. Study of doping rate effect on parallel vertical junction silicon solar cell under magnetic field [2] .

Photocurrent density and capacitance decrease with doping rate and magnetic field;the photovoltage decreases with the magnetic field and increases with the doping rate ;the intrinsic capacity depends on the doping rate and not on the magnetic field.

2. Surface recombination velocity concept as applied to determinate silicon solar cell base optimum thickness with doping level effect [3].

The diffusion coefficient increases when the doping rate increases, on the other hand, the recombination velocity on the back face decreases there.

3.Investigation of base high doping impact on the npn solar cell microstructure performance using physically based analytical mode [4].

for $p+$ base doping concentration ranging from $5\times10^{17}\,cm^{-3}$ to $2\times10^{19}\,cm^{-3}$, the npn microstructure efficiency decreases from 15.9% to 9% respectively.

4.AC back surface recombination in $n+pp+$ silicon solar cell : effect of temperature [5]

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The Sb recombination velocity decreases with the temperature. The effect of temperature on back surface recombination velocity was explained by umklapp process.

Thus being, we study in our article the combined effects of the base doping rate and the temperature on the density of the minority charge carriers and on the recombination velocity at the back face of a $n+pp+$type silicon solar cell under polychromatic illumination instatic regime.Throughout the article, we will work with a recombination velocity at the junction $Sf = 2\times10^{2}\,cm/s$ and a depth $z = 2\times10^{-4}\,cm$.

Theoretical Study:-

Figure 1 shows our study solar cell schematically [6]:

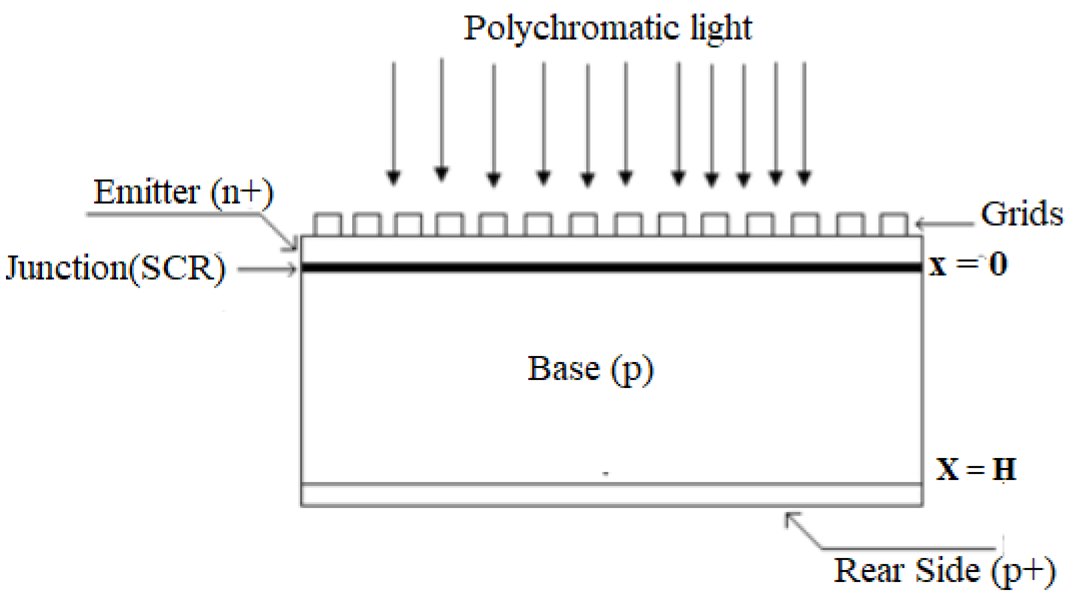

Figure 1:- An $n+pp+$ silicon solar cell.

All of the physical phenomena present when the solar cell is illuminated is translated by the following continuity equation:

$$D(Nb,T)\frac{\partial^2\delta(x,j,p,Nb,T,z)}{\partial x^2}-\frac{\delta(x,j,p,Nb,T,z)}{\tau}+g(z)=0 \quad (1)$$

Where :

$D(Nb,T)$ represents the diffusion coefficient of the minority charge carriers in the base, a function of the base doping rate and of the temperature, respectively.

$$D(Nb,T)=D(T)\times D(Nb) \quad (2)$$

With $D(Nb)$ the diffusion coefficient, a function of the base doping rate, expressed as follows [7]:

$$D(Nb)=\frac{1350\times V_T}{\sqrt{1+81\times\frac{Nb}{Nb+3.2\times10^{18}}}}=\frac{\mu\times V_T}{\sqrt{1+81\times\frac{Nb}{Nb+3.2\times10^{18}}}}=\frac{D}{\sqrt{1+81\times\frac{Nb}{Nb+3.2\times10^{18}}}} \quad (3)$$

The mobility μ of the free carriers [8] is of the order of $1350\,cm^{2}.V^{-1}.s^{-1}$ for an N type doping with a concentration at the temperature $T=300K$; V_T is the thermal potential $(Volt)$.

$$V_T=\frac{k_B\times T}{q} \quad (4)$$

k_B is Boltzmann's constant; q the absolute charge of an electron in Coulomb; T the absolute temperature in Kelvin (K).

As our study is done with temperature variation, the mobility $\mu = f(T)$ is expressed as follows [9] [10] :

$$\mu(T) = 1.43\times10^{9} T^{-2.42} cm^{2} / V.s$$

$D(T)$ is the temperature dependent diffusion coefficient given by Einstein's relationship :

$$D(T) = \frac{\mu(T)\times V_T}{q} = \mu(T)\times\frac{k_B\times T}{q} \quad (5)$$

Thus, $D(Nb,T)$ is expressed as follows:

$$D(Nb,T) = \mu(T)\times\frac{k_B\times T}{q\sqrt{1+\frac{Nb}{Nb+3.2\times10^{18}}}} \quad (6)$$

τ isexcess minority carrier's lifetime in the base.It depends on the most dominant recombination mechanism [11] .The equation (7) below explains the minority carrier lifetime τ from minority carriers concentration $\Delta n = \delta(x, j, p, Nb, T, z)$ and recombination rate R [12].In the base, the recombination mechanisms are of the Auger, SRH (Shockley Read Hall) and Radiative type.As the base is lightly doped (from 10^{15} to $10^{17}\ cm^{-3}$), the Auger recombinations are negligible there compared to those in volume within the base of the cell.The expression for lifetime can be rewritten (see equation (8)).

$$\tau = \frac{R}{\delta(x, j, p, Nb, T, z)} = \frac{R}{\Delta n} \quad (7)$$

$$\frac{1}{\tau} = \frac{1}{\tau_{volumique}} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{Auger}} + \frac{1}{\tau_{SRH}} \quad (8)$$

We take as a reference the figure 2 extracted from Sébastian DUBOIS' thesis [13], we then set our lifespan $\tau = 10^{-5} s$.

$$L(Nb,T)^{2} = \tau\times D(Nb,T) \quad (9)$$

$L(Nb,T)$ is the diffusion length of the minority charge carriers, a function of the doping rate and the temperature.

$g(z)$ represents the generation rate of minority charge carriers under polychromatic illumination [14].

$$g(z) = \sum_{i=1}^{3} a_i e^{-b_i z} \quad (10)$$

Coefficients a_i and b_i are obtained from tabulated values of radiation in $AM1.5$ conditions [15].

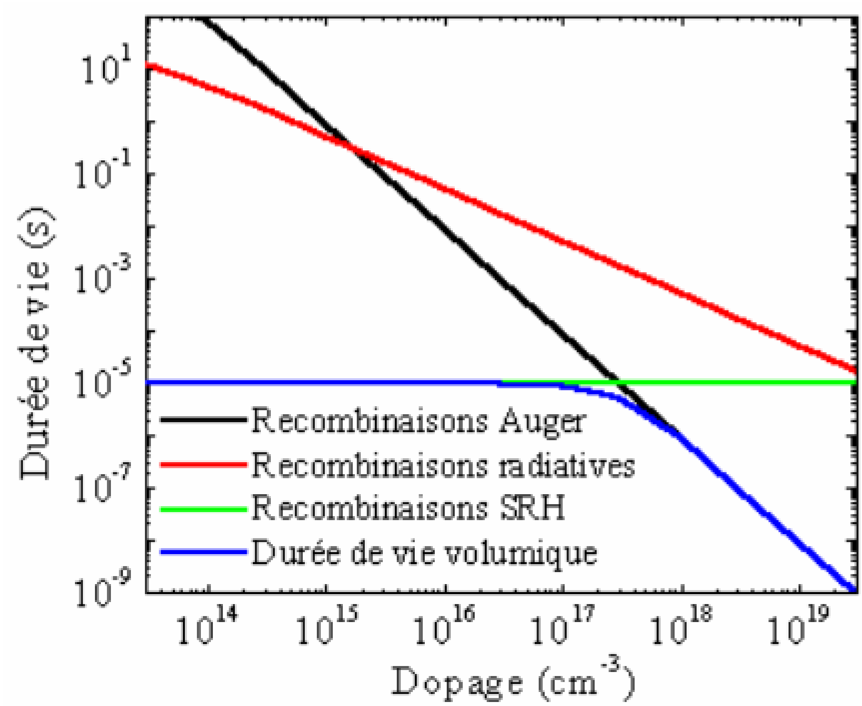

Figure 2 :- Evolution of Radiative, Auger, SRH volumic lifetimes and global according to the level of injection for $\tau_{SRH} = 10^{-5} s$, $Nb = 10^{15} cm^{-3}$ [13].

Minority carrier's density determination: -

From the resolution ofthe equation (1) and by paying very particular attention to the expressions and the conditions of study of our previous articles, we obtain the continuity equation known as the equation of the density of the following minority charge carriers :

$$\delta(x, j, p, Nb, T, z) = A \times \cosh(\frac{x}{L(Nb,T)}) + B \times \sinh(\frac{x}{L(Nb,T)}) + \tau \times g(z) \quad (11)$$

The coefficients A and B are determined by the following boundary conditions:

- **at the base transmitter junction** $(x = 0)$

$$D(Nb,T) \frac{\partial^2 \delta(x, j, p, Nb, T, z)}{\partial x^2}\Big|_{x=0} = Sf \times \delta(0, j, p, Nb, T, z) \quad (12)$$

- **on the back side** p^+ / p **in the base** $(x = H)$

$$D(Nb,T) \frac{\partial^2 \delta(x, j, p, Nb, T, z)}{\partial x^2}\Big|_{x=H} = -Sb \times \delta(H, j, p, Nb, T, z) \quad (13)$$

Sf represents the recombination velocity of the minority charge carriers at the junction,its full expression can be found in the article by Ba and al [16].

$Sb$is the excess minority carrier recombination velocity at the back face $(x = H)$ or back surface field [17]. There is a rear electric field which allows the return of the minority carriers towards the junction SCR where there is a potential barrier.

Back surface recombination determination:-

The resolution of the equation gives the effective expression of the back face surface recombination velocity $Sb(cm/s)$ which is :

$$Sb(x, j, p, Nb, T, z) = \frac{1}{\delta(x, j, p, Nb, T, z)} \left[\frac{D(Nb, T)}{L(Nb, T)} \tanh\left(\frac{H}{L(Nb, T)}\right) A - Sf(j)\left[(A + \tau \times g(z)\right] \right] \quad (14)$$

Results and Discussions:-

Effects of doping rate and temperature on minority charge carrier's density

We represent in the following figures $(3,4,5)$, the variation of the density of the minority charge carriers according to the thickness of the base for various values ofthe base doping rate and various values of the temperature.

We work with $Sf = Sb = 2 \times 10^2 \, cm/s$.

To Figures $(3,4,5)$, the density of minority charge carriers decreases with the thickness of the base for different values of the doping rate (figure 3) and the same for different values of the temperature (figures $4,5$).At a certain optimum thickness for each of the curvatures, an inversion of the variation thereof is noted.Before a thickness $x_{optimale}$, the amplitude of the density of the minority charge carriers is maximal at a low doping rate and a low temperature.On the other hand, after a thickness $x_{optimale}$, the amplitude of the density of the minority charge carriers is maximum at a high doping level and a high temperature.

Indeed, the increase in the doping rate generates impurities within the material, consequently the vacancies will intensify , thus causing a strong recombination of the minority charge carriers hence the decrease of the latter.

Under the effect of thermal agitation, there is a disordered movement of the charge carriers.The latter in excess, generated will have difficulty in recombining completely from where this inversion of situation recorded in an optimal thickness closer $xoptimale(T = 380K) < xoptimale(T = 310K)$; the amplitude of the density of charge carriers is increasing there.

In the table below, we list the maximum values of the density of the minority charge carriers for different doping rate and different temperatures:

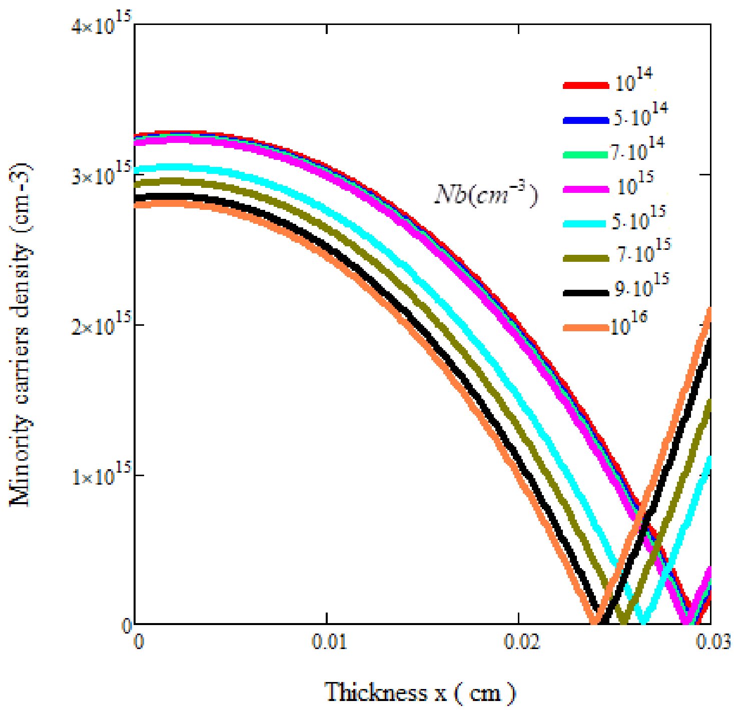

Figure 3:- $|\delta(x)| = f(x)$ for various Doping rate at $T = 310K$.

Table1:- Variations in the density of the charge carriers and the optimal thickness according to different temperatures and different base doping rate :

$T(K)$	310	320	330	340	350	360	370	380
	$Nb = 10^{14}cm^{-3}$							
$\lvert\delta\rvert \max_{x \prec x_{optimale}} (\times 10^{15} cm^{-3})$	3.24	3.07	2.89	2.68	2.45	2.18	1.88	1.53
$x_{optimale}$ (cm)	0.029	0.027	0.025	0.023	0.020	0.018	0.016	0.013
$\lvert\delta\rvert \max_{x \succ x_{optimale}} (\times 10^{15} cm^{-3})$	0.21	0.88	1.65	2.53	3.54	4.73	6.12	7.76
	$Nb = 10^{15}cm^{-3}$							
$\lvert\delta\rvert \max_{x \prec x_{optimale}} (\times 10^{15} cm^{-3})$	3.20	3.03	2.84	2.62	2.38	2.10	1.78	1.41
$x_{optimale}$ (cm)	0.028	0.026	0.024	0.022	0.020	0.018	0.015	0.013
$\lvert\delta\rvert \max_{x \succ x_{optimale}} (\times 10^{15} cm^{-3})$	0.37	1.07	1.86	2.79	3.86	5.10	6.57	8.32
	$Nb = 10^{16}cm^{-3}$							
$\lvert\delta\rvert \max_{x \prec x_{optimale}} (\times 10^{15} cm^{-3})$	2.78	2.54	2.27	1.95	1.58	1.14	0.62	0.14
$x_{optimale}$ (cm)	0.024	0.021	0.019	0.016	0.014	0.011	0.007	0.003
$\lvert\delta\rvert \max_{x \succ x_{optimale}} (\times 10^{15} cm^{-3})$	2.09	3.13	4.34	5.78	7.50	9.59	12.16	15.36

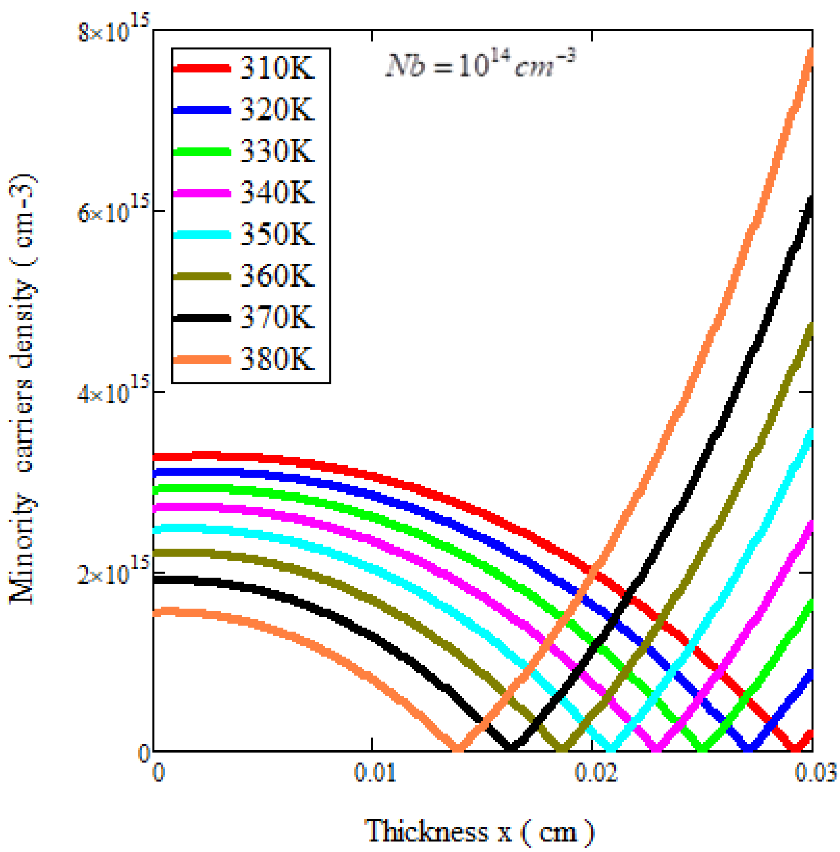

Figure 4 :- $\lvert\delta(x)\rvert = f(x)$ for various temperatures.

Effects of doping rate and temperature on the Back surface recombination velocity:-

We represent in the following figures $(6,7,8)$ the variation of the recombination velocity at the back face as a function of the thickness x of the base for differents values of the base doping rate and different values of the temperature.

We obtain an extremum of the thickness for each of these curvatures (figures $6,7,8$).The maximum of thickness is obtained with the lowest temperature and the lowest doping rate.The peak of the recombination rate at the back face is obtained for a low level of base doping rate $(Nb = 10^{14} cm^{-3})$ and an optimum temperature $T = 380K$, on the other hand at $Nb = 10^{16} cm^{-3}$, this peak appears at $T = 330K$ .The back face is a zone overdoped with donor atoms relative to the base $(10^{17}$ to $10^{19} atomes / cm^{3})$.This induces the existence of a rear electric field which allows the minority carriers generated near the rear face to be returned to the emitter-base interface and increases the collection of charge carriers.

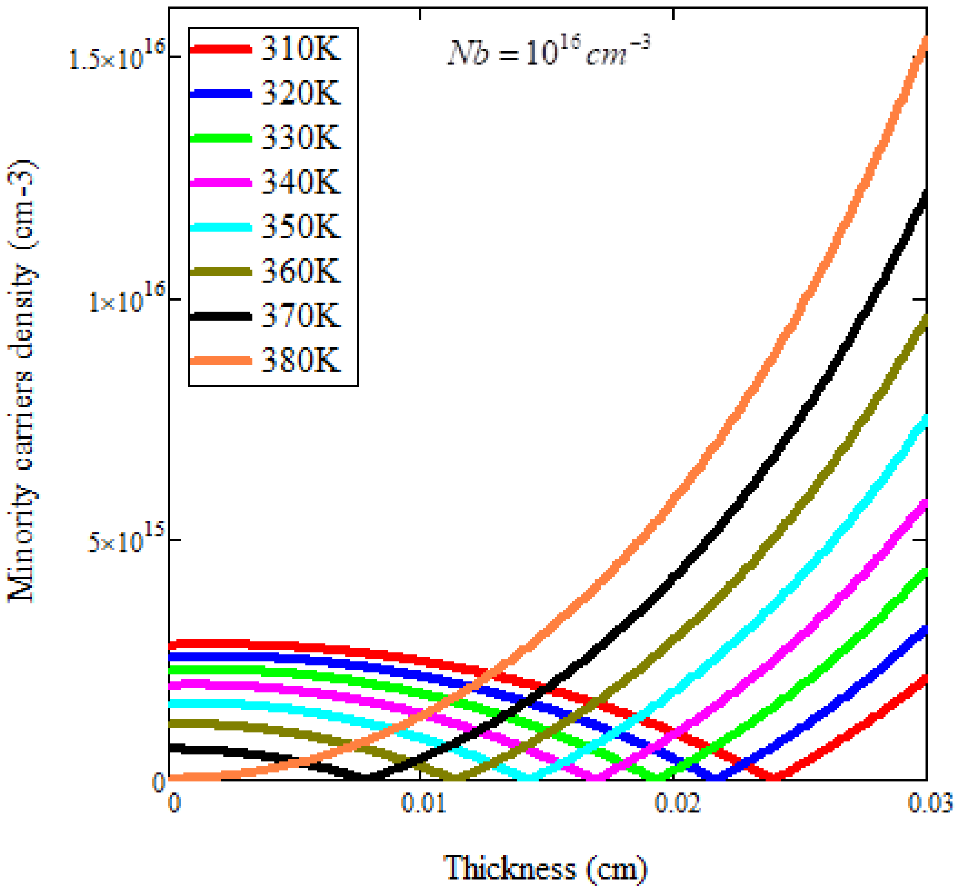

Figure 5:- $|\delta(x)| = f(x)$ for various Temperatures.

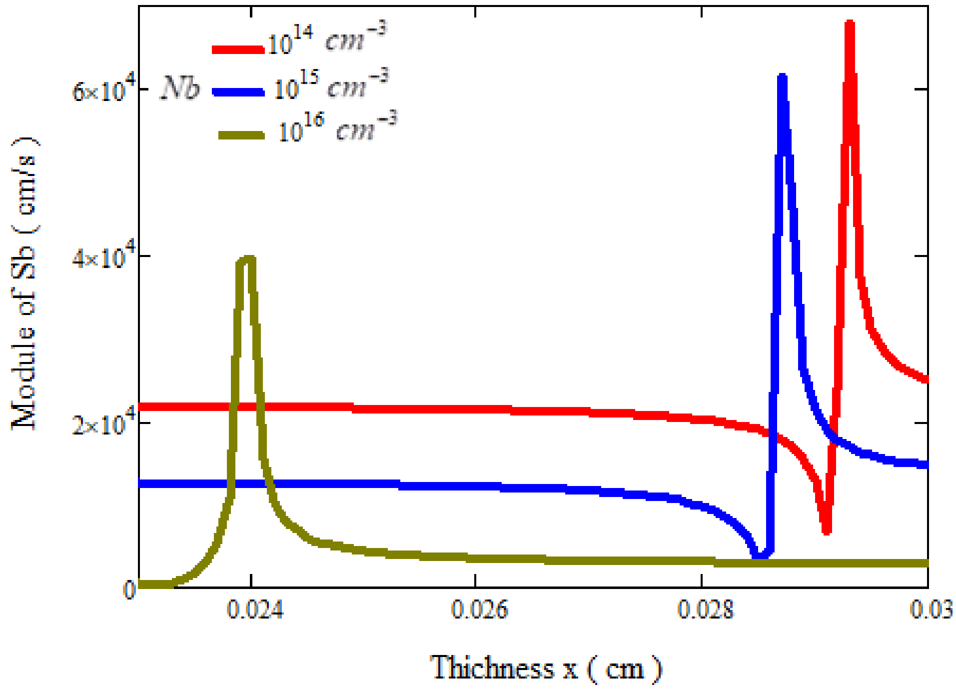

Figure 6 :- $|Sb| = f(x)$ for various doping rate at $T = 310K$

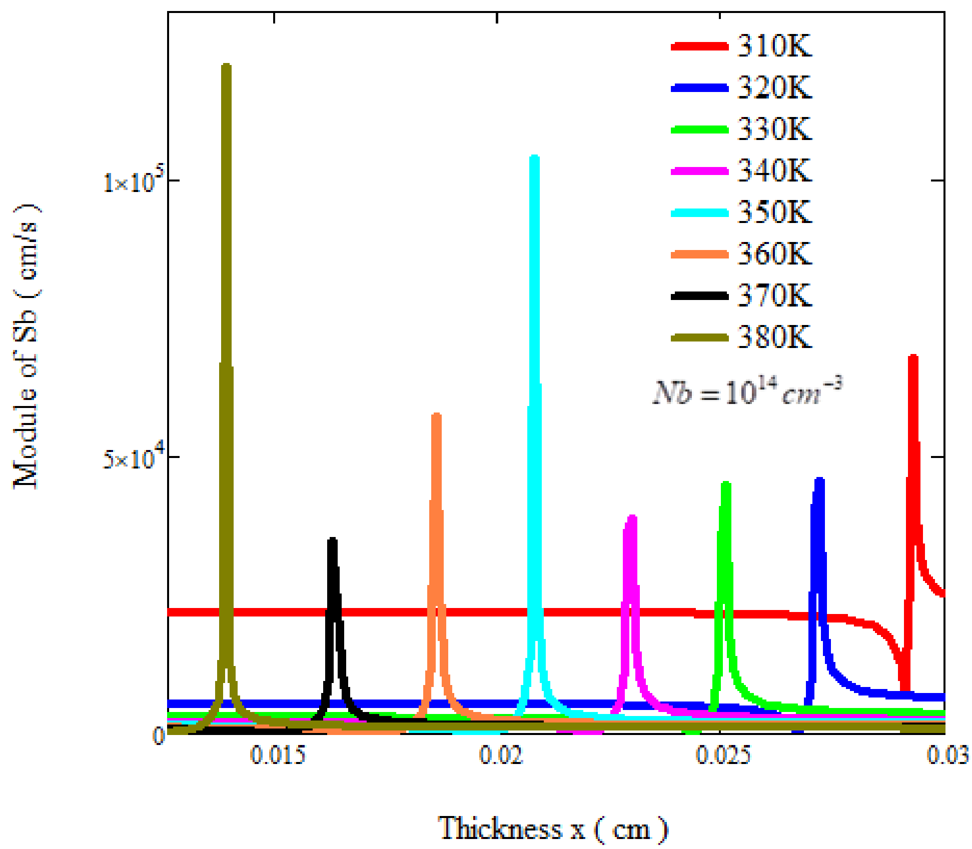

Figure 7 :- $|Sb| = f(x)$ for various Temperatures.

Conclusion:-

At the end of our study, we have under the effect of the doping rate synonymous with the addition of impurities, the density of the minority charge carriers and the recombination velocity on the back face which decrease to a limiting thickness.Beyond that, an inversion is noted in their variation.Before the optimal thickness, the density of the carriers decreases, after the optimal thickness it increases with the rise in temperature.As for the increase in temperature, it is at the origin of a strong thermal agitation resulting in an unordered mobility of the carriers.The peak of the amplitude of the recombination velocity at the back face is obtained for a low doping rate with a certain thermal agitation.

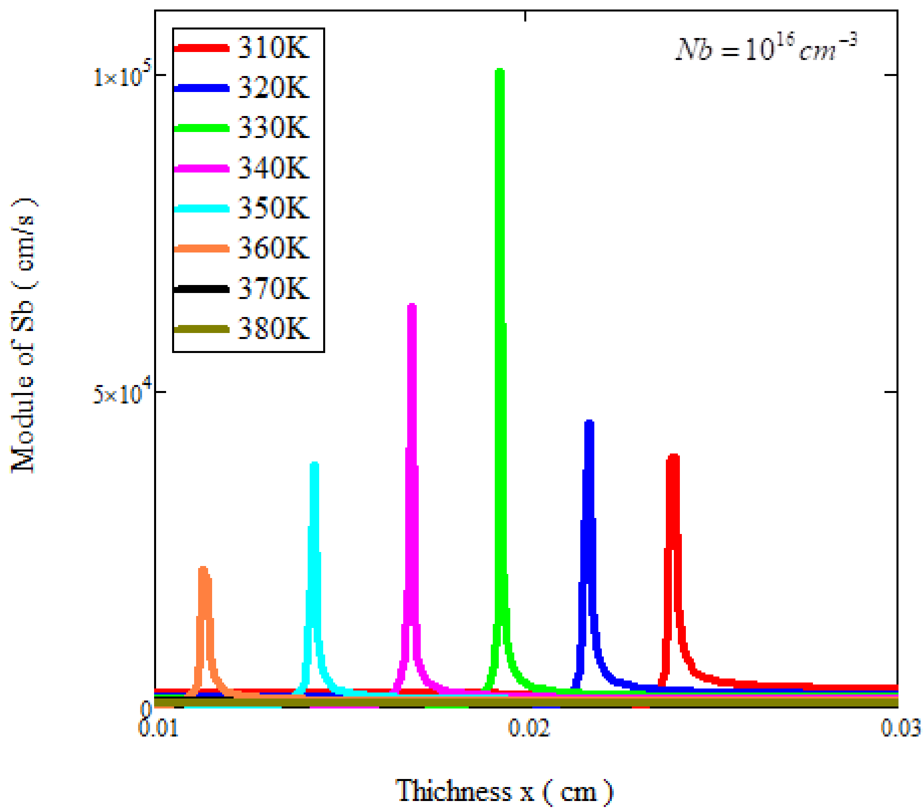

Figure 8 :- $|Sb| = f(x)$ for various Temperatures.

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