High Photo Switching Response of n-ZnO/i-MoS2/p-Si Heterojunction Solar Cell

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Research Article

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High Photo Switching Response of n-ZnO/i-MoS_2/p-Si Heterojunction solar cell

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Abstract

In this research work, We investigate the enhancement of photo conversion efficiency from ZnO nanostructure and MoS_2 switching mechanism of heterostructure solar cell.The carrier transport of MoS_2 generating more electron-hole pairs in the MoS2/Si interface.The photo switching resistance of MoS_2 active layer that increasing in short circuit density to 40.9964[mA/cm^2], and the effective light trapping of ZnO nanostructure with optimized thickness of ZnO,MoS_2 better thermal stability.The SRH heating and Joule heating are minimized by photoswitching characterstics.The Joule and SRH heating rate evaluated from stationary mode of study and the values in the magnitude order of 10^{13} W/m^3 and 10^{12} W/m^3 The use of both ZnO and MoS_2 nanostructure leads to total generation rate,charge carrier transport are improved.The photo conversion efficiency is achieved by 27.7364%

Keywords Photo switching resistance;Joule Heating;MoS_2;SRH heating

1 Introduction

The recent experiments have explored the heterojunction of ZnO-Si solar cell which promotes excellent nanostructure property and energy harvesting from the sun.However,surfacebarrier,surface/interface recombination are limiting Si based solar cell performance.The effective modulate the band structure could be tuned by fast switching response property and the trap density at the interface reduced,which could be promoted the better efficiency of the solar cell.In these above statement might be developed high performance solar cells.In this section explained, literature survey of various heterostructure based on ZnO,MoS_2 and Si and their limitation. The interface defect density in the ZnO-Si interfaces is the main centre for recombination process and reducing the solar cell performance,The ZnO/p-Si heterojunction solar with low defect density in the range of 10^{10}[cm^{-2}] shows the solar cell performance parameters of J_{sc},V_{oc} and PCE :35.65[mA/cm^2],0.541[V] and 15.34%[1].The energy band offset of both conduction and valence band is used to increasing the solar cell performance.The optimized bandgap and electron affinity of the ZnO introduced the best values as 37.7[mA/cm^2] of J_{sc},0.662[V] of V_{oc},0.815 of FF and the PCE is 20.34%[3].The poor surface defect density at the interfaces of ZnO/Si is the main centre for recombination process and the efficiency reached to low values.Bytuning of conduction band offset through insertion of buffer layer with lattice constant could be achieved better efficiency .The ZnO/ZnO-B/Si heterojunction solar cell reaches the efficiency 17.16% and Jsc:30.24[mA/cm^2].Voc:0.6758[V] and the FF:83.96%.The band alignment configuration could be tune the solar cell performance[5].

The doping concentration could be tuned the bandgap engineering and the optimized structure of each layer thickness with 10^{18}cm^{-3}of doping profile obtained the theJsc ,Voc,FF and PCE are 28.96[mA/cm^2],0.84[V],0.85, and 23.69%[6].The conversion efficiency of Graphene/MoS_2 based solar cell is achieved by 11.5%.The thickness of ZnO emitter layer are predominant for power conversion efficiency of the solar cell.The 500[nm] of ZnO layer thickness reveals the efficiency 10.9%[14].

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The modelling and numerical simulation of ZnO /c-Si heterostructure solar cell analyzed and the defect state density affects the Open circuit Voltage.The heavily doped on the back surface field is to reduced the defect density and the increase the solar cell performance.The Charge carrier transport at the junction and photogeneration properties modified by the variation of doping concentration and thickness of the layer[16].In ZnO/p-Si heterostructure solar cell with recombination velocity of $1.1*10^7$cm/s configuration exhibits better solar cell performance [17].In the presence of defect density the series resistance increases and the shunt resistance decreases and the Fillfactor(FF) will degraded.The doping profile of acceptor concentration enhanced and the FF improved[18].The Joule heating and SRH heating are affects the solar cell performance.The contact of front and rear degraded by temperature distribution.In the junction, the recombination of electrons and holes are increased by SRH heating profile [28]-[31].In this proposed article,we developed thermal stability of optimized structure of emitter layer of ZnO,buffer layer of MoS_2 and the Substrate Si layer have been simulated from electromagnetic field module coupled to semiconductor module in the COMSOL package.

2.Physical and Mathematical Modelling Device Structure

The bulk defect density of emitter layer of ZnO nanostructures with optimized thickness demonstrates excellent photon conversion efficiency in the visible range,and to increase the short circuit current density as 33.6[mA/cm^2].The altering ZnO layer thickness exhibits lowest average reflectance of 8.5% in the wavelength range of 400-900[nm][15].The ZnO is used to promotes transport of photogenerated charge carriers and effectively charge carrier separation. In order to controlling the thickness of ZnO emitter layer suppressed the maximum reflection and the ZnO layer added in the top of the solar cell simulation structure.The intermediate layer of $MoS_2$with suitable doping profile followed by emitter layer.The MoS_2 material good stability was performed at operation at 10[mA/cm^2] with production of heat and electricity simultaneously and its could be used for hybrid solar cell[7].The energy bandgap of MoS_2 is 1.23[eV] and indirect property and the absorption coefficient of MoS_2 is in the range of over 10^4[cm^{-1}]to all over the solar spectrum.The thin layer of MoS_2 is found direct bandgap of 1.8[eV] was reported[8].The 10% 0f incident light absorbed by 1[nm] thickness of MoS_2 layer as in [9].

The resistance of MoS_2 switching device can be controlled the photons by the modulation electric field and providing multilevel resistance switching mechanism which could be a great potential for make multifunctional device[11].The variation of bandgap energy is more suitable in photovoltaic application for extracting energy[12].The buffer layer of MoS_2 controls the trap density of defects and photons controlled behaviour by an electric field which produces the effective charge separation in the interface.The 30[nm] thickness of MoS_2 perform as buffer layer in the above the stack of Si layer. The optimized proposed simulation structure depicted in Fig.1.a.The 2D geometry was simulated using semiconductor equation in the COMSOL Multiphysics.The electron and hole current density denoted as J_n and J_p and the expression as follows:

$$\nabla . J_n = 0 \quad (1)$$

$$\nabla . J_p = 0 \quad (2)$$

The minority carrier current density in the n-region and the p-region [3] and [4]

$$J_n = qn\mu_n \nabla E_c + \mu_n k_B T \nabla n + qnD_{n,Th} \nabla \ln(T) \quad (3)$$

$$J_p = qp\mu_p \nabla E_v - \mu_p k_B T \nabla p - qpD_{p,Th} \nabla \ln(T) \quad (4)$$

(a) (b)

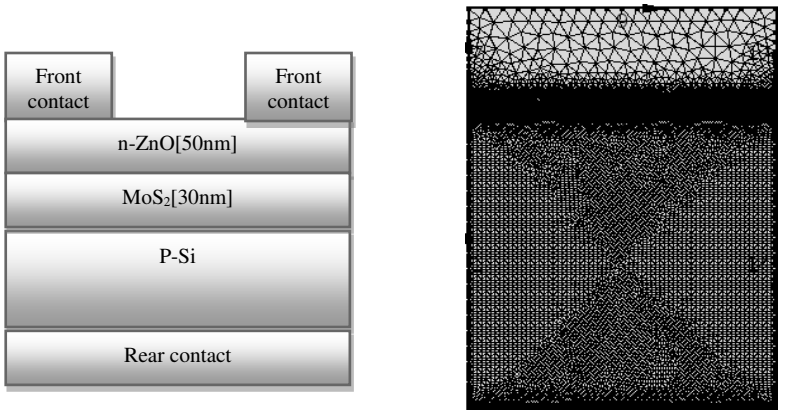

Fig.1.(a) Geometry structure of Solar cell.(b) meshed structure

Where μ_n and μ_p are the electron and hole mobility, Boltzmann constant denoted as k_B, $D_{n,Th}$ and $D_{p,Th}$ are the electron and hole thermal diffusion coefficients, ∇n, ∇p are excess carrier concentration,T as Temperature and ∇E_c, ∇E_v are conduction and valence band offset energy level.The charge transport using the field expression by the continuity equations to:

$$\frac{dn}{dt} = \frac{1}{q}\nabla . J_n - U_n + G_n \quad (5)$$

$$\frac{dp}{dt} = \frac{1}{q}\nabla . J_p - U_p + G_p \quad (6)$$

$$\nabla . J_n = qR_n \quad (7)$$

$$\nabla . J_p = -qR_p \quad (8)$$

The recombination rate of electrons and holes is given in [9]

$$R_n = R_p = \frac{np - \gamma_n \gamma_p n_i^2}{\tau_p (n+n_1) + \tau_n (p+p_1)} \quad (9)$$

τ_p, τ_n are hole and electron life times, The recombination rate of electrons and holes as R_n and R_p .The n_1, p_1 are equllibrium concentration of electrons and holes,The surface recombination velocity of electron and hole called to γ_n , γ_p .

$$n_1 = \gamma_n n_{i\,eff} \exp\left(\frac{\Delta E_t}{k_B T}\right) \quad (10)$$

$$p_1 = \gamma_p \, n_{i\,eff} \exp\left(\frac{-\Delta E_t}{k_B T}\right) \quad (11)$$

$$\Delta E_t = E_t - E_i \quad (12)$$

$$n_{i\,eff} = \sqrt{N_{co} N_{vo}} \exp\left(\frac{-(E_g - \Delta E_g)}{2 k_B T}\right. \quad (13)$$

$$\gamma_n = \frac{S_n L_n}{D_n} \quad (14)$$

$$\gamma_p = \frac{S_p L_p}{D_p} \quad (15)$$

The Minority Carrier Diffusion length(L_n)for p-side can be determined as [16]

$$L_n = \sqrt{\frac{k_B T \mu_n \tau_n}{q}} \quad (16)$$

The Minority Carrier Diffusion length(L_p)for n-side given by:

$$L_p = \sqrt{\frac{k_B T \mu_p \tau_p}{q}} \quad (17)$$

The above semiconductor equation are used in solar cell simulation from Equ.1 to Equ.17 were configured in the physics section of COMSOL multiphysics.The meshed configuration as seen in Fig.2.b from meshing study.The user controlled mesh is specified in mesh1,the physics controlled mesh specified in mesh2 for semiconductor.The ZnO,MoS_2 are thinnest of all other layers and finely meshed.this suitable mesh used for further simulation analysis.

3.Optimization of MoS_2 layer Thickness

The MoS_2/semiconductor structure offers new platform for designing solar cell.MoS_2 heterostructure shifts the fermi energy level by suppress the static charge transfer and exhibits an improved photo conversion efficiency.Therefore the optimized MoS_2 layer thickness leads to decreasing the barrier height and effectively subtracting the static charge tranfer between MoS_2/Si junction.its very clear that the 30nm thickness of MoS_2 layer gives highest short circuit current density in the range of 27.56mA/cm^2 and the open circuit Voltage too reached at peak in the range 1V .The enhanced of IV characterstics achieved by unaffected transport of holes and the electrons of MoS_2 and Si layer and series resistance is reduced due to the doping profile in the value of 10^{18}cm^{-3}.Due to effects in series resistance,the FF increased.In 25nm thickness the Fill factor value reached to low and the series resistance increased and the strong recombination developed and the overall performance of solar cell degraded.

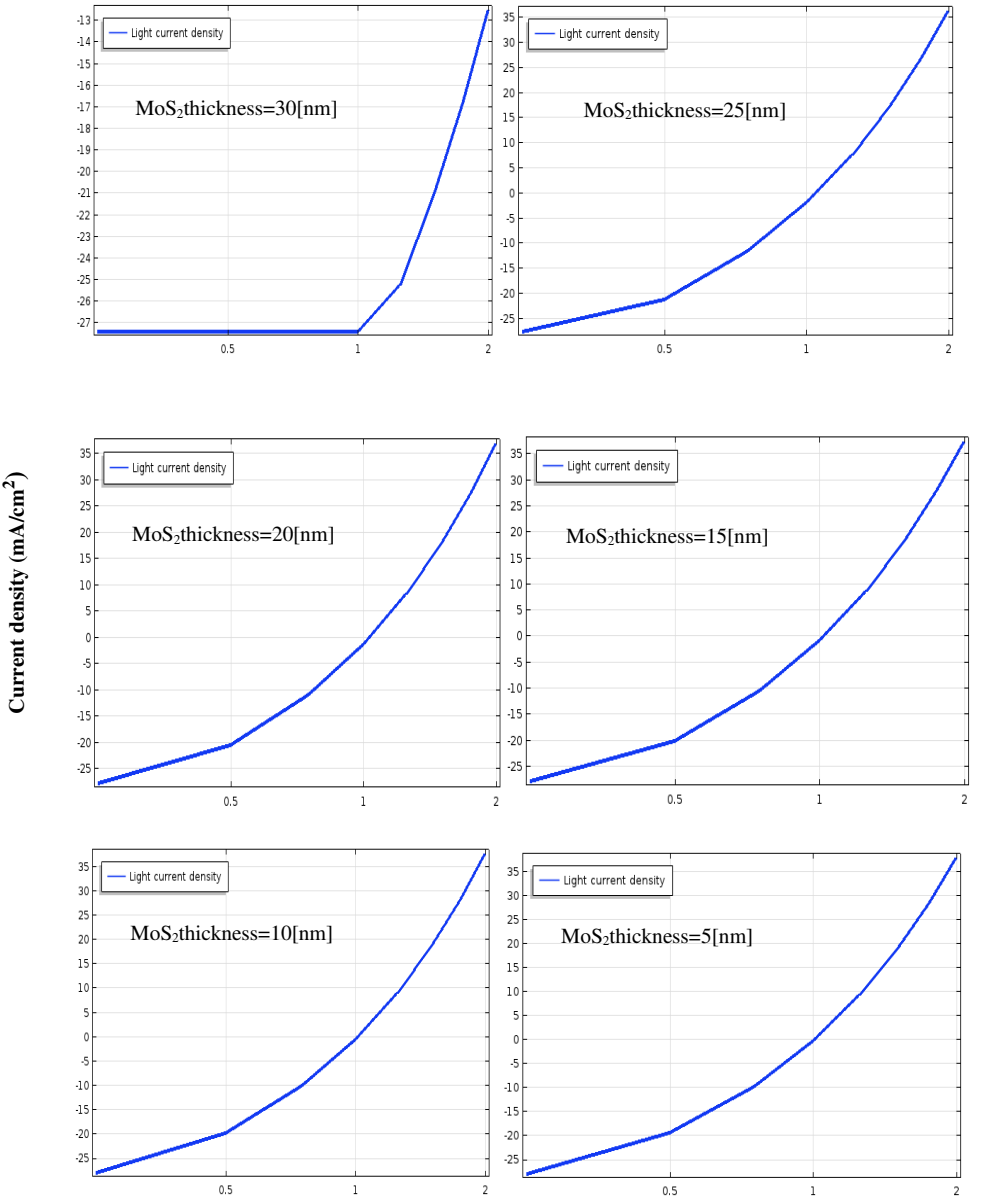

Fig.2 J-V Characterstics of heterojunction solar with different thickness of MoS_2

The various thickness from 5nm to 20 nm with the interval of 5nm were simulated and the IV characterstics are shown in Fig.2.The area of fill factor curve is too reduced than 25nm and 30nm thickness of the layer.The static charge suppressed not effectively for the minimum thickness of active layer.The optical tranmittance reached to high so that excess electron generating rate decreased thus,no free carriers were available in the interface. As the result shows lowest Jsc and conversion effciency.We observed that the fermi level started pinning to conduction energy level.

4.Energy Band Diagram of n-ZnO/MoS_2/p-Si Heterostructure

In Fig.3. shows Energy band diagram of the heterostructure.The band alignments are based on the work function of ZnO,MoS_2 and Si.The light exposure on the MoS_2 layer decreases the interface barrier height and the charge injection controlled by external electric field forming the conduction channel.In the high electric field, the electrons are injected into the MoS_2 region through tunneling process.The high density of point defects could be controlled by multilevel resistance switching mechanism behavior of MoS_2[11].In this proposed structure have three semiconductor stacked together,n-type ZnO integrallydeplete electrons at the interface,which way to rising band-bending in MoS_2 and the p-type Si deplete holes,which give increase to downward bending,so that a junction barrier is formed for n-ZnO and MoS_2 ,MoS_2 and Si as shown in Fig.5.smilarly, for the light illumination condition,the photoelectric effect occurs on the semiconductor materials (ZnO,MoS_2,Si)and the electrons-holes pair produced.The photon conversion of electrons tunneled through junction and reached to MoS_2.The switching of resistance moves to low resiststive state and the electrons moves to p-Si region.The photo-generated holes jumped into Si-MoS_2 junction and the breakthrough the barrier height and the holes moves towards n-ZnO region.The output current associates inner electric-field and more carriers passed through heterojunction.The modulation of electric-field tuned to the bandgap energy.

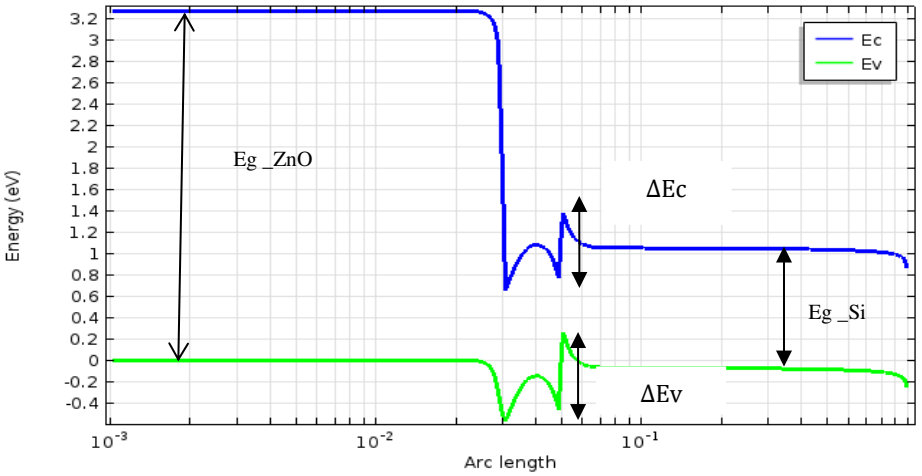

Fig.3.Valance and Conduction energy band diagram n-ZnO/MoS_2/p-Si solar cell

Here,as density surface of p-Si is lower than n-ZnO and MoS_2.The energy band level of MoS_2 will be raised up and the barrier increased therefore, more electrons are trapped in the middle of ZnO-MoS_2 interfaces and the modulation of photon energy controlled the electrons by an electric-field and the energy band level lowered of the depletion region between n-ZnO and MoS_2meanwhile the trapped electrons in MoS_2 will be relased to n-ZnO,which could be help to increase photo-generation rate of photons controlled carriers.Therefore,The flow of trapped electrons in the ZnO-MoS_2 interface resulting in increase of Jsc and Voc.Therefore relasing of trapped electrons improve the solar cell efficiency.in the below section described about carrier collection and their efficiency.

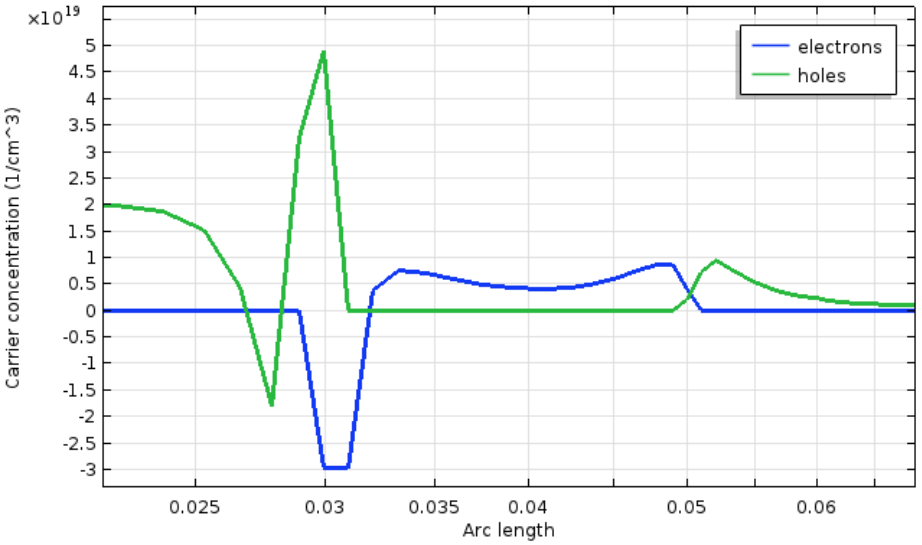

Fig.4. Carrier concentration profile for n-ZnO/MoS2/p-Si heterostructure solar cell

The n-type background doping has given better collection effciency from photogenrated electrons even at low electric-field.The PPN structure of solar cell have high recombination rate at the weakest electric-field.eventhough PNN structure suppression of recombination rate due to higher electric-field[24].the carrier concentration in the region of MoS_2 were increased as in Fig.4.because of background carrier distribution in the interface region.Based on the PNN configuration of n-ZnO/n-MoS_2/p-Si the photogenerated electrons move across the interface and the drift transport is considered for photon current .The electron current increment(ΔJ_n) denoted as

$$\Delta J_n = q\mu_n E \Delta n \tag{18}$$

The electron density increment due to light illumination and width of the region take into the account for calculated the collection efficiency.based on L_n and L_p of MoS_2 remarkably suppressed the recombination rate by the doping results in carrier concentration and the photocurrent drop across the MoS_2 active layer region.The n-ZnO/MoS_2 configuration inceased the electron carrier distribution in the arc length from 0.03um to 0.05um as in Fig.4.Therfore the figure shows that quantum efficiency depends on the carrier distribution, effective mobility,electronhole life time and electric field.

5. Solar cell Performance

The n-MoS_2/i-SiO_2/p-Si structure,photogenerated carriers passed through SiO_2 layer by the mechanism of tunneling due to larger built-in-potential.The coversion efficiency of the solar cell reached to 4.5%.However,the optimized thickness of SiO_2 offers higher potential barrier to prevents the charge carriers in the front and rear contact side and the performance solar cell degraded[22]. The Al_2O_3 passivation layer at MoS_2 interface is reduce in surface trap density and the effective charge carrier separation helps to improve the conversion efficiency.The built-in field in the junction was enhanced and the electron-hole pairs photogeneration rate increased.Generally the efficiency too poor by the effect of charge recombination and the electron movement controlled by undetermined doping profile[23].

From the simulation study, effective thickness of ZnO and MoS_2 stack for significantly improvement in J_{sc} and V_{oc}.The polarization of MoS_2 and the electric field are controlled the resistance through charge modulation by photons.The multilevel switching response of MoS_2 have better potential and used for multifunctional device [9].The high density of point defects were suppressed by resistive mechanism of MoS_2 layer and their multilevel states.Its worth point that a different resistive state operation modulating the barrier height at the MoS_2/Si interfaces and the photogeneration increases with an external electric field.The polarization process quickly done and the ion drift process slow[21].The MoS_2/Si stacked nanostructure controlling the defect density state leads to increase photogenerated carriers and the short circuit current density is 27.5864[mA/cm^2] at MoS_2 thickness of 30[nm] in Fig.5.In the absence of ZnO nano layer,MoS_2/p-Si nano structure have poor surface passivation and the conversion efficiency is limited by the low value of open circuit voltage in the range 0.667V.Furthermore,The improvement of Voc by added optimized thickness of ZnO stacked on MoS_2 layerThe formation of n doped ZnO nanostructure boost the light trapping ability and the surface reflectance is reached to low.The photo conversion is enhanced in the range 300-1100nm by the improvement in the anti-reflection performance.

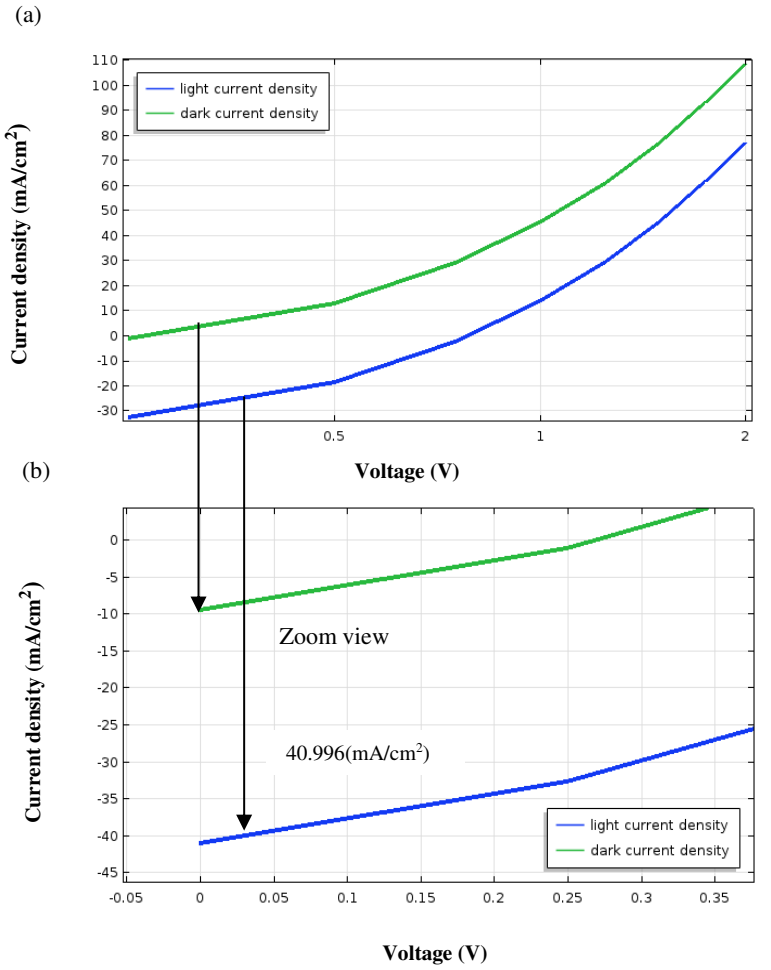

Fig.5.(a)J-V characteistics of n-ZnO/MoS_2/p-Si heterostructure solar cell.(b)Zoom view of J-V curve

Structure	V_{oc}(V)	J_{sc}(mA/cm^2)	*FF*	PCE (%)
ZnO/p-Si [1]	0.541	35.65	-	15.34
n-ZnO/p-Si[3]	0.662	37.7	0.815	20.34
ZnO/ZnO-B/Si [5]	0.6758	30.24	0.8396	17.16
ZnO/MoS_2/CZTS[6]	0.84	28.96	0.85	23.69%
nMoS_2/SiO_2/pSi [22]	0.3	5.5	-	4.5
Al_2O_3/n-MoS_2/p-Si[23]	0.34	4.29	0.429	5.65
Graphene/MoS_2/Si[12]	0.56	33.4	0.60	11.5
n-ZnO/MoS_2/p-Si	**0.7878**	**40.9964**	**0.8588**	**27.7364**

Table.1.Solar cell performance of various heterostructrure solar cell

6.Thermal analysis of n-ZnO/MoS_2/Si solar cell

The light absorption, Shockley-Read-Hall non-radiative recombination, and Joule heating are main sources for heat generation.The thin film contact solar cell reduces the heat dissipation in the top and bottom contacts[29].The mismatch of each layer thickness and absorption could be leads to heat generation and the solar cell performance degraded [30].The high concentration profile with trap defect density controlled the carrier collection. The heat conduction increased in the top of the electrode by Joule heat and the approximated in the order of 10^{13} W/m^3 as in Fig.6.The joule heat expressed as:

$$H_{joule} = E \times J \tag{18}$$

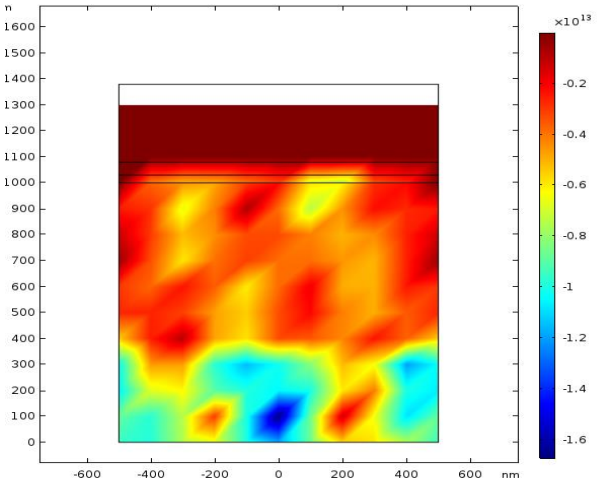

Fig.6.Joule heating profile for ZnO/MoS_2/Si device

E and J are electric field and current density.However the heat dissipation at the contact side degraded the device performance and reduces the operational efficiency.The non radiative recombination heat distribution across the cell reduces then the reliability of device improved.
The temperature profile derived from differential equation of conduction with internal heat generation

$$-k\nabla^2 T + Q_T = \rho_p C_p \frac{dT}{dt} \quad (19)$$

The nonradiative recombination heating profile based on the junction interface.In the bulk region the heat generation increased and the excess carriers involved in the recombination process.the junction of ZnO/MoS_2 and MoS_2/Si are the main source for accumulating of charges.The charges controlled by modulation control photons allowed by photoresistive mechanism of MoS_2.The optimized structure of MoS_2 tune the energy level and reducing the heat disspation in the interface and the value of SRH heating rate as few magnitude order of 10^{12} W/m^3 as in Fig.7.

$$H_{SRH} = (E_g + 3kT) + Q_{SRH} \quad (20)$$

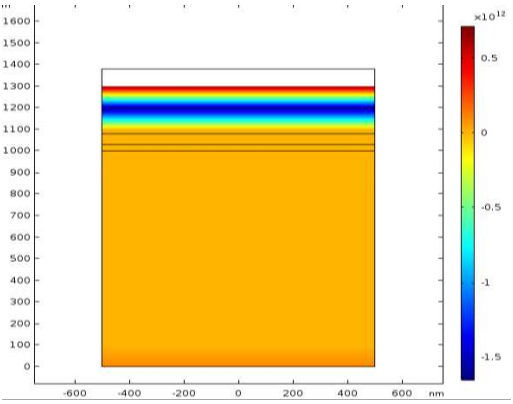

Fig.7. nonradiative recombination profile for ZnO/MoS_2/Si device

The optimized structure of MoS_2 and the effective modulation charges in an electric field controlled by photoswitching characterstics are enable to tuned the excess charge carrier and reducing the trap density in the junction.in the thermal analysis could help to improve the solar cell performance with thermal stability.The solar cell performance degradation controlled by optimized thermal behaviour structure.In this view,this kind of herterostructure solar cell life time improved.

8.Conclusion

We demonstrated the active layer of MoS_2 , emitter layer of ZnO and their resistance can be controlled by the polarization charges and switched by an electric field in the light and dark condition.The charge modulation by photons to control the photoswitching behavior. Based on charge modulation,the charge carriers are increased by an strong electric field.therefore,the photogeneration rate too increased in the visible range and the short circuit current density improved.The top layer ZnO with effective thickness shows excellent quantum efficiency.The modulation energy band give the Voc as 0.7878V.The ZnO nanostructure with switching controlled for the light intensity active layer give up the efficiency to 27.7364%.In order to thermal analysis could be able to improve the solar cell performance and to prevents the excess carriers during thr recombination function.

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Figures

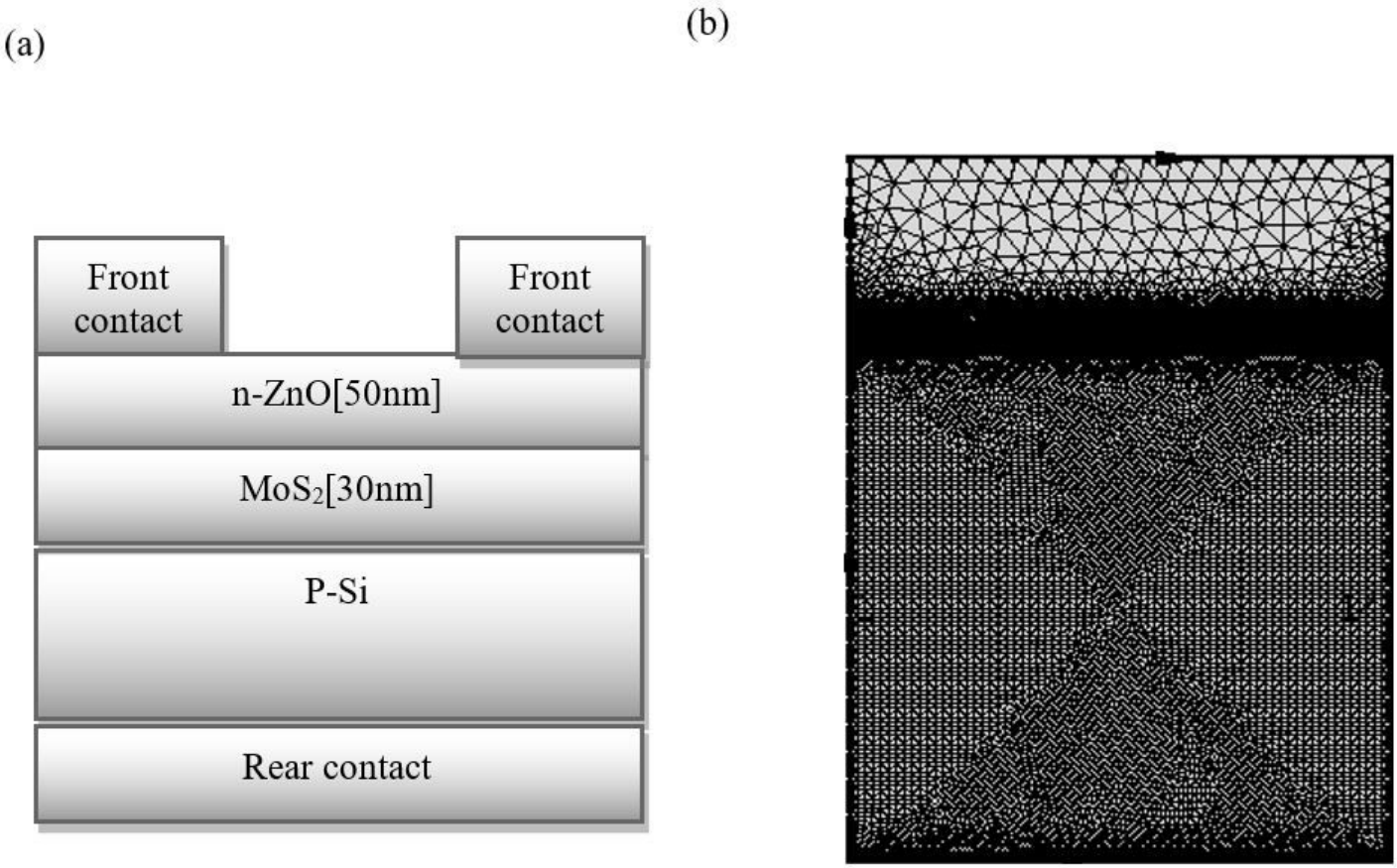

Figure 1

(a) Geometry structure of Solar cell.(b) meshed structure

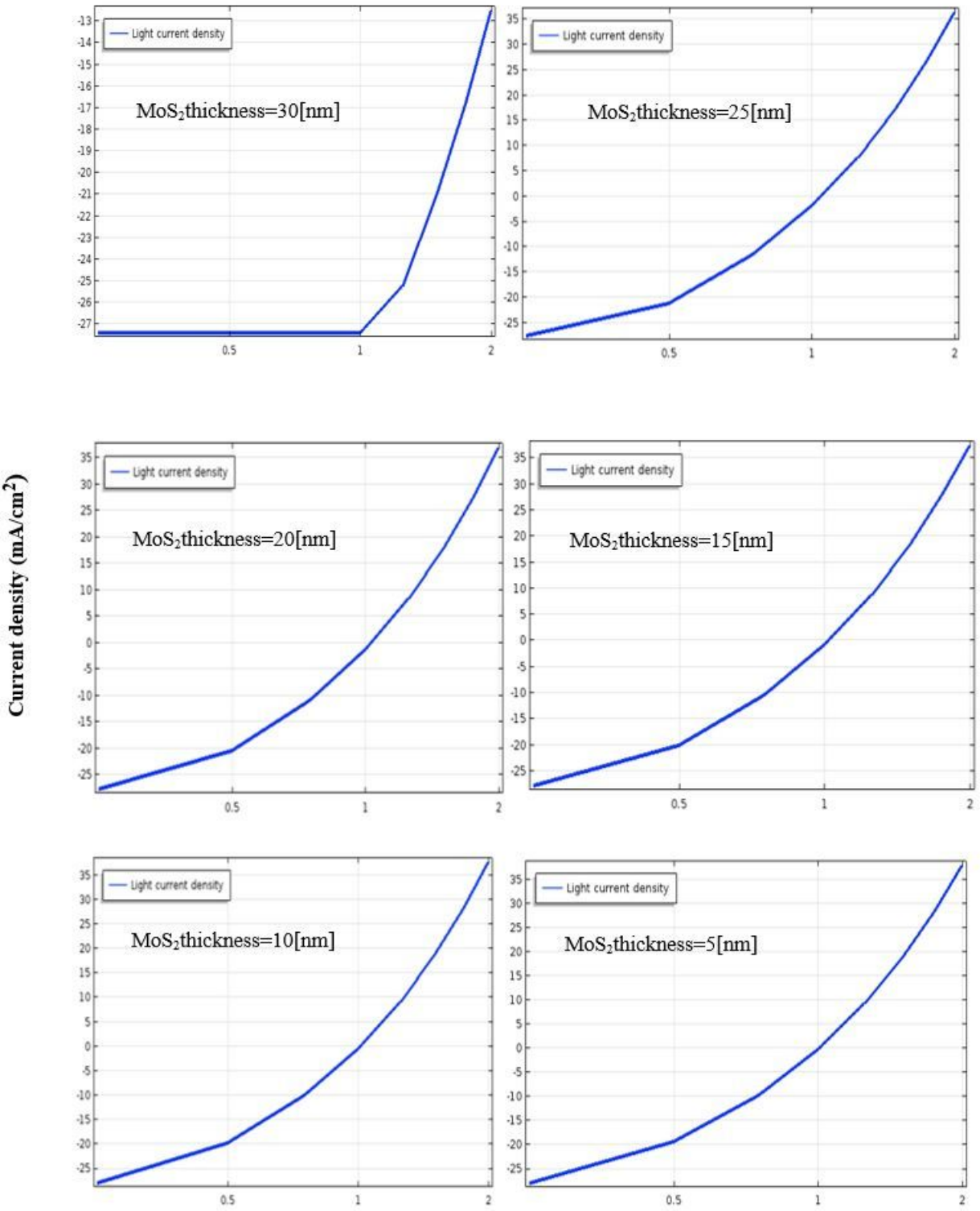

Figure 2

J-V Characterstics of heterojunction solar with different thickness of MoS2

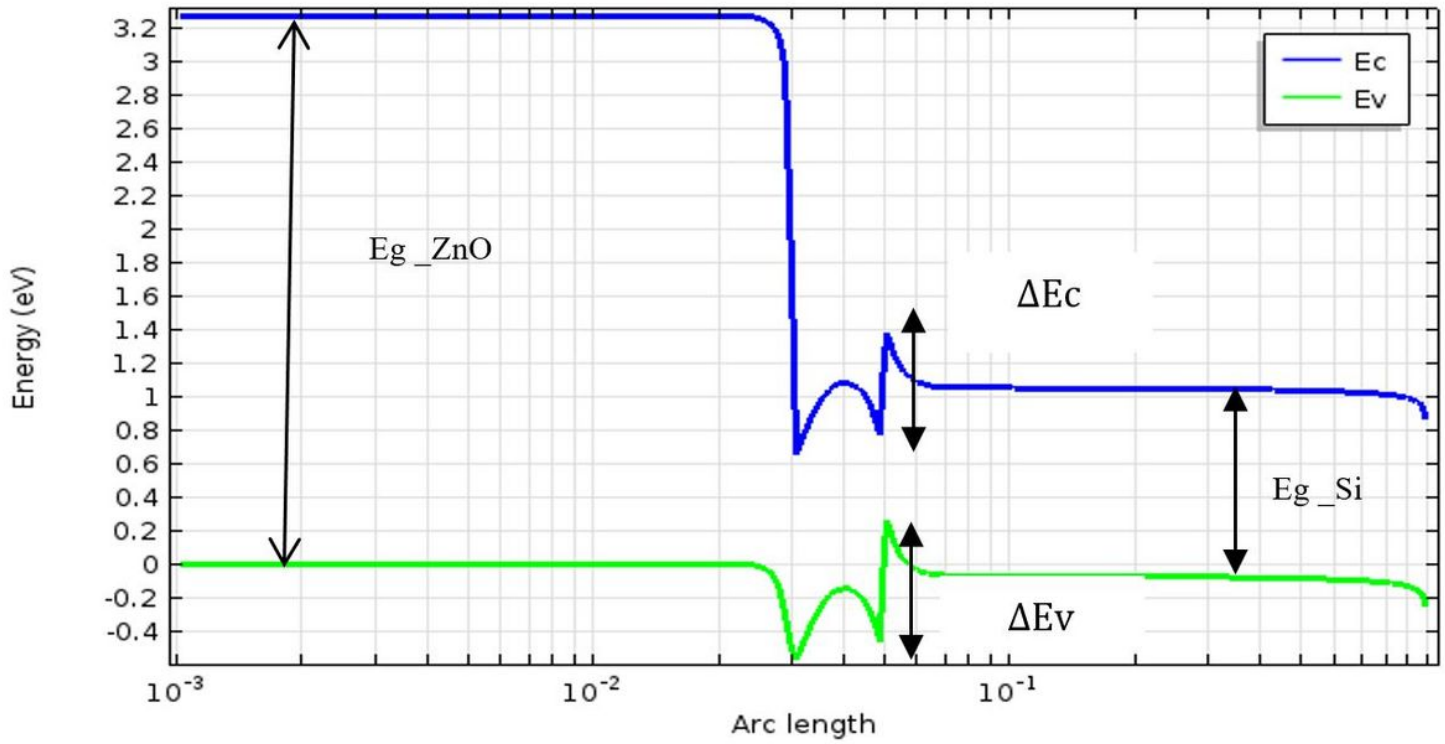

Figure 3

Valance and Conduction energy band diagram n-ZnO/MoS2/p-Si solar cell

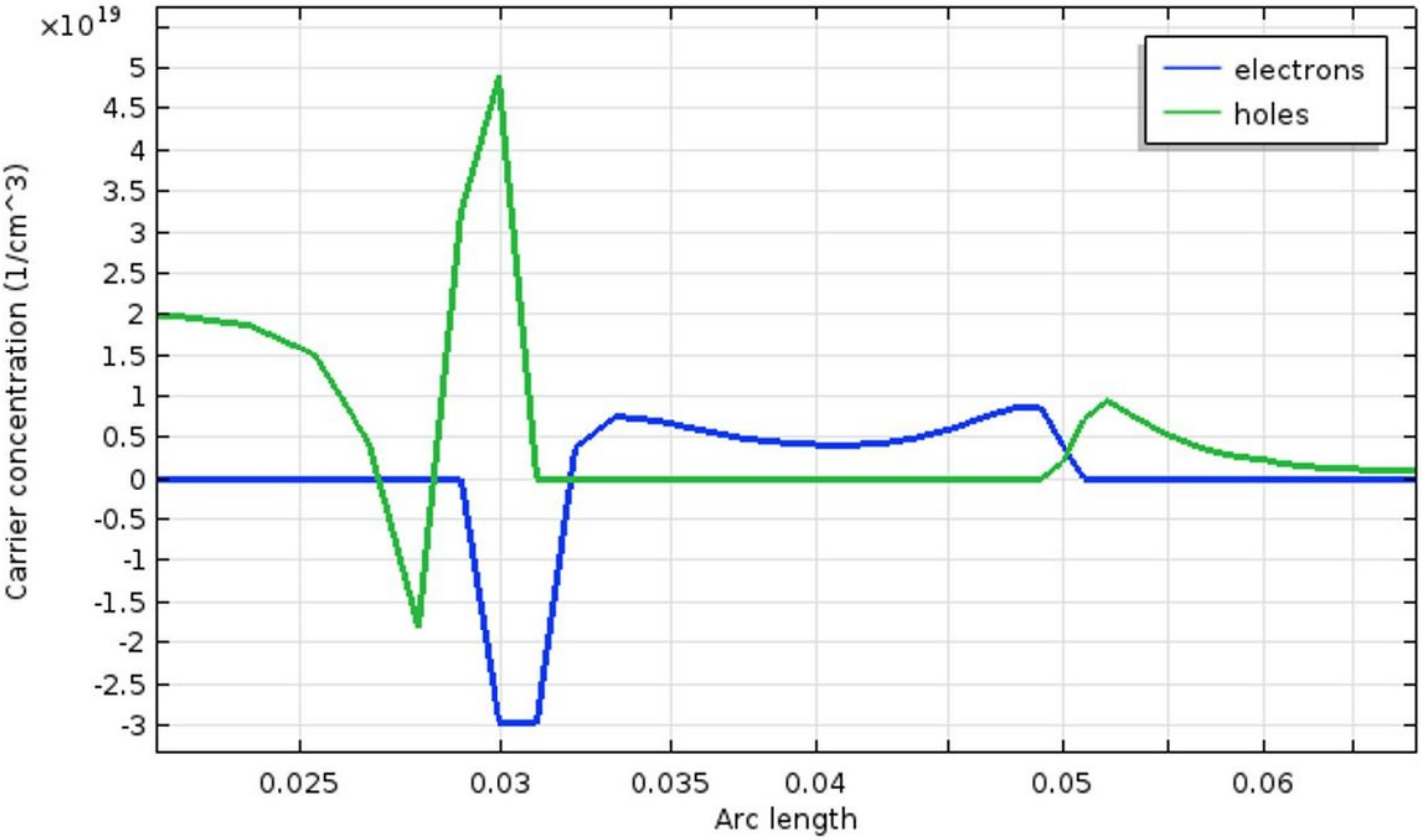

Figure 4

Carrier concentration profile for n-ZnO/MoS2/p-Si heterostructure solar cell

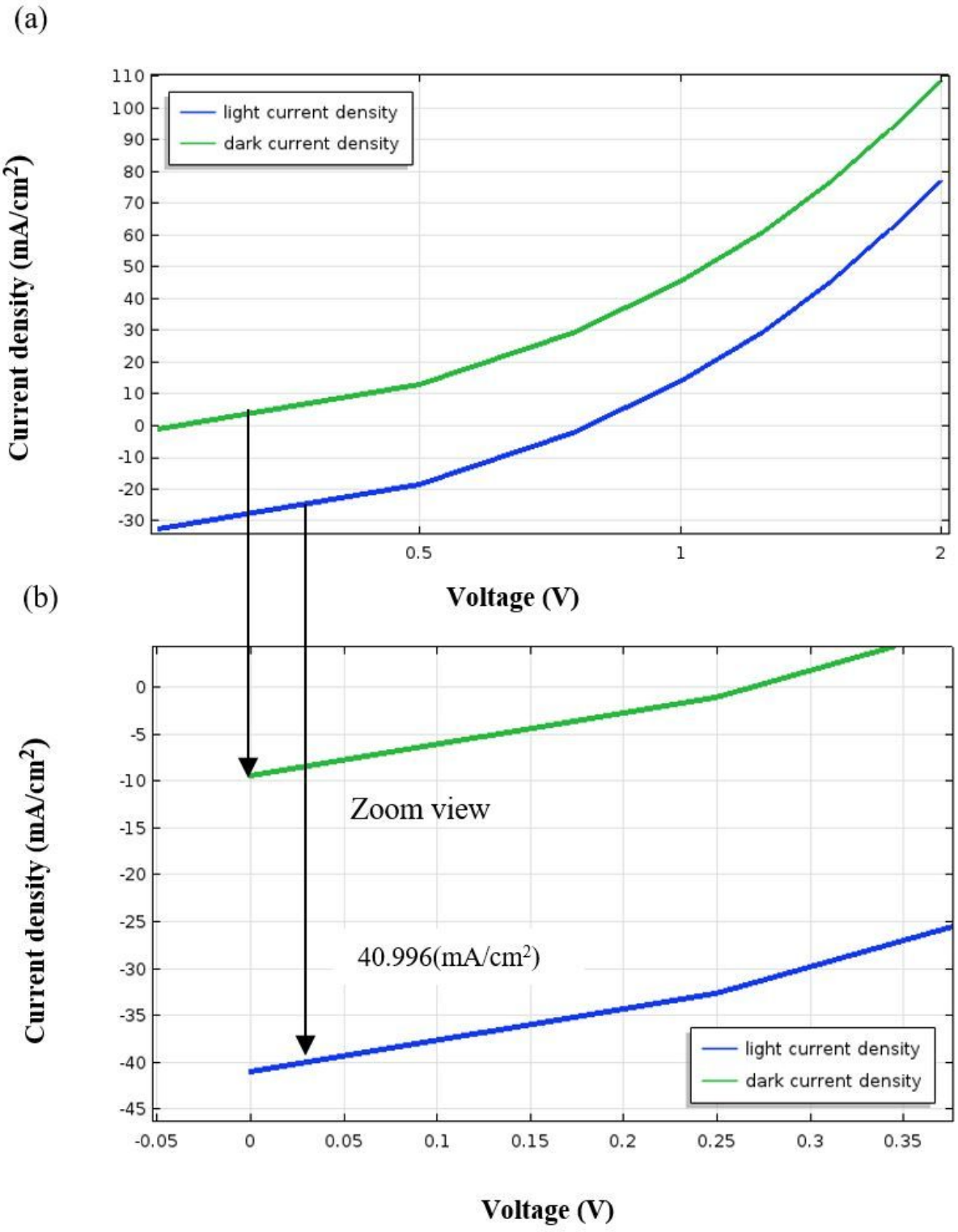

Figure 5

(a)J-V characteistics of n-ZnO/MoS2/p-Si heterostructure solar cell.(b)Zoom view of J-V curve

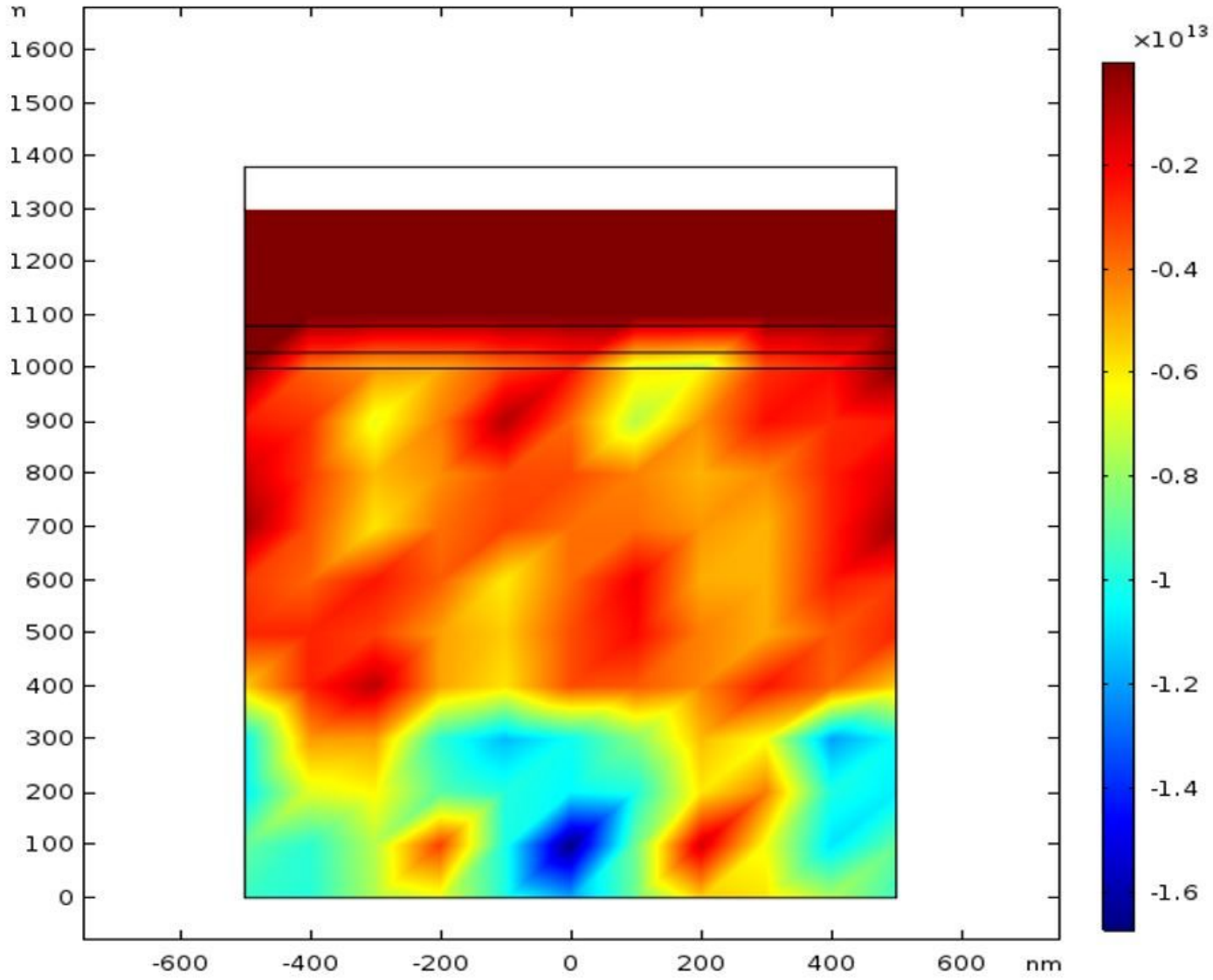

Figure 6

Joule heating profile for ZnO/MoS2/Si device

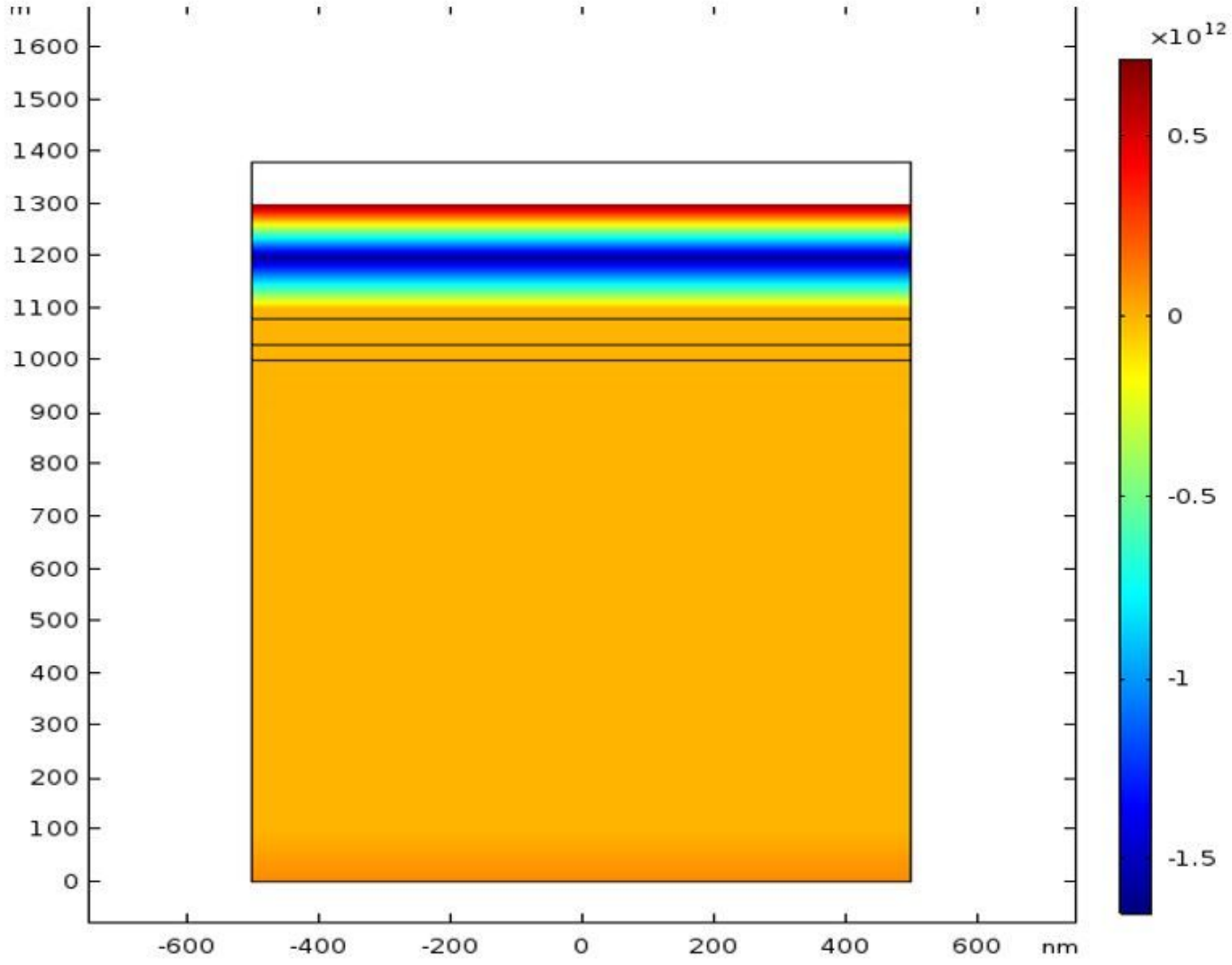

Figure 7

nonradiative recombination profile for ZnO/MoS2/Si device