ENVIRONMENTAL CHALLENGE CATER TANDEM SOLAR CELL DESIGN ON SI

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Abstract- The renewable energy as energy mix with conventional power sources can contributes a lots to minimize environment CO_2. Solar cell, the most attractive and sustainable renewable source is capable to grip this issue if it could provide sufficient efficiency. Currently 1.1 eV Si (silicon) solar photovoltaic (SPV) efficiency limitation and scope of hetero-junction tandem cell have driven SPV research towards advanced environmental friendly solar cell. Aims to efficient carrier transport properties, Si based advanced cell design using potential absorbing materials (higher permittivity) /cell has been widely investigated. Nearly current matching series cells configuration with higher absorption edge top cell design on silicon is essential for this drive. Si cell ultimate efficiency improvement if the thermalisation and optical band reflection effect could be minimized. Carrier capturing before thermalisation by employing ≤1.8 eV cell and its effective photonic conversion by III-Ns (InGaN) may progress efficiency. The μ-Si and a-Si as Si nanostructure was realized to enhance wide band absorption. But direct and wide band gap III- nitride advancement of carrier dynamics has key carrier transport properties over Si nanostructure. Therefore, novel III-N materials SPV technologies towards efficiency progression have been studied.

Index Terms- Environment compatible, green nanostructure, tandem, InGaN, Si, SPV

I. INTRODUCTION

Massive energy demand and non-renewable track power generation are linked to huge carbon production that is related to global warming. To minimize carbon emission 50% by 2050, environmental friendly energy generation and energy sustainability issues, efficient utilization of renewable energy (RE) resources as energy mix is essential [1]. At present 90% SPV demand has been roofed by natural abundant, eco-friendly silicon materials [2]. Advance processing technologies, sensible photonic conversion techniques, modeling and surface architecture has notably improved light trapping in silicon solar cell.

The effective photo conversion of higher band edge solar spectrum is highly desire in Si SPV efficiency progression. Si reflection tendency of solar irradiation is significant and it does environment heating effect due to extra reflection result. Even Si does not offer higher efficiency due to its inability to convert infrared range photons into photo current and lower open circuit voltage. Micro or nanostructure minimizes the thermal effect and residual stress at the surface. As a result, the over layer is found very impressive to improve photo-luminescence (PL) related quantum efficiency. The porous structure on silicon was found promising to improve SPV efficiency. Even honeycomb textured cell using thermally grown SiO_2 surface was also found favorable to enhance efficiency. Therefore several researchers have focused in nanostructure on silicon cell to upsurge efficiency [3-9]. Thermal or residual stress is related to problematic defects issue for the fabrication of active layer on Si cell. It also limits opto-electronic properties. It appears to be related to surface defects, contacts recombination related electrical loss minimization issues. Extensive research has been carried out by silicon nanostructured thin films to intensify higher energy band photo conversion to minimize surface recombination in silicon hetero-junction cell (HJC).

Due to higher absorption coefficient, the absorption of high energy photon is generally occurred at the surface of silicon cell. To avoid thermalisation ($h\upsilon \neq k_\beta T$), the surface processing transition materials band gap (1.8 eV) is prerequisite in silicon HJC.. Photo carrier capturing before thermalisation (hot carrier) by employing (higher band gap (1.8 eV) active silicon nanostructures and III-Ns in silicon HJC and HJTC are novel approaches [4, 10]. High energy photon absorption is taken place at reduced depth that could maximize electrical efficiency at minimum wafer thickness or cost. The μ-Si and a-Si was realized to enhance both wide band absorption and quantum efficiency [11-12]. But the critical issues of nanostructures electromagnetic properties and its critical linkage to higher band intense photonic absorption to boast up HJTC voltage and electrical properties have very little been investigated. Further direct and wide band gap III- nitride advancement of carrier dynamics has key carrier transport properties over Si nanostructure. Therefore, novel III-N materials SPV technologies towards efficiency progression have been studied.

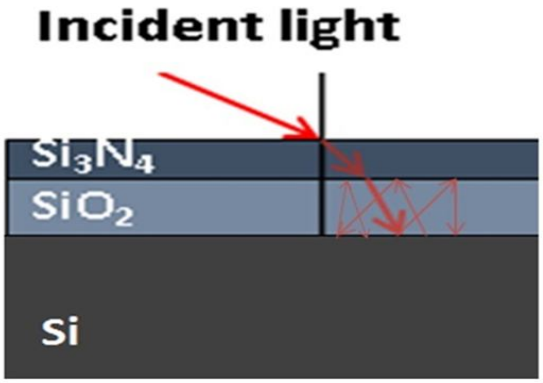
II. SCIENTIFIC RELEVANCE

Higher energy edge photons capturing realizing additional Si_3N_4 layer on SiO_2 layer is found promising. As compared to single SiO_2 coating layer or bared c-Si cell, applications of double coating layer enhances the UV band photo response. The effective incidence angle lowering (tends to normalization on Si cell) effect due to insertion of SiO_2 layer on c-Si and additional Si_3N_4 layer insertion on SiO_2 layer for coating of c-Si cell is found the same. Enhancement of high energy edge photo response as well as visible spectra is precisely observed in the analysis. But without Si_3N_4 layer, due to high absorption coefficient of UV band, it`s may absorb at the top of Si as a result poor photo response is realized. It's also realized that whatever the energy level of the solar spectrum are, applying suitable technique to absorb this band photons effectively in the depletion region could possible to enhance the photocurrent. It is closely relevance to the UV energy detection and overall photo response improvement of cSi solar cell.

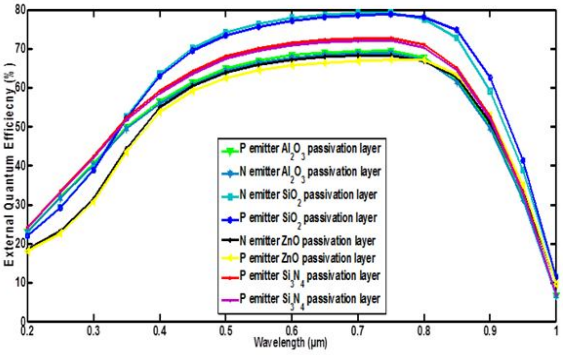
The graded refractive-index (RI) profiles that reduce surface reflectivity and enhance absorption. Material selection techniques upsurges optical absorption. Incorporation of semiconductor nanostructures enables to simultaneous improvements of optical absorption and generated carrier collection. The impact of harmonized double layers (SiO_2 + Si_3N_4) graded coating layer for photon management in Si based detectors is studied[13] .The Si RI is quite large as compared to air leads to high reflection from the Si surface. Innovative antireflection coating with minimized reflection, maximize photo-current generation and collection are desirable as photon management and environmental heating reduction scheme. The InGaN surface of Si solar cell enhances solar absorption. Due to higher and direction band gap materials the carrier generation and drift also support to enhance current density. Its dynamic band absorption increases the overall cell open circuit voltage and higher carrier dirft velocity enhances the current density. As a result promote efficiency [10].

III. RESULTS

In Fig. 1, it is considerable to adjust the refractive index geometric mean as it was found effective between air- cSi interfaces as 3D films. The Si based green nanostructures are referred as abounded in the universe. The compatible permittivity and band edge are suitable on cSi to promote photo response. It is also environmental friendly. The dielectric/ semi-conducting oxide used as thin film, appears to enhance absorption and photon in different angle to resolve at the surface to realize its efficiency progress.



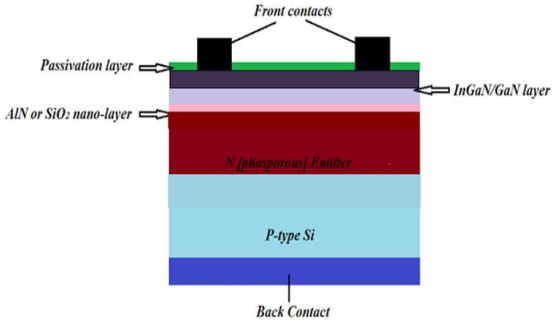
(a)



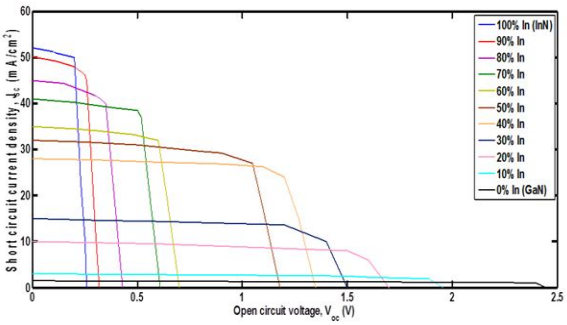
(b)

Fig. 1. (a) 3D thin film HLS on cSi and (b) 3D thin films HLS EQE on cSi

In Fig.2, it is recognized that the materials matrix related photonic effect in InGaN nanostructures are crucial to control the surface absorption, photo coupling and it is supported differently by different stoichiometric nanostructure in Si HJC. The In/Ga molar ratio and its effect in lattice dynamics are possible ways to materialize the desired 1.8 eV InGaN on Si (1.1 eV).

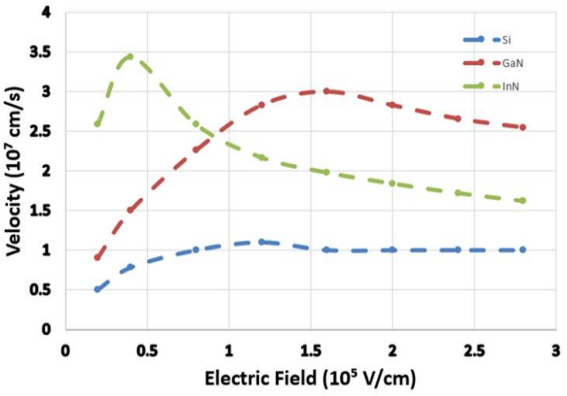


(a)

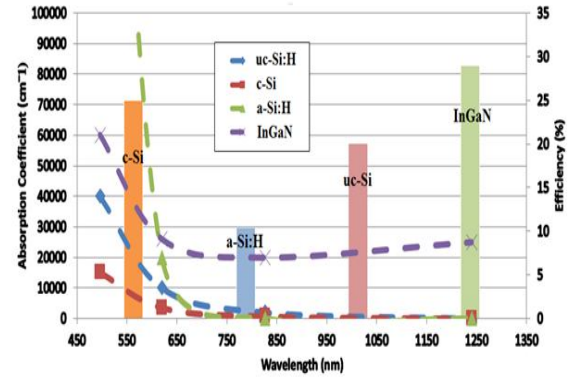


(b)

Fig. 2. (a) InGaN on Si with interlayer, (b) Advance InGaN (b) In molar ratio influence in InGaN for current density and Voc



(a)



(b)

Fig. 3. (a) Si, InN and GaN drift velocity comparison (b) Different materials photon wavelength based absorption comparison

In Fig.3, the carrier transport properties and absorption of different line edge photons realize the superiority of InGaN layer over Si nanostructure for quantum efficiency progression. The free standing materials based nanostructure as quantum dot /quantum line likely to favor higher photonic absorption but significant improvement of efficiency has not been realized [14-15]. P type InGaN ropes to enhance carrier drift velocity thus thin silicon wafer are likely to support auspicious efficiency. µcSi/aSi is an option as µcSi offer higher band gap with significant quantum efficiency [16]. Progress of aSi/cSi HJC has achieved 20% efficiency is considered promising [17]. Further efficiency improvement is quiet challenging for the all Si HJC. The carrier saturation drifts velocity only in effect for free standing structure or nanostructure and advance III-N materials on Si SPV. The current Si market, the efficiency on surface processing technologies and its crystal quality are related (cSi>mcSi>aSi) to defects and carrier transport properties. The carrier drift velocity is an influential feature to improve current density,

$$Jc = ne\mu E = neVd \qquad (5)$$

Where, V_d is drift velocity for given field, E. The higher drift velocity InGaN electrical properties must be improved. The nearly adjustable band gap (~ 1.8 eV) and current density matching with underneath cell are most significant for silicon HJTC. In this aspect, the nitride semiconductor very high drift velocity supports to increase the current density for adjusting to base silicon cell current density. Silicon nanostructure absorption trends nearly similar as InGaN, justify its higher current density, Jc may influence the series cell structures. The higher doping profiles without degenerative effect for higher band gap InGaN material can minimize the surface velocity and ease the contact problems. It may due to minimization of defect for higher doping is a measure to improve over all electrical properties. Thus the nitride materials are highly favorable to overcome the current density matching and tunneling issues. In this feature, cSi as base cell (lower band gap) and high energy absorption trends III-nitride top cell (higher band gap) is prospective in silicon SPV as discussed elsewhere [18-20].

CONCLUSION

Existing Si solar cell advanced surface processing to enhance absorption of thermally induced higher energy band photons and higher electrical performance are related to quantum efficiency progression. Through this process significant reflection effect can be minimized by introducing advance absorption nanostructure on Si SPV. Hence wide band edge effective absorption and photo carrier generation enhances. Both the Si based dielectric nano- structures and III-nitrides are promising route

to improve efficiency in Si hetero-junction tandem cell. In design and development aspect, III-nitride controllable band gap and large band bowing are potential for required current density and series cells configuration could minimize tunneling effect. It's excellent absorption at high energy band and carrier transport properties are so attractive to adjust the top cell current density to the beneath Si cell current density at minimum Si wafer thickness. The gradual progression of efficiency and advanced research in these fields claim to materialize its prospect.

ACKNOWLEDGEMENTS

I would like to thanks to our colleagues specially NEM group in SKTM, UMS. I would like to thanks the UMS authority for supporting me financially to attend the conference.

REFERENCES

[1] CedricPhilibert.,http://www.iea.org (2014). "Technology Roadmap: Solar Photovoltaic Energy"

[2] Tatsuo Saga, NPG Asia Materials 2 (2010)96-102; doi:10.1038/asiamat.2010.82

[3] K.Masuko,M.Shigematsu,T.Hashiguchi,D.Fujishima,M.Kai, N.Yoshimura,T.Yamaguchi,Y.Ichihashi,T.Mishima,N.Matsubara,T.Yamanishi,T.Takahama,M.Taguchi,E.Maruyama,S.Okamoto,Achievementofmorethan 25% conversion efficiency with crystalline silicon hetero-junction solar cell, IEEE J. Photovolt.4(2014) pp.1433–1435.Conibeer G, Green M, Cho EC, König D, Cho YH, Fangsuwannarak T, Scardera G, Pink E, Huang Y, Puzzer T, Huang S. Silicon quantum dot nanostructures for tandem photovoltaic cells. Thin Sol. Films. 516 (2008) pp. 6748-6756.

[4] Rahman MZ, Khan SI. Advances in surface passivation of c-Si solar cells. Mat. Ren. Sust. Ener. 1 (2012) pp.1-11.

[5] Narasimhan VK, Cui Y. Nanostructures for photon management in solar cells. Nanophotonics. 2 (2013) pp. 187-210.

[6] Heidarzadeh H, Baghban H, Rasooli H, Dolatyari M, Rostami A. A new proposal for Si tandem solar cell: Significant efficiency enhancement in 3C–SiC/Si. Optik-Int. J. Light Elect. Opt. 125 (2014) pp.1292-1296.

[7] Aberle AG. Overview on SiN surface passivation of crystalline silicon solar cells. Sol. Energy Mater. Sol. Cells. 65 (2001) pp.239-248.

[8] Beard MC, Knutsen KP, Yu P, Luther JM, Song Q, Metzger WK, Ellingson RJ, Nozik AJ. Multiple exciton generation in colloidal silicon nanocrystals. Nano letters. 7(2007) pp.2506-2512.

[9] Bablu K. Ghosh, Saiful S. Mohd Zainal ,Khairul Anuar Mohamad, Ismail Saad, "InGaN photocell significant efficiency enhancement on Si - An influence of interlayer physical properties"; International Journal of Energy Research, 40(9), (2016) pp. 1271-1279

[10] Hsu L, Walukiewicz W. Modeling of InGaN/Si tandem solar cells. J. Appl. Phys. 104(2008) 02450; pp.1-7.

[11] Peters M, Goldschmidt JC, Löper P, Groß B, Üpping J, Dimroth F, Wehrspohn RB, Bläsi B. Spectrally-selective photonic structures for PV applications. Energies. 3 (2010) pp.171-193.

[12] BK Ghosh, SSM Zainal, I Saad, K Anuar. Investigation of Harmonized Layers (HLs) Impact on Quantum Efficiency for N or P Type Emitter of cSi Solar Detector.Wseas Trans. Env. Dev. 11 (2015) 1-7.

[13] Abolmasov S, iCabarrocas PR, Chatterjee P. Towards 12% stabilized efficiency in single junction polymorphous silicon solar cells: experimental developments and model predictions. EPJ Photovolt. 7(2016) 70302.

[14] Mallick SB, Agrawal M, Wangperawong A, Barnard ES, Singh KK, Visser RJ, Brongersma ML, Peumans P. Ultrathin crystalline-silicon solar cells with embedded photonic crystals. Appl. Phys Lett. 100 (2012) 053113.

[15] Shah AV, Meier J, Vallat-Sauvain E, Wyrsch N, Kroll U, Droz C, Graf U. Material and solar cell research in microcrystalline silicon. Sol. Energy Mater. Sol. Cells. 78 (2003) 469-491.

[16] Korte L, Conrad E, Angermann H, Stangl R, Schmidt M. Advances in a-Si: H/c-Si heterojunction solar cell fabrication and characterization. Sol. Energy Mater. Sol. Cells. 93 (2009) 905-910.

[17] V. Polyakov and F. Schwierz, ``Nonparabolicity Effect on Bulk Transport Properties in Wurtzite InN," J.Appl.Phys. 99(2006) 113705.

[18] Korte L, Conrad E, Angermann H, Stangl R, Schmidt M. Advances in a-Si: H/c-Si heterojunction solar cell fabrication and characterization. Sol. Energy Mater. Sol. Cells. 93 (2009) 905-910.

[19] Bremner SP, Levy MY, Honsberg CB. Analysis of tandem solar cell efficiencies under AM1. 5G spectrum using a rapid flux calculation method. Prog. Photovolt: Res. Appl. 16(2008) 225-233.

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