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Luminescence efficiency Enhancement for different solar cells designs

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ABSTRACT

Solar cell materials are often evaluated on the basis of two properties: how strongly they absorb light and whether the created charge carriers reach the electrical contacts successfully. Indeed, the short-circuit current in the solar cell is determined entirely by those two factors. However, the power output of the cell is determined by the product of the current and voltage, and it is, therefore, imperative to understand what material properties (and solar cell geometries) produce high voltages. Shockley and Queisser showed that high solar cell efficiency is accompanied by a high concentration of carriers, and by strong luminescent emission of photons.

Key words: Solar cell, Shockley Queisser Equation, semiconductor material, luminescence efficiency.

1. INTRODUCTION

In excessive-performance solar cells, it's far important to engineer the photon dynamics. In a good solar cell, the photons which are emitted internally are probably to be trapped, reabsorbed, and reemitted at open circuit. The SQ limit assumes best outside luminescence yield at open circuit. on the other hand, inefficient external luminescence at open circuit is an indicator of non radiative recombination and optical losses. The SQ limit requires a 1oo% outside luminescence to balance the incoming sunlight at open circuit. Indeed, the external luminescence is a thermodynamic measure of the available open-circuit voltage [1]. owing to the narrow break out cone for internal photons, they discover it tough to break out through the semiconductor floor. Besides for the restricting case of a super fabric, external luminescence performance is continually significantly lower than internal luminescence performance. Then, the SQ restriction is not performed. The extraction and get away of inner photons is now recognized as one of the most urgent problems in mild-emitting diodes (LEDs). In this work, we assert that luminescence extraction is similarly important to solar cells. The SQ restrict cannot be completed until light extraction physics is designed into excessive performance solar cells, simply as in LEDs. A hundred% outside extraction at open circuit is exactly what is wanted to achieve the SQ restrict. The paradox is resolved through recognizing that high extraction efficiency at open circuit is an indicator, or a gauge, of small optical losses. A good solar cell should be designed as a good LED, with good mild extraction. In a manner, that is not sudden. Most ideal machines work by means of reciprocity, this is, similarly well in reverse [25].

This has important ramifications. For best materials, the burden of excessive open-circuit voltage, and thereby high performance, lies with optical layout: The solar cellular should be designed for optimal mild extraction below open-circuit conditions. The assumption of best inner luminescence yield is a seductive one. The SQ limit receives a enormous boost from the perfect photon recycling that occurs in a super device. Unfortunately, for most substances, their extraordinarily low internal luminescence yields mean that the upper bounds on their efficiencies are plenty lower than the SQ limit. For the few fabric structures which might be almost perfect, along with GaAs, there is still a tremendous burden on the optical design of the solar cellular. A very good rear mirror, for example, is of the utmost importance. In addition, it becomes clear that sensible material radiation efficiencies should be included in a credible evaluation of any substances' prospects as a solar cellular technology. There is a nicely-known distinct balance equation bearing on the spontaneous emission rate of a semiconductor to its absorption coefficient [2]. Nevertheless, it is not genuine that all good absorbers are good emitters. If the non radiative recombination charge is higher than the radiative fee, then the probability of emission might be very low. Amorphous silicon, for example, has a totally big absorption coefficient of about a hundred and five/cm, yet the probability of emission at open circuit is ~1o-4 [3]. The probability of internal emission in super GaAs has been experimentally examined to be 99.7% [4]. GaAs is a unique material in that it both absorbs and radiates well, enabling the excessive voltages required to attain >3o% efficiency. The concept that increasing light emission improves open-circuit voltage seems paradoxical, as it is tempting to equate mild emission with loss. Basic thermodynamics dictates that materials that absorb daylight ought to also emit in proportion to their absorptivity. Thus, electron–hole recombination producing outside luminescent emission is a necessity in solar cells. At open circuit, outside photon emission is a part of a vital and unavoidable equilibration process, which does not represent loss at all.

2. METHODOLOGY

The SQ limit includes a major role for external luminescence from solar cells. Accordingly, internal luminescence followed by light extraction plays a direct role in determining theoretical efficiency. To understand these physical effects, a specific material system must be analyzed, replacing the hypothetical step function absorber stipulated by SQ. GaAs is a good material example, where external luminescence extraction plays an important role in determining the fundamental efficiency prospects. The quasi-equilibrium approach developed by SQ [5] is the most rigorous method for calculating such efficiency limits. Properly adapted, it can account for the precise incoming solar radiation spectrum, the real material lab sorption spectrum, the internal luminescence efficiency, as well as the external extraction efficiency and light trapping [6].Calculations including such effects for Silicon solar cells were completed more than 25 years ago [6], [7]. Surprisingly, a calculation with the same sophistication has yet to be completed for GaAs solar cells. Previous GaAs calculations have approximated the solar spectrum to be a blackbody at 6000 K and/or the absorption coefficient to be a step function [5], [8], [9]. The efficiency limits calculated with these assumptions are all less than or equal to 31%.In this work, we will calculate that the theoretical maximum efficiency of a GaAs solar cell, using [10] the proper absorption curve of GaAs, is in fact 33.5%. Allowing for practical limitations, it should be possible to manufacture flat-plate single-junction GaAs solar cells with efficiencies above 30% in the near future. As we have already shown, realizing such efficiencies will require optical design such that the solar cell achieves optimal light extraction at open circuit.

When the cell is irradiated by the sun, the system will no longer be in thermal equilibrium. There will be a chemical potential separation μ between electron and hole quasi-Fermi levels [10-12]. The emission spectrum, which depends on electrons and holes coming together, will be multiplied by the normalized np product, i.e., (np/n2 i), where n, p, and ni are the excited electron and hole concentration, and the intrinsic carrier concentration, respectively. The law of mass action is [13,14]:

$$np= n_i^2.exp\{\mu/kT\} \qquad (1)$$

for the excited semiconductor in quasi-equilibrium, where μ is the internal chemical potential created by the sunlight. Then, the total photon emission rate is:

$$R_{ext} = exp\left\{\frac{\mu}{kT}\right\}\int\int a(E,\theta)b(E)dEcos\theta d\Omega \qquad (2)$$

for external solid angle Ω and polar angle θ. Equation is normalized to the flat-plate area of the solar cell, meaning that the emission rate Rext is the emissive flux from only the front surface of the solar cell[15-18]. We consider only non-concentrating solar cells, meaning the solid angle integral is taken over the full hemisphere. There will, generally, be a much larger photon flux inside the cell, but most of the photons undergo total internal reflection upon reaching the semiconductor–air interface. If the rear surface is open to the air, i.e., there is no mirror, then the rear surface emission rate will equal the front-surface emission rate. As already discussed, restricting the luminescent emission to the front surface of the solar cell improves voltage, whereas a faulty rear mirror increases the avoidable losses, significantly reducing the voltage.

In the past decades studies revealed that Gallium arsenide (GaAs) solar cells gives better luminous efficiency as compared to Silicon (Si). A theoretically efficiency of 33.5% is achieved in GaAs for both plane and textured front surfaces with rear mirror surfaces. But a lot of analystical challenges are still incomplete for GaAs solar cells design. Studies requires focus on radiation and absorption spectrum, internal and external luminescence, light trapping efficiency and the absorption material and light extraction. In this work search for the best parameter set of radiation, incident angle (θ), temperature range, front surface thickness (L), and design in terms of absorbing material and extraction surface that satisfies objective of searching maximum output power and external luminescence is performed. First of all literature review based on last 10 years research work related to GaAs solar cell design, luminescence efficiency and power and is performed. It helped in selection of design equations and algorithm development for finding open circuit voltage, short circuit current and luminescence efficiency for designs with (i) Plane front surface and reflecting rear surface [P+R] , (ii) Textured front surface and reflecting rear surface [T+R], (iii) Plane front surface and absorbing rear surface [P+A] and (iv) Textured front surface and absorbing rear surface [T+A] .Thereafter collection of equation parameters for GaAs solar cell is done. Development of algorithm on MATLAB platform for searching value of radiation, incident angle, thickness, temperature (I, θ, L and T) at which we can get highest luminescence and power efficiency is accomplished. Finally result are generated and comparative analysis for all designs isperformed [19 - 21].

3. RESULTS AND DISCUSSIONS

To explore the physics of light extraction, we will consider the GaAs solar cells with three possible geometries. The first geometry is the most ideal, with a randomly textured front surface and a perfectly reflecting mirror on the rear surface. The surface texturing enhances absorption and improves light extraction, while the mirror ensures that the photons exit from the front surface and not the rear. The second geometry uses a planar front surface while retaining the perfectly reflecting mirror. Finally, the third geometry has a planar front surface and an absorbing rear mirror, which captures most of the internally emitted photons before they can exit the front surface. We will find the optimized configuration that helps to achieve almost the same short-circuit current as the others, but minimum suffering of voltage and, consequently, increased efficiency. In this work, we will calculate that the theoretical maximum efficiency of a GaAs solar cell, using the proper absorption curve of GaAs. Allowing for practical limitations, it should be possible to manufacture flat-plate single-junction GaAs solar cells with efficiencies above 30% in the near future.

Realizing such efficiencies will require optical design such that the solar cell achieves optimal light extraction at open circuit. Improvement of power output and luminous efficiency by optimizing following parameters like Incident angle(‘θ’), temperature range, front surface thickness(‘L’), design in terms of absorbing material and extraction surface. It has been observed that GaAs solar cells have a better luminous efficiency as compared to Si. An efficiency of 33.5% can be theoretically achieved with GaAs for both plane and textured front surfaces with rear mirror surfaces. Hence GaAs solar cells are found to be better than Si solar cells. A lot of analysis is still incomplete for GaAs solar cells in terms of radiation and absorption spectrum, internal and external luminescence, light trapping efficiency, absorption material and light extraction. In this work focus is on searching the best parametric set of radiation intensity, incident angle (θ), temperature range, front surface thickness (L), and design in terms of absorbing material and extraction surface that satisfies objective of searching maximum output power and external luminescence. The performance of solar cell is evaluated at different parameters like activation energy and surface thickness. Figure 1shows the absorptivity of the material with respect to the activation energy. It is observed that the absorptivity become high at the value of E getting higher than 1.4Joule.After getting the absorptivity dependency on activation energy the value of surface thickness is changed and it varied from 0 to 4.5 micro metre as shown in figure 2.It is found that Front surface absorptivity for the planat surface steps to 1 simlar to figure 1.

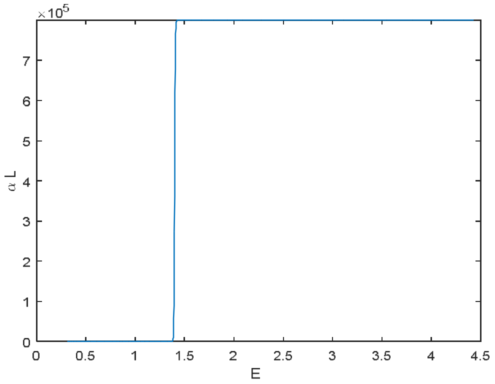

Figure 1: Absorptivity with respect to activation energy plot

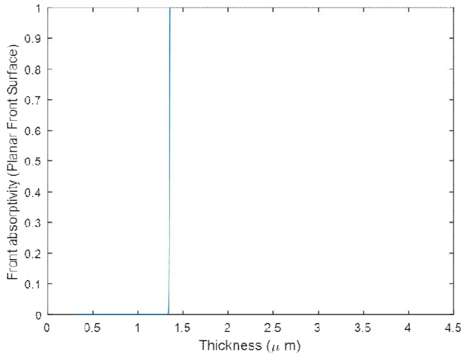

Figure 2: Front surface absorptivitywith respect to thickness

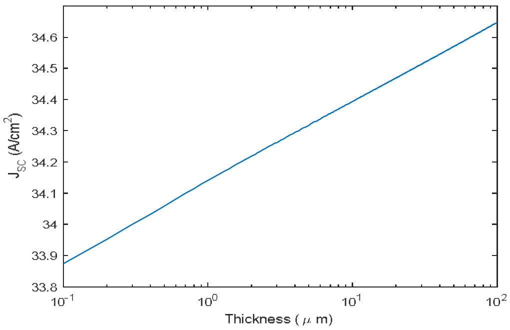

Figure 3: Current density (J_{SC})with respect to thickness

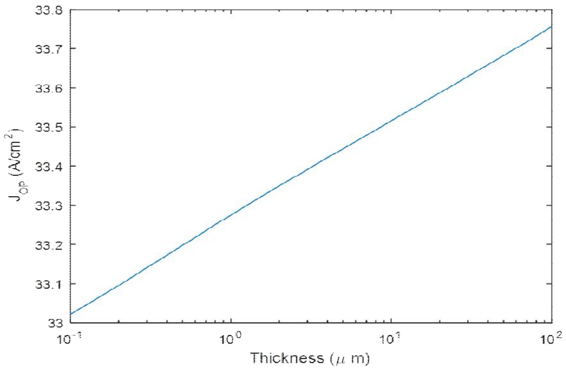

Figure 4: Current density (J_{OP})with respect to thickness

Figure 3 shows the current density at short circuit condition. The J_{SC}can be observed to increases linearly as a function of surface thickness. Here thickness is varied from 0.1 to 100 micro meter and respectively J_{SC} is varying from 33.9 to 34.7 A/cm^2.Figure 4 shows the current density during operating condition. The J_{OP} also increases linearly as a function of surface thickness. Here again thickness is varied from 0.1 to 100 micro meter and J_{OP} is varying from 33 to 33.8A/cm^2.The value of J_{SC} is found to be higher than J_{OP}. The value of J_{SC} is found to be higher than J_{OP}.

For different surface thickness the solar cell current performance are calculated and shown in figure 1 to 4.Simlarly figure 5 and 6 shows the open circuit and operating voltage performance at different thickness. In figure 5 the voltage V_{OC} is plotted against thickness. The voltage gradually decreases as thickness is increased. Here as thickness is varied from 0.1 to 100 micro meter and V_{OC} is varying from 1.1V to 1.08V.In figure 6 the V_{OP} is plotted against the thickness on the same range. Initially the V_{OP} is 1.005V and a small drop occurs and it reaches to0.985V. It is also gradually decreasing as thickness is increased. The open circuit voltage is higher than the operating voltage $V_{OP.}$

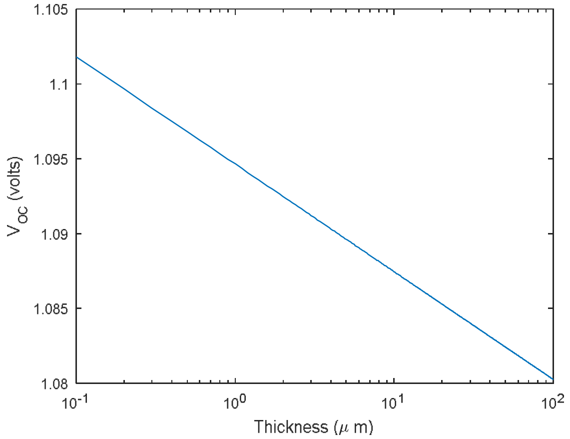

Figure 5: Open circuit voltage with respect to thickness

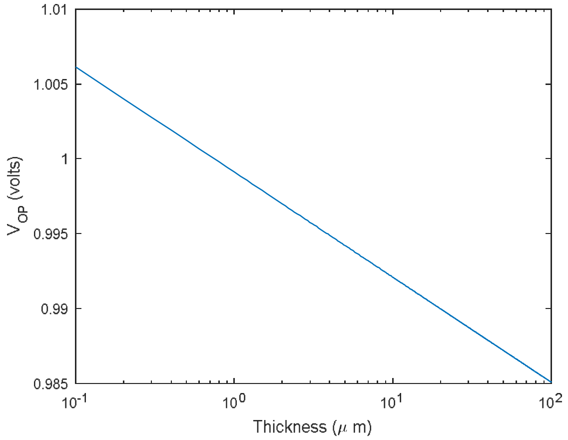

Figure 6: Operating Voltage with respect to thickness

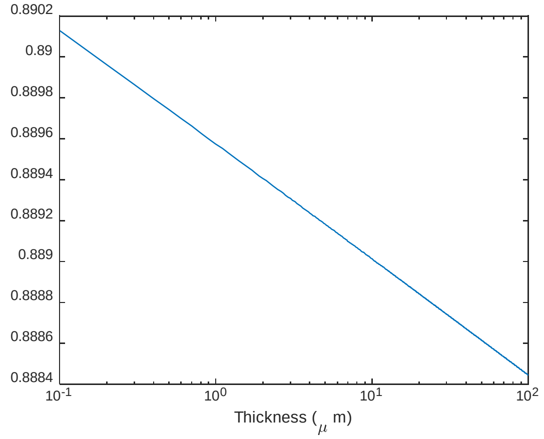

Figure 7: Fill Factor at different surface thickness

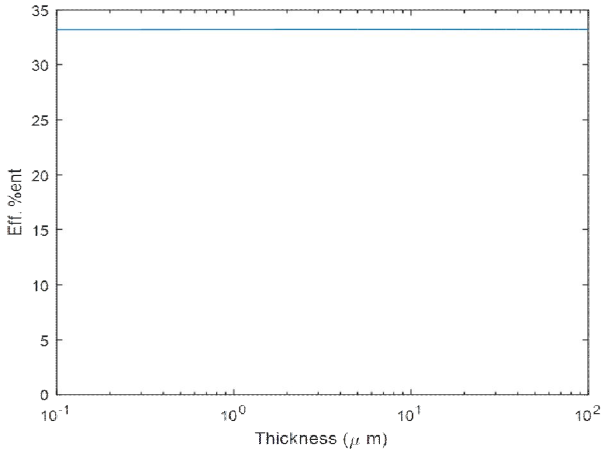

Figure 8: Percent efficiency at different surface thickness

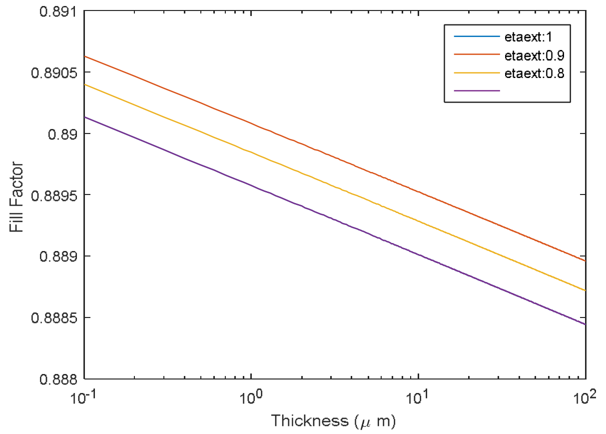

Figure 9: Fill Factor at different surface thickness and $\eta_{external}$

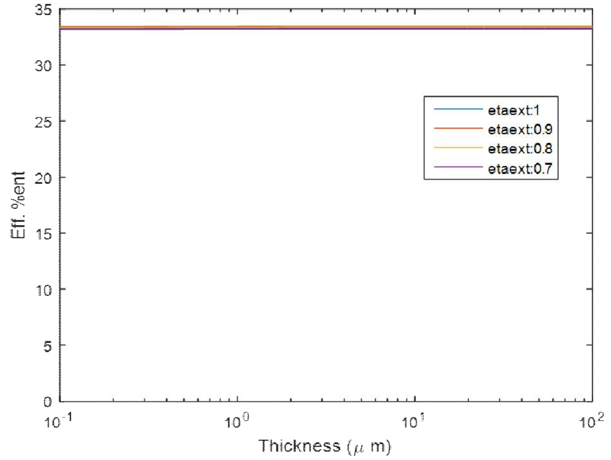

Figure 10: Percent efficiency at different surface thickness and $\eta_{external}$

Using the value of voltage and current the power output is calculated and consequently the fill factor and efficiency of cell is obtained. The fill factor and efficiency for the solar cell is observed wrt thickness and shown in figure 7 and 8.It is observed in the figure 7 that the fill factor (FF) is very high approx. 0.89 and it decreases to 0.8885 at thickness 100 micro meter. In the figure 8 the % efficiency is shown.

It is observedto be closer to the theoretical value in between 30 to 35%.No significant variation in observed in % efficiency wrt to thickness. Figure 9 is the representation of further steps of evaluation in terms of performance at different η_{external} values impact on fil factor.As it is increased the fill fctor is decreased.Figure 10 represents further steps of evaluation in terms of performance at different η_{external} values impact on percnt efficiency i.e 33% as can be seen in this figure 10. Pecent efficiency is independent of η_{external} but the FF increases as η_{external} is increased..%efficiency is independent of η_{external} but the FF increases as η_{external} is increased.

4. CONCLUSION

To explore the physics of light extraction, we will consider the GaAs solar cells with three possible geometries. The first geometry is the most ideal, with a randomly textured front surface and a perfectly reflecting mirror on the rear surface. The surface texturing enhances absorption and improves light extraction, while the mirror ensures that the photons exit from the front surface and not the rear. The second geometry uses a planar front surface while retaining the perfectly reflecting mirror. Finally, the third geometry has a planar front surface and an absorbing rear mirror, which captures most of the internally emitted photons before they can exit the front surface. We will find the optimized configuration that helps to achieve almost the same short-circuit current as the others, but minimum suffering of voltage and, consequently, efficiency.

Physics of light extraction in GaAs solar cells have been done by utilizing three possible geometries. First geometry which consists of randomly textured front surface and a perfectly reflecting mirror on the rear surface provides near ideal response. Texturing of front surface improves absorption, while the mirror ensures that the photons exit from the front surface and not the rear.

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REFERENCES

[1] R. T. Ross, “Some thermodynamics of photochemical systems,” J. Chem. Phys., vol. 46, pp. 4590–4593, Jun. 1967.
https://doi.org/10.1063/1.1840606

[2] W. van Roosbroeck and W. Shockley, “Photon-radiative recombination of electrons and holes in Germanium,” Phys. Rev., vol. 94, p. 1558, 1954.
https://doi.org/10.1103/PhysRev.94.1558

[3] M. A. Green, “Radiative efficiency of state-of-the-art photovoltaic cells,” Progr. Photovoltaic: Res. Appl., vol. 20, pp. 472–476, Jun. 2012.

[4] I. Schnitzer, E. Yablonovitch, C. Caneau, and T. J. Gmitter, “Ultrahigh spontaneous emission quantum efficiency, 99.7% internally and 72% externally, from AlGaAs/GaAs/AlGaAs double heterostructures,” Appl.Phys. Lett., vol. 62, pp. 131–133, Jan. 1993.

[5] W. Shockley and H. J. Queisser, “Detailed balance limit of efficiency of p-n junction solar cells,” J. Appl. Phys., vol. 32, pp. 510–519, Mar. 1961.
https://doi.org/10.1063/1.1736034

[6] T. Tiedje, E. Yablonovitch, G. D. Cody, and B. G. Brooks, “Limiting efficiency of Silicon solar cells,” IEEE Trans. Electron Devices, vol. ED-31, no. 5, pp. 711–716, May 1984.
https://doi.org/10.1109/T-ED.1984.21594

[7] P. Campbell and M. A. Green, “The limiting efficiency of Silicon solar cells under concentrated sunlight,” IEEE Trans. Electron Devices, vol. ED-33, no. 2, pp. 234–239, Feb. 1986.
https://doi.org/10.1109/T-ED.1986.22472

[8] J. L. Balenzategui and A. Marti, “The losses of efficiency in a solar cell step by step,” in Proc. 14th Eur. Photovoltaic Solar Energy Conf., 1997,pp. 2374–2377.

[9] A. Marti, J. L. Balenzategui, and R. F. Reyna, “Photon recycling and Shockley’s diode equation,” J. Appl. Phys., vol. 82, pp. 4067–4075, Oct.1997.

[10] National Renewable Energy Laboratory. Reference Solar Spectral Irradiance: Air Mass 1.5, ASTM G-173-03. (2012)

[11] F. Dimroth*et al.*, “Wafer bonded four-junction GaInP/GaAs//GaInAsP/GaInAs concentrator solar cells with44.7%efficiency,” *Prog. Photovolt.Res. Appl.*, vol. 22, no. 3, pp. 277–282, 2014.
https://doi.org/10.1002/pip.2475

[12] V. Sabnis, H. Yuen, and M. Wiemer, “High-efficiency multijunction solar cells employing dilute nitrides,” *AIP Conf.Proc.*, vol. 1477, no. 1, pp. 14–19, Oct. 2012.

[13] R. M. France *et al.*, “Design Flexibility of Ultrahigh Efficiency Four-Junction Inverted Metamorphic Solar Cells,” *IEEEJ. Photovolt.*, vol. 6, no. 2, pp. 578–583, Mar. 2016.

[14] M. Ochoa, E. Barrigón, L. Barrutia, I. García, I. Rey Stolle, and C. Algora, “Limiting factors on the semiconductorstructure of III–V multijunction solar cells for ultra-high concentration (1000–5000 suns),” *Prog. Photovolt.Res. Appl.*,vol. 24, no. 10, pp. 1332–1345, 2016.

[15] E. Barrigón, L. Barrutia, M. Ochoa, I. Rey Stolle, and C. Algora, “Effect of Sb on the quantum efficiency of GaInP solarcells,” *Prog.Photovolt. Res. Appl.*, vol. 24, no. 8, pp. 1116–1122, Aug. 2016.
https://doi.org/10.1002/pip.2777

[16] J. F. Geisz, M. A. Steiner, I. García, S. R. Kurtz, and D. J. Friedman, “Enhanced external radiative efficiency for 20.8%efficient single-junction GaInP solar cells,” *Appl. Phys. Lett.*, vol. 103, no. 4, p. 041118, Jul. 2013.
https://doi.org/10.1063/1.4816837

[17] M. Hinojosa, I. García, L. Cifuentes, and I. Lombardero, “Low temperature annealed Pd/Ge/Ti metal systems for concentrator inverted metamorphic solar cells,” *AIP Conf. Proc.*, vol. 2012, no. 1, p. 030007, Sep. 2018.

[18] R. Sharma, Anurag, " Detect Skin Defects by Modern Image Segmentation Approach, Volume 20, Issue 1, 2020.

[19] Anurag, R. Sharma, " Modern Trends on Image Segmentation for Data Analysis- A Review", International Journal of Research and Development in Applied Science and Engineering, Volume 20, Issue 1, 2020.

[20] M. P. Lumb, M. A. Steiner, J. F. Geisz, and R. J. Walters, “Incorporating photon recycling into the analytical drift diffusion model of high efficiency solar cells,” *J. Appl. Phys.*, vol. 116, no. 19, p. 194504, Nov. 2014. https://doi.org/10.1063/1.4902320

[21] E. Ochoa-Martínez*et al.*, “Refractive indexes and extinction coefficients of n- and p-type doped GaInP, AlInP and AlGaInP for multijunction solar cells,” *Sol. Energy Mater. Sol. Cells*, vol. 174, pp. 388–396, Jan. 2018.

[22] R. Dagan, Y. Rosenwaks, A. Kribus, A. W. Walker, J. Ohlmann, and F. Dimroth, “Minority carrier recombination ofordered Ga0.51In0.49P at high temperatures,” *Appl. Phys. Lett.*, vol. 109, no. 22, p. 222106, Nov. 2016. https://doi.org/10.1063/1.4971282

[23] E. E. Perl, D. Kuciauskas, J. Simon, D. J. Friedman, and M. A. Steiner, “Identification of the limiting factors for high temperature GaAs, GaInP, and AlGaInP solar cells from device and carrier lifetime analysis,” *J. Appl. Phys.*, vol. 122,no. 23, p. 233102, Dec. 2017 https://doi.org/10.1063/1.5003631

[24] Young Soo Jang et. al., "Development of the cost-effective, miniaturized vein imaging system with enhanced noise reduction", International Journal of Advanced Trends in Computer Science and Engineering, Volume 8, No.6, November – December 2019. https://doi.org/10.30534/ijatcse/2019/80862019

[25] Irma T. Plata1, et. al., "Development and Testing of Embedded System for Smart Detection and Recognition of Witches’ Broom Disease on Cassava Plants using Enhanced Viola-Jones and Template Matching Algorithm", International Journal of Advanced Trends in Computer Science and Engineering, Volume 8, No.6, Volume 8, No.5, September - October 2019.