Int. J. Pure Appl. Sci. Technol., 25(1) (2014), pp. 1-7

International Journal of Pure and Applied Sciences and Technology

ISSN 2229 - 6107

Available online at www.ijopaasat.in

Research Paper

Quaterly Assessment of Irradiance Variation on Power Output and Storable Excess Power of Solar Panels

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(Received: 27-8-14; Accepted: 23-10-14)

Abstract: *This research work verified the input solar irradiance and average power output per day of a 10W polycrystalline silicon solar panel (PsSp) and a 10W gallium arsenide (GaAs) solar panel, both of dimension 350x290x25mm^{3,} fill-factor 0.7 in the four different quarters of the year 2013. The average power output in KWh/m2 per day in four quarters of the year were compared to determine which quarter of the year do we have excess solar power output that can be stored for future use at the period of low solar irradiance in the experimented area.. The research was carried out at Ilesa city located at coordinates 7037'0"N 4^{0}43'0^{0}E / 7.61667^{0}N4.71667^{0}E, in Osun State of Nigeria. The input irradiance and power output of the two panels were measured and the average power available for storage beside the power demand of the consumers in the experimented area of Ilesa was quarterly determined. The research results show that each quarter is capable of taking care of the energy demand of power consumers in the experimented area of Ilesa with some excess for storage. The average power available for storage (APAS) is highest during 2nd quarter with approximate value of (1.094+ K_2-3x) KWh/m^2/day, followed by the value obtained for 1st quarter, (0.954+K_1-3x) KWh/m^2/day. In 3rd quarter, APAS value is (0.646+K_3-3x) KWh/m^2/day and the value for 4th quarter is (0.913+k_4-3x)KWh/m^2/day. The research results suggest that effort be made to provide enough and good energy storage facilities (batteries and capacitors) during each quarter to meet up with the excess solar energy that will be available for future use.*

Keywords: Irradiance, polycrystalline, panel, quarter, reserve.

Introduction

Solar cells constitute a critical technology for overcoming global environmental and energy problems. The invention of the p-n junction in 1949 formed the basis of the discovery of the crystalline Si solar cell by Pearson in 1954. Since then, solar cells have been developed and produced with polycrystalline silicon, CdTe, and GaAs. Needless to mention, remarkable progress has been made in past four decades. Megawatt solar power generating plants have been built, solar cells are being combined with building materials, and very recently the first solar-cell-powered plane demonstrated a transcontinental flight across the United States. Applications of solar cell are now an important and integral part of our daily lives, ranging from calculators and wristwatches to solar powered irrigation systems. Over 95% of solar cells in production are silicon based (Bhattacharya, 2010).

The energy output from the sun is primarily electromagnetic radiation, which covers the spectral range of 0.2 to 3.0µm. The radiation reaching Earth is scattered and absorbed in the atmosphere and the intensity is dependent on angle of incidence. Depending on this angle, the intensity can vary between 500 and 1000 W/m^2. The power level of the solar spectrum in outer space, where there is no absorption of radiation, is 140mW/cm^2.This is commonly termed the air-mass-zero (AM0) spectrum. On Earth at sea level, with the sun at zenith, the power level is reduced to nearly 100mW/cm^2. This is the AM1 spectrum. At an angle of incidence that results in twice the path length through the atmosphere, the power level drops to approx. 80mW/cm2 and the corresponding spectrum is termed AM2. The conversion of radiation energy into electrical energy is, in general, the photovoltaic effect. The most important photovoltaic device is the solar cell. The primary requirement for a material to be applicable to solar cells is a bandgap matching the solar spectrum with high mobility and lifetime of the charge carriers. These conditions exist in GaAs and many other group III-V compounds (J.L. Shay et al, 1975).

Solar energy: The most efficient and reliable alternative source of electricity to hydro-electric and oil fired power supply. This research examines the quality, reliability and efficiency of two inorganic solar cells - a 10W polycrystalline silicon solar panel (PsSp) and a 10W gallium arsenide (GaAs) solar panel both with a fill-factor of 0.7. They were positioned and rotated to have optimum irradiation at each experimental measurement at a good location in Ilesa. The method used involves direct exposure of the solar panels to sunlight for a length of time (6hours, 10a.m to 4p.m) daily for ten consecutive days, between 10th and 19th day of a month for 1year with readings taken at interval of 1hour. The results of the research indicate that the energy conversion efficiency of each of the panels used is high, and also the power output is stable and steady, reliable, safer and economically viable. From the research, the conversion efficiency of silicon based solar panel is 31.1% and that of GaAs solar panel is 25.2%. These are high values, which can be improved if more cells are combined to form a multijunction panel, as seen in multijunction tandem solar panel with increased maximum thermodynamic achievable efficiencies of 50%, 56% and 72% for stacks of 2, 3 and 5(Familusi T.O. et al, 2014).

A very simple experiment that allowed measurement of important photovoltaic parameters and the plot of I-V characteristic curve of a solar cell by college students in an introductory physics course was demonstrated in the Department of Physics, Monash University, Australia. The cell fill-factor and light conversion efficiency were determined (Michael J Morgan, Greg Jakovidis and Ian McLeod, 1991).

A research work that was focused on the optimization of metal back reflectors of thin-film solar cells was carried out and it was discovered theoretically that the conversion efficiency can be improved through the insertion of intermediate energy band in the fundamental energy gap. The theoretical aspect of intermediate band photovoltaic devices was investigated and the predicted high efficiency was confirmed by drift-diffusion modelling. A practical way to spectrally decoupling absorption spectrum was proposed, and the practicability of intermediate band concept was assessed and compared to experimental work (Albert S.L., 2010).

Under varying atmospheric conditions on the site of Algiers, global solar radiation incident on solar cells was simulated using a spectral transmittance model. The effect of changes in total intensity and spectral distribution on the short circuit current and efficiency of different kinds of solar cells (amorphous, monocrystalline and multicrystalline) was examined. The results show a reduction in the short circuit current due to increasing turbidity. It is 4.41%, 4.79%, and 7.34% under global radiation for mono-crystalline, multicrystalline and amorphous silicon cells respectively (Chegaar M., Mialhe P., 2008).

The extent of effect of dust deposit on power delivered by a 10watt polycrystalline silicon solar panel with a fill-factor of 0.7 was experimented in this research work. The research experiment was carried out between December 10^{th} and 23^{rd}, 2013. The dust deposit concentrations of sieved fine mud dust used on the solar panel are 0.0ml, 2.5ml, 5.0ml, 7.5ml, 10.0ml, 12.5ml and 15ml respectively in the experiment with the measurement of short circuit current (I_{sc}) and open circuit voltage (V_{oc}) values at intervals 1hour from 10.00am till 5.00pm taken. From the research, the efficiency of the panel is 31.42% when it operated under 0.0ml dust deposit and reduced to 26.98% at dust volume of 2.5ml; and to as low as 8.85% at a very high volume, 15.0ml of dust deposit. This is equivalent to drop in efficiency by 22.5%, which is a very high power loss. Therefore, it is necessary to wash the surface of solar panels at a chosen periodic interval, especially during the dry season when rain hardly falls (Familusi, T. O., et al).

The dye-sensitized solar cells (DSC) provide a technically and economically credible alternative concept to present day p–n junction photovoltaic devices. In contrast to the conventional systems where the semiconductor assume both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor. Charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of the solid. Carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrystalline morphology permits to harvest a large fraction of sunlight. Nearly quantitative conversion of incident photon into electric current is achieved over a large spectral range extending from the UV to the near IR region. Overall solar (standard AM 1.5) to current conversion efficiencies (IPCE) over 10% have been reached. There are good prospects to produce these cells at lower cost than conventional devices. Here we present the current state of the field, discuss new concepts of the dye-sensitized nanocrystalline solar cell (DSC) including hetero junction variants and analyze the perspectives for the future development of the technology (Michael G., 2003).

The methods for evaluating the atmospheric turbidity parameters, introduced by the present author in 1929-30, are subjected to a critical examination. A method first suggested by M. Herovanu (1959) is here simplified and expanded, and used for deriving the named parameters in adherence to a procedure described by the present author in a previous paper in this journal (1961). The procedure is applied to the pyrheliometric observations at Potsdam in 1932-36, published by Hoelper (1939) A comparison between the frequency distribution of the coefficient of wave-length dependence a at the high level station Davos and the low level station Potsdam gives results which are discussed in detail. In all the figures of the present paper, where the turbidity coefficients occur, they are multiplied by lo3 (Anders A., 1963).

The maximum power delivered by a solar panel was determined from its voltage and current and the curve of the result was illustrated as a function of time. With conclusion that solar power is neat and reliable (Gerald & Scott, 2010.).

This research work verified the input solar irradiance and average power output per day of a 10W polycrystalline silicon solar module (PsPs) and a 10W gallium arsenide (GaAs) solar module, both of dimension 350x290x25mm^{3}, fill-factor 0.7 in the four different seasons of the year 2013. The average power output in KWh/m2 per day in summer, autumn, winter and spring were compared to determine the particular season(s) of the year when excess energy can be stored for future use at the period of low solar irradiance. The research was carried out at Ilesa, Osun State of Southern Western Nigeria. The major aim of the research is to determine seasonal viability of the available solar irradiance with the main objective to know the particular season when effort should be stepped up to store excess power for future use, especially when a bad input irradiance will be experienced in a year. The research results show that each season is capable of taking care of the energy demand of power consumers in the experimented area of Ilesa with some reserve for storage. The average power available for reserve (APAR) is highest during autumn with approximate value of ($1.248+ K_2-3x$) $KWh/m^2/day$, followed by the value obtained for summer, ($1.077+K_2-3x$) $KWh/m^2/day$. In winter, APAR value is ($0.728+K_3-3x$)$KWh/m^2/day$ and ($0.554+k4-3x$)$KWh/m^2/day$. The research results suggest that effort should step up to provide enough and good energy storage facilities (batteries and capacitors) during our season to meet up with the excess solar energy that will be available for future utilisation if well tapped.

Materials and Methods

The major materials used for the practical research are - a 10W polycrystalline silicon solar panel (PsSp) and a 10W gallium arsenide (GaAs) solar panel, two numbers of high impedance voltmeters, two numbers of low impedance ammeter, two 12v batteries and loads. The methods used include positioning of the solar panels vertically with their receiving flat surface facing sunlight directly. The short circuit current was taken at intervals of 1hour for 6hours between 9.00a.m and 4.00p.m daily for ten consecutive days monthly for a year. All measurements were made under standard test conditions (STC), which specifies a temperature of 25 °C and an irradiance of 1000 W/m^2 with an air mass 1.5. The conditions correspond to a clear day with sunlight incident upon a sun-facing 37°-tilted surface with the sun at an angle of 41.81° above the horizon. Then, the power output for the two solar panels were calculated, averaged and finally analysed quarterly to determine which quarter is having the highest power output with highest possible excess power for storage against a period of low solar irradiance in the experimented area. Tables 1 and 2 under result and discussion.

Results and Discussion

Table 1: Readings of the year 2013 AVI, AI (I/P), I_{sc}, AP (O/P) and APAS

YR2013	**AVI**	**AI(I/P)**		**I_{sc}**		**AP(O/P)**		**APAS**
Month	Ilesa	PsSp	GaAs	PsSp	GaAs	PsSp	GaAs	$(y_{1n}+..y_{2n}) - x$
Jan.	0.032	0.0033	0.0033	0.004	0.003	$0.1x10^{-4}$	$0.1x10^{-4}$	$(0.2+M_1)10^{-4} - x$
Feb.	4.83	0.4903	0.4903	0.612	0.496	0.251	0.243	$0.494 + M_2 - x$
Mar.	4.44	0.4507	0.4507	0.564	0.457	0.254	0.206	$0.460 + M_3 - x$
Apr.	4.22	0.4283	0.4283	0.536	0.435	0.230	0.186	$0.416 + M_4 -x$
May	3.99	0.4050	0.4050	0.507	0.411	0.205	0.167	$0.372 + M_5 - x$
June	3.62	0.3674	0.3674	0.460	0.373	0.169	0.137	$0.306 + M_6 - x$
July	3.09	0.3136	0.3136	0.392	0.318	0.123	0.100	$0.223 + M_7 - x$
Aug.	2.92	0.2964	0.2964	0.371	0.301	0.110	0.089	$0.199 + M_8 - x$
Sept.	3.10	0.3147	0.3147	0.394	0.319	0.124	0.100	$0.224 + M_9 + x$
Oct.	3.76	0.3816	0.3816	0.477	0.387	0.182	0.148	$0.330 + M_{10} - x$
Nov.	0.032	0.0033	0.0033	0.004	0.003	$0.1x10^{-4}$	$0.1x10^{-4}$	$(0.2+M_{11})10^{-4} - x$
Dec.	5.00	0.5075	0.5075	0..635	0.515	0.322	0.261	$0.583 + M_{12} - x$

Table 2 below shows the quarterly analysis of data in table 1.

Table 2: Quarterly Analysis of data

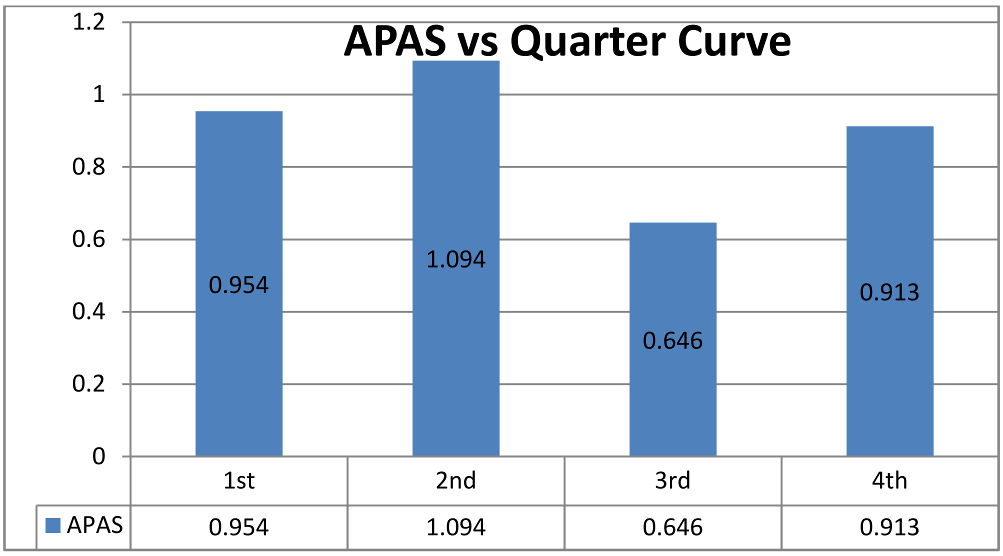
1st Quarter		**2nd Quarter**		**3rd Quarter**		**4th Quarter**	
Month	APAS	Month	APAS	Month	APAS	Month	APAS
Jan.	$(0.2+M_1)10^{-4}-x$	Apr.	$0.416 + M_4 - x$	Jul.	$0.223 + M_7 - x$	Oct.	$0.330 + M_{10} - x$
Feb.	$0.494 + M_2 - x$	May	$0.372 + M_5 - x$	Aug	$0.199 + M_8 - x$	Nov	$(0.2+M_{11})10^{-4} - x$
Mar.	$0.460 + M_3 - x$	Jun.	$0.306 + M_6 - x$	Sep.	$0.224 + M_9 - x$	Dec	$0.583 + M_{12} - x$
Av.	$0.954 + K_1 - 3x$	Aver.	$1.094 + K_2 - 3x$	Av.	$0.646 + K_3 - 3x$	Av.	$0.913 + K_4 - 3x$

From table 2, we discover that each quarter has enough APAS. The APAS in the four quarters are $0.954+K_1-3x$, $1.094+K_2-3x$, $0.646+K_3-3x$ and $0.913+K_4-3x$ respectively. The least value is obtained in the 3rd quarter, which is still a very high average power available for storage. The sum APAS in the four quarters is very good, which implies that the power storage in a year with good solar isolation can provide for another year power demand when the tested area experiences a poor weather condition.

This result has made it clear that solar energy is a reliable and efficient alternative power source for the nation and can provide a permanent solution to the nation power problems. The supply in Nigeria today is very poor and inadequate, which has constituted the major setback factor for the nation economic development. It affects both the poor and the rich. Power failure has caused death of so many people in their urge for an alternative power source via a fuel-power-generator. The carbon II oxide (CO), a gas from the incomplete combustion of the fuel that is coming out of a power generator is highly poisonous in it agitation to become fully and stably oxidized to form carbon IV oxide (CO_2) that is not harmful. All these problems are solved using solar energy as the best, reliable, stable, readily available and renewable alternative power source to both hydro- and-oil-fired-power sources; knowing fully that the fuel for solar power supply is the free sunlight.

The curve of APAS against quarter is shown in figure QAPAS below. The curve shows clearly the APAS for each quarter in a bar chat with legend reflecting the APAS value for each quarter.

Figure QAPAS: Curve of APAS and Quarter for the year 2013



Conclusion and Recommendation

Since the sum of APAS in the four quarters is very good, this implies that the power storage in a year with good solar isolation can provide for another year power demand of an area if the weather condition of such year is not favourable. Then it is a fact that if we can improve on tapping and utilizing the available solar power via good management of our solar cells, panels and modules, we can solely depends on solar power source in Nigeria.

Therefore, I wish to use this research result to advice the various arms of Nigeria Government to look into generation of power from solar source. It is safer, reliable, available and less expensive.

Glossary

- YR2013 means year 2013.
- AI (I/P) is the average input irradiance measured in KWh/m2per day.
- AVI is average isolation (for Ilesa) measured in KWh/m2 per day.
- Isc is the short circuit current.
- APAS is the monthly average power available for storage.
- X is the monthly power demand of the experimental area at Ilesa.
- y1n and y2n are the average power output {AP(O/P)} of PsSp and GaAs respectively, n denotes the number of each solar panel used.
- M_1, M_2, M_3, M_4,..,,M_{11} and M_{12} = $y_{11} + y_{21}+y_{12}+y_{22}+\ldots +y_{1n} + y_{2n}$.

References

[1] A. Smee, Elements of Electro-Biology, or The Voltaic Mechanism of Man: Of Electro-Pathology, Especially of the Nervous System and of Electro-Therapeutics, London: Longman, Brown, Green, and Longmans, 1849.

[2] S. Baldwin, Energy efficiency & renewable energy, Colorado State University, U.S., (2011), Department of Energy.

[3] M. Chegaar and P. Mialhe, Simulation of global solar radiation incident on solar cells, *Journal of Electron Devices*, 6(1) (2008), 173-176.

[4] R. Collins, A.S. Ferlauto, G.M. Ferreira, C. Chen, J. Koh, R.J. Koval, Y. Lee and J.M. Pearce et al., Evolution of microstructure and phase in amorphous, protocrystalline and microcrystalline silicon studied by real time spectroscopic ellipsometry, *Solar Energy Materials and Solar Cells*, 78(1-4) (2003), 143.

[5] J. Deans and A. Weerakoon, The thermal performance of solar air heater, *5th European Thermal Sciences Conference*, (2008).

[6] T.O. Familusi et al., Determination of the effect of dust deposit on a solar panel power output, *A Paper Presented at the ASUP International Conference*, Osun State Polytechnic, Iree, (2014).

[7] T.O. Familusi et al., Solar energy: The most efficient and reliable alternative source of electricity to hydro-electric and oil –fired power supply, *A Paper Presented at the ASUP International Conference*, Osun State Polytechnic, Iree, (2014).

[8] V.M. Fthenakis, Life cycle impact analysis of cadmium in CdTe PV production, *Renewable and Sustainable Energy Reviews*, 8(4) (2004), 303-334.

[9] M.P. Genovese, I.V. Lightcap and P.V. Kamat, Sun-believable solar paint: A transformative one-step approach for designing nanocrystalline solar cells, *ACS Nano*, 6(1) (2012), 865-72.

[10] H. Gerald and C. Scott, Maximum power from a solar panel, *Undergraduate Journal of Mathematical Modelling*, 3(1) (Article 22) (2010), Fall.

[11] C. Guo, Y.H. Lin, M.D. Witman, K.A. Smith, C. Wang, A. Hexemer, J. Strzalka, E.D. Gomez and R. Verduzco, Conjugated block copolymer photovoltaic efficiency: Microphase separation, *Nano Letters*, 13(6) (2013), 130522121011001.

[12] N. Gupta, G.F. Alapatt, R. Podila, R. Singh and K.F. Poole, Prospects of nanostructure-based solar cells for manufacturing future generations of photovoltaic modules, *International Journal of Photoenergy*, Article ID 154059(2009), 13 pages.

[13] P. Gevorkian, Sustainable Energy Systems Engineering: The Complete Green Building Design Resource, McGraw-Hill Professional, 2007.

[14] P.V. Kamat, Boosting the efficiency of quantum dot sensitized solar cells through modulation of interfacial charge transfer, Available on Enviro-News.com, (2012).

[15] D.S. Kim, A.M. Gabor, V. Yelundur, A.D. Upadhyaya, V. Meemongkolkiat and A. Rohatgi, String ribbon silicon solar cells with 17.8% efficiency, *Proceedings of 3rd World Conference on Photovoltaic Energy Conversion*, 2(2003), 1293-1296.

[16] R.R. Lunt, Theoretical limits for visibly transparent photovoltaic, *Appl. Phys. Lett.*, 101(4) (2012), 043902.

[17] R.R. Lunt, P.O. Timothy, R.B. Patrick, A.R. Jill and B. Vladimir, Practical roadmap and limits to nanostructured photovoltaics, *Adv. Mat.*, 23(48) (2011), 5712-5727.

[18] R.R. Lunt and B. Vladimir, Transparent, near-infrared organic photovoltaic solar cells for window and energy-scavenging applications, *Appl. Phys. Lett.*, 98(11) (2011),1-5.

[19] G. Michael, Review Dye-sensitized solar cells, 4(2) (2003), 145-153.

[20] A. Mayer et al., Polymer-based solar cells, *Materials Today*, 10(11) (2007), 28.

[21] S. Moon, Y. Itzhaik, J. Yum, S.M. Zakeeruddin, G. Hodes and M. GräTzel, Sb2S3-based mesoscopic solar cell using an organic hole conductor, *The Journal of Physical Chemistry Letters*, 1(10) (2010), 1524.

[22] T. Oku, K. Kumada, A. Suzuki and K. Kikuchi, Effects of germanium addition to copper phthalocyanine/fullerene-based solar cells, *Central European Journal of Engineering*, 2(2) (2012), 248-252.

[23] G. Parkinson, P.V. Solar and A. de Vos, Detailed balance limit of the efficiency of tandem solar cells, *Journal of Physics D: Applied Physics*, 13(5) (2013), 839-846.

[24] J. Pearce and A. Lau, Net energy analysis for sustainable energy production from silicon based solar cells, *Proceedings of American Society of Mechanical Engineers Solar*, (2002).

[25] J.M. Pearce, N. Podraza, R.W. Collins, M.M. Al-Jassim, K.M. Jones, J. Deng and C.R. Wronski, Optimization of open-circuit voltage in amorphous silicon solar cells with mixed phase (amorphous + nanocrystalline) p-type contacts of low nanocrystalline content, *Journal of Applied Physics*, 101(11) (2007), 114301.

[26] J. Perlin, The silicon solar cell turns 50, National Renewable Energy Laboratory, (2004), En.wikipedia.org/wiki/solar_cell, Retrieved 5 October (2010).

[27] J.C. Rudolf, Transparent photovoltaic cells turn windows into solar panels, Available on green.blogs.nytimes.com, July 24 (1204).

[28] P.K. Santra and P.V. Kamat, Mn-doped quantum dot sensitized solar cells: A strategy to boost efficiency over 5%, *Journal of the American Chemical Society*, 134(5) (2012), 2508-11.

[29] I. Schnitzer *et al*., Ultrahigh spontaneous emission quantum efficiency, 99.7% internally and 72% externally from AlGaAs/GaAs/AlGaAs double hetero-structures, *Applied Physics Letters*, 62(2) (1993), 131.

[30] O.E. Semonin, J.M. Luther, S. Choi, H.Y. Chen, J. Gao, A.J. Nozik and M.C. Beard, Peak external photocurrent quantum efficiency exceeding 100% via meg in a quantum dot solar cell, *Science*, 334(6062) (2011), 1530-3.

[31] The Prashant Kamat lab at the University of Notre Dame, Solar Cell Research, Nd.edu 22 February (2007), Retrieved on 17 May (2012).

[32] L.M. Terry, I.A. Straub, S. Daniel, A. Dengyuan and G. Armin, Large open-circuit voltage improvement by rapid thermal annealing of evaporated solid-phase-crystallized thin-film silicon solar cells on glass, *Applied Physics Letters*, 86(17) (2005), 172108.

[33] X. Wang et al., Design of gas solar cells operating close to the shockley–queisser limit, *IEEE Journal of Photovoltaics*, 3(2) (2013), 737.

[34] I.P. Widenborg and A.G. Aberle, Polycrystalline silicon thin-film solar cells on ait-textured glass superstrates, *Advances in Opto Electronics*, 1(2007), 1.