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Perovskite Thin-Film Solar Cell: Study of Optical and Electrical Performance Parameters for Nano Textured Surface

By Niajul Karim, Md. Golam Rabbi, Md. Lutful Sadiq Mim & Sakib Ahammad
American International University

*Abstract-*An optical and electrical investigation has been conducted for CH3NH3PbI2Clx based organic-inorganic halide thin-film perovskite solar cells for smooth and pyramid textured surfaces. A reference structure of perovskite solar cell has been reproduced for short-circuit current density and external quantum efficiency and further used in designing pyramid textured solar cell. The actual investigation was done by varying the period and height of the pyramid for better light trapping and enhancing effective thickness of the cell which is quite new for this type of emerging material solar cell. The complete study was carried on theoretically using a commercial Finite Difference Time Domain (FDTD) mathematical simulation tool where Maxwell's curl equations are rigorously solved. An optimized perovskite solar cell has been designed and developed for 600 nm of period and 300 nm of height, exhibiting maximum of 19.15% conversion efficiency and 23.61 mA/cm2short-circuit current density, compared to 18.27% and 22.53 mA/cm2 conversion efficiency and short circuit current, respectively in smooth substrate solar cell.

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PEROVSKITETHIN-FILMSOLARCELLSTUDYOFOPTICALANDELECTRICALPERFORMANCEPARAMETERSFORNANOTEXTUREDSURFACE

Strictly as per the compliance and regulations of:

Perovskite Thin-Film Solar Cell: Study of Optical and Electrical Performance Parameters for Nano Textured Surface

Niajul Karim [α], Md. Golam Rabbi [σ], Md. Lutful Sadiq Mim [ρ] & Sakib Ahammad [Ѡ]

Abstract- An optical and electrical investigation has been conducted for CH3NH3PbI2Clx based organic-inorganic halide thin-film perovskite solar cells for smooth and pyramid textured surfaces. A reference structure of perovskite solar cell has been reproduced for short-circuit current density and external quantum efficiency and further used in designing pyramid textured solar cell. The actual investigation was done by varying the period and height of the pyramid for better light trapping and enhancing effective thickness of the cell which is quite new for this type of emerging material solar cell. The complete study was carried on theoretically using a commercial Finite Difference Time Domain (FDTD) mathematical simulation tool where Maxwell's curl equations are rigorously solved. An optimized perovskite solar cell has been designed and developed for 600 nm of period and 300 nm of height, exhibiting maximum of 19.15% conversion efficiency and 23.61 mA/cm2short-circuit current density, compared to 18.27% and 22.53 mA/cm2 conversion efficiency and short circuit current, respectively in smooth substrate solar cell.

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I. Introduction

The energy demand is increasing day by day with ever growing increment of population. Developing countries like Bangladesh still depend on the non-renewable energy such as fuel, diesel and gas to relive the enormous requirement of energy. But those non-renewable sources are confined and not favorable to the environment. On the contrary, the renewable sources of energy are sustainable, abundant and environment friendly such as solar cell. Solar energy is an important form of renewable energy and in the field of solar energy the Perovskite based solar cell has attracted a great attraction due to their high efficiency and low production cost. As we proceed towards the future with more cost efficient solar cells, the absorber layer of thin-film silicon solar cells are inversely getting thinner. Therefore the importance of efficiently absorbing the incident light within very thin absorber layers becomes more crucial. In order to design optically efficient solar cells, it is imperative to understand the interplay between the optical wave propagation within the cell and the surface texture at its interfaces. Within the scope of this thesis, the influence of periodic surface texture was investigated by rigorously solving the Maxwell's equations in two and three-dimensions. By studying the varying parameters in surface textured solar cells,

Their performance in terms of the quantum efficiency and short circuit current was evaluated.

II. Fundamentals of Nanotextured Perovskite Solar Cell

a) Basic concepts of perovskite solar cell

Solar or photovoltaic cell converts the sun energy into electricity whether they adorning our calculator or orbiting our planet on satellites, they rely on the photoelectric effect. Solar Cell does the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, electric current results that can be used as electricity. When photons are absorbed by matter in the solar cell, their energy excites electrons higher energy states, where, the electrons can move more freely. The perhaps most well-known example of this is the photoelectric effect, where photons give electrons in a metal enough energy to escape the surface. A perovskite solar cell is a type of solar cell which includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer.

b) Basic Structure of perovskite solar cell

Perovskite take their name from the mineral, which was first discovered in the Ural Mountains of Russia by Gustav Rose in 1839 and is named after Russian mineralogist L. A. Perovskite. The compound that has similar crystal structure like CaTiO3 are basically known as Perovskite material. A perovskite solar cell is a type of solar cell which includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer. Structure of a perovskite with a chemical formulaABX3. The red spheres are X atoms (usually oxygen's), the blue spheres are B-atoms (a smaller metal cation, such as

Author α σ ρ Ѡ: Faculty of Engineering, American International University-Bangladesh (AIUB). e-mail: niajulkarim@gmail.com

Ti4+), and the green spheres are the A-atoms (a larger metal cation, such as Ca2+). Pictured is the undistorted cubic structure; the symmetry is lowered to orthorhombic, tetragonal or trigonal in many perovskites [1,2].

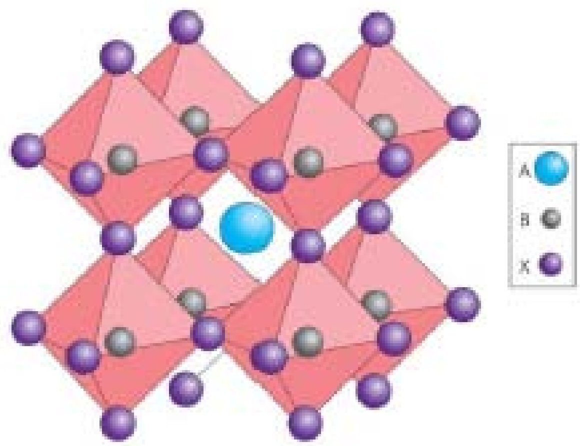

Figure 1: Basic structure of perovskite solar cell [2].

c) Nano textured solar module

Light trapping scheme based on Nano textured sur-faces/interfaces of thin film Perovskite solar cells (amorphous, microcrystalline) deposited on textured transparent conducting oxide(TCO) is modeled with the help of Monte Carlo method taking into account the effects of light coherence. Spectral response and short circuit current density are computed as a function of Nano roughness, angular distribution of scattered light, thickness and optical constants of all layers of single or multifunction solar cells. The spectral response of Nano textured solar cells geometrical optics cannot be used; therefore, usual ray tracing programs cannot be applied. On the other hand, a rigorous treatment using Maxwell electromagnetic theory (being available only for periodically repeating sure-face features) is very complicated and time-consuming. The ultimate performance of Nano textured thin film solar cell in terms of maximum achievable short circuit current, for a given thickness of all layers and the light scattering parameters of layers and interfaces. It enables us to analyze and identify the losses due to each parameter, where an efficient light trapping is absolutely necessary for the efficient thin-film Perovskite solar cells [3-5].

Figure 2: Sketch of n-i-p thin film solar cell [5]

d) Proposed Model

The model as represented above is of smooth surface heterojunction solar cell. With the dependency of technology, solar cell can be deposited in either the superstrate or substrate form. In superstrate configuration the incident light passes.

Through the glass substrate before it enters the ITO and p-i-n layer of the solar cell and the following model states the superstrate configuration as an example. Since the texturing is also happened in this model that's why an efficient light trapping scheme is absolutely worked for the efficient thin film solar cell .moreover, Our optical model of solar cell gives the ultimate performance of Nano textured thin film solar cell in terms of maximum achievable short circuit current, for a given thickness of all layers and the light scattering parameters of layers and interfaces and also It enables us to analyze and identify the losses due to each parameter. Finally the model gives the desired results within few minutes.

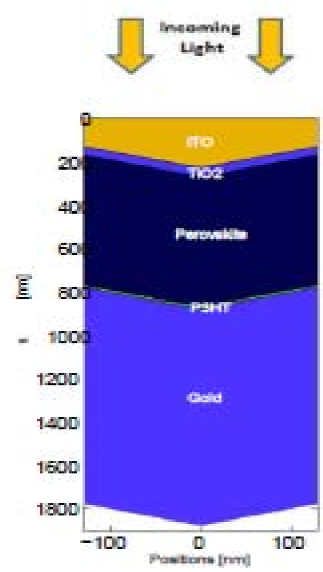

Figure 3: Schematics sketch of unit cell of periodically texture perovskite thin film solar cell with pyramid texture.

III. Properties of Perovskite Solar Cell Material

In our thesis work, we have investigated the efficiency enhancement of a Perovskite solar cell varying thickness of different materials and different contact materials. Then we investigated the efficiency enhancement of same cell after Nano texturing the cell. We also used the optical constants of Perovskite materials, which were extracted, optimized and inserted into the simulation environment to perform the simulation. In our cell the layers consist of Glass as substrate, ITO as Transparent Conducting Oxide (TCO), TiO2 as P-layer, Perovskite (CH3NH3PbI3 xClx) as intrinsic layer, and P3HT as N-layer and Gold as metal reflector. Same material is used for Nano texturing each layer of the Perovskite solar cell.

IV. Designed and Simulation a

a) Short circuit current

Within the scope of this thesis, the optical simulation results were concentrated on periodically textured thin-film Perovskit Solar cells. But in reality, the surface texture in the solar cells are ordered randomly where the period and height of such textures can vary significantly. Which is shown in fig 4 in following. The analysis of such textured surfaces can be done and gives us the height profile and statistics on the surface. Along with the height information, the spatial distribution with regards vto the period is also a necessary quality which determines the light trapping potential of a surface. In order to get a more accurate representation of the surface texture, a tuple of <period-height> information would be desirable. The influence of the perovskite solar cell thickness on the performance of the solar cell is shown in Figure: 4. the overall short circuit current is simulated for perovskite thin film solar cell for different periods and heights. In terms of the simulations performed, the maximum short circuit current is 23.8mA=cm2 and the minimum short circuit current is 22.55mA=cm2.The overall current is gained by 1.25 mA=cm2. The calculated short circuit current for overall perovskite thin film solar cell is shown in Figure: 4 under (wavelength 300 – 800 nm) illumination. The maximum short circuit current is observed for grating period of 600nm and the grating height of 80nm. On the other hand, the minimum short circuit is observed for grating period of 300nm and the grating heights of approximately 25 nm. Since, we have been observed from the simulation the total short circuit current for perovskite thin film solar cell is 22.53 mA=cm2 and the total short circuit current for perovskite thin film solar cell on textured surface is 23.8 mA=cm2. So, compared with the short circuit current of a solar cell on a smooth substrate, the short circuit current is increased by 1.27mA=cm2.

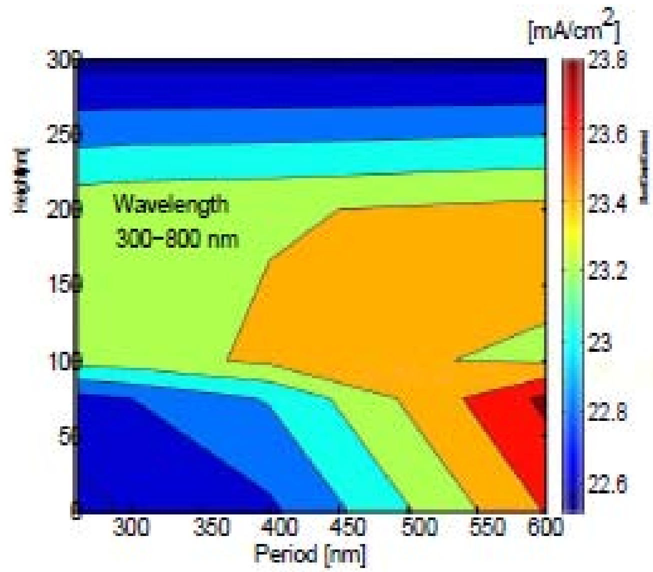

Figure 4: Short circuit current for Perovskite thin film solar cell as function of the grating period and height illuminated under entire sun spectrum (wavelength 300 – 800 nm).

b) Quantum efficiency with varying periods

The quantum efficiency can be viewed as the collection probability due the generation profile of a single wavelength, integrated over the device thickness and normalized to the incident number of photons. It is the ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell. The curve in Figure: 5 shows the quantum efficiency of perovskite based thin-film solar cell with the variation of periods of (260-600 nm) with a particular height of 75 nm. As Quantum efficiency refers to the ratio of the number of carrier collected by the solar cell due to the incident of photons, it is directly related with the absorption coefficient and mobility of the electron, holes as well as to increase the effective thickness and the diffraction of light. With high absorption we will get higher carrier collection. As we get high short circuit current flows in 600 nm, the quantum efficiency is also high here.

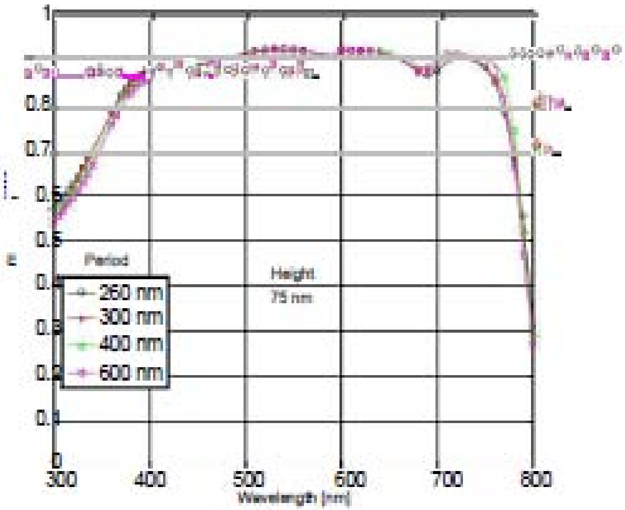

Figure 5: Quantum efficiency for Perovskite thin film solar cell with pyramid structures of height 75 nm and different period.

c) *Quantum efficiency with varying heights*

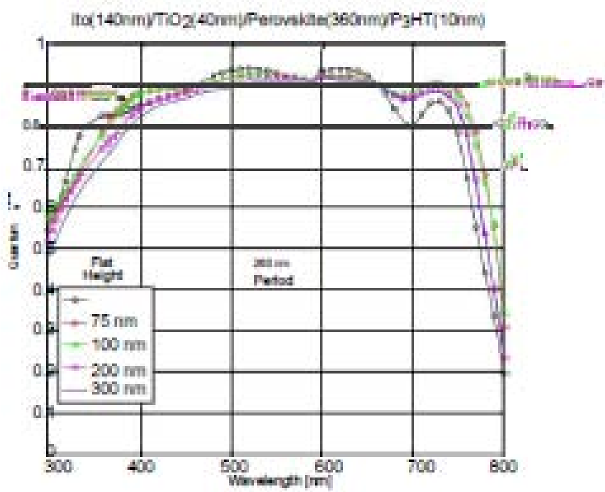

Figure 6: Quantum efficiency for Perovskite thin film solar cell with pyramid structures of period 260 nm and different height

The following curve shows the quantum efficiency of perovskite based thin-film solar cell with the variation of heights of (75-300 nm) with a particular period of 260 nm in Figure:6. As Quantum efficiency refers to the ratio of the number of carrier collected by the solar cell due to the incident of photons, it is directly related with the absorption coefficient and mobility of the electron, holes as well as to increase

The effective thickness and the diffraction of light. With high absorption we will get higher carrier collection. As we get high short circuit current flows in 75 nm, the quantum efficiency is also high here.

Optimized period and height for maximum short circuit current

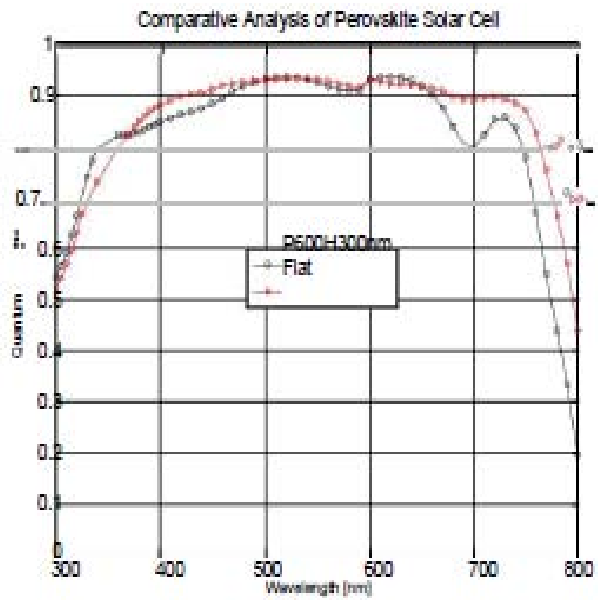

Figure 7: Quantum efficiency for Perovskite thin film solar cell with pyramid structures of period 600 nm and height of 300 nm

The above curve in Figure:7 shows compared with flat solar cell, it has been observed from the curve blue under illumination of (300-500 nm) has a maximum short circuit current and also red which is under illumination (700-800 nm) has a maximum short circuit current. The maximum short circuit current measured as 23.61 mA/cm2. Therefore we got the maximum quantum efficiency and overall efficiency is 19.15 %.

V. Efficiency Calculation and Result

a) *Efficiency calculation for varying different periods and heights*

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$h = \frac{V_{oc}\, I_{SC}\, FF}{nPi}$$

Table I: Solar Cell Characteristics Analysis for Different Period (260-600 Nm) and Height of 75 Nm for Efficiency

Period (nm)	Short circuit Current, Isc (Ma/cm?)	Open Circuit Voltage, Voc (V)	Fill Factor, FF	Effieiency ɳ(%)
260	23.33	0.9268	0.8751	18.92
300	23.36	0.9268	0.8751	18.92
400	23.36	0.9268	0.8751	18.92
600	23.46	0.9268	0.8751	18.92

Table II: Solar Cell Characteristics Analysis For Different Height (0-1000 Nm) And Period Of 260 Nm For Efficiency

Height (nm)	Short Circuit Current, I_{sc} (ma/cm$_2$)	Open Circuit Voltage Voc (v)	Fiil Factor, FF	Effieiency ɳ(%)
0	22.53	0.9268	0.8751	18.27
75	23.33	0.9268	0.8751	18.27
100	23.29	0.9268	0.8751	18.27
200	22.72	0.9268	0.8751	18.27
300	22.51	0.9268	0.8751	18.27
600	22.60	0.9268	0.8751	18.27
800	22.75	0.9268	0.8751	18.27
1000	22.82	0.9268	0.8751	18.27

b) *Comparatively Characteristic Analysis*

Table III: Comparatively Characteristic Analysis for Optimized Perovskite Thin Flim Solar Cell With Textured Surface And Flat Surface

Period (nm)	Height (nm)	Short Circuit Current, I_{sc} (ma/cm$_2$)	Open Circuit Voltage Voc (v)	Fiil Factor, FF	Efficiency, n (%)
600	300	23.61	0.9268	0.8751	19.15
260	0	22.53	0.9268	0.8751	18.27

From the table we got the maximum quantum efficiency and overall efficiency is 19.15% of perovskite solar cell for texture surface and also it is observed from the table for smooth surface the efficiency is 18.27%.

VI. Conclusion

The results from this study provide a solid foundation in exploring into more intricate issues which are intertwined with the optical response of thin-film silicon solar cells. With optics playing a major role in enhancing the absorption efficiencies of Thin-film Perovskite solar cells, there still awaits exciting areas of research which are yet to be solved. In this research we have analyzed different simulation results and observe Power loss profile of flat solar cell for the wavelength of 630 nm and 730 nm. Also it is analyzed through the research and successfully identified the short circuit current and quantum efficiency of perovskite thin film solar cell for smooth surface as well as for textured surface with the variations of different periods and heights. The efficiency of a perovskite thin film solar cell is determined as the fraction of incident power which is converted to electricity as we investigated from overall result. From the result we have been observed that optimum variation of solar cell for different wavelength spectrum from 300 nm to 800 nm and about 80% light is absorbed at 500- 550 nm of wavelength spectrum as well as the total short circuit current is for textured surface of perovskite solar cell is 23.8mA=cm2.whereas the total short circuit current for smooth surface which we have been observed before is 22.53mA=cm2. These currents are observed with the variation of periods by fixing height or with the variation of heights by fixing period. Finally, the Quantum efficiency of optimized period and height of maximum current for textured surface of perovskite thin film solar cell is analyzed and a delightful maximum efficiency (19.15%) found out which is comparatively higher than the flat Surface of perovskite thin film solar cell.

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