PEROVSKITE PHOTOVOLTAIC CELL WITH 7.2% CONVERSION EFFICIENCY

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Abstract: The main purpose of the work is to find an optimal way for the preparation of the perovskite photovoltaic cell with high conversion efficiency. An active perovskite layer is form as $CH_3NH_3PbI_{3-2}Cl_2$. In total has been created six solar cells. Conversion efficiency of best sample 1 has reached η_{MAX} = 7. 22 %. Samples were further analyzed and based on that were implemented other techniques for their improvement.

Keywords: Perovskite photovoltaic cells, organic – inorganic solar cells, 7% conversion efficiency.

1. INTRODUCTION

Well-known scientist Michael Grätzel called perovskite as "unusually cheap" material that could operate successfully in solar cells and combine the seemingly incompatible - low acquisition cost and high efficiency of energy conversion of sunlight into elektricity [1]. Advantages of perovskite solar cells lies in their potential use in a broad application such as windowpanes, facade systems and much lower production costs (also availability of materials) in comparison to a traditional silicon solar cells with a relatively easier methods of its preparation. Perovskite solar cells can be considered as promising power source worthy attention. On the other hand, the biggest problem of perovskite solar cells is their degradation.

2. PEROVSKITE PHOTOVOLTAIC CELLS

2.1. STRUCTURE OF PEROVSKITE SOLAR CELLS

Perovskite in general is a name for a group of substances with the same crystal structure as $CaTiO_3$. The presented work deals with the perovskite solar cells known as $CH_3NH_3PbI_{3-2}Cl_2$ / $PC_{61}BM$. Its structure is indicated in Fig. 1. A semiconductor is created as an organic-inorganic hybrid composition of $CH_3NH_3PbX_3$ (X = Cl, I, Br).

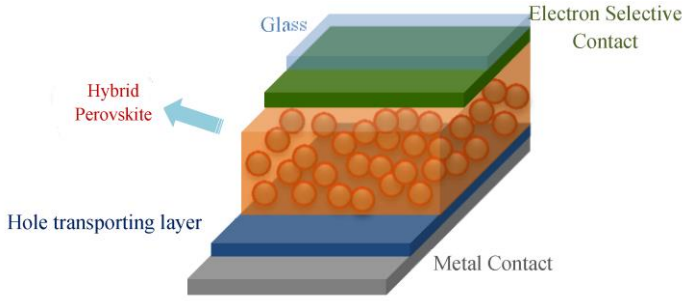

Figure 1: General structure of perovskite solar cells: Glass + ITO, HTM – Hole transporting material, Electron selective contact and cathode (eg. Au, Al) [1]

The advantage of perovskite solar cells is in a relatively easy preparation from a generally available raw materials [2]. Complication is the fact that the material of an active layer includes toxic lead. This problem can be solved by replacing the lead for other metal (eg. by tin, but the structure doesn´t reached the conversion efficiency of perovskite solar cells with lead). Another problem is that perovskites are generally water soluble (prepared from the solution), so that exposure to atmospheric moisture can quickly degrade the solar cell. Material exposed to an atmospheric moisture within a few hours passes into the undesirable "unperovskite" crystalline structure. Still is not possible to create perovskite solar cells entirely resistive to degradation influences. The lifetime of common photovoltaic cells is counted in months.

2.2. MANUFACTURING PROCESS OF PEROVSKITE PHOTOVOLTAIC CELL

In total it was prepared six samples with composition.

- Cathode: vapor-deposited Al
- Electron selective contact: $PC_{61}BM$ methyl-ester [6,6]-fenyl C_{61} butyric acid
- Perovskite layer: $CH_3NH_3PbI_{3-x}Cl_x$
- Hole transporting layer: PEDOT:PSS (Poly3,4etylenedioxythiofen): poly(styrensulfonate)
- Glass: ITO (Indium Tin Oxide) In_2O_3-SnO_2

Solar cells were fabricated on PEDOT coated indium tin oxide glass (ITO) with emphasis on the optimal way of heat treatment. The ITO substrates were before this process cleaned in an ultrasonic bath. $CH_3NH_3PbI_{3-2}Cl_2$ film was formed through a spincoating from a mixture of CH_3NH_3PbI, PbI_2 and $PbCl_2$. After verifying that the precursor solutions were successfully synthesized, the organic semiconductor $PC_{61}BM$ was deposited. Finally, aluminum cathode was deposited through a mask on the active layer. A detailed description of the preparation is given in the following text.

Preparation of the carrier substrates with an ITO layer was proceeded as follows: the substrates were firstly put into the beaker with a 5-10% of NaOH solution. Subsequently, after a period of 3-5 minutes, were left in the ultrasonic bath, then rinsed with MilliQ water and finally cleaned with an isopropylalcohol.

PEDOT: PSS was before applying filtered through a 45 μm PVDF filter. A 55 ml of solution was used. Spin-coating was adjusted to a rotational speed of 3000 rpm (with the acceleration speed of 500 rpm) for 30 seconds. The cathode strip was after this process purified by MilliQ water.

Perovskite layer was prepared from molar solution of the mass fraction of 1:1:4 with a total concentration of 9 percentage by weight. In numbers it means: of CH_3NH_3PbI (0.19561g), PbI_2 (0.141822 g) and $PbCl_2$ (0.08555 g). The solution was prepared within the laboratory conditions for 12 hours at the temperature of 70 °C with the stirring speed of 650 rpm. The solution was then filtered with a 45μm filter and applied to a preheated glass slides (100 °C for a 30 sec) by spin-coating in an amount of 40 μl with the 3000 rpm with the 320 rpm speed acceleration. After deposition was on the slides cleaned anode strip. After this step were slides transferred to a hot plate with an 80 °C temperature for a period of 1 minutes.

The layer of $PC_{61}BM$ was applied similarly. The solution was prepared from 10 mg / ml of $PC_{61}BM$ in a mixture of anhydrous solvents of chloroform-chlorobenzene (1:1). Deposition was performed through a spin-coating at 1200 rpm for 60 sec. in an amount of 50 ml, but this time without a subsequent annealing. Cathode strip was refined with a chloroform.

In the end an aluminum electrodes were vapor-deposited with a thickness of 100 nm followed by encapsulation of the samples with the epoxy resin. Cover glass with contacts were also attached.

a) b)

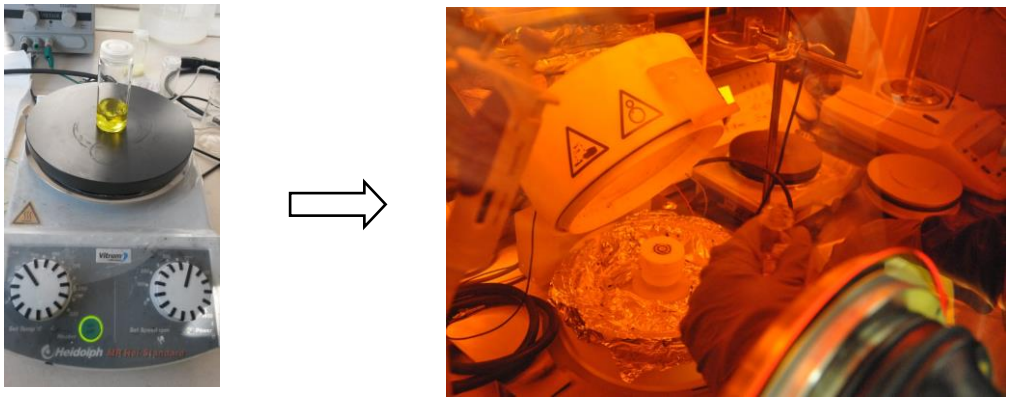

Figure 2: a) Preparation of $CH_3NH_3PbI_{3-2}Cl_2$ solution and b) applications of perovskite by spin coating

3. MEASURED DATA

3.1. RESULTS OF MANUFACTURING PROCESS

Conversion efficiency of perovskite solar cells was during the initial measurement equal to approximately 6 %. The highest conversion efficiency was reached by cells No. 1 (η_{MAX} = 7.22%); No.2 (η_{MAX} = 5.57%) and No.4 (η_{MAX} = 5.21%). Measurements were performed on the solar simulator with light source of 1000 W / m^2 value. The average final values are shown in Table I. Current-voltage characteristic of sample 1 is at Fig. 3.

TABLE I. Average parameters of manufactured perovskite solar cells and the best one 1_P2

Device	I_{sc} [mA]	V_{oc} [mV]	I_{mpp} [mA]	V_{mpp} [mV]	P_{mpp} [W]	FF [%]	η [%]
1_P1	0.49	958.67	0.42	786.58	0.33	70.92	7.12
1_P2	0.51	918.46	0.45	746.54	0.33	71.34	7.22
1_P3	0.50	646.28	0.42	466.44	0.19	61.01	4.22
1_P4	0.40	634.01	0.34	466.39	0.15	61.38	3.40
1_P5	0.45	890.32	0.39	693.14	0.27	68.21	5.90
1_P6	0.44	936.06	0.38	773.30	0.29	71.57	6.35
3_P1	0.24	928.53	0.18	666.48	0.12	54.91	2.62
3_P2	0.48	883.62	0.41	666.43	0.27	65.62	5.95
3_P3	0.50	475.34	0.40	319.87	0.13	53.74	2.78
3_P5	0.44	838.21	0.36	612.95	0.22	59.22	4.72

Efficiency of solar cells during their measurements were not constant. Sometimes efficiency has increased and then decreased to original value. The reason probably lies in the heating of the cells during their measurements because solar cells were measured in a short intervals.

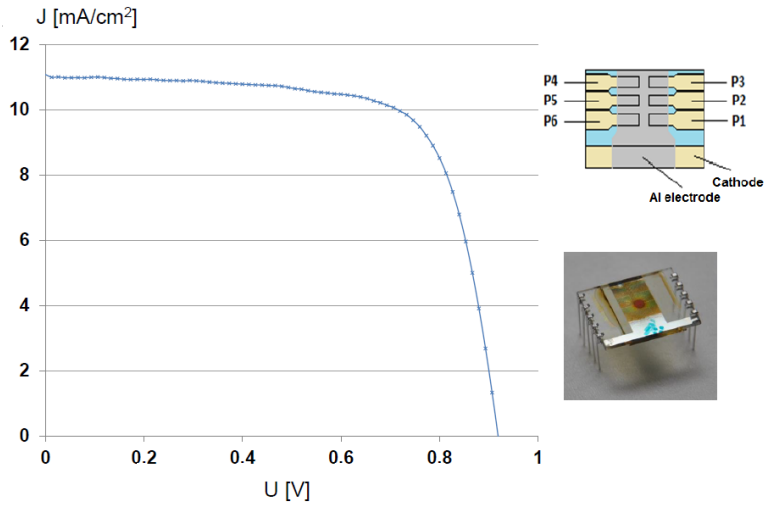

Figure 3. Sample 1 current-voltage characteristic

Spectral response of the sample no. 2 was measured. Known properties of the perovskite crystals is its response to UV light (3). In this way is possible to verify the obtained structure. From Figure 5 it is evident that the overall response of the sample is concentrated near 470 nm (between the UV and visible spectrum). Produced solar cells therefore had an active perovskite structure.

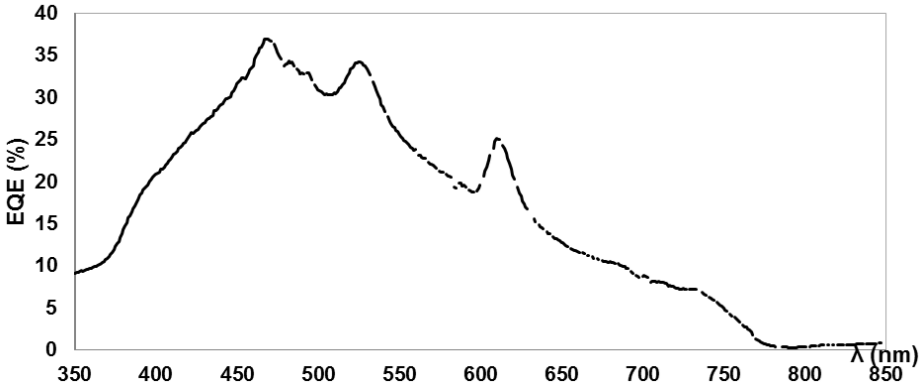

Figure 5. Spectral response of perovskite solar cell – sample no. 2.

3.2. IMPACT OF MOISTURE TO PEROVSKITE STRUCTURE

With a measurement during illumination the efficiency has increased to a certain value, then again has dropped. The reason is probably in the temperature of the sample during measurements (samples were rapidly heating). Samples were also measured consecutively in short intervals. The gradual degradation of the material, well-known phenomenon of perovskite solar cells, has occurred later. The conversion efficiency of the cells has decreased significantly after 20 hours of its function from η_{MAX} = 7.22 % to η_{MAX} = 5.48 %. Degradation of the perovskite solar cells is currently one of the biggest problem of these materials [3].

Degradation and changes in the parameters of the perovskite samples is most influenced by moisture, which despite encapsulation may partially penetrate into the layers [1]. An interesting phenomenon has ocurred related to the gradual increasing and lowering of conversion efficiency. The grains have unified gradually leading to the enlargement of its volume. This may involve into the reducing of the number of grain boundaries which forms a barrier to the flow of current, which could explain the increasing and decreasing of the efficiency. AFM microscope analysis was done because of observation of ongoing processes – Figure 5. This phenomenon will be given additional measurements on perovskite photovoltaic cells.

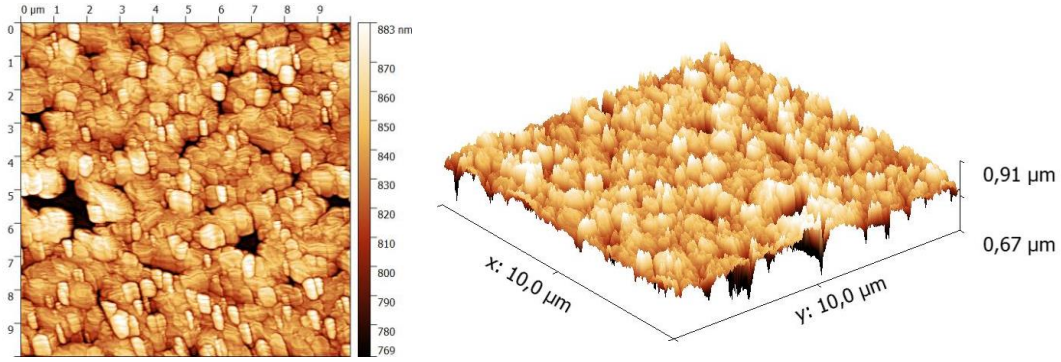

Figure 5: left: AFM microscopy analysis of perovskite solar cell active layer, right: 3D model of perovskite solar cell active layer

4. CONCLUSION

Originally, there were perovskite solar cells prepared in combination with liquid electrolyte, but there has occurred rapid degradation due to dissolution of crystals of perovskite. Substantial development progress has been achieved by optimizing the parameters in terms of manufacturing process or by the intervention in the chemical structure of the cells.

In total has been created a six solar cells. Manufacturing process were adjusted by analyzing the perovskite solar cells. Conversion efficiency of created cells was equal to approximately 6 %. The best sample no.1 has reached promising 7.22 % conversion efficiency. Follow-up work will try to improve the manufacturing process and prevent the perovskite solar cell degradation.

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