**Uzbek Journal of Physics**
**25(1), 67-72, 2023. DOI: https//doi.org/ 10.52304/.v25i1.408** 

# Improving parameters of inorganic perovskite solar cells by more than one spin coating method

**Erkin Zakhidov[1], Sherzod Nematov[2], Aziz Saparbaev[*,1,3], Tajibaev Ilkhomjon[1], Lobar Nurumbetova[1], Boburbek Khidirov[1], Ilhom Boynazarov[1], Abror Turgunboev[1], Farid Ruziyev[1]**

[1] Institute of Ion-Plasma and Laser Technologies, Uzbekistan Academy of Sciences, Durmon Yuli st. 33, 100125, Tashkent, Uzbekistan
[2] Tashkent State Technical University named after Islom Karimov, University st. 2, 100174, Tashkent, Uzbekistan
[3] National University of Uzbekistan named after Mirzo Ulugbek, University st. 4, 100174, Tashkent, Uzbekistan

Received 13.03.2023, revised 25.03.2023

*Corresponding author: e-mail: saparbaevaziz83@gmail.com, Phone +998 88 78014 41

В этой работе сообщается о процессе изготовления перовскитных пленок с морфологией хорошего качества и оптимальной толщины с помощью простого процесса более чем одного спин коатинга или метода множественного спин коатинга (MSC). Следует отметить, что перовскитные пленки с хорошей морфологией и оптимальной толщиной получаются без применения антирастворителей в условиях полного воздуха. В этой работе мы получили оптимальное хорошее значение эффективности преобразования энергии для $CsPbI_3$ перовскитных солнечных элементов на уровне 11.69%. Хотя результат эффективности преобразования энергии недостаточно высок, тем не менее этот метод MSC обеспечивает простой и несложный подход к изготовлению перовскитных солнечных элементов.

**Ключевые слова:** перовскит $CsPbI_3$; многократное покрытие, солнечные элементы; модификация поверхности, антирастворитель.

This work reports the fabrication process for preparation of perovskite films with good quality morphology and optimal thickness by a simple process of more than one spin coating or multiple spin coating (MSC) method. It should be noted that perovskite films with good quality morphology and optimal thickness are prepared without antisolvent engineering in full air conditions. In this work, we obtained an optimal good power conversion efficiency (PCE) value for $CsPbI_3$ perovskite solar cells (PSCs) at 11.69%. Although, the PCE result is not high enough, however, this MSC method provides a simple and uncomplicated approach for fabrication of PSCs. (PCE) value for at 11.69%. $CsPbI_3$.

**Keywords**: $CsPbI_3$ perovskite; multiple coating; solar cells; surface modification; antisolvent engineering.

## I. Introduction

Perovskite materials are among the most abundant elements on Earth, and perovskites are notable for their low cost and low energy consumption in the manufacturing of solar cells. So, it will be very suitable for large-scale production techniques in the future. There has been considerably large amount of attention paid to improvement of performance and simplification of manufacturing processes based on perovskite photovoltaic technology. However, there are many challenges in the field of PSCs for achieving these goals. The major challenge is to prepare quality perovskite solution and its coating for perovskite films with high quality morphology. The issues like limited solubility of perovskite materials in solution and very complex fabrication process stand in the way of solving this problem [1-5]. To solve such problems and improve the efficiency of organic and inorganic PSCs, various techniques have been developed to uniformly

coat the perovskite active layers (PAL), for example, heating, gas flow in the vacuum conditions, antisolvent engineering [6-10], one step and two steps coating methods, chemical additives such as acid additives [11] and surface modification via different fabrication methods [12]. In recent times, inorganic perovskite materials have attracted great attention due to good thermal stability as compared to hybrid and organic perovskite. Notably, PCE of PSCs is also impressively high, but complex device fabrication method and high temperature for annealing process are key problems [4]. Some researchers reported the fabrication process employing complex multiple solvent engineering process, excessive energy and tedious steps [13-15]. For instance, the synthesis of $PbI_2$·xDMAI (dimethylammonium iodide (DMAI)) (x=1.1−1.2) was done by $PbI_2$ and 57% w/w hydroiodic acid (HI) (molar ratio 1:1.2) in dimethylformamide with treatment of excess HI to guarantee completion of reaction. After the product purification processes like precipitation, evaporation under high vacuum, centrifugation and washing, the coating of laser patterned FTO (TEC-7) substrate was done with a dense $TiO_2$ layer by spray pyrolysis of 0.2 M Ti(IV)bis(ethyl acetoacetate)-diisopropoxide. Later on, the annealing process was done at 450 °C for 1 h. The preparation of 0.6M $CsPbI_3$ perovskite precursor by dissolving stoichiometric CsI, $PbI_2$·xDMAI with 1:1 molar ratio was succeeded by the $CsPbI_3$ active layer spin-coating by pre-warmed c-$TiO_2$/FTO substrate with 210°C annealing treatment for 5 min in a dry box. Afterwards, the spin coating of 0.5CHI-$CsPbI_3$, CHI-$CsPbI_3$, 2CHI-$CsPbI_3$, respectively, was done on the annealed perovskite films. It is very important to mention that the fabrication process in this work was performed with complex more step process in dry air box, rather than in open full air conditions and one more key detail, cathode zinc, silver or gold were used in there was employed [16-18]. Here in this work, freshly synthesized $CsPbI_3$ was employed for preparation of PSCs and a facile coating method was adopted in combination of fabrication for high-grade perovskite films without antisolvent solution at low temperature in air condition.

## II. Description of the object and research mthods

### II.1. Materials

Indium tin oxide (ITO) coated glass substrates with a sheet resistance of 15 Ω/sq[1] were purchased from Shenzhen Display (China). Hydroiodic acid (HI) was purchased from Sino pharm chemical reagent Co Ltd. (China). Cesium iodide (CsI) and lead iodide ($PbI_2$) were bought from Xi'an polymer light technology Inc. (China). The poly(3,4-ethylenedioxythiophene/poly(styrenesulfonate) (PEDOT:PSS) solution (Clevios PVP AI4083) and [6.6]-phenyl-$C_{61}$-butyric acid methyl ester ($PC_{61}BM$) were purchased from H.C. Starck (Germany.

### II.2. Device fabrication method

In the first step, CsI and $PbI_2$ perovskite material were dissolved in dimethylformamide (DMF) solution with 1:1 M ratio (0.4 M) and stirred overnight at room temperature in full air condition. Then, HI acid (66 microL) was added into $CsPbI_3$ precursor solution before two hours of preparing perovskite film. ITO glass was cleaned via ultrasonic bath in acetone, deionized water and isopropyl alcohol for ten minutes each, after finishing all process dried by highly pure nitrogen gas. Subsequently, the ITO glasses were cleaned with oxygen plasma for six minutes. Afterwards, PEDOT:PSS was spin coated on the ITO glass and baked in an oven at 150°C for 15 minutes under full air condition. A simple MSC process was used for fabrication of good quality $CsPbI_3$ PALs in ambient condition. The ITO glass/PEDOT:PSS/$CsPbI_3$ perovskite substrates were thermally annealed at 100°C for 10 minutes on hot plate under ambient conditions (humidity is ~30%) and without antisolution treatment.

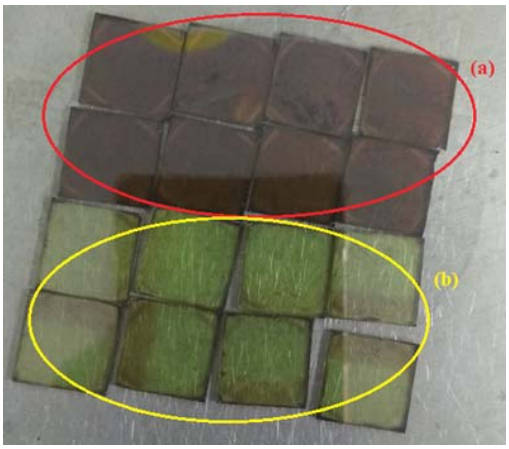



**Figure 1.** Photo of (a) black phase or cubic structure of perovskite films and (b) yellow phase or orthorhombic structure of $CsPbI_3$ perovskite films.

The color of perovskite films changed from yellow phase or orthorhombic structure to black phase or cubic structure (Fig. 1). After thermal annealing process of perovskite films, $PC_{71}BM$ (concentration of 20 mg/mL in 1.4-Dichloro-benzene) was spin coated on the CsPbI3 PALs. Finally, cathode lithium fluoride

©Academy of Sciences of Republic of Uzbekistan, 2023

(LiF) (thickness of ~1 nm) and Al (thickness of ~100 nm) was deposited in vacuum conditions at $5\times10^{-4}$ Pa via thermal evaporation method, a simplest form of physical vapor deposition (PVD). The active area 0.1 $cm^2$ of Al cathode device is denied by a shadow mask.

### II.3. Characterization

The absorption spectra of $CsPbI_3$ perovskite films on the quartz glass were obtained by spectrophotometer (Shimadzu, Japan). Bruker D8 Advance was employed to get the X-ray diffraction (XRD) spectra for $CsPbI_3$ perovskite. The analysis of defects and pinholes of perovskite films was done by Hitachi S-4800 scanning electron microscopy (SEM). The Current density-voltage (J-V) characterization of PSCs was performed by a Keithley 2420 source measurement unit under simulated 100 mW/$cm^2$ (AM 1.5G) irradiation from a Newport solar simulator.

## III. Results and discussion

The absorption spectra of the $CsPbI_3$ films are shown in Fig. 2, which were synthesized with CsI and $PbI_2$ (molar ratio 1:1) in DMF solution prepared perovskite films by MSC method and annealing at 100°C temperature in ambient condition. Absorption spectra (shown in Fig. 2) is very poor of perovskite film of yellow phase (orthorhombic structure) and the optical band gap $E_g$ of orthorhombic structured $CsPbI_3$ perovskite was ~2.81 eV [19].

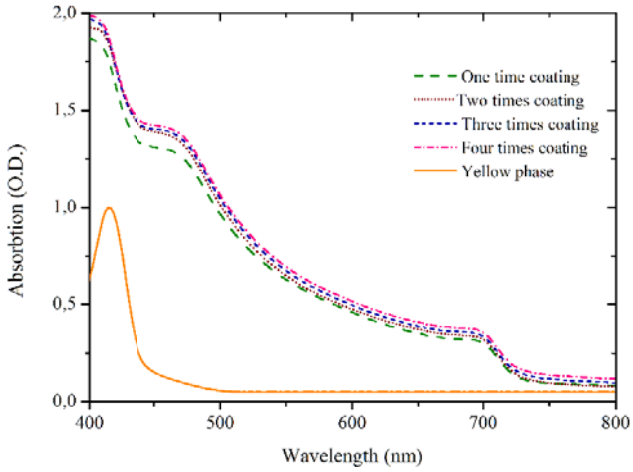



**Figure 2.** Absorption spectra of the perovskite films prepared under different conditions.

The perovskite film with orthorhombic shaped molecular structure shows an absorption peak indicated at ultraviolet wavelength and other device parameters (PCE=0.09%) are also very poor [20]. After annealing yellow phase perovskite films, the absorption area of black phase was higher than absorption area of yellow phase, and optical band gap is $E_g$ ~1.72 eV of black phase perovskite films [21,22]

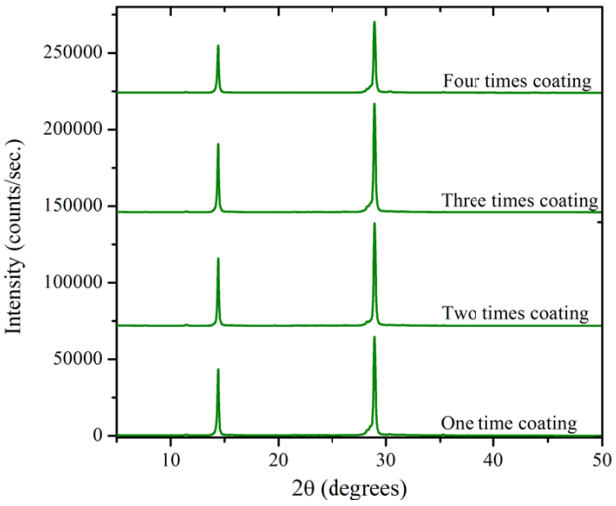



**Figure 3.** XRD patterns of the perovskite films prepared by different coatings at 100 ºC temperature

Figure 3 shows XRD spectra that were obtained to characterize the $CsPbI_3$ perovskite structures prepared by multiple spin coating method. By using once spin coating method for preparation of perovskite films, there were too many pinholes and defects with low cubic crystallinity, but XRD spectra peaks at diffraction angles 14º (100) and 28.8º (200) indicated formation of black phase structure of $CsPbI_3$ perovskite. We propose that this low cubic crystallinity could be due to the rapidly dried very thin film. Hence, device parameters are not good due to the reasons of thin thickness and poor morphology of perovskite films. In XRD analysis results, we could see that after two times spin coating of perovskite films, the crystallinity was comparatively improved than once spin coated perovskite films.

It should be noted that large grain size of perovskite black phase structure contributed to an excellent charge separation and assembly. So, these results also improved device parameters of PSCs. However, we controlled improvement of crystal structured phase by increasing thickness via MSC (once more) method, which resulted in perfect transformation into high quality morphology without anti-solvent engineering. Our method shows that the existence of the pinholes and defects is completely dependent on the MSC method [23-27]. These results indicated that $CsPbI_3$ perovskite films attain good surface morphology and crystallinity by MSC method

©Academy of Sciences of Republic of Uzbekistan, 2023

and thermal annealing at low temperature in ambient condition.

For analysis of grown size (not thickness of perovskite film) of perovskite structure, the particle size of $CsPbI_3$ perovskite black phase structure was calculated by Scherrers equation. Therefore, the line broadening at half of the maximum intensity (FWHM) was taken from highest intensity of the diffraction peaks at (200) with diffraction angle 2θ of 28.8º (Fig. 4 and Table 1). The Scherrer equation can be written as:

$$t = \frac{k\lambda}{\beta \cos\theta}, \qquad (1)$$

where $t$ is mean size of domains in perovskite structure, $k$ is a dimensionless shape factor value of about 0.9, λ is X-ray wavelength value of 1.5406 Å, β is the FWHM, and θ is the Bragg's angle.

The average crystallite size of perovskite structure formed for multiple coated active layers was calculated as: 39.46 nm for one time coating, 39.49 nm for two times coating, 40.46 nm for three times coating, and 39.96 nm is for four-times coating (Table 1). The XRD spectra explain that the positions of the spectra peaks of X-ray did not change after once more spin coating process, but the peak intensity and crystal size of $CsPbI_3$ perovskite structure did change due to MSC method (Fig. 4 and Table 1) [26].

**Table 1.** Average crystallite size of $CsPbI_3$ calculated by using Scherrer equation annealed at 100ºC**.**

| Spin coating | 2θ (°) | λ (Å) | K | hkl | FWHM (rad) | $t$ (nm) |
|---|---|---|---|---|---|---|
| One time | 28.8 | 1.5406 | 0.9 | 200 | 0.001155 | 39.46 |
| Two times | 28.8 | 1.5406 | 0.9 | 200 | 0.001154 | 39.49 |
| Three times | 28.8 | 1.5406 | 0.9 | 200 | 0.001126 | 40.46 |
| Four times | 28.8 | 1.5406 | 0.9 | 200 | 0.00114 | 39.96 |

In Fig. 4, we can see SEM images to assess pinholes and defects in PALs. The image in Fig. 4a shows many pinholes and defects, that means the surface morphology with defects and density of traps as recombination centers, low shunt resistance leads to poor device parameters of PSCs. After two times spin coating process, quality of surface morphology of perovskite active layers (PALs) is less than once time coated perovskite film (Fig. 4b).

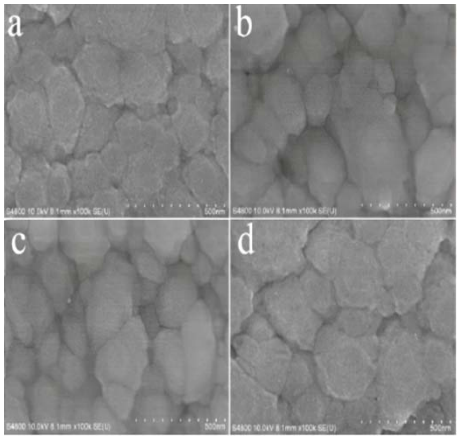



**Figure 4.** The SEM images of the perovskite layers with (a) one, (b) two, (c) three and (d) four times coating and annealing at 100ºC temperature.

As we employed three times coating process for preparation of PALs modified film thickness and fixed defects greatly improved with nearly complete eradication of pinholes and regrown sizes in perovskite structure. Perovskite film were prepared by four times coating method, and the quality of surface morphology and crystal size was lesser than other coating PALs. The morphological characteristics were not very high-grade like two and three times coated films. Therefore, the XRD spectra peaks and SEM patterns were poor for four times coated $CsPbI_3$ perovskite films.

The device parameters based on $CsPbI_3$ PSCs prepared by multiple coating methods are shown in Table 2 and Fig. 5.

**Table 2.** Device performance under different conditions and annealing at 100°C.

| Spin coating | $V_{OC}$ (V) | $J_{SC}$ (mA/cm$^2$) | FF (%) | PCE (%) |
|---|---|---|---|---|
| One time | 0.98 | 11.7 | 71.8 | 8.23 |
| Two times | 1.02 | 14.2 | 72.2 | 10.33 |
| Three times | 1.05 | 15.4 | 72.3 | 11.69 |
| Four times | 0.99 | 15.7 | 65.5 | 10.18 |

The one-time coated PSCs showed lower open circuit voltage ($V_{oc}$) values at 0.98 V and four times coated PSCs also had lower $V_{oc}$ value at 0.99 V. It should be noted that one-time coated PCSs exhibited almost same $V_{oc}$ value with four times coated PSCs. By using two times coating method for preparing PSCs films, the PSCs notably had good $V_{oc}$ value at 1.02 V, and three times coated PSCs also resulted high $V_{oc}$ value at 1.05 V. The PSCs device parameter results indicated that PAL's thickness and surface

©Academy of Sciences of Republic of Uzbekistan, 2023

morphology improved by increasing number of coating times. Hence, PSC's current density ($J_{sc}$) parameter values also increased and *J-V* curve optimal area of Fill Factor (FF) of PSCs with three times coating (Fig. 5). In detail, the $J_{sc}$ values were 11.7, 14.2, 15.4, and 15.7 mA/cm$^2$ of $CsPbI_3$ PSCs prepared by one-time, two times, three times and four times coating (MSC) methods, respectively. Consequently, the PCE value of $CsPbI_3$ PSCs prepared by MSC method were 8.23, 10.33, 11.69, and 10.18 %, respectively.

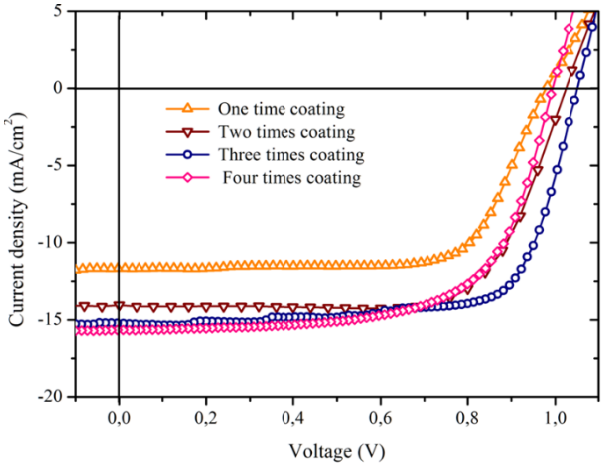



**Figure 5.** The current density-voltage characteristics of the $CsPbI_3$ annealing at 100ºC temperature.

We noted that although, the parameters and fabrication method of $CsPbI_3$ PSCs shown are not exceptionally efficient, but with further optimization, it could perform well like the silicon photovoltaic devices. However, the $J_{sc}$ values of devices prepared by three and four times coated $CsPbI_3$ PSCs stay almost same (15.4 and 15.7 mA/sm$^2$, respectively), but their FF values are very different. In detail, FF values of three times coating $CsPbI_3$ PSCs are higher than other (one time, two and four times) MSC methods (Table 2).

The FF values are nearly similar (FF~72%) for two and three times spin coated $CsPbI_3$ PSCs. The FF values, SEM and XRD results suggest that the quality of surface morphology and crystal size are very similar for two and three times coated $CsPbI_3$ PSCs. The $J_{sc}$ value of four times coated $CsPbI_3$ PSCs are better than other (one, two and four times) MSC methods (Table 2). We can explain these $J_{sc}$ results by attributing it to the increased thickness of PSCs by all MSC process, but with increased thickness, the quality of surface morphology was broken due to more than three times coating on $CsPbI_3$ PSCs. Hence, the FF, $V_{oc}$ and PCE values are lower than other MSC $CsPbI_3$ PSCs (Table 2 and Fig. 5). The lower FF values and SEM results suggest that surface morphology quality is low for four times coated $CsPbI_3$ PSCs. It should be noted that all spin coating processes are accomplished in ambient condition (humidity is ~30%) and without antisolution treatment (see device fabrication method).

## IV. Conclusion

In conclusion, in order to get better results in the organic and inorganic perovskite semiconductor technology, we need to find optimal approaches for the device fabrication process, for example, low cost, scalability, long time stability, low $V_{oc}$ loss and solvent/solution compatibility, etc. It is demonstrated that the planar structured inorganic $CsPbI_3$ PSC can be processed with high performance by simple methods at low temperature and without antisolution treatment. The MSC method has optimized surface morphology of $CsPbI_3$ perovskite film. It displayed that uncomplicated process of multiple coatings is key in device fabrication for good quality surface morphology of $CsPbI_3$ perovskite films under ambient conditions. As shown by results, the defects and pinholes were repaired in perovskite structures and the thickness along with the quality of film was improved by MSC method. In addition, our results reveal that such MSC method is promising for simplifying device fabrication processes and designing highly efficient PSCs.

**Acknowledgments.** This work was supported by Ministry of Innovative Development of the Republic of Uzbekistan (project FZ-20200929177) and Institute of Ion Plasma and Laser Technologies of Academy Science of Uzbekistan.

## References

[1] J. Cui, H. Yuan, J. Li, X. Xu, Y. Shen, H. Lin, M. Wang. Sci. Technol. Adv. Mater. **16**, 1-14 (2015)..
[2] R. Anbarasan, M. Srinivasan, J. Kalyana Sundar, P. Ramasamy. Mater. Technol. **37**,1026-1030 (2022).
[3] Jun Wang, Chaoyang Jin, Di Mei, Yan Ding, Lei Chang, Shijie Zhu, Liguo Wang, Yashan Feng & Shaokang Guan. Surf Eng. **37**, 963-971 (2021).
[4] B.G. Krishna, D.S. Ghosh, S. Tiwari. Solar Energy **224**, 1369-1395 (2021).
[5] N.R. Ashurov, N.S. Ashurov, J.T. Azimov, S.E. Maksimov, S.S. Rashidova. Appl. Sol. Energy **55**, 8-11 (2019).
[6] H-B. Kim, H. Choi, J. Jeong, S. Kim, B. Walker, S. Song, J.Y. Kim. Nanoscale **6**,, 6679-6683 (2014).
[7] M. Zhang, Z. Wang, B. Zhou, X. Jia, Q. Ma, N.X. Yuan, J. Zheng, Ding., W.H. Zhang. Sol. RRL. **2**, 1700213 (2018).

©Academy of Sciences of Republic of Uzbekistan, 2023

[8] R.E. Beal, D.J. Slotcavage, T. Leijtens, A.R. Bowring, R.A. Belisle, W.H. Nguyen, F.B. George, T. Eric, M.D. McGehee. J. Phys. Chem. Lett. **7**, 746-751 (2016).
[9] Y. Cao, Z. Liu, W. Li, Z. Zhao, Z. Xiao, B. Lei, W. Zi, N. Cheng, J. Liu, Y. Tu. Sol. Energy**220**, 251-257 (2021).
[10] L. Chao, Y. Xia, B. Li, G. Xing, Y. Chen, W. Huang. Chem. **5**, 995-1006 (2019).
[11] C. Gao, H. Dong, X. Bao, Y. Zhang, A. Saparbaev, L. Yu, Sh. Wen, Y. Renqiang, L. Dong. J. Mater. Chem. C **6**, 8234-8241 (2018).
[12] G.E. Eperon, V.M. Burlakov, P. Docampo, A. Goriely, H.J. Snaith. Adv. Funct. Mater. **24**, 151–157 (2014)..
[13] Y. Wang, T. Zhang, M. Kan, Y. Li, T. Wang, Y. Zhao. Joule **2**, 2065-2075 (2018).
[14] E. Zakhidov, M. Imomov, V. Quvondikov,Sh. Ne'matov, I. Tajibaev, A. Saparbaev, I. Ismail, B. Shahid. Appl. Phys. A **125**, 1-7 (2019).
[15] E.A. Zakhidov, M.A. Zakhidova, M.K. Imomov, V.O. Kuvondikov, S.K. Nematov, A.A. Saparbaev, I.I. Tazhibaev. J. Appl. Spectrosc.**87**, 464-470 (2020).
[16] B. Zhao, S-F. Jin, S. Huang, N. Liu, J-Y. Ma, D-J. Xue, Q. Han, J. Ding, Q-Q. Ge, Y. Feng, J-S. Hu. J. Am. Chem. Soc. **140**, 11716-11725 (2018).
[17] E.G. Shmagina, E.A. Konshina, D.P. Shcherbinin, P.D. Khavlyuk, M.S. Stepanova. Surf. Eng. **37**, 437-444 (2021).
[18] Y. Yang, H. Huang, F. Wang, J. Zheng, J. Wang, Z. Tang, F. Zhou, M. Chen, Q. Wang. Surf. Eng. **37**, 1-8 (2021)
[19] J.A. Steele, H. Jin, I. Dovgaliuk, R.F. Berger, T. Braeckevelt, H. Yuan, M.B. Roeffaers. Science **365**, 679-684 (2019).
[20] H. Choi, J. Jeong, H-B. Kim, S. Kim, B. Walker, G.H. Kim, J.Y. Kim. Nano Energy **7**, 80-85 (2014).
[21] R.J. Sutton, M.R. Filip, A.A. Haghighirad, N. Sakai, B. Wenger, F. Giustino, H.J. Snaith. ACS Energy Lett. **3**, 1787-1794 (2018).
[22] W. Ahmad, J. Khan, G. Niu, J. Tang. Sol. RRL.**1**, 1700048 (2017).
[23] D.Y. Heo, S.M. Han, N.S. Woo, Y.J. Kim, T.Y. Kim, Z. Luo, S.Y. Kim. J. Phys. Chem. C **122**, 15903-15910 (2018).
[24] Y. Hu, F. Bai, X. Liu, Q. Ji, X. Miao, T. Qiu, S. Zhang. ACS Energy Lett. **2**, 2219-2227 (2017).
[25] Y. Jiang, J. Yuan, Y. Ni, J. Yang, Y. Wang, T. Jiu, M. Yuan, J. Chen. Joule **2**, 1356-1368 (2018).
[26] Y. Wang, M.I. Dar, L.K. Ono, T. Zhang, M. Kan, Y. Li, Z. Lijun, X. Wang, Y. Yang, Y. Qi, G. Michael, Y. Zhao. Science **365**, 591-595 (2019).
[27] A. Saparbaev, C. Gao, D. Zhu, Z. Liu, X. Qu, X. Bao, R. Yang. J. Power Sources **426**, 61-66 (2019).

## Ноорганик перовскит қуёш элементларининг параметрларини бир нечта спин қоплама усули билан яхшилаш

**Э. Захидов[1], Ш. Нематов[2], А. Сапарбаев[1,3], И. Таджибаев[1], Л. Нурумбетова[1], Б. Хидиров[1], И. Бояназаров[1], А. Тургунбаев[1], Ф. Рузиев[1]**

[1]ЎзРФА Ион-плазма ва лазер технологиялари институти, Дурмон йули 33, 100125, Тошкент, Ўзбекистон
[2]Ислом Каримов номидаги Тошкент давлат техника университети, Университет кўчаси 2, 100174 Тошкент, Ўзбекистон
[3]Мирзо Улуғбек номидаги Ўзбекистон Миллий университети, Университет кўчаси 4, 100174 Тошкент, Ўзбекистон

Ушбу мақолада бир неча спин коатинг ёки кўп қатламли спинли қоплама усули орқали яхши сифатли морфологияга ва оптимал қалинликка эга перовскит плёнкаларини ишлаб чиқариш жараёни ҳақида маълумотлар келтирилган. Шуни таъкидлаш керакки, яхши сифатли морфология ва оптимал қалинликдаги перовскит плёнкалари тўлиқ ҳаво шароитида эритувчига қарши муҳандисликсиз тайёрланади. Ушбу ишда биз $CsPbI_3$ перовскит қуёш элементлари учун оптимал яхши 11.69% энергия ўзгартирилиш самарадорлигига (ЭЎС) эришилди. Бироқ, ЭЎС натижаси етарлича юқори бўлмасада, бу кўп қатламли спин коатинг усули перовскит қуёш элементлари тайёрлаш учун оддий ва мураккаб бўлмаган ёндашувни таъминлайди.

**Калит сўзлар:** $CsPbI_3$ перовскит; бир неча қоплама; қуёш элементлари; сирт модификацияси; антисолвентларсиз.

©Academy of Sciences of Republic of Uzbekistan, 2023