

Conference materials

UDC 539.1

DOI: <https://doi.org/10.18721/JPM.153.217>

## Electrical characteristics of CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> lead halide Pervoskvite nanocrystal films deposited on Si-c solar cells for high-efficiency photovoltaics

L. Boudjemila<sup>1</sup>✉, V. V. Davydov<sup>1,2,3</sup>, A. N. Aleshin<sup>4</sup>,  
V. M. Malyshkin<sup>4</sup>, E. I. Terukov<sup>4</sup>

<sup>1</sup>Peter the Great Saint-Petersburg Polytechnic University, Saint Petersburg, Russia;

<sup>2</sup>The Bonch-Bruевич Saint Petersburg State University of Telecommunications, Saint Petersburg, Russia;

<sup>3</sup>All-Russian Research Institute of Phytopathology, Moscow Region, Russia;

<sup>4</sup>Ioffe Institute, St. Petersburg, Russia

✉ [lariessai21@gmail.com](mailto:lariessai21@gmail.com)

**Abstract.** The high performance of hybrid solar cells based on nanoparticles to improve optical and electrical performance is the subject of many current studies. For this purpose, nanoparticles of perovskite CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> are used as their optical properties have provided good interaction with crystalline silicon (Si-c), the absorption coefficient ( $\alpha$ ) is significantly high in different ranges which increases the generation of photocurrent in the range 370-900nm. The degradation quickly reduces the efficiency and for specific results, developed equipment is required. CsPbI<sub>3</sub> has shown a textured surface while CsPbBr<sub>3</sub> surface is smooth, according to this better measurement for iodine content became possible.

**Keywords:** hybrid solar cells, nanoparticles, optical properties, perovskite, photocurrent, degradation factor

**Citation:** Boudjemila L., Davydov V. V., Aleshin A. N., Malyshkin V. M., Terukov E. I. Electrical characteristics of CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> lead halide pervoskvite nanocrystal films deposited on Si-c solar cells for high-efficiency photovoltaics, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 15 (3.2) (2022) 91–96. DOI: <https://doi.org/10.18721/JPM.153.217>

This is an open access article under the CC BY-NC 4.0 license (<https://creativecommons.org/licenses/by-nc/4.0/>)

Материалы конференции

УДК 539.1

DOI: <https://doi.org/10.18721/JPM.153.217>

## Электрические характеристики пленок нанокристаллов перовскита галогенидов свинца CsPbI<sub>3</sub> и CsPbBr<sub>3</sub>, нанесенных на Si-c солнечные элементы для высокоэффективной фотовольтаики

Л. Беджамилла<sup>1</sup>✉, В.В. Давыдов<sup>1,2,3</sup>, Ф. Н. Алешин<sup>4</sup>,  
В. М. Малышкин<sup>4</sup>, Е. И. Теруков<sup>4</sup>

<sup>1</sup>Санкт-Петербургский Политехнический университет Петра Великого,  
Санкт-Петербург, Россия;

<sup>2</sup>Санкт-Петербургский государственный университет телекоммуникаций  
им. проф. М. А. Бонч-Бруевича, Санкт-Петербург, Россия;

<sup>3</sup>Всероссийский научно-исследовательский институт фитопатологии, Московская область, Россия;

<sup>4</sup>Физико-Технический институт им. А.Ф. Иоффе, Санкт-Петербург, Россия

✉ [lariessai21@gmail.com](mailto:lariessai21@gmail.com)

**Аннотация.** Высокая производительность гибридных солнечных элементов на основе наночастиц для улучшения оптических и электрических характеристик является

предметом многих текущих исследований. Для этого по результатам предыдущей работы использованы наночастицы перовскита  $\text{CsPbI}_3$  и  $\text{CsPbBr}_3$ , их оптические свойства обеспечили хорошее взаимодействие с кристаллическим кремнием (Si-c), коэффициент поглощения ( $\alpha$ ) становится значительно выше в разных диапазонах, что увеличивает генерацию фототока в диапазоне 370-900нм. Фактор деградации быстро снижает эффективность, и для конкретных результатов требуется развитое оборудование.  $\text{CsPbI}_3$  показал текстурированную поверхность, в то время как поверхность  $\text{CsPbBr}_3$  является гладкой, в соответствии с этим стало возможным лучшее измерение содержания йода.

**Ключевые слова:** гибридные солнечные элементы, наночастицы, оптические свойства, перовскит, фототок, фактор деградации

**Ссылка при цитировании:** Беджамил Л., Давыдов В. В., Алешин Ф. Н., Малышкин В. М., Теруков Е. И. Электрические характеристики пленок нанокристаллов перовскита галогенидов свинца  $\text{CsPbI}_3$  и  $\text{CsPbBr}_3$ , нанесенных на Si-c солнечные элементы для высокоэффективной фотовольтаики // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2022. Т. 15. № 3.2. С. 91–96. DOI: <https://doi.org/10.18721/JPM.153.217>

Статья открытого доступа, распространяемая по лицензии CC BY-NC 4.0 (<https://creativecommons.org/licenses/by-nc/4.0/>)

### Introduction

Recently, many research into improving performance and effectiveness of solar cells on perovskites has been provided. The research carried out to date makes it possible to consider the development of heterostructure tandem cells in order to limit various optical losses. As well as the Oxford Laboratories guarantee that currently, the best partner for Si-c is the perovskite material [1] due to the strong absorption of the light coefficient [2], tread structure [3], high mobility of charge carriers [4] and low manufacturing cost. Optically resonant nanostructures constitute a bridge between optics and nanometric scales, making it possible to reduce the confinement of light to the nanometric scale via the excitation of highly localized optical modes. This reduces a certain number of important optical devices such as wave guides, lasers, sensors, etc. historically, metal nanostructures paved the way to novel nanoscale optical phenomena and applications related to the effective light management in the deeply subwavelength regime [5]

This work mainly concerns how to improve the optical and electric properties of a solar cell with one junction by adding nanoparticles of perovskite of iodine and bromine  $\text{CsPbI}_3$  and  $\text{CsPbBr}_3$ , for their properties, strong absorption and/or emission, higher quantum yields of photoluminescence. This type of Np represents greater liaison energies of excitons and longer time of decrease of carriers by comparing them to those of massive crystals. [7]. The lead halide (Ncs)  $\text{CsPbI}_3$  and  $\text{CsPbBr}_3$  perovskite nanocrystals used in the current work are deposited on a crystalline silicon substrate coated with an ITO conductive layer. They are characterized respectively by a band gap granted between 1.75 and 2.13 eV [6] and 2.34 eV [8] while silicon band gap is 1.2 eV, which makes a varied heterostructure with a wider total band gap.

### Experimental Techniques of Elaboration and Characterization

The type of substrate used is crystalline silicon provided by Research and development center for thin-film technologies in energetics R&D Center TFTE LLC. Thin crystalline silicon substrates are doped to create the p-n junction. Subsequently, in order to reduce optical losses, the solar cells used are coated with a hydrogenated anti-reflection layer to reduce the risk of contamination. This layer is dark blue in color. It is commonly used as an insulator in microelectronics and as an antireflection layer in the photovoltaics. An additional layer is conductive ITO layer. And finally the deposition of  $\text{CsPbI}_3$  and  $\text{CsPbBr}_3$  perovskite nanoparticles is made. Two types of  $\text{CsPbI}_3$  and  $\text{CsPbBr}_3$  nanoparticles in the form of a compact solution were provided by the chemical laboratory of LETI University of Saint Petersburg.

The deposition of this solution is done by the spin coating technique. It is a deposition method which makes it possible to deposit a homogeneous film on a substrate. The film was deposited by centrifugation on the Si-c substrates at 2000 rpm for 30 s. The solution is dispersed at high speed. A homogeneous film is obtained. Molecular crystal synthesis of perovskite nanoparticles occurs during this deposition, during which the solvent evaporates, through a process of self-organization. And finally, an electrode made of ITO material with a thickness of 80 nm was deposited on top of the device by thermal evaporation. This structure is presented in Figure 1

After having prepared the substrates, the topography of the surface of the deposited layers is characterized by atomic force microscopy (AFM) of the SOLVER P47-PRO NT-MDT type. It makes it possible to quantitatively determine the roughness of surfaces as well as its thickness.

One of the most important properties of perovskite materials is the ability to emit light with high efficiency. The study of photoluminescence allows us to study this emission of light, the

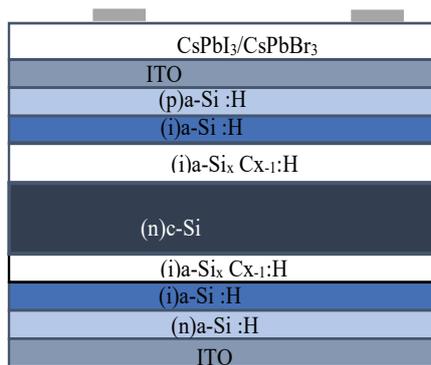


Fig. 1. The structure studied

nature of the halogen in the composition of the perovskite, or even whether the purity of the crystal is greater or lesser. The substrates were excited by ultraviolet LED UVTOP280TO39HS with a  $\lambda = 285$  nm. LED radiation focused on the surface of the samples using a quartz lens at an angle of  $10^\circ$  from the normal of the surface of the sample at a point 2 mm in diameter. The reflectance measurement was performed by the CARY5000 scan type spectrophotometer, which scans the entire ultraviolet, visible and near infrared solar spectrum from 200 to 2500 nm in R&D Center TFTE LLC.

The current-voltage (I-Vs) characteristics of the samples were measured in the vertical configuration by the two-probe scheme. The photocurrent current-voltage ( $I_{ph}$ -V) curves of the solar cells were measured with a Keithley 2400 source meter under simulated lighting from a homemade lamp at a calibrated solar simulator intensity of  $50 \text{ mW/cm}^2$  at room temperature in the air, and the scan direction is from open circuit at 0.5 V to short circuit at  $-0.5$  V with variable pitch. The contacts with the flat electrodes were made using gold wire and copper.

### Investigation results and discussion

The morphology was examined using an atomic force microscope (AFM) for two types of Ncs in the form of thin films, formed from a solution, deposited by spin-coating under the same conditions. Figure 2a, b show the AFM images. There is a noticeable difference in surface texture for  $\text{CsPbBr}_3$ , which is smooth and flat with complete absence of any spherical structure, unlike  $\text{CsPbI}_3$  for which spherical structures of various sizes were present with a random distribution, with an RMS value of:  $Sq = 10.32$  nm and 12.8 nm, respectively. Such a significant difference in RMS and average roughness can be explained by an increase in the size and density of  $\text{CsPbI}_3$  crystals. The latter can be attributed to light trapping and reducing optical losses, which increase the rate of absorption.

In view of the graphs shown in Figure 3 we find that the ratio decrease results in a shift of the

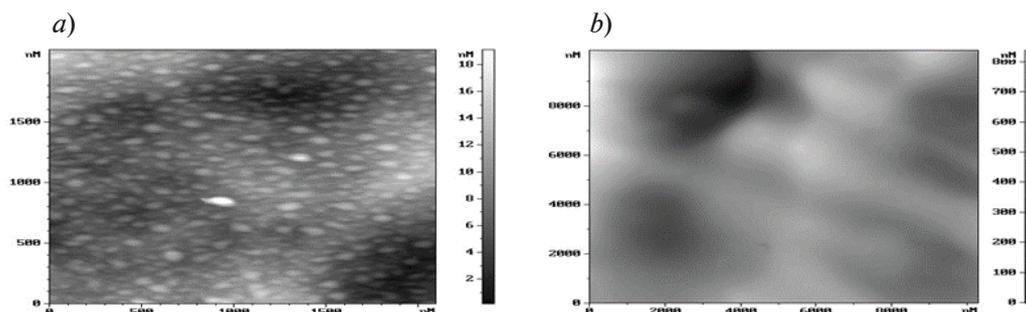


Fig.2. AFM images of  $\text{CsPbI}_3$  (a)  $\text{CsPbBr}_3$  (b)

reflectivity spectrum towards the near infrared region, which is due to an increase in the effective refractive index, the latter varies with the content of Ncs within the layer. Note also that the fringes are regularly spaced for Si-c and CsPbI<sub>3</sub>. This suggests that their refractive index is wavelength dependent in the same way. These effects are generally due to the increase in the depth refractive index of the layer. While for CsPbBr<sub>3</sub> the refractive index must be very different from the last two.

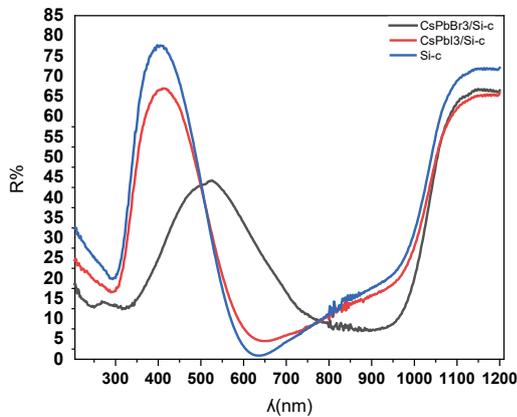


Fig. 3. Reflectance spectra of composite layers of perovskites and Si-c

The reflection rate remains quite high in the three substrates, which is far from meeting our expectations. And this is because of the absence of the anti-reflective layer which significantly decreases the reflection rate. Si-c and CsPbI<sub>3</sub> show quite similar results and for CsPbBr<sub>3</sub> the reflection rate is rather moderate, not exceeding 40%. The interaction of CsPbI<sub>3</sub> with Si-c is very weak while CsPbBr<sub>3</sub> gives another behavior totally different from Si-c.

For CsPbI<sub>3</sub>, the absorption rate is high in the range of 710–980 nm, while for CsPbBr<sub>3</sub> Ncs ( $\rho$ ) it is lower, but in a different range of 580–970 nm. This is related to the different role of Ncs as an indirect energy converter with Si-c. These results show a particular absorption in the UV region.

Figure 4 shows the photoluminescence spectra at ambient temperature of the thin films containing CsPbI<sub>3</sub> and MAPbI<sub>3</sub>, deposited on a crystalline silicon substrate.

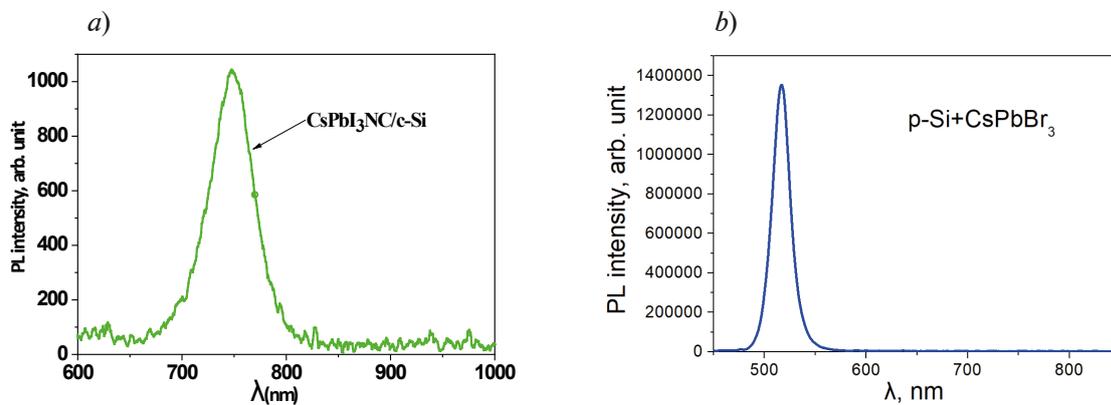


Fig. 4. Photoluminescence spectrum at room temperature for CsPbI<sub>3</sub> (a) and CsPbBr<sub>3</sub> (b)

The samples were excited with the 285 nm light. We find an emission peak centered at 2.47 eV for CsPbI<sub>3</sub> and MAPbI<sub>3</sub>. These are excitonic peaks, there are no peaks associated with possible defects, so it is intrinsic photoluminescence that we see on these spectra.

The PL intensity of iodine Ncs films at room temperature is observed with a maximum peak of about 740 nm, and the PL intensity of bromine Nc film has a maximum of about 550 nm, which confirms the results from literature [9]

The current-voltage characteristic  $I = f(V)$  of a solar cell makes it possible to determine the current as a function of the voltage for a given illumination. This measurement is carried out using a solar simulator whose irradiance spectrum is very close to the AM1.5 spectrum. The results obtained for the two types of perovskite nanoparticles CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> are presented in Figure 5. The essential parameter of our study is the short-circuit current since the main gain obtained with the nanoparticle structure is at the level of  $J_{sc}$ . The measured current for CsPbI<sub>3</sub> nanoparticles is higher comparing it with CsPbBr<sub>3</sub>, and CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> have higher current than the base substrates.

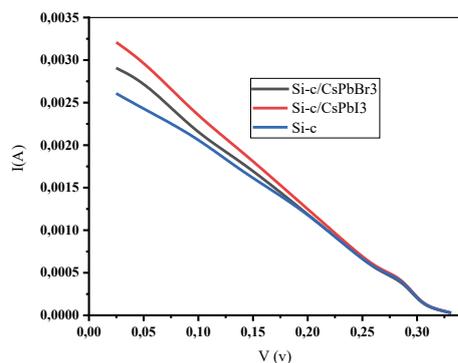


Fig. 5. The I-V characterization of CsPbI<sub>3</sub>, CsPbBr<sub>3</sub> and Si-c

The analysis of the dependences obtained shows that the currents coincide in the area of voltage increase. It is difficult to establish differences between the structures in terms of this dependence.

### Conclusion

However, 2D perovskite nanoparticles still offer a great potential due to the structure-dependent optic and electronic properties. Below the most important points are summarized from this work. The study of the external structure (morphology), a spherical form of nanoparticles makes a kind of textured surface which means it helps to provide an appropriated adjustment for optical optimization of

perovskite solar cells in addition, these nanoparticles are 0-dimension type. As a result, the size difference of CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> leads to a different interaction with the semiconductor based on crystalline silicon: a different absorption peaks in different ranges for CsPbI<sub>3</sub> it is 350–450 nm, and for CsPbBr<sub>3</sub> 530–850 nm, which means, this improves the absorption of our heterostructure (before perovskites nanoparticles fast degradation). It has been found that the absorption coefficient of SCs with NC layers of inorganic perovskites is much higher in the visible region of the spectrum, which increases photocurrent generation in SCs in the range of 370–900 nm. The reflectance measurement shows that the combination CsPbBr<sub>3</sub>/c-Si shows a better absorbance in a different range comparing to CsPbI<sub>3</sub>/c-Si. The photocurrent measurements of Si-c coated with CsPbI<sub>3</sub> and CsPbBr<sub>3</sub> perovskites nanoparticles show higher photocurrent comparing them with Si-c.

I-V characteristic showed higher current for CsPbI<sub>3</sub> about 3,25 mA for a 1cm<sup>2</sup> substrate which proves that this kind of nanoparticles has higher electrical properties than CsPbBr<sub>3</sub> which gives the current is 2.88 mA. And substrates coated with active layer with perovskites have higher current then a simple substrate Si-c for which it is about 2,55 mA.

### REFERENCES

1. Jung S., Enhancement of Photoluminescence Quantum Yield and Stability in CsPbBr<sub>3</sub> Perovskite Quantum Dots by Trivalent Doping. *Nanomaterials*. 2020, 10 (4) 710.
2. Chen Q., De Marco N., Yang Y., Song T.B., Chen C.C., Zhao H., Hong Z., Zhou H., Yang Y., Under the spotlight: The organic-inorganic hybrid halide perovskite for optoelectronic applications. *Nano Today* 2015, 10, 355–396.
3. Noh J.H., Im S.H., Heo J.H., Mandal T.N., Seok S.I., Chemical management for colorful, efficient, and stable inorganic-organic hybrid nanostructured solar cells. *Nano Lett.* 2013, 13, 1764–1769.
4. Oga H., Saeki A., Ogomi Y., Hayase S., Seki S., Improved understanding of the electronic and energetic landscapes of perovskite solar cells: High local charge carrier mobility, reduced recombination, and extremely shallow traps. *J. Am. Chem. Soc.* 2014, 136, 13818–13825.
5. Zheludev N. I., Kivshar Y. S., *Nature Materials* 11, 917 (2012).
6. Almosni S., Robert C., Thanh T. N., Cornet C., Letoublon A., Quinci T., Levallois C., Perrin M., Kuyyalil J., Pedesseau L., Balocchi A., Barate P., Even J., Jancu J. M., Bertru N., Marie X., Durand O., Le Corre A., Evaluation of InGaPN and GaAsPN 18 materials lattice-matched to Si for multi-junction solar cells. *J. Appl. Phys.* 2013, 113 (12), 123509-123509-6.
7. Wei, Y., Lauret, J. S., Galmiche, L., Audebert, P., Deleporte, E., Strong exciton photon coupling in microcavities containing new fluorophenethylamine based perovskite compounds. *Opt. Express* 2012, 20 (9), 10399–10405.
8. Giovanni M., Temperature-Dependent Optical Band Gap in CsPbBr<sub>3</sub>, MAPbBr<sub>3</sub>, and FAPbBr<sub>3</sub> Single Crystals *J. Phys. Chem. Lett.* 2020, 11, 7, 2490–2496.
9. Stoumpos C. C., Malliakas C. D., Kanatsidis M. G., Semiconducting Tin and Lead Iodide Perovskites with Organic Cations: Phase Transitions, High Mobilities, and Near-Infrared Photoluminescent Properties (*Inorganic Chemistry*, A, 2015).

## THE AUTHORS

**BOUDJEMILA Linda**

ariessai21@gmail.com

ORCID: 0000-0003-3589-8941

**ALESHIN Andrey N.**

aleshin@transport.ioffe.ru

**DAVYDOV Vadim V.**

davydov\_vadim66@mail.ru

ORCID: 0000-0001-9530-4805

**MALYSHKIN Vladislav M.**

mal@gromco.com

**TERUKOV Evgenyi I.**

e.terukov@hevelsolar.com

*Received 05.08.2022. Approved after reviewing 21.09.2022. Accepted 21.09.2022.*