

### III. CONCLUSIONS

It is established that the temperature of the substrate directly affects the size of microcrystallites in the perovskite film deposited on the hot substrate. With increasing temperature, fine crystallites coalesce and form crystallites of much larger size. The resulting crystallites have a leaf-shaped structure. It is also found that the size of microcrystallites when deposited on a hot substrate varies from 1  $\mu\text{m}$  to 50  $\mu\text{m}$  (at a substrate temperature of 120  $^{\circ}\text{C}$ ) and 100  $\div$  500  $\mu\text{m}$  (for 200  $^{\circ}\text{C}$ ).

It has been established that as a result of experimental studies, the method of depositing a layer of perovskite on a hot substrate is very promising. Since the substrate temperature is maintained at the boiling point of the precursor solution with this method of deposition, the solvent evaporates very rapidly, which makes it possible to obtain large crystalline grains. From these data, it can be concluded that the use of high-boiling solvents can provide ideal conditions for the growth of large crystalline grains.

### REFERENCES

- [1] Wanyi Nie, Hsinhan Tsai, Reza Asadpour, High-efficiency solution-processed perovskite solar cells with millimeter-scale grains // Science – 2015. – Vol. 347. – P. 522-525.
- [2] Tsai H., Nie W., Lin Y-H., Blancon J. C., Tretiak S., Even J., Gupta G., M. Ajayan P., and D. Mohite A. Effect of Precursor Solution Aging on the Crystallinity and Photovoltaic Performance of Perovskite Solar Cells // Adv. Energy Mater. – 2017. – Vol. 7. – P. 1–9.

## NANOSTRUCTURED THIN FILM OF HALIDE PEROVSKITES VIA TWO-STEP SOLVENT-SOLVENT EXTRACTION

D. Rudnitskaya, A. Shakhnovich, B. Shulitski  
Belarusian State University of Informatics and Radioelectronics, Minsk Belarus

### I. INTRODUCTION

The combination of electrical properties and absorption characteristics of hybrid perovskites made it possible to increase the efficiency of energy conversion of solar cells on their basis during 2012-2013 from 7.2 % to 20 % [1]. It can be used in solar cells instead of silicon or as an upper-layer of silicon solar cells to increase energy production by absorbing light from a part of the spectrum, that silicon can not absorb.

The key problems of the perovskite solar cells (PSCs) are the uniformity of the films, the lack of stability and the durability of perovskite solar cells, which are directly related to the methods of film formation on the substrate. Among the methods of obtaining perovskite films, an interesting method is the solvent-solvent extraction from solution (SSE) [2]. The advantages of the SSE method – room-temperature process, rapid crystallization, uniform application, film-thickness control, film smoothness and compounds versatility.

However, there are a number of disadvantages in this method. There are through holes between the individual crystals of the film, the materials of hole-transporting and electron-transporting layers meet, forming parasitic contacts, which are shunting the organometallic perovskite and reducing the open-circuit voltages of the solar cell. And a small grain size, which reduces the effectiveness of PSCs. In this article we proposed and researched a two-step SSE method with following thermal annealing.

### II. EXPERIMENTAL

A schematic illustration of the two-step SSE method for obtaining perovskite films is shown in Figure 1.

The perovskite solution obtained by mixing  $\text{CH}_3\text{NH}_3\text{I}$  and  $\text{PbI}_2$  in an organic solvent of N-methylpyrrolidone is spin-coated to a previously applied ITO template on a glass substrate and immediately immersed in a bath of diethyl ether (DEE). After two minutes, the perovskite film acquires brown color, after which the sample is removed from the bath and dried in the oven. After that, the sample was returned to the spin-coating, where the second layer of perovskite was applied to the sample. Further, the extraction and drying operations were carried out in the same way as the first step. It was found that during rotation on a spin-coating, the perovskite film began to change color from pale yellow to light brown, which may indicate the onset of crystallization of perovskite already at the centrifugation stage. In this case, the start time of the color change of the film is inversely proportional to the rotational speed of the spin-coating.

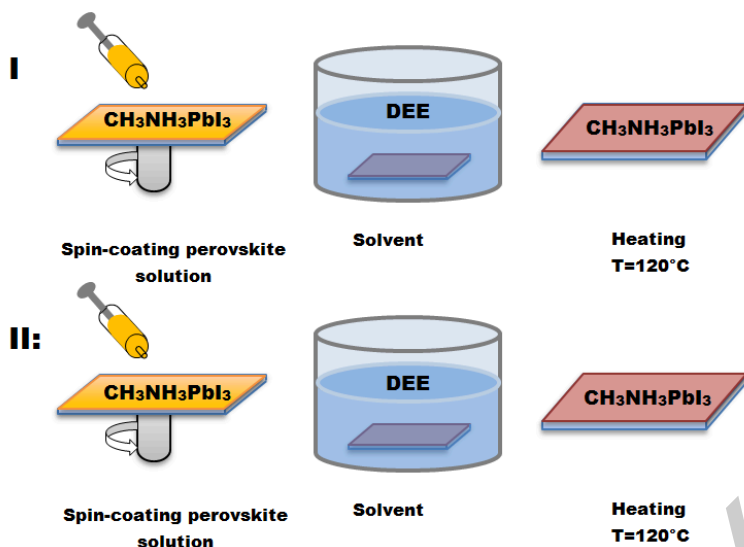


Figure 1 – Schematic illustration of the two-step SSE method for obtaining perovskite films

A microphotograph of a perovskite film obtained by a two-step SEE method followed by thermal annealing is shown in Figure 2. As can be seen from the figure, the film thickness is 615 nm. The film has a nanoporous structure with a pore size in the range of  $20 \div 200$  nm and a microcrystallite size of about 200 nm. At the same time, as we see on the microphotograph of the chip (Figure 2b), pores of a through nature are lack, which excludes the possibility of closing the functional layers of the photovoltaic cell.

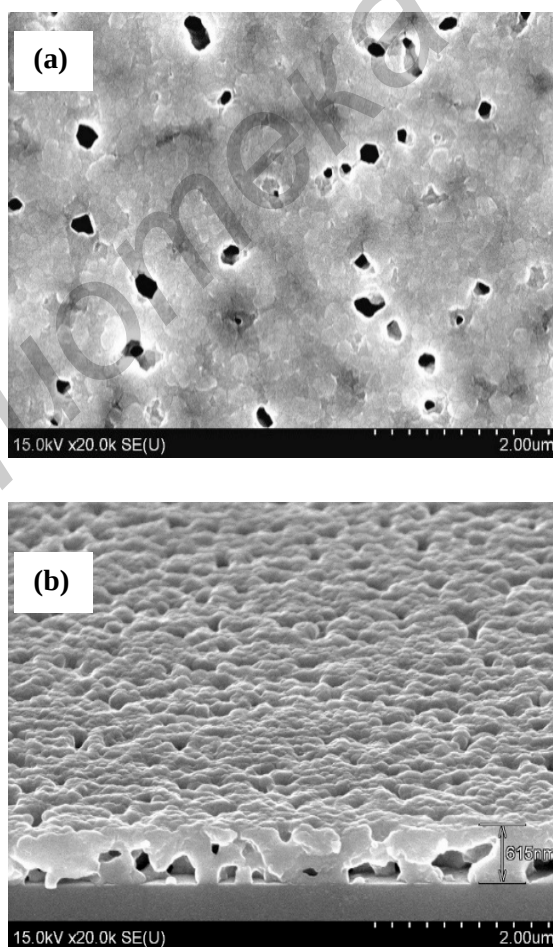


Figure 2 – Microphotographs of a perovskite film obtained by a two-step SSE method

### III. CONCLUSIONS

Thus, it was found that, in contrast to the one-step application of the perovskite precursor and drying of the perovskite film at room temperature, the two-step SSE method makes it possible to improve the crystal structure of thin perovskite films. Due to overlapping of the two layers of the film, porosity is reduced and there are no through holes that short-circuit the functional layers of the photovoltaic cell. Moreover, the annealing promotes consolidation and packing of film grains.

### REFERENCES

- [1] Park, N.G. Organometal perovskite light absorbers toward a 20% efficiency low-cost solid-state mesoscopic solar cell // *J. Phys. Chem. Lett.* – 2013. – Vol. 4. – P. 2423-2430.
- [2] Zhou Y., Yang M., Wu W., Vasiliev A. L., Zhu K., Padture N. P. Room-Temperature Crystallization of Hybrid-Perovskite Thin Films via Solvent-Solvent Extraction for High-Performance Solar Cells // *J. Mater. Chem. A.* – 2015. – Vol. 15. – P.1–18.

## THE EXCITATION POWER DEPENDENCE OF THE RAMAN G AND 2D PEAKS OF SUSPENDED GRAPHENE GROWN BY CHEMICAL VAPOR DEPOSITION

K. Nigirish, M. Mikhalik, N. Kovalchuk, I. Komissarov  
 Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

### I. INTRODUCTION

Increasing the power densities of electronic device makes the problem of an efficient heat removal crucial for their performance. High electron mobility transistors (HEMT) based on GaN provide an order of magnitude higher power densities than GaAs based transistors do [1]. In such high-power density devices the hot spots formed by non-uniform heat generation significantly reduce devices efficiency [2]. Balandin and co-authors showed that graphene quilts can be used for thermal management of GaN HEMTs [3]. Indeed, graphene has exceptional thermal conductivity [4], but its value strongly varies with defects density [5], number of layers and their stacking order [6]. The heat conductivity measurement of graphene is itself a challenging task. One of the most common methods to measure thermal transport in graphene (or in 2D materials in general) is optothermal Raman thermometry [4, 7]. The ideology of these experiments is based on the opportunity to heat graphene and measure its temperature simultaneously at the same point by the laser beam, where the positions of G and 2D peaks are used to trace the temperature rise.

In this article we present the results of the excitation power dependence study of the Raman G and 2D peaks of graphene grown by chemical vapor deposition and suspended over copper grid with 100  $\mu\text{m}$  diameter holes.

### II. SYNTHESIS AND TRANSFER OF GRAPHENE

The synthesis of graphene was carried out by atmospheric pressure chemical vapor deposition (APCVD). This process is described in more detail in work [8]. In this work, we employed a wet-chemical room temperature transfer process of graphene. The copper foil was totally dissolved in a water solution of  $\text{FeCl}_3$ . The graphene film was gently washed several times in a bath with distilled water prior to the transfer onto copper grid, which includes through holes.

### III. EXPERIMENT

Raman spectra were recorded using Confotec NR500 confocal micro-Raman spectrometers, with 473 nm excitation wavelength. Micro Raman spectrometer mapping,  $20 \times 20 \mu\text{m}^2$ , procedure was performed with 1  $\mu\text{m}$  step and beam size spot  $\approx 600 \text{ nm}$ . The scheme of Raman experiment is presented in Figure 1. The transferred procedure leads about 10 % of holes coverage. The Figure 2 demonstrates optical and Raleigh images of suspended graphene which fully covers the hole in the grid. It is clearly seen that the graphene morphology is non homogeneous (light and dark spots) which are related to the thicker and thinner parts of the film [9]. Taking in the account the observed non-homogeneity we have decided instead to study Raman spectra locally perform mapping of the central part of the suspended graphene and study how the distributions of G and 2D bands positions change with the power of the laser beam. In the course of the