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Experimental study of heat transfer in thin-film perovskite-based structures using a low-coherent tandem interferometry

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The heat transfer in an archetypal system solar cell/environment was analyzed, in which the solar cell was a thin-film multilayer structure with a hybrid lead-iodide perovskite photoabsorber. The temperature field was mathematically modeled and heat maps of the cell at various irradiation intensities were calculated. It was found that the heating by a diffuse insolation does not exceed the threshold critical for the stability of the perovskite phase owing to dissipation into the environment, with the temperature maximum close to half of the overall thickness of the structure.

Keywords: perovskite, thin film, heat transfer, solar cells, diffuse insolation.

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At present, perovskite-like hybrid photoabsorbers are the most promising materials for thin-film solar cells of a new generation, including ones of tandem architecture [1], due to specific combination of optoelectronic properties, manufacturability, and ease of fabrication. However, such photoabsorbers are not sufficiently resistant to chemical degradation, which can be represented as photolysis, pyrolysis [2,3] and electrolysis [4] , i.e. side processes, which in the power generation mode on time scales are more several hundred hours significantly affect the efficiency of a solar cell. We have previously investigated the problems of photolysis and electrolysis of a perovskite layer under 1) application of the constant electric field and 2) irradiation in the short-wavelength part of the visible range [4,5]. But little attention is still paid in the literature to the question of whether the absorption of light by perovskite is accompanied by the increase in local temperature, which can also lead to degradation (pyrolysis), or whether heat is dissipated inside the cell [3]. Alternating functional (photoabsorbent, charge-transport, buffer) layers with different thermal conductivity : inorganic, for example, molybdenum oxide (MoO_3), $\varkappa = 25\,\mathrm{W/(m\cdot K)}$ [6], and molecular ones, such as metal phthalocyanine, $\varkappa < 0.6\,\mathrm{W/(m\cdot}\ textK)$ [7], can affect the efficiency of heat removal from the perovskite film to the substrate. It should be noted that the large number of interfaces, characteristic of multilayer hybrid photovoltaic converter, is the reason for significant errors in temperature measurements by optical methods (for example, using pyrometers) due to interference effects. Conventional „contact" methods of temperature control (thermocouple, etc.) are also unsuitable for solving this problem due to the measurement of the temperature of the sensor itself instead of the specific working area of the sample. Therefore, it is more correct to use non-contact optical methods, among which low-coherence tandem interferometry with nanometer resolution provides the most adequate temperature estimation in multilayer thin-film structures even under extreme conditions [8].

In this work, using the combination of vacuum and liquid deposition methods, multilayer thin-film structures of the type glass/doped tin oxide (FTO)/MoO_3(10 nm)/phthalocyanonin titanyl TiOPc(25 nm)/hybrid tricationic iodoplumbate perovskite $(Cs_{0.1}MA_{0.8}BA_{0.1})PbI_3$(300 nm)/$MoO_3$(10 nm)/TiOPc(25 nm)$MoO_3$(10 nm), were obtained. Such a scheme was due to the need for the subsequent production of a prototype of tandem configuration with two complementary photoabsorbers, buffer- and/or transport layers. High-pressure xenon arc-discharge lamp with AM1.5G filter and focusing lens with a diaphragm was used as a radiation source. Detailed description of sample preparation methodology can be found in the works [5,9]. With the help of an original installation for non-contact temperature measurement based on the tandem low-coherence interferometer (Fig. 1), developed at the Institute for Physics of Microstructures RAS, the change in the real temperature of the samples under continuous exposure to simulated solar radiation of various duration and intensity was analyzed. Detailed description of the temperature measurement methodology can be found in the work [8] and references therein. Numerical simulation of heat transfer processes in the thin-film structure was performed under certain boundary conditions: ambient temperature, incident radiation power, thickness and material of substrate. The calculations were carried out in the Wolfram Mathematica system by the finite element method using Runge–Kutta algorithms of the fourth order. Due to the large difference in size between the transition regions in the layers of the

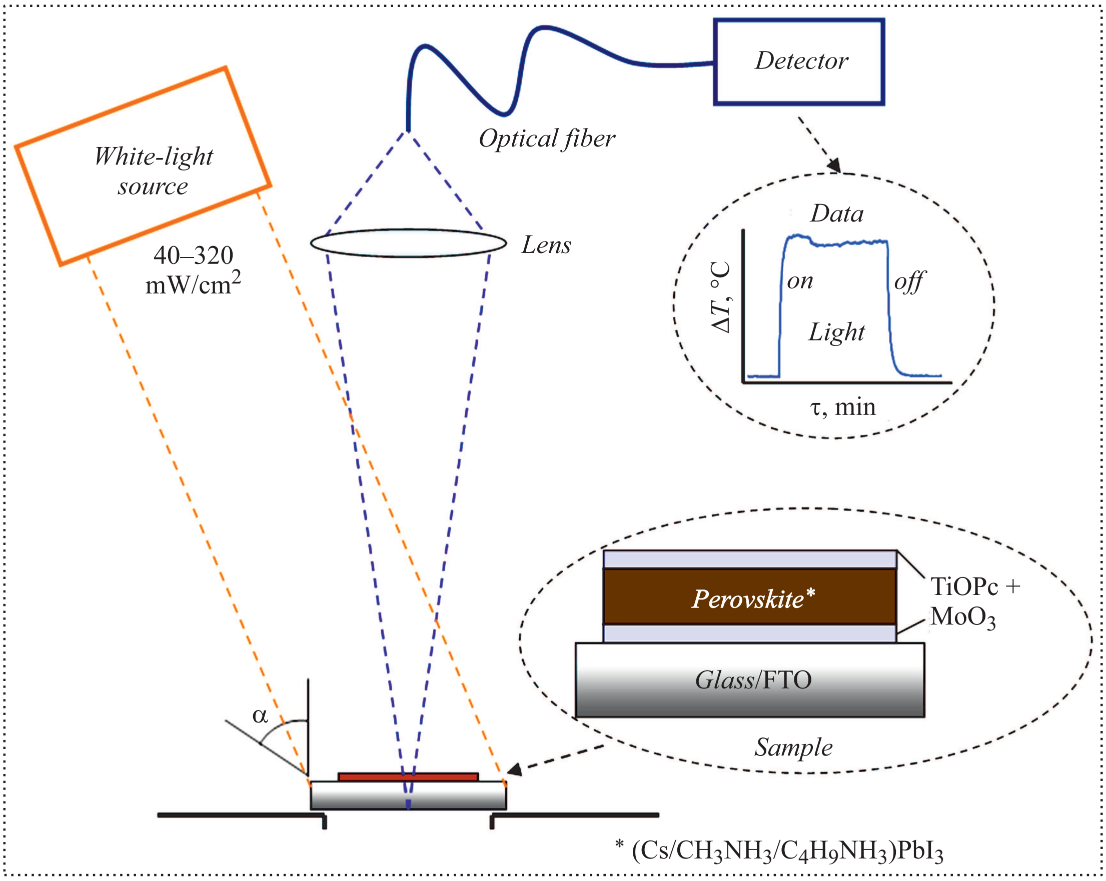

Figure 1. Scheme of the stand for non-contact temperature control of thin-film samples.

device, the thicknesses of the layers themselves and the thickness of the substrate, grids of different scales were used.

The samples under study were placed on bronze section bar coated with polished black alkyd enamel, or on support of two parallel optical fibers with diameter of 250 μm. Two variants were tested: 1) standard solar cell, designed in such a way as to absorb the maximum amount of incident radiation; 2) semi-translucent solar cell with the functionality of a decorating energy-generating coating. The power of the incident radiation was varied in the range 40–320 mW/cm^2 in order to simulate different levels of insolation. One sun corresponds to ~ 100 mW/cm^2, in real conditions, insolation is determined by geographic coordinates, meteorological conditions and the presence of the solar concentrator in the photoconverter circuit.

At the irradiation power of 40 mW/cm^2, the clean glass/FTO substrate placed on a dark surface is heated by 15°C, and the substrate with multilayer thin-film structure (coating) by 20°C (Fig. 2, *a*) relative to the ambient temperature ($\sim$ 23°C). On the support made of optic fiber, with similar irradiation power, the temperature difference between the sample and the environment does not exceed 10°C in the cases of the presence or absence of the coating.

At 100 mW/cm^2 on the support, the clean substrate and coated substrate are heated by 15 and 25°C, respectively. It is interesting that the substrate, on the surface of which only 50 nm thick TiOPc layer is deposited, heats up by almost 20°C.

At 120 mW/cm^2 on the dark surface (Fig. 2, *a*) the coated substrate was heated by 40°C.

At 320 mW/cm^2 on the dark surface (Fig. 2, *a*) the coated substrate was heated by record-setting 90°C relative to the temperature environment ($\sim$ 23°C).

Theoretical calculations of the change in the temperature of the samples, carried out under the appropriate boundary conditions, showed good agreement between the results and the experimental data (Fig. 2, *b*). The heat map of the photoconverter prototype (Fig. 2, *c*) showed that thermal energy is not accumulated in the thin-film coating, but is quickly dumped onto the substrate and then slowly dissipates into the environment.

Thus, under the conditions of average annual diffuse insolation observed in the vast majority of territories of the Russian Federation, the temperature of the converter does not reach the critical (even for methylammonium Iodoplumbate, MAPbI$_3$) temperature of 75–80°C [10]. Adapting the cell schematic and/or technology to minimize perovskite pyrolysis through better heat removal is a minor issue compared to other degradation processes such as photolysis or eletrolysis.

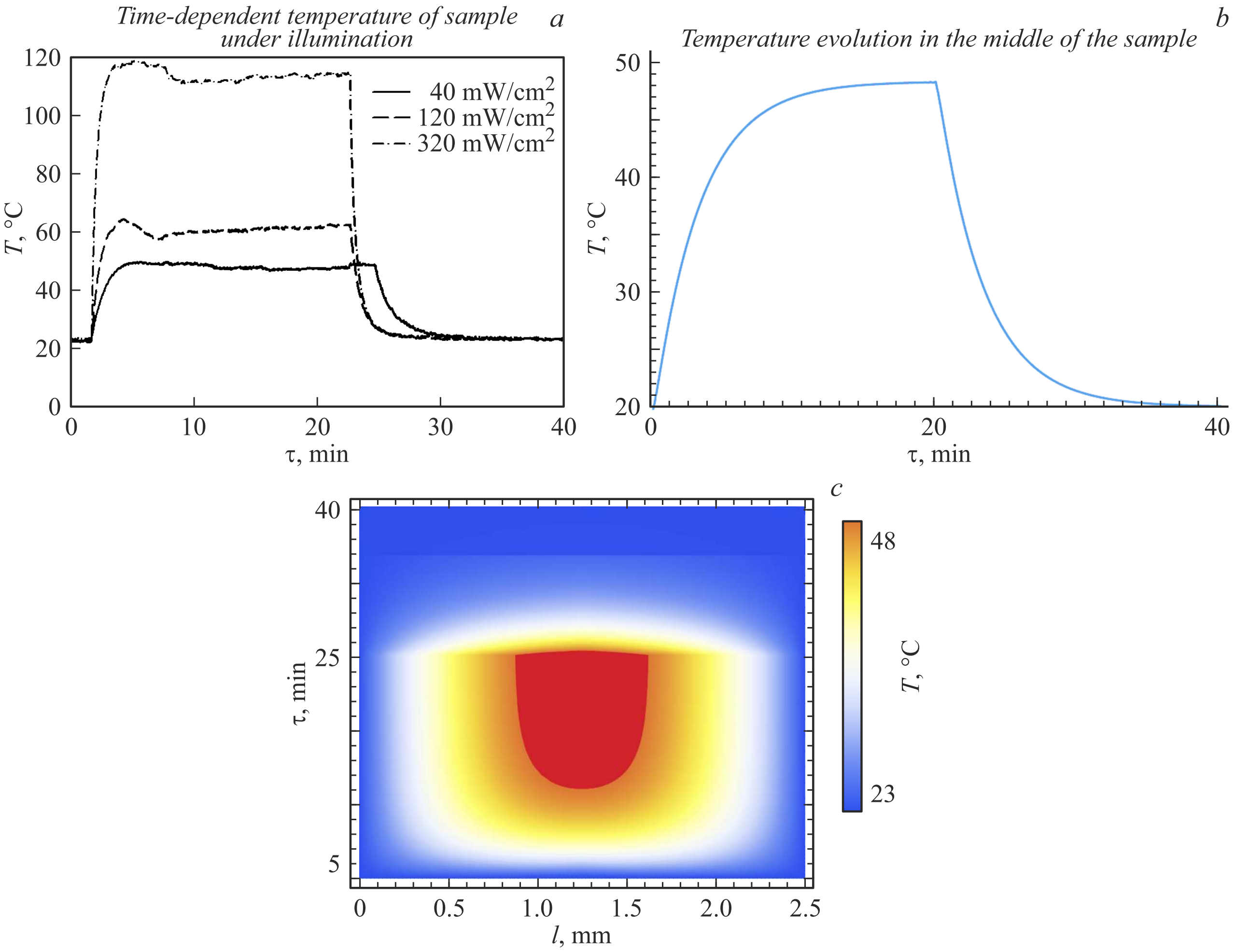

Figure 2. Experimental profiles(a) and calculated one (b) of temperature change of the perovskite-based thin-film structure on glass/FTO substrate under illumination with simulated solar radiation of various intensities. c is heat map for the calculated profile ($l = 2.5$ mm -is sample thickness).

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Conflict of interest

The authors declare that they have no conflict of interest.

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