

Photoelectric Properties of Solar Cells Based on Perovskites

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Abstract

Here we discuss materials and construction of particular solar cells that could be possible replacement for the current silicon-based photovoltaic cells, and methods of studying their performance. Solar cells based on the general perovskite structure (ABX₃) attracted in recent years much attention. These materials, due to the possible variability of both cations and anions in their composition, offer almost endless possibilities for synthetic preparation. For the active layer of a solar cell is often used the CH₃NH₃PbI₃₋₂Cl₂ perovskite structure, i.e., a structure containing an organic component. We have built photovoltaic cells with such an active layer and tested them by static and dynamic methods using the unique photoelectric research instrument by Zahner using the method CIMPS (Controlled Intensity Modulated Photocurrent Spectroscopy).

Keywords: Perovskite structure, photovoltaic cell, CIMPS

THE PEROVSKITE CELLS

relatively large size tolerance allowing inclusion of various ions [1].

Perovskite derived compounds

From the several methods of obtaining energy from sunlight photovoltaics is often favored as it provides directly electric energy, typically the most convenient energy source. In a solar cell the absorbed light in a semiconductor must generate an electron-hole pair, the opposite types of the charge carrier must be separated and a separate extraction of these carries to the external circuit must occur. Commercial sustainability of solar cell deployment requires financial affordability, which can be achieved in some combination of high efficiency, inexpensive materials used up per unit of generated energy, longevity and lately, as early solar cells are coming to end of their useful life, uncomplicated disposal or recycling.

One of the possible materials suitable as semiconductors for photovoltaic purposes is a class of compounds known as perovskites. Perovskite proper is the name of a mineral, chemically calcium titanate (CaTiO₃). The perovskite name is then used as a class names for compounds with the same crystal structure (CaTiO₃) known as the perovskite structure. The general structure has a formula ABX₃, where the A-site ion is usually an alkaline earth or rare-earth element, the B-site ion could be transition metal elements (3d, 4d and 5d) and X is usually oxygen anion. However, in the A-sites can be also placed functional groups such as CH₃- or NH₃- and the X can be for example also a halogen. Additionally, the compounds can be of a mixed nature as well, for example with chloride and iodide in a mixture serving as the negative charge site. The existence (and stability) of these structures is predicated on the fact that there is

Electric Measurements

One of the fundamental measurements of complete cells is their characterization in the dark, i.e., under conditions where electrons-holes are not generated by photons, and the overall conductivity of the system lies only in the presence of thermally generated electrons, and holes that can exist both fundamentally and as impurities. Electrical impedance measurements in the frequency range between 100 kHz and 0.1 Hz without illumination are easy to implement and provide useful information on charge transfer in the system and the rate of electron recombination. To characterize the rate of recombination, a procedure is used in which the impedance measurement is carried out step by step at many bias potentials, thereby changing the driving force of the charge transfer through the perovskite-HTM interface.

Electrical measurements of the photovoltaic cells under illumination are a natural verification of their function. One suitable characterization is their behavior in standard white light, for example with intensity of 100 mW·cm⁻² (so-called 1.5 AM). Of these characteristics, three parameters are typically determined for photovoltaic cells, suitable for comparing the results of different laboratories - open circuit potential, short circuit current and the so called fill factor. Fill factor is a figure of merit of a solar cell, a ratio of a maximum power obtained from the cell, divided by the maximum theoretical power, obtained by multiplying the short circuit current by the open circuit potential.

Modern experimental method, the intensity-modulated photocurrent spectroscopy (IMPS) and the related light-modulating photovoltage spectroscopy (IMVS) provide two basic parameters, the characteristic charge time and the characteristic electron recombination time, which we explored in this work. These parameters are determined from the frequencies in IMPS and IMVS minima of the impedance curves [2, 3].

Experiments

A set of samples based on commercial precursors manufactured by Ossila, Ltd, UK was prepared with an active area of 0.06 cm^2 . A basic simulation was verified on a solar radiation simulator and the functionality and power parameters of the samples were ascertained. The best cells, used in further studies, are listed in Table I.

	J_{sc} mA/cm ²	V_{oc} [mV]	FF [%]	η [%]	R_{shunt} k Ω ·cm ²	R_{series} Ω ·cm ²
ref	7.81	914	57.11	4.08	17.26	11.8.
1 b	19.06	854	32.61	5.31	1.02	17.9
2 e	21.35	896	32.80	6.28	0.98	16.4
3 f	18.65	919	35.37	6.07	1.54	26.8
4 e	24.05	934	35.18	7.90	1.04	17.4
5 b	24.81	905	33.33	7.48	0.83	15.7
6 f	15.50	844	36.70	4.81	1.60	15.4

Table 1: Parameters of the perovskite cells obtained from the measurement on the solar simulator.

The static and dynamic properties of the prepared samples were then studied on the research equipment by Zahner. The performance characteristics and the fill factor were measured at illumination 50-350 W/m² with a LED broadband light source and a characteristic wavelength of 608 nm. The results are summarized in Table 2. Static transfer functions were measured in a potentiostatic mode at 0-0.8 V, see Fig. 2.

light intensity (W·m ⁻²)	U_{max} (V)	I_{max} (μ A)	P_{max} (μ W)	Fill factor
50	0.871	-368.7	111.1	0.346
100	0.892	-543.5	168.4	0.348
150	0.902	-693.1	216.9	0.347
200	0.909	-830.1	261.4	0.346
250	0.914	-957.6	303.0	0.346
300	0.918	-1079	342.6	0.346
350	0.921	-1197	381.8	0.346

Table 2: Power parameters and the fill factor obtained with the Zahner equipment.

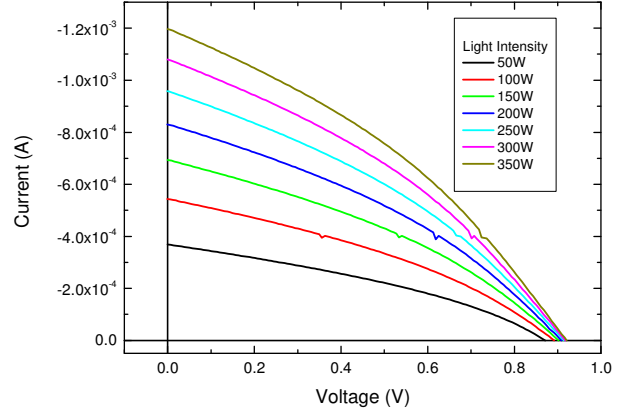


Fig. 1: Power characteristics of a research cell P3, sample 4.

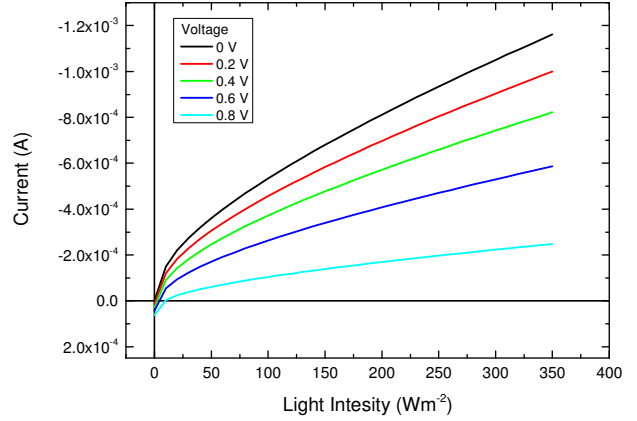


Fig. 2: Static transfer power characteristics of a research cell P3, sample 4.

Both the current and voltage methods, IMPS and IMVS, were used to provide the needed dynamic parameters for the assembled cells. For the measurement a $200 \text{ W} \cdot \text{m}^{-2}$ direct light intensity was chosen and the AC component was about ca. 10% of the DC component. The frequency range of the light excitation was within the capability of the instrument 7 MHz-100 mHz. The high frequencies, though, pretty much in parallel with electrochemical impedance, where there are many similarities, did not provide useful information at this stage. Thus, the evaluated frequency range in this work was about 50 kHz-100 mHz. Examples of the measured waveforms are shown in Figs. 3 and 4.

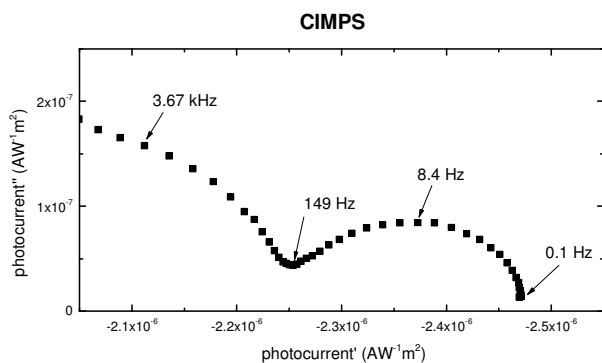


Fig. 3: IMPS (intensity modulated photocurrent spectroscopy) response with the several significant frequencies marked.

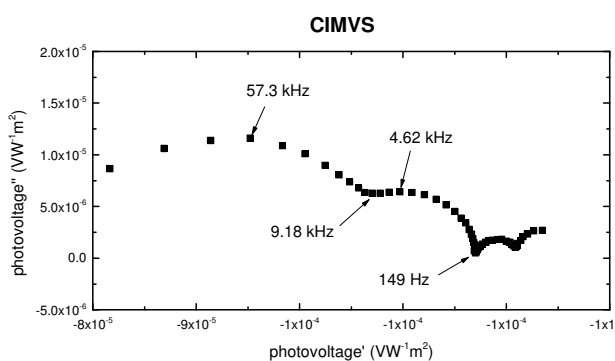


Fig. 4: IMVS (intensity modulated photovoltage spectroscopy) response with the several significant frequencies marked.

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