Perovskite solar cell efficiency improvements: new device simulation

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***Abstract*— Trihalide perovskite photovoltaic (PV) solar cells have a promise to be connected into tandems with inorganic PV systems. In this paper we present p-i-n GaAs & PV cells in either in-series way or parallel connection. Comparisons made for two types of tandems by a non-monolithic connection of two experimental sub-cells and results are being discussed based on simulation analysis. It is shown that parallel connection is always more preferable when the subcells photocurrent is not balanced Total efficiency over 20 % is demonstrated for GaAs shadding effect of by $MAPbI_3$ film, with achieved J_{sc} 41 mA/cm^2 and high V_{oc}, cell has better FF.**

Keywords*— *perovskite photovoltaic solar cell, simulation, tandem structure

I. Introduction

Even pero-photovoltaics (P-PV), that recently have created a fastest growing solar cell efficiency in the history, needs efficiency improving. New way has been suggested to obtain the organic transport layer based planar P-PV with very high J_{sc}. In-series tandem generates the minimal current of the subcell with lowest I_{sc}. A parallel connection allows to obtain I_{sc} which is sum of two currents, and two organic photovoltaic (OPV) have created tandems with semitransparent carbon nanotubes (CNT) interlayers.

Ag in in-series tandems the interlayer does not need to have low lateral resistance, in parallel tandem the low surface resistance is needed to provide lower loss due to R_{series} of the device. The P-PV with such laminated AgNW/CNT have been simulated and after it compared with experimental results.

II. Experimental Part

For such inorganic sub-cell we have chosen a p-i-n GaAs diodes, that are usually used as sensitive photodetectors due to their high mobility of charge carriers and sample design. Tandem device front view is presented in the Fig. 1, where perovskite sub-cell is installed directly on the top of GaAs sub-cell (shading area). Light measurements were done in standard 1.5 AM G conditions (100 mW/cm^2) with aperture mask usage (1 mm^2) to balance current densities of sub-cells.

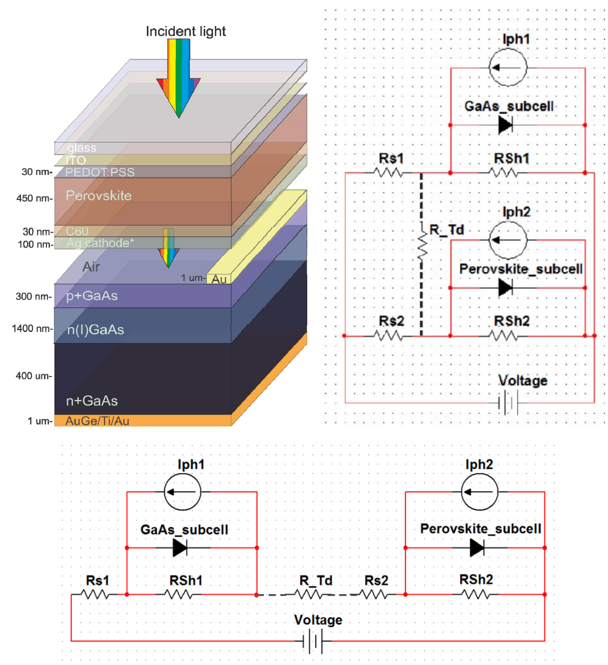

Fig. 1 Tandem device schematics (GaAs- perovskite tandem at short circuit regime); equivalent circuits of parallel and in-series tandems for single diode simulation

For simulation below mentioned model was used. Single diode model for extracting of parameters, such as R_{series}, R_{shunt}, non-ideality factor, J_o (dark saturation current), fitting of experimental and simulated curves and then calculation and simulation of tandem I-V characteristics for comparison with experimental results were used. Accordingly for tandem connection regimes GaAs and Perovskite sub-cells were connected in parallel and in series, respectively (Fig. 1).

Basic equation (1) for parameters extraction during filling with experimental data curve :

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$$J = J_{Ph} - J_0 \left\{ \exp\left[\frac{q(V+JR_S)}{kT}\right] - 1 \right\} - \frac{V+JR_S}{R_{Shunt}} \quad (1)$$

In this work the aim is to find tendencies for different tandem configurations using high – current sub-cells, based on GaAs p-i-n detector structure and $CH_3NH_3PbI_3$ perovskite. So for output parameters extraction we simplified the calculation route to single diode model.

Tandem device in-parallel and in–series connection was investigated with using Thermo Oriel ABA solar simulator and Keithley 2400 SMU for I-V output characterization and QE X6 system for external quantum efficiency measuring. In parallel connection with unbalanced sub-cells, we have no such current loss because, shunt and series resistances can be leveled in parallel circuit with current sum, that's why tandem operation tends to be closer for better sub-cell . Of course, this way have advantages only when V_{oc} of sub-cells has similar value, in opposite situation they can cut power of tandem with mismatch of current generation direction.

III. RESULTS AND DISCUSSION

Analyzing the results of this work, it should be noted that GaAs and perovskite technologies are the most effective and promising at the moment for applications in their areas –substrate and solid-state technology, thin-film technology of organometallic semiconductors. The main advantage of this device is the high photocurrent production, which allows to obtain high power.

Therefore, in this paper we have developed a tandem in a parallel, nonmonolithic connection showing a high short-circuit current from a square centimeter 39 mA and obtained an efficiency of about 19 % (Fig. 2).

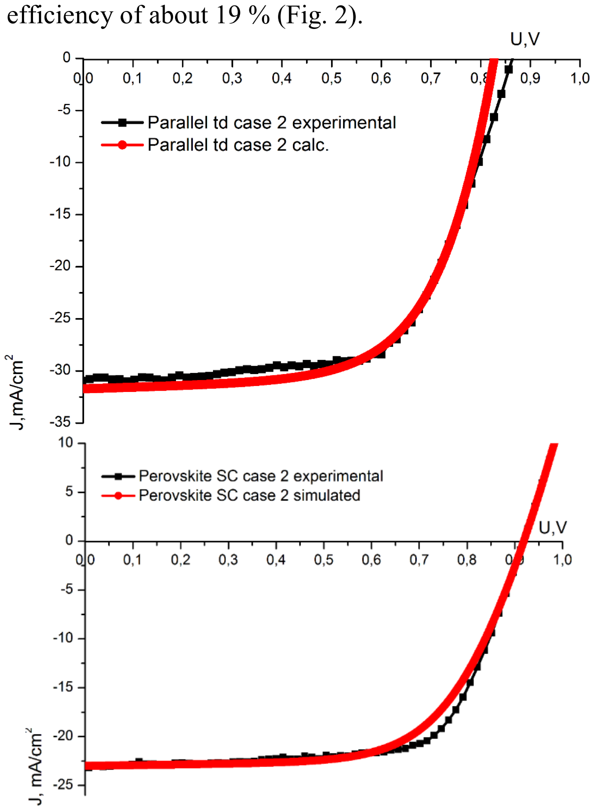

Fig. 2 Simulated and experimental dependences with connecting in-parallel and in-serious

IV. CONCLUSIONS

The approach presented in this paper clearly shows the advantages of parallel tandems over in-serious ones with appropriate balancing the output characteristics: the filling factor and the idling voltage. Calculation of a simplified single diode model allows us to assume that a parallel connection allows to have not only advantage in the sum of the sub-cell currents, but also eliminates shunt leakage and possible tandem imbalance in the filling factor. Therefore, the resulting characteristic of the in-parallel tandem has a fill factor close to the best of the sub-cells, while the in-series tandem, on the contrary, produces less power, the losses of which are due to increased series resistance, current leakage, and displacement of the maximum power point. It is seen the development of the proposed concept of a 4-electrode tandem in the gradual integration of a monolithic connection with three electrodes and spectral separation due to the wide possibilities of optoelectronic modifications of the perovskite band gap width to achieve record efficiencies of more than 25 % and the possible integration of a tandem structure on flexible substrates. The main result of this work besides quantitatively high parameters (the efficiency of more than 17-19 % in various configurations) is the demonstration of the parallel architectures potential, which have obvious advantages in the device functioning before series tandems.

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