Optical and electrical modelling for high efficiency perovskite/silicon tandem solar cells

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***Abstract* — A tandem arrangement of high and low bandgap solar cells is a promising way to achieve high efficiency solar energy conversion at low cost. Four-terminal tandems, in which each cell is connected independently, avoid the need for current matching between the top and bottom cells, giving greater design flexibility. We perform optical and electrical modelling of the efficiency potential for perovskite/silicon tandems, and show that efficiencies of over 30% are realistically possible. We further show that optimizing the transparent conducting layers and applying a grid are important steps to achieving high efficiency. Finally we demonstrate an efficiency of over 20% for a perovskite/silicon tandem in a four-terminal stack, and 23% in a reflective configuration.**

I. INTRODUCTION

Perovskite solar cells have emerged as the new key material for the photovoltaic community. With a tunable high band gap for the active material (1.55-2.3 eV) and high diffusion lengths, perovskite cells are an ideal candidate for the top cell in a tandem configuration with a silicon bottom cell.

The efficiency record for silicon solar cells is around 25%. This is not likely to improve significantly, because Auger recombination leads to a material-limited efficiency of 27% for silicon. Perovskite-silicon tandem cells present the first low-cost devices capable of improving standalone 25% efficiencies.

There are two possible tandem configurations: two-terminal and four-terminal. Whilst offering potentially lower costs and a requirement of only one transparent contact, the two-terminal tandem requires current matching between top and bottom cell and an efficient tunneling junction between the two sub-cells. The four-terminal tandem does not require current matching, instead only requiring optical coupling between the two sub-cells. Although introducing additional complexity, the four-terminal tandem allows individual cells to be optimized separately yielding greater flexibility in the cell design.

We identify the optical requirements to reach high efficiencies, and use optical and electrical modelling to guide the design and demonstration of a high efficiency perovskite/silicon tandem.

II. RESULTS

The four-terminal tandem configuration places strict conditions on material parasitic absorption and transmission of contacts: Absorption of 20% of sub-bandgap light leads to required top-cell efficiencies of 18% at a bandgap of 1.5 eV to break even with a single cell efficiency of 25%. Even higher top cell efficiencies of 23% are required to reach tandem efficiencies of 30%. Hence it is crucial to minimize parasitic absorption of sub-bandgap light by the top cell.

For a perovskite-based top cell, characterized by high luminescence efficiency and low parasitic absorption, our modeling shows that tandem efficiencies greater than 30% are possible with a bandgap of E_g = 1.55 eV and carrier diffusion lengths less than 100 nm. At an optimal top-cell bandgap of 1.7 eV, with diffusion lengths of current perovskites, we show numerically that tandem efficiencies beyond 35% are achievable with careful light management [1],[2].

Because of the large parasitic losses in transparent conducting layers, it is important to carefully optimize these layers. We show that it is also highly desirable to include a metal grid in contact with the conducting layer, and that this reduces the requirements on the sheet resistivity of the layer [3].

Applying these insights in experiments, we are able to demonstrate a 20% efficient four-terminal tandem solar cell [4]. The top cell is a perovskite cell with transparent front and back contacts made of indium tin oxide (ITO). The rear contact also has an evaporated metal grid to aid current collection. The bottom cell is a crystalline silicon solar cell. The top cell has around 80% transparency in the long wavelength region, which is the main reason for the high performance we observe.

An alternative configuration is to place the perovskite solar cell at a 45 degree angle, and the silicon solar cell vertically. In this case light that is reflected from the perovskite cell can enter the silicon cell. Low parasitic losses are also very important in this arrangement, as long wavelength light passes through the perovskite cell twice before travelling to the silicon solar cell to be absorbed. We demonstrate a 23% efficiency in this configuration, using a top perovskite cell with ITO front contact and a gold rear contact [5]. The

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perovskite cell has a long wavelength reflectance of about 90%, so almost all of the long wavelength light can be directed to the silicon cell.

III. Conclusions

Using optical and electrical modeling we design a four-terminal tandem for perovskite/silicon solar cells. We show the importance of minimizing parasitic absorption and demonstrate that thin transparent conducting layers in conjunction with a grid provide low effective sheet resistance and high transparency. We use the insights gained in the modelling to experimentally demonstrate tandem efficiencies up to 23%.

References

[1] Thomas P. White, Niraj N. Lal and Kylie R. Catchpole, “Tandem solar cells based on high efficiency bottom cells: top cell requirements for >30% efficiency”, IEEE Journal of Photovoltaics, 4(1), 208 (2014).

[2] Niraj N. Lal, Thomas P. White and Kylie R. Catchpole, “Optics and light-trapping for tandem solar cells on silicon”, IEEE Journal of Photovoltaics, 4(6), 1380 (2014)).

[3] Daniel A. Jacobs, Kylie R. Catchpole, Fiona J. Beck, and Thomas P. White, “A Re-Evaluation of Transparent Conductor Requirements for Thin-Film Solar Cells”, Journal of Materials Chemistry A, DOI: 10.1039/C6TA01670G, (2016).

[4] The Duong, Niraj Lal, Dale Grant, Daniel Jacobs, Peiting Zheng, Shakir Rahman, Heping Shen, Matthew Stocks, Andrew Blakers, Klaus Weber, Thomas P. White, and Kylie R. Catchpole, “Semi-transparent perovskite solar cell with sputtered front and rear electrodes for a four-terminal tandem”, IEEE Journal of Photovoltaics, in press (2016).

[5] The Duong, Dale Grant, Shakir Rahman, Andrew Blakers, Klaus J. Weber, Kylie R. Catchpole and Thomas P. White, submitted.