Large scale integration of new flexible and semitransparent solar cells in the built environment for a robust and renewable electricity system (ÅForsk -19-570)

Abstract:

In the project we have performed research new for new flexible and semi-transparent solar cell techniques, solar cells which can be placed on many different areas, for example windows, facades, car-parking areas, sun-screening roofs etc., for a complete integration in the city environment without reducing esthetical and architectural values and also to a low cost. Through this large-scale integration of solar energy, the city may to a large extent be self-sustainable in energy, which also make the energy system more robust.

We have in the project developed a range of new materials for the semi-transparent and/or flexible solar cells based on metal-halide perovskites and perovskite-like materials. For example we have developed metal-halide materials with the possibility to tune the colour by changing the halide ratio of bromide and iodide. We have also succeeded to make a flexible metal-halide perovskite solar cell based on metal-bromide, which is orange and semi-transparent. We have also developed a combination of dye-sensitized and quantum dot based solar cells, where we combine different dye molecules to tune the colour of the dye-sensitized solar cell, and different sizes of the quantum dots to tune the colour of the quantum dot solar cell. Some of the results are already published in scientific articles in scientific journals, and for some results we are now writing scientific manuscripts for later publication.

In the project we have therefore successfully obtained a range of new materials with tunable colour and tested these materials in solar cells. This can therefore be of interest for application of solar cells in buildings or other areas, such as in the city environment with high esthetical or architectural values, where the colour of the solar cells can be tuned to fit the environment.

Research background:

The supply of energy is one of the greatest challenges of the 21st century. Solar energy may be an important contribution to future energy production and already today the production of solar cells is increasing rapidly. However, to be a large scale energy source, the production cost of devices for solar energy conversion must be reduced.

If solar cells are incorporated into materials for buildings, it may be economical advantageous even compared to conventional low cost energy sources such as coal and nuclear energy, since the cost of the building is not dramatically increased by using these "building integrated solar cells". Building integrated solar cells are therefore a particularly interesting alternative for future energy saving in buildings. Silicon based building integrated solar panels are commercially available, and different thin film building integrated solar panels based on CIGS (Copper Indium Gallium Selenide) or CdTe (Cadmium Telluride) thin film solar cells are also on the market. Using the newly discovered quantum dot solar cell materials, this may be an even more interesting option since efficient semitransparent, flexible and lightweight solar cells might be produced from these new materials with very low production costs. To increase the possibility to use solar cells on a variety of surfaces for building integration, it would also be beneficial if the solar cells are produced on a flexible and lightweight film, which can be attached to any surface. For solar cells based on silicon this is difficult, since silicon is brittle, and other solar cell technologies such as metal halide perovskites, dye-sensitized or quantum dot solar cells are better suited. A future development of flexible, semitransparent lightweight solar cell materials may therefore be expected to be important for building integration of solar energy to a larger extent.

New materials for flexible and semitransparent solar cells

In this project we have investigated a range of new types of materials, both different metal halide materials, dyes, and quantum dot based materials.

For the metal halides, we have investigated the possibility to change the color by exchanging iodide to bromide. We prepared Formamidinium (FA) lead bromide material from solution with a spin-coating method (see figure 1 and ref.1), and also investigated the effect of different additives.

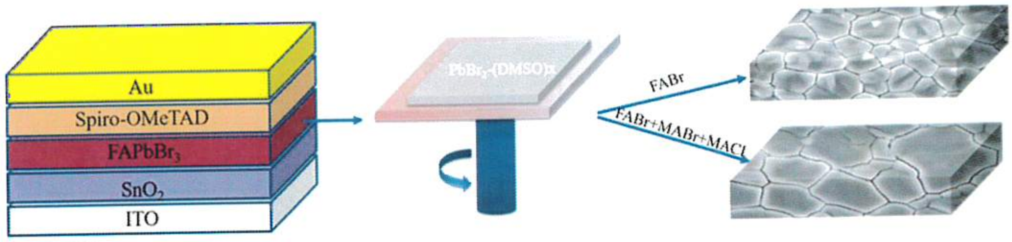

Figure 1. The schematic structure and diagram of the perovskite layer prepared without and with additives.

We found that with additives of methylammonium bromide and methylammonium chloride, it was possible to make better crystal quality of the material and a more smooth film (see figure 2), possible to use also on flexible substrates.

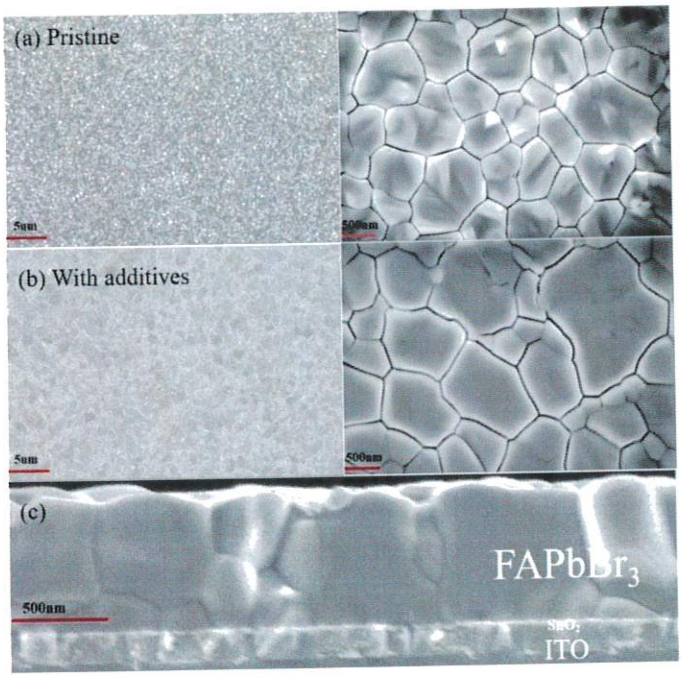

Figure 2. SEM top view micrographs of $FAPbBr_3$ films (a) without and (b) with additives. Below: cross-section of the $FAPbBr_3$ film with additives (c).

With this method it was possible to obtain an orange solar cell material, which is also semitransparent. We also made this material on a flexible substrate, and prepared a flexible solar cell (see figure 2 below). The work is now published in the journal ACS Applied Energy Materials [1].

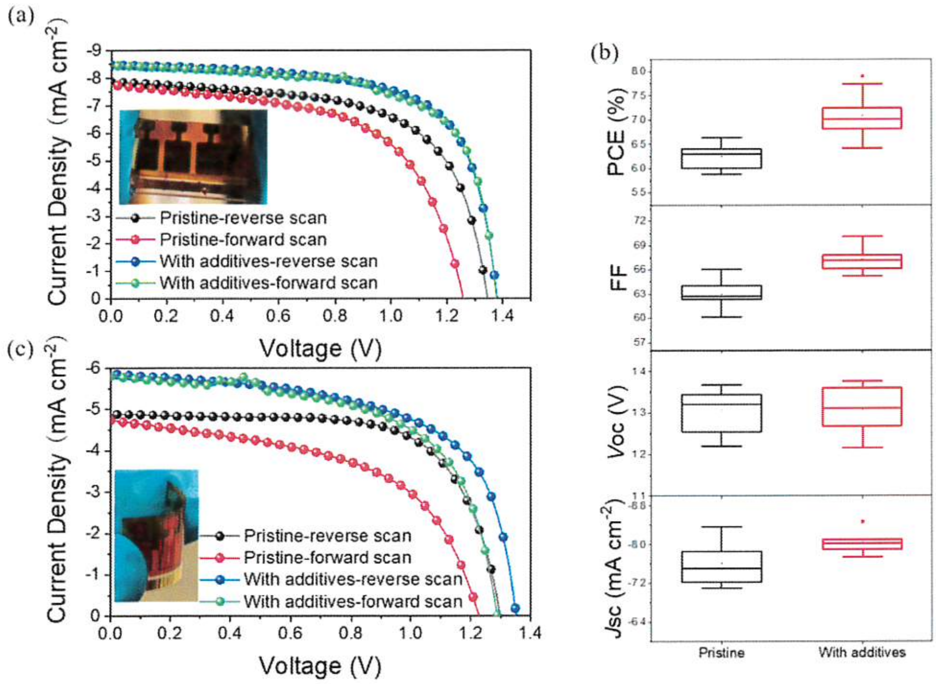

Figure 3. (a) *J–V* characteristics (champion cells), (b) Statistics photovoltaic parameter (10 devices) of PCE, fill FF, V_{oc} and J_{sc} of $FAPbBr_3$-PSCs without and with additives based on rigid substrate. (c) *J–V* characteristics (champion cells) of $FAPbBr_3$- PSCs without and with additives based on flexible substrate. The data were recorded under AM 1.5G one sun illumination (100 $mWcm^{-2}$). A black mask with an aperture area of $0.065 cm^2$ was used during measurement.

In the project we have also investigated the possibility to combine semitransparent dye-sensitized solar cells and quantum dot solar cells, in order to obtain a high efficiency together with a possibility to tune the color of the solar cell (see figure 4 and ref.2). Both the dye-sensitized solar cells and the quantum dot solar cells are prepared from solution. We have in this work used a combination of dye-molecules to tune the color, and we also used the possibility to tune the color of the quantum dots by changing the size on the quantum dots. We especially compared the efficiency of the complete system with dye-sensitized and quantum dot solar cells.

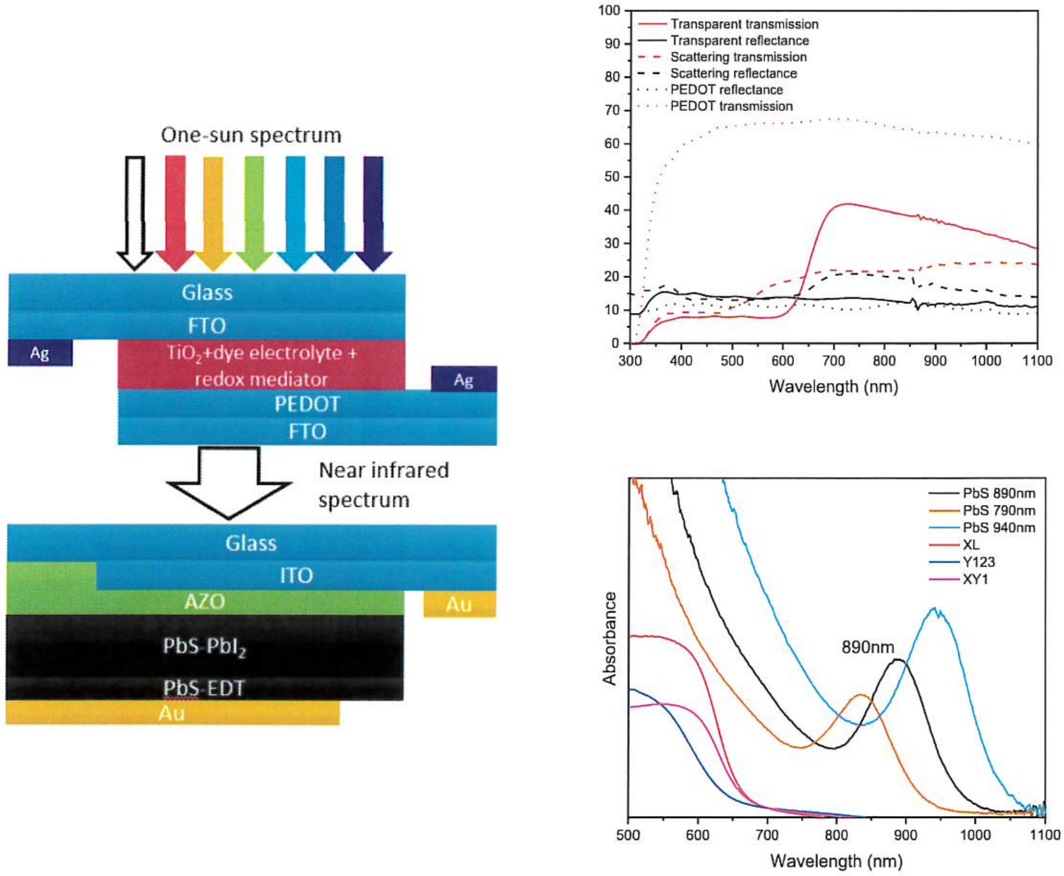

Figure 4. (a) schematic figure of the four-terminal DSSC/PbS solar cell tandem device. (b) Transmission, reflectance and absorption spectra for XL DSSCs with and without scattering layer. (c) UV-VIS-NIR absorbance for XL dye, PbS QDs and PbS film after solution ligand exchange process.

For the combination of dye-sensitized and quantum dot solar cells, we were able to obtain a photocurrent generation spectrum extending from visible light to the near infrared region of light (see figure 5).

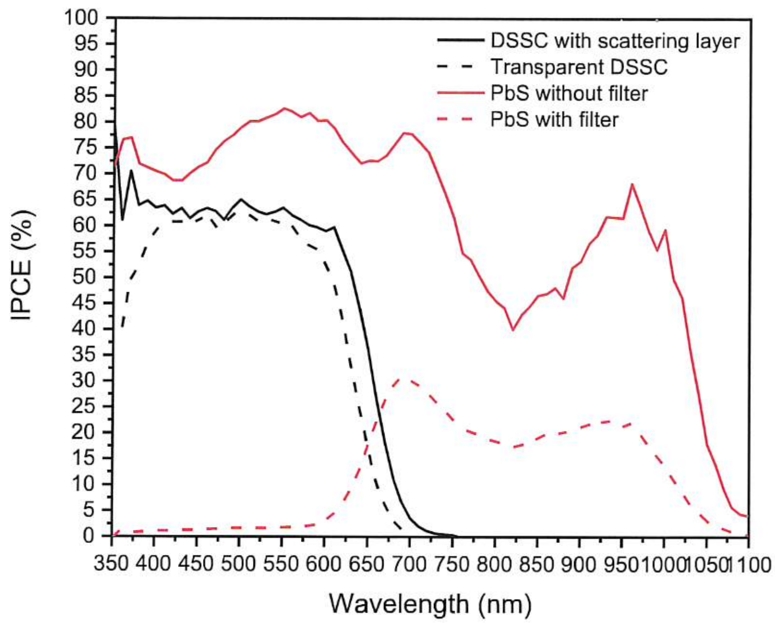

Figure 5. Incident photon to current conversion efficiency (IPCE) of XL DSSC and 890 nm PbS CQDSC under different conditions.

In the project we have also investigated a new material combination at the interface between the photoactive material (perovskite in this case) and the hole transport material. We specifically introduce the 2D material MoS_2 between the perovskite and the holetransport material (spiro-OMeTAD), and the results show an improvement in both efficiency and stability of the solar cells. This MoS_2 2D material also is very flexible, which also may increase the flexibility of the solar cell device. This type of device will be further developed and later the results will be published in a scientific journal.

Conclusions

We have in this project made very promising progress in new materials for semitransparent and flexible solar cell devices. We have shown that formamidinium lead bromide perovskite can be used for flexible and semitransparent solar cell devices, with very promising solar cell efficiency. In this case the experimental preparation of the perovskite, using a number of additives, was very important in order to obtain a high quality perovskite film, that could be used in flexible solar cell devices.

In the project we have also investigated a combination of dye-sensitized and quantum dot solar cells to obtain a tandem solar cell device, with tunable color and high efficiency for conversion of solar light to electricity. By using a mix of dye molecules the color of the dye-sensitized solar cell was tuned, and by using different sized quantum dots, the color of the quantum dot layer could also be tuned.

Finally we have started to investigate a new material combination for better stability and efficiency of flexible solar cell devices. Using the 2-dimensional material MoS_2, we could obtain both higher flexibility and higher stability, and we will continue to investigate this material combination in more detail for high efficiency flexible solar cell devices.

The project was therefore very successful in finding new materials for semitransparent and flexible solar cell devices, with tunable color. The ÅForsk grant was very important in order to do this research, which not only already now give important conclusions for this type of solar cells, but also points out new directions for further development.

Publications based on this ÅForsk grant:

[1] Yawen Liu, Byeong Jo Kim, Hua Wu, Lin Yuan, Huimin Zhu, Aijie Liu, and Erik M. J. Johansson* ACS Applied Energy Materials 2020, 3, 10, 9817-9823

[2] Lin Yuan, Hannes Michaels, Rajarshi Roy, Malin Johansson, Viktor Öberg, Aneta Andruszkiewicz, Xiaoliang Zhang, Marina Freitag*, and Erik M. J. Johansson*, ACS Applied Energy Materials 2020, 3, 4, 3157-3161