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Efficient thin luminescent solar concentrator based on organometal halide perovskite

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ABSTRACT

The Luminescent solar concentrators (LSCs) consist of a film containing optically active centers, converting part of the absorbing radiation into a specific emitting wavelength, when exposed to sunlight. The emitting centers are also crucial factors regarding their efficiency, so the selection must be done carefully. Here, we introduce organometal halide perovskite as a new class of phosphors, to use in luminescent solar concentrators. The coating of a Si PV cell with an organometal halide perovskite is tested. The obtained results reveal that, to find a suitable condition for effective LSC, it is necessary to determine appropriate molar ratio of organic and inorganic portion in synthesis perovskite, as well as concentration of halide perovskite in LSC. It is found that $CH_3NH_3PbBr_3$ perovskite with the CH_3NH_2/$PbBr_2$: 6/1 M ratio and 7.0 wt% perovskite concentration in Polyvinyl Alcohol (PVA) leads to the highest efficiency (increased about 45%, compared to uncoated cell).

1. Introduction

Despite the development of photovoltaic (PV) systems over the last few decades, conversion of solar energy into electricity is not efficient enough and cost-competitive, yet. Luminescent solar concentrators (LSCs) are photon-management devices. The primary idea behind LSCs is to concentrate sunlight with an inexpensive polymer-based device onto photovoltaic cells and thus moderate the price of solar electricity [1–3]. The sunlight of relatively short wavelength can be shifted to long wavelength light through the photoluminescence process of fluorophore, and the reemitted light can be concentrated via total internal reflection in the optical waveguide construction. Therefore, solar cells attaching to LSC can generate more electric power than conventionally used solar cells [4,5]. Development of the short wavelength response of PV devices via Luminescent Down-Shifting (LDS) appears in the literature, in 1970 in the area of luminescent solar concentrators (LSCs), as the useful result of the concentration process [6]. Hovel et al. [7] was the first to apply the concept of LDS in a planar luminescent sheet placed on top of PV cells, with promising initial results. Therefore, such thin films of LSCs can decrease self-absorption losses.

To date, three types of fluorophores have been exploited and tested, as emitting centers to use in LSCs: (i) fluorescent organic dyes [8,9]; (ii) quantum dots (QDs) [10] and (iii) lanthanide complexes [11]. Organic dyes and quantum dots, beside high fluorescence quantum yield (FQY), have tunable and wide absorption range, have been thoroughly examined. However, photobleaching and overlapping between absorption and emission bands of organic dyes and quantum dots is a great dilemma, which results in serious self-absorption effect within the waveguide structure of LSC [12]. Besides the other benefits, the drawback of lanthanide complexes, that limits their application as LSC centers, is the narrow absorption range. Most lanthanide complexes have absorption only within UV region. Thus, extending the absorption range is the key problem needs to be solved [13].

Compared to other types of fluorophores, Organic–inorganic perovskite structures emit light in the wavelength range of 500–600 nm, which can be efficiently absorbed by solar cells [14,15]. This material combines the excellent chemical stability of inorganic portions with the unique luminescent features of organic

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ions including (1) a broad absorption bandwidth, to utilize the solar spectrum efficiently, (2) large Stokes shift, to minimize the overlap of absorption and emission spectra and consequently omitting self-absorption losses, and (3) high fluorescent quantum yield and high stability under illumination [16,17]. These features are particularly desirable for producing efficient and durable LSCs.

This paper introduces a novel Organic–inorganic hybrid structure, for solar cell enhancement through Down-Shifting [18]. Among many possible applications, nowadays one attracting special interest includes the application of down-converters in PV cells. In the case of c-Si-based cells, photons with energy above the Si band gap, otherwise converted into heat, could split to low energy photons that will be converted into electricity [19,20]. The solar spectrum received at Earth's surface covers a broad range of wavelengths from 290 nm to 3790 nm. In an ideal condition, the absorption spectrum of photovoltaic materials should completely match the whole solar spectrum, in order to convert the maximum photons from solar radiation to electricity. However, there is a large mismatch between solar spectrum and the absorption properties of the present PV materials. Indeed, the absorption band of the best PV materials can be found between 400 and 1200 nm, depending on the case. Much of the available solar energy is not being used, due to the limited absorption spectrum of the solar cells. The luminescent solar concentrators permit the conversion of the whole UV light of solar spectrum (290 nm–400 nm) to a suitable radiation region for solar cells. This radiation is mainly in the visible range, for commercial PV modules (Si, a-Si and GaInP) and those under development (organic solar cells). Therefore, Organic–inorganic perovskites have considerable promise for applications in LSC.

In this paper, an UV light sensitized $CH_3NH_3PbBr_3$ organic–inorganic hybrids were prepared. Quality thin films of Organic-inorganic hybrids, in polymeric matrix, were fabricated on the surface of commercial solar cells, to construct thin film LSCs. Performances of these LSCs in practical application were investigated and compared with each other.

2. Experimental

2.1. Preparation of materials and LSCs

Organic–inorganic perovskite of $CH_3NH_3PbBr_3$ hybrids with the three proportions of $CH_3NH_2/PbBr_2$: 1/1, 3/1, 6/1 M ratio, are prepared by solution chemistry method. The experimental details of hybrid preparation have been reported elsewhere [21].

In brief, CH_3NH_3Br was first prepared by reaction of Methylamine (CH_3NH_2, 40% solution in water, merck) with a stoichiometric amount of hydrobromic acid (HBr, 47%, merck) aqueous solution in a chilled glass bottle at 0 °C to remove reaction temperature. Then stoichiometric amount of CH_3NH_3Br was added to lead bromide ($PbBr_2$, sigma aldrich) dissolved in dimethyl sulfoxide solution (DMSO, ≥ 99.9% merck) and stirred. All materials were used without further purification. Each product was air dried at room temperature on a watch glass and then dried at 60 °C for a week and organic-inorganic perovskites are formed. The next step is to deposit thin film on solar cell substrates. In this work, $CH_3NH_3PbBr_3$ Organic–inorganic hybrids, with the various molar ratios, were employed as fluorophore, for fabricating the luminescent solar concentrators (device A, device B, device C). Where, the fluorophore component with the various molar ratio and several concentration (4.2 wt%, 7.0 wt% and 8.4 wt%) is dispersed in a Polyvinyl Alcohol (PVA) solution and covered on top of a commercial solar cells, using doctor blading technique. Thin films with an excellent homogeneity and thicknesses about 100 microns are obtained after evaporation of the solvent in ambient conditions. A schematic diagram of the device and energy levels is shown in Fig. 1.

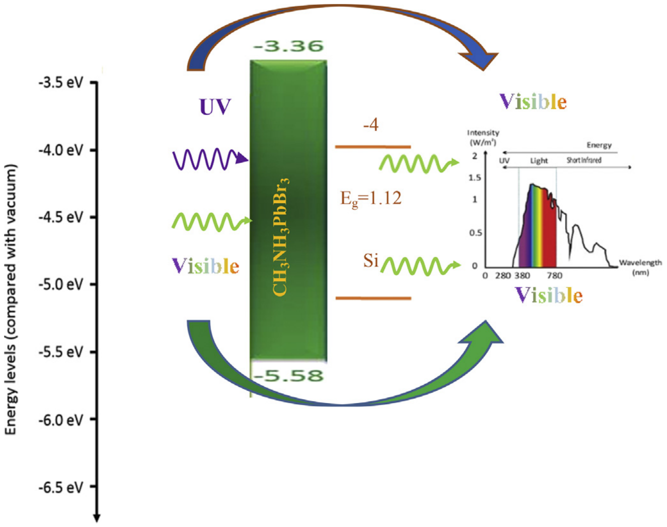

Fig. 1. Schematic diagram of the LSC device based on organometal halide perovskite.

Using the LDS layer on top of the solar cell scan enhance the PV cell's performance [22]. In this case, the emitted light is transmitted directly to the PV cell, without optical guidance [23]. Potentially, the performance of this solution can exceed the LSCs' efficiency, since the propagation losses are much smaller due to the inexistence of optical guidance (the trapping losses are identical) [24].

2.2. Characterization techniques

UV–visible optical absorption and photoluminescence (PL) spectra were measured with (Shimadzu UV-2450) spectrophotometer in the range of 200–800 nm, and (JASCO FP-6200) spectrofluorometer at room temperature, respectively. The area of the Si solar cell covered with the LSCs is 35 mm × 15 mm. A Mercury lamp (Philips 12 W) was used as an excitation source. The photovoltaic parameters of LSC were obtained through measuring the current–voltage (I–V) curves under irradiation of a Mercury lamp. Incident photon-to-current efficiency (IPCE) was measured by mono-chromatic incident light of 1×10^{16} photon/cm^2 under 100 mW/cm^2, with bias light in DC mode (Jarrel Ash monochromator, using a 100 W halogen lamp). Scanning electron microscopy (SEM) (MIRA3 FEG-SEM, Tescan) was used to determine the morphology of organic–inorganic hybrids in PVA. A pulsed N_2 laser (5 Hz) was used as an excitation source to characterize the evolution of PL intensity as a function of time for LSC.

3. Results and discussion

3.1. Optical study

Fig. 2(a) shows the typical UV–visible absorption spectra of the thin film of $CH_3NH_3PbBr_3$ perovskite, with molar ratio of $CH_3NH_2/PbBr_2$:1/1, at room temperature. The exciton absorption is located at 522 nm. Moreover, the absorption spectrum covers a large part of the UV region of solar spectrum. It can be seen from this result that extending absorption region of organometal halide perovskites and larger Stokes shift between absorption and emission can be used to