(REVIEW ARTICLE)

Effect of conversion efficiency of electroluminescence and solar cell with change of perovskite thickness

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Abstract

Evidence suggests that the combination of a diode structure with a hybrid organic-inorganic perovskite may give rise to multifunctional device phenomena, such as the high power conversion efficiency of a solar cell and the strong electroluminescence efficiency of a light-emitting diode. This might open the door for the creation of a device with several uses. These multifunctional devices have a limited ability to approach the Shockley-Queisser efficiency limit due to the nonradiative losses that lower the open circuit voltage (V_{oc}) . Here, we investigate and quantify the radiative limit of current carrying capacity in a perovskite solar cell as a function of absorber thickness. We seek to get a deeper understanding of the limiting elements that contribute to a low V_{oc} by developing a link between PCE and EL efficiency over a variety of thicknesses. The efficiency of power conversion increases with increasing perovskite thickness, whereas the efficiency of energy conversion declines. To control light while also minimisingnonradiative losses, it is necessary to consider both of these figures of merit of a solar cell and tie them together. The findings suggest that increasing the efficiency of absorption and emission is critical for enhancing device performance.

Keywords: Conversion Efficiency; Electroluminescence; Solar Cell; Perovskite Thickness

1. Introduction

Due to its high efficiency, lead halide-based perovskite solar cells have recently sparked a revolution in the photovoltaic sector. As a result of their cheap cost, remarkable charge transport capabilities, and solution processability, amorphous semiconductors have shown a lot of promise for usage in photovoltaic and light-emitting diode devices. These solar cells have an open circuit voltage of less than the 1.32 V theoretical maximum, but having a power conversion efficiency of roughly 25% in AM 1.5 G sunlight. Nonradiative recombination of photogenerated charge carriers causes this loss; hence, it is essential to have a complete knowledge of the prevailing recombination mechanisms and a quantitative description of them. The relationship between absorption and emission was first postulated by Uwe Rau as part of the wider Shockley-Queisser paradigm. Thus, a solar cell with a perfect power conversion efficiency (PCE) would also generate electroluminescence with a perfect external quantum efficiency (EQE) of 100%. There have been cases of high EL efficiency correlating with high-efficiency devices, but there is still much space for advancement in this area. Furthermore, it is difficult to create a device that has both excellent PV performance and remarkable EQEEL. High-efficiency devices can only be made better by optimising absorption and emission [1].

In any practical PV installation, nonradiative losses from defects, traps, and geometrical loss will ensure that the EQEEL. As a result, the true radiative limit, given by, is higher than the V_{oc} values obtained experimentally from solar cells [2].

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$$V^{cell}_{oc} = V^{rad}_{oc} - \frac{kT}{q} \ln EQE_{EL} \mid$$

While Voc cell is the solar cell's computed Voc, Voc rad is the radiative limit. A strong EQEEL-Voc relationship may be inferred from their link. Solar cells and EL operate in different ways physically, however their achievable Voc is connected because to eq 1. To get an initial estimate of Voc, we used eq 1. toanalyse data from a MAPbI3 PSC. While a thick PV device is necessary for adequate light absorption and charge carrier collection, a thin EQEEL device is essential for minimizing waveguiding loss and quenching of EL emission. We would like to stress that we are not aiming to get the best possible PSC or EL emission performance by optimising the device's construction. We want to investigate whether or not the absorber thickness influences PCE and EL efficiency. By varying the perovskite thickness while keeping the number of layers and deposition procedure constant, we may analyse the photoabsorber's non radiative losses. The current density in thicker perovskites is higher, which is essential for good PV performance. Because the emitted photons are more likely to be captured or reabsorbed at this thickness, the EL performance suffers. Because of this, there is a limit on both the Voc value and the luminescence output. For planar structure (n-i-p) solar cells, we develop a one-step method for fabricating a high-performance MA-free perovskite with a stable and well-studied composition, and we define the effect of its thickness, morphology, and transparency on the PCE and EL performance and illustrate how it defines the inherent losses. When the results of these two symmetrical device methods are combined, it may be able to assess absorber quality and reduce faults in the bulk absorber [3].
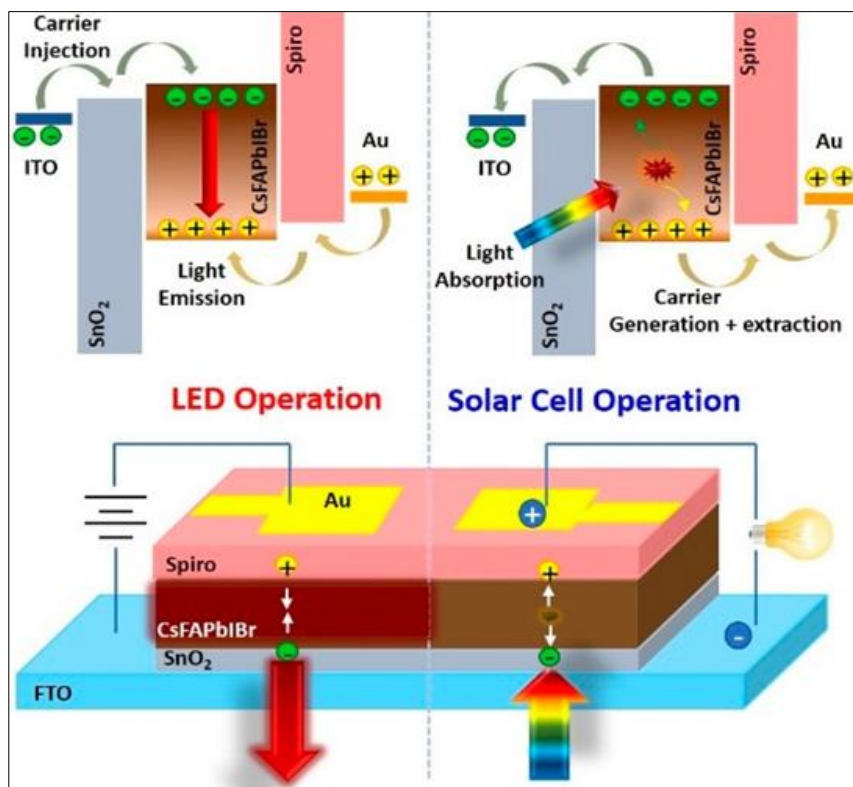

Figure 1 Schematics of perovskite LEDs and solar cells show recombination and carrier extraction in energy level graphs

When charges are injected into the perovskite via their respective charge transport layers, they recombine to produce strong NIR emission, which is required for EL. Subjecting the same stack to sun's worth of light, the PV device generates electron hole pairs. As a result of their complementary band structures, the SnO_2 layer serves as both an electron transport layer (ETL) and a hole transport layer (HTL) for the extracted electrons. There is no difference in functionality between forward and reverse bias when using the PV device [4].

For optimal EL performance, EQEEL. In this situation, the radiative limit of the V_{oc} for a solar cell is approached, as shown by the equation V_{oc} cell V_{oc} rad, which is obtained by maintaining the same device stack. It is not simple or easy to create a device that excels at both tasks at once. Due to its low trap density and the fact that most radiative recombination occurs via a band-to-band transition, perovskite is tolerant of defects.

In Figure 2, we see the PCE distribution statistically as a function of perovskite solution concentration. As demonstrated in the Figure 2 inset, the absorber thickness translates directly to the concentration (in molarity) of the perovskite precursor solution..
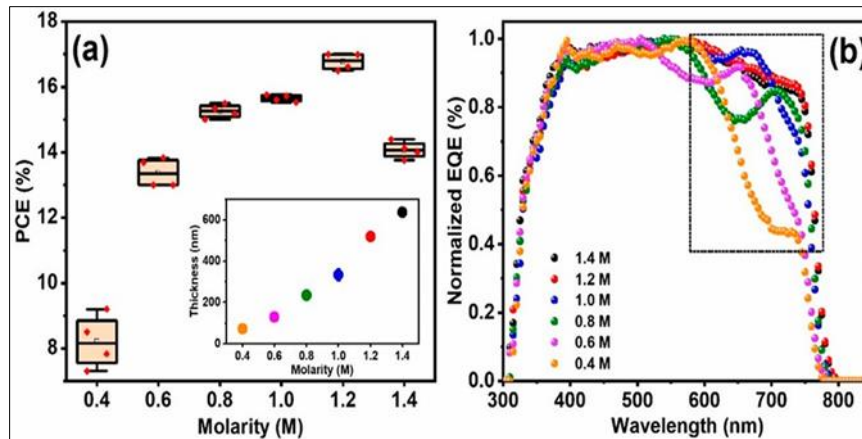

Figure 2 Concentration-dependent Perovskite solar cell performance. Inset depicts perovskite concentration-dependent thickness. Equal-weighted-element spectra

It is displayed in Figure 3 for the remaining PV parameters. For 1.4 M perovskite, Jsc saturates at 22 mA/cm² and increases inexorably with thickness. As can be seen, the absorber's thickness is a critical factor in achieving maximum carrier production. When the crystal quality is optimized, the nonradiative losses of photogenerated carriers at grain boundaries and other lattice defects can be reduced. The importance of a high-quality absorber becomes more pronounced at thin layers, where carrier production is low to begin with. Perovskite's electrical properties, such as the generation, transport, and collection of photogenerated carriers, are shown to change as the grain size of the material decreases. If the perovskite is thin enough, the amount of precursor solution available for nucleated particles to develop is reduced, leading to smaller grains. The higher the perovskite content, the more likely the grains will ripen via Ostwald ripening, which favours the development of large grains [5].

Perovskite's primary contribution to the current is in devices with greater thickness, as this is where the majority of the material can be found. A similar trend can be seen in the PCE, which starts to decrease at 1.4 M due to a sharp drop in Voc and FF brought on by an excessively thick perovskite layer that exacerbates recombination loss. The decrease in Jsc is more noticeable at longer wavelengths (>600 nm), as seen by the normalised external quantum efficiency (EQEPV) of the PV devices in Figure 2. Since the absorption coefficient of perovskite varies with wavelength, this is to be anticipated. Thin perovskites have reduced absorption, which has a notably negative impact on photogeneration at longer wavelengths. Band edge absorption has not changed much. As a result, we anticipate that all of the devices will have the same radiative limit of V_{oc} [6].

When determining the optical band gap, the Tauc plot is used. As is summarised throughout, concentration reduces the overall visibilities. As most of the absorbed light contributes to the photogenerated current, high AVT is not necessary for high EQEPV, but high AVT is necessary for high EQEEL as it effectively suppresses waveguiding and promotes light outcoupling. A significant amount of energy is lost as a result of waveguiding modes in perovskite owing to its high refractive index, and this loss is very sensitive to the thickness of the perovskite layer. The potential for these losses is eliminated when semitransparent PSC is used for window construction. Therefore, it is increasingly important to regulate the thickness with interfacial texturing to improve light trapping, which in turn increases the number of charge carriers and the value of Jsc. Perovskite has an optical band gap of -1.62 eV, as seen in Figure 3 [7].

We then injected charge carriers of varying densities into the same set of PV devices and measured EL. While under forward bias, charge carriers are injected in the ETL and HTL through the EL mechanism. See Figure 3 for a plot of current density and EL radiance as a function of voltage (a-e) . One possible explanation for the poor EL performance of 1.4 M films is that their absorber is of poor quality and that they have been fully quenched. Our working hypothesis is that the junction temperature increases due to joule heating, with a thicker perovskite layer acting as a more formidable barrier to effective thermal dissipation [8].
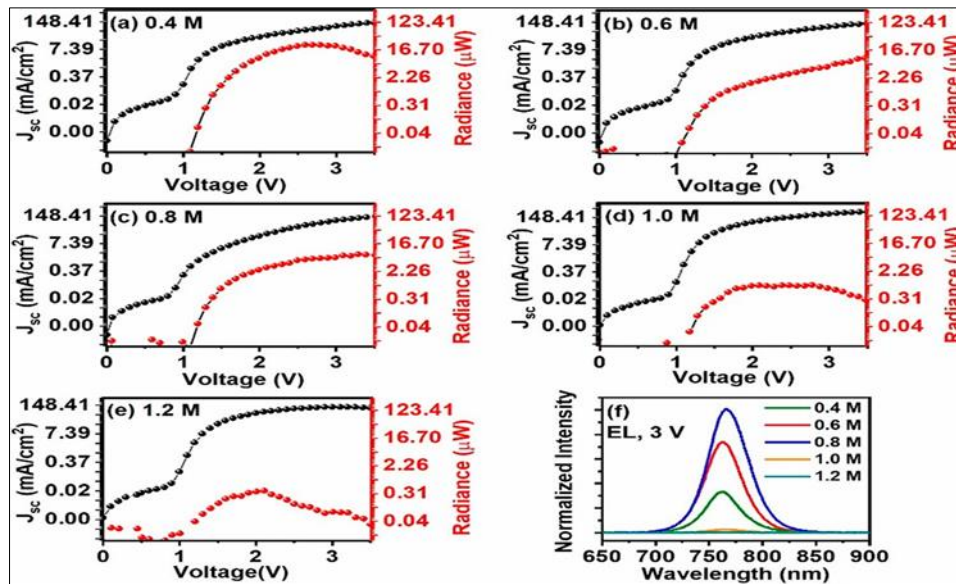
Figure 3 EL spectra at 3 V applied bias (a-e) and current density-voltage (JV) (blacks dots) (red dots) (f) for various concentrations

Beginning EL emission occurs at a voltage of 1 V regardless of concentration, which is close to the Voc. The EL radiance plateau area consistently decreases in size between 0.4 and 1.2 M as the absolute value decreases. Therefore, it seems that the effectiveness and stability of an EL layer decline with increasing thickness. This may be the case because most of the energy is lost as heat or is utilised to suppress the EL emission. Degradation of the EL in devices with a thicker perovskite layer occurs more rapidly because of the heat generated and accumulated by the device [9].

2. Solar cells

The use of the sun's rays as a source of energy is a modern and cutting-edge alternative to the utilisation of more conventional energy sources. This could become a reality thanks to solar cells, which can convert sunlight into usable electricity. Solar cells are reliable, can last for a very long time, and do not pollute the environment because they do not contain any moving parts, which also helps to reduce noise pollution and air pollution [10].

2.1. Solar cell operation

The solar cells employed in this study are shown in Figure 4 at their most fundamental. The transparent conducting oxide (TCO) in a solar cell is where light particles enter the device and go to the absorption layer, where they are converted into an electron and a hole. This process is seen in Figure 4. An electron-hole pair will be created if and only if the energy of the incoming photon is larger than the band gap of the absorption layer. Charge carriers are produced when the pair dissociates, and they are captured by films selected for their electronic structure. In particular, the electric field at the p-n junction acts to partition the carriers. However, the electron-hole pair is destroyed and no current or power is produced if the carrier recombines. shows that current is flowing from the n-doped film into the electron transport layer (ETL), and that current is flowing from the p-doped film into the hole transport layer (HTL) . The current in the external circuit caused by the electron's passage through the load is shown to originate from the collected carriers in Fig. 5. Within the device, electron and hole transport is shown by the band diagram in Fig. 6. The active layer takes in the photons, and the resulting excitons dissociate to create the free charges. With a difference in work function between the electrodes, the holes are pushed along the valence band of the active layer and eventually end up at the anode. However, the conduction band's electrons are shuttled to the cathode. When the bandgap is big enough, the ELT and HTL may inhibit recombination between holes and electrons, respectively [11].
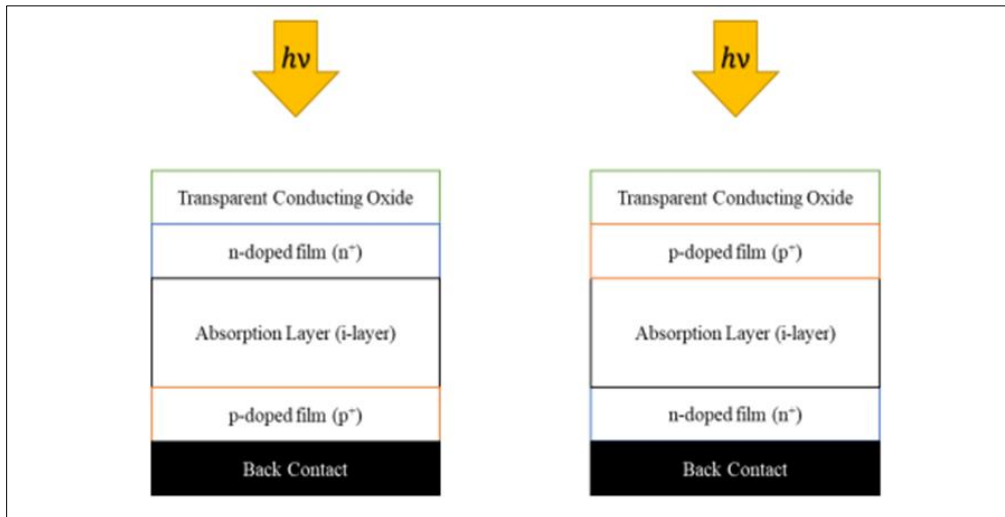
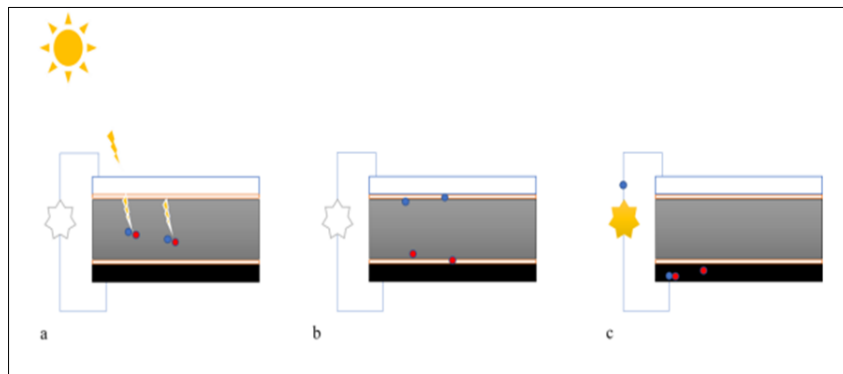**Figure 4** Solar cell structures with n-i-p (left) and p-i-n (right) single junctions

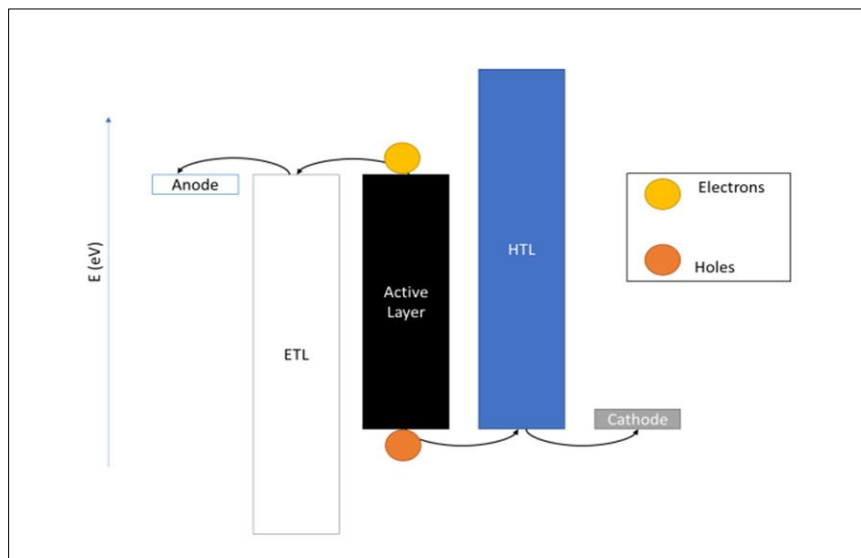**Figure 5** An n-i-p solar cell with an ideal short circuit flow of electrons and holes

Figure 6 Band diagram showing electron and hole transport in a photovoltaic cell

3. Perovskite solar cells

A full introduction to the chapter that you will find to be of use is provided by us. The efficiency of perovskite solar cells in converting sunlight into usable electricity has grown from 3.9% in 2009 to 23.3% in 2018. The AMX3 structure of perovskite crystals is obtained when A represents either an organic or inorganic cation, M represents a metal cation, and X represents an anion that binds to both of these cations. Elements denoted by the symbols A=caesium (Cs), methylammonium (CH_3NH_3 - MA), and/or formamidinium (CH_2NHCH_2 - FA) ; M=lead (Pb) ; and X=chlorine (Cl), bromine (Br), and/or iodine (I) are required for the task at hand [12].
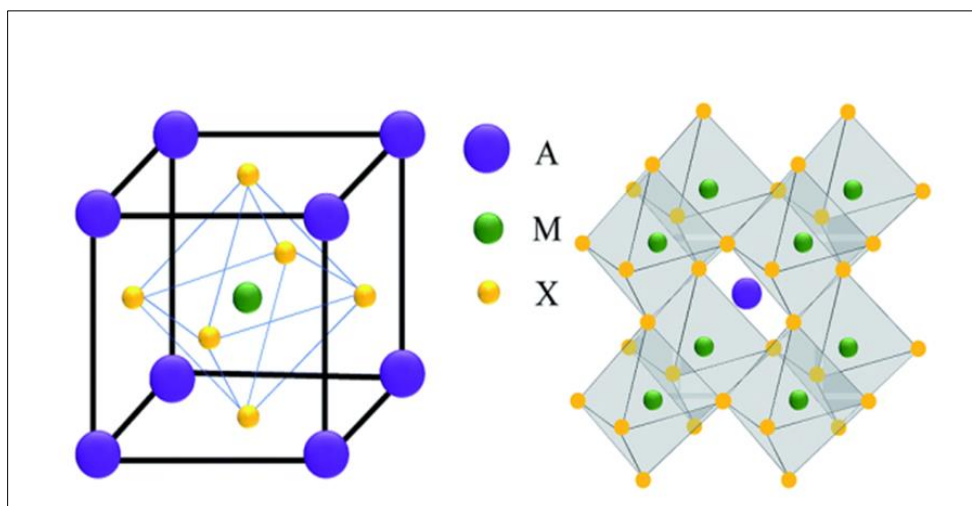

Figure 7 Chemical formula AMX3 perovskite crystal structure

The remarkable qualities of AMX3 lead perovskites are the result of the sum of their parts. Long carrier lifetimes may be related to the presence of a polar organic moiety (A) in the materials, which has been linked to a high dielectric constant, the formation of ferroelectric domains, and a nanoscale charge localization at the valence band maximum and conduction band minimum. By adjusting the concentration of X (halides), the perovskite crystal structure may undergo a drastic shift in the band gap. High defect tolerance, low electron effective mass, and a large dielectric constant are all attributes that may benefit from using a metal ion with a 6s2 or 5s2 lone pair. where they found that the perovskite's outstanding capabilities could be traced back to the material's dielectric constant and carrier effective mass. To boost, the low-injection electron and hole lifetimes, they explored how a high dielectric constant may reduce the carrier capture cross-section. The authors also discussed how the high dielectric constant and low carrier effective mass may improve mobility [13].

4. Weaknesses of perovskite solar cells

There are certain limitations to using perovskite solar cells, and one of them is the possible risk presented by the lead-based substance. water's effect on the structure and characteristics of organo-lead-iodide perovskite was investigated using first-principles simulations. According to their findings, the large interspace in AMX3 perovskite is easily permeable by water, which can lead to corrosion over time. studied the effects of high humidity on the active layer of perovskite, and showed its significance, empirically. In-situ absorption spectroscopy was utilised to demonstrate that relative humidity has a role in the degradation rate of perovskites. They determined the rate of degradation by tracking the wavelength at 410 nm as a function of time for perovskite films exposed to varying degrees of relative humidity. In this preliminary work, the following equation was proposed to characterise the fracturing of the MAPbI3 perovskite crystal [14].

$$4CH_3NH_3PbI_3 + 2H_2O = (CH_3NH_3NH_3)_4PbI_6 * 2H_2O + 3PbI_2$$
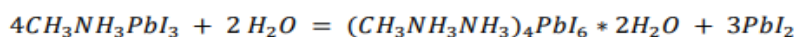
Their ex situ pXRD examination showed that CH3NH3I was broken down into CH3NH2 and HI, with PbI2 being the sole remaining product. They also showed that the stability of a material is significantly affected by whether or not it has a sufficient transport layer.
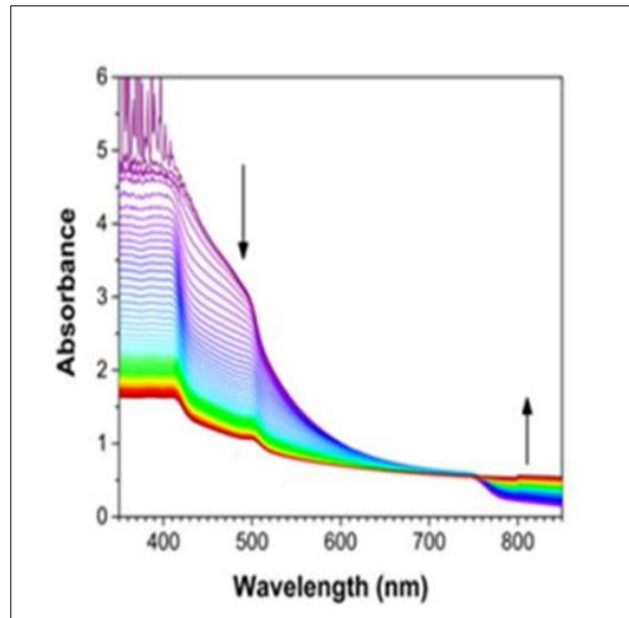
Figure 8 Time-dependent Perovskite Deterioration (published with express written consent)
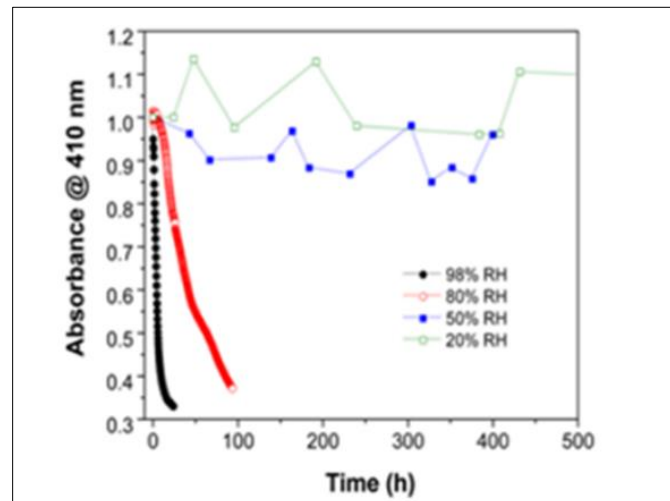

Figure 9 Rate of deterioration in response to changes in relative humidity

Furthermore, perovskite solar cells frequently exhibit hysteresis and have reproducibility issues. During current-voltage measurements, hysteresis can be seen because the values of power conversion efficiency are so sensitive to changes in scan rate, scan direction, scan history, and illumination. Engineering the band alignment of perovskite solar cells has received a lot of attention recently as researchers try to improve efficiency and reduce hysteresis by applying different materials to the problem [15].

5. Conclusion

In conclusion, we investigated both the PV and EL behaviours using the identical n-i-p device stack. We achieve this by manipulating the perovskite's overall thickness and keeping an eye on the Voc deficit, which ultimately decides the material's overall efficiency. In addition, we compared the Voc calculated from the EL to the Voc measured experimentally from the PV. Thickness unavoidably introduces substantial loss mechanisms, which lowers EQEEL. Reduced PV performance is due to the thinner device's inability to prevent SRH recombination and generate enough carriers via photogeneration. To achieve EL in a thicker device, a large carrier injection is necessary, which reduces device stability and speeds up degradation paths. This leads us to the conclusion that optimising absorption and

emission is key to achieving the highest possible PCE and EL efficiencies. To do this, we can measure how much of a Voc boost we can get from modifying the absorber. Thin PSCs with high EL but low current density may get over carrier constraint by using a photon management/concentration method. Passivation of defects, especially at grain boundaries and interfaces, may reduce nonradiative recombination. Texturing the device can help reduce optical losses for typical thicknesses that have high PV efficiency but poor EL.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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