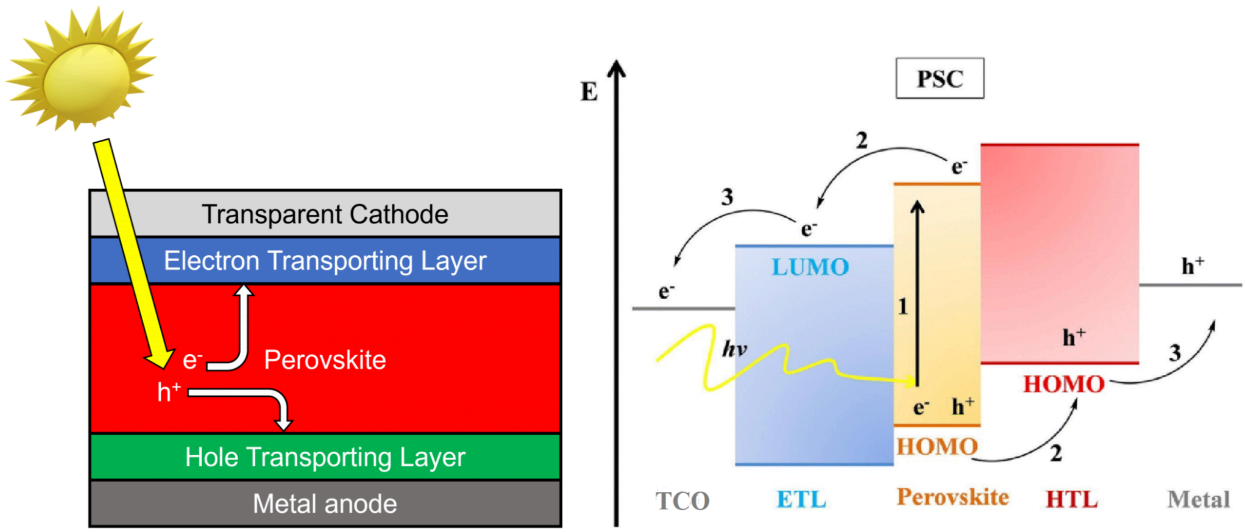
PHY6011 - SOLAR CELL LABORATORY

EXPERIMENT 4 | DATA ANALYSIS OF PEROVSKITE SOLAR CELLS



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INTRODUCTION

In this experiment, a large dataset collected during a series of experiments for studying both perovskite solar cells (PSCs) and perovskite thin films was analysed and plotted, with all measurements performed in the labs of the University of Sheffield. The experiments explored the effect of using different techniques to deposit different layers in PSCs. Here, the techniques used were "spray-coating" and "spin-coating".

CONTEXT

Run 9 and 10: Two sets of experiments were conducted to explore the relative effects of spin coating and spray deposition on PSC efficiency/performance.

Device Architecture: ITO/nanoparticle-SnO_2/Triple-cation Perovskite/Spiro-OMeTAD/Au.

Experiment Splits: The experiments are divided into devices based on four "splits," each using a different combination of spin and spray-casting methods:-

Sprayed Perovskite Only: Only the perovskite layer is deposited using the spray method, while the other layers are spin-coated.

Sprayed Perovskite and SnO_2: Both the Perovskite and SnO_2 layers (ETL) are deposited using the spray method, while the other layers are spin-coated.

Sprayed Perovskite and Spiro-OMeTAD: The Perovskite and Spiro-OMeTAD layers (HTL) are deposited using the spray method, while the other layers are spin-coated.

All Layers Spray-Cast: All layers of the PSCs are deposited using the spray method.

EXPERIMENTAL DATA ([Link to the Data])

1. PL and UV-vis data for determining the bandgap of perovskite thin films
2. EQE data for determining the J_{SC} of the PSC devices
3. Profilometry data for determining the thickness of the films
4. Solar Simulator J-V Scans data for determining the device parameters of the PSCs.

RESULTS & DISCUSSION

Run 9 Devices

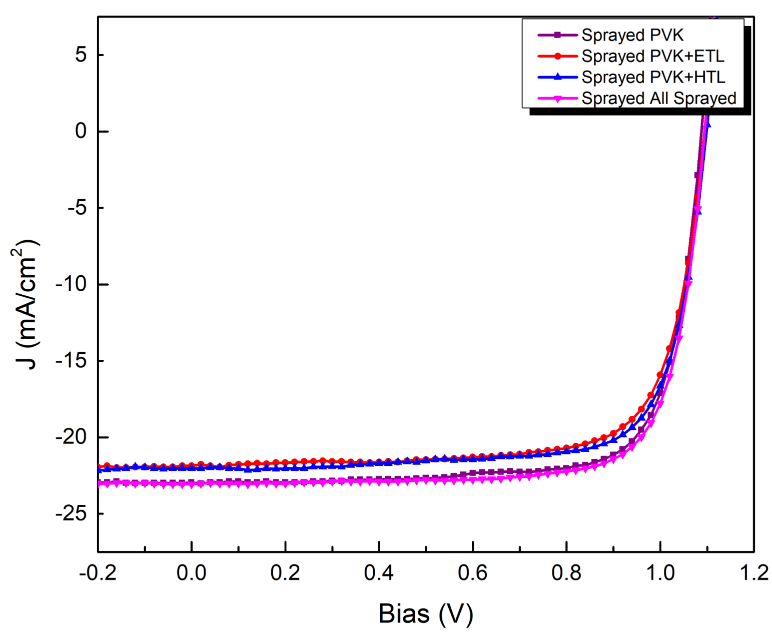

FIG. 1. Comparison of the J-V curves for the Run-9 champion PSC devices with sprayed perovskite only, sprayed perovskite+ETL, sprayed perovskite+HTL, and all sprayed layers.

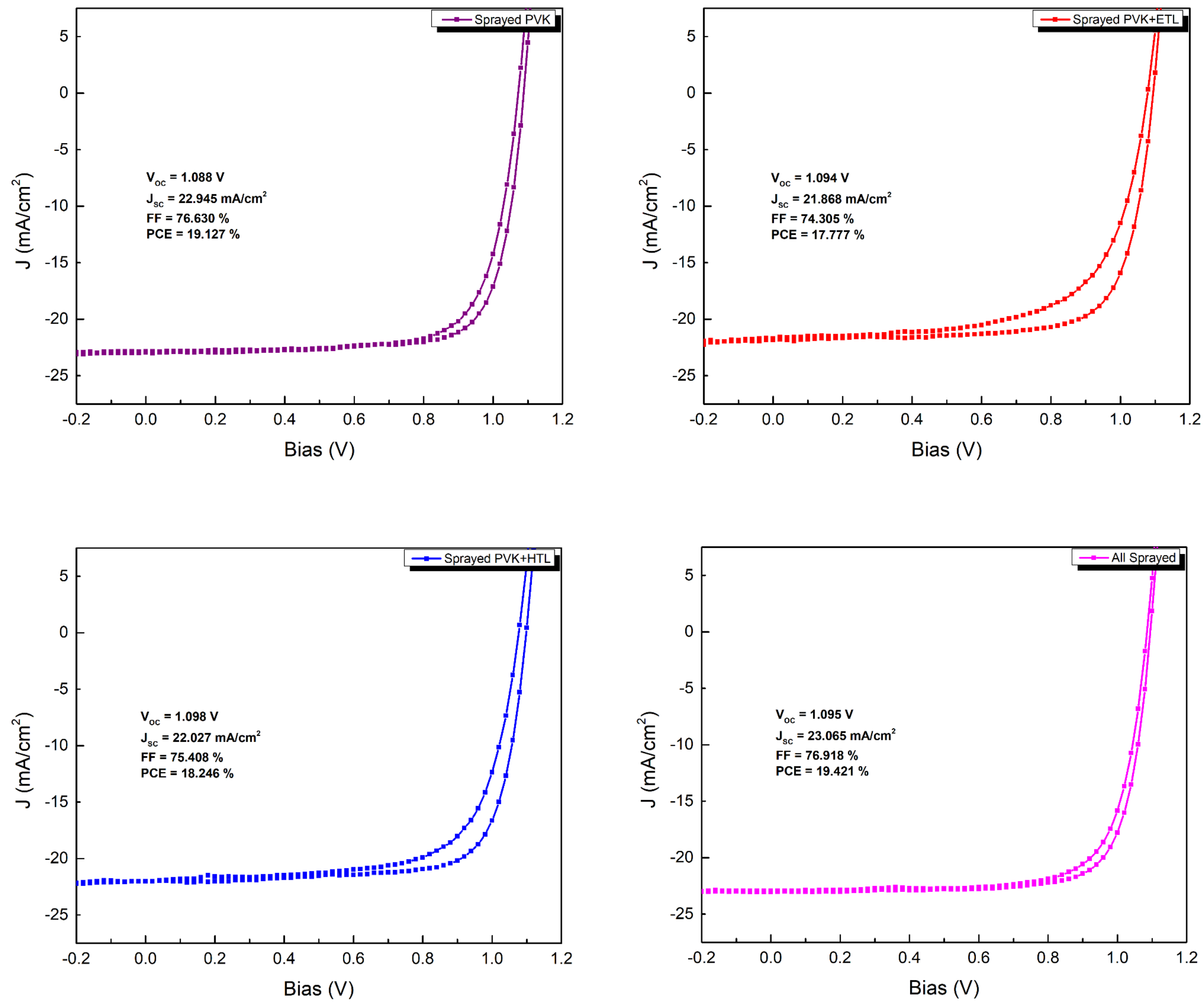

FIG. 2. Full forward and reverse J-V scans of the Run-9 champion PSC devices, showing the hysteresis loss.

As can be seen, the ‘sprayed perovskite-only’ PSC device and ‘all sprayed layers’ PSC device are better in terms of J_{SC}, FF, and PCE from FIG. 1 and 2. While the sprayed ‘perovskite+ETL only’ PSC device and ‘sprayed perovskite+HTL only’ PSC devices, with similar V_{OC} as all devices, showcase higher hysteresis loss, as seen in FIG. 2. This lack of performance in the ‘sprayed perovskite+ETL only’ and ‘sprayed perovskite+HTL only’ devices can be attributed to the mismatch of the deposition techniques between ETL, perovskite, and HTL. A unique thing is that the performance of the ‘sprayed perovskite-only’ and ‘all sprayed layers’ devices are quite similar, which means that the deposition of the perovskite layer doesn’t affect the performance, perovskite being a thicker layer than ETL and HTL. Thinner ETL and HTL layers deposition, if not controlled properly, can create non-homogeneous film interfaces, and affect PCE.

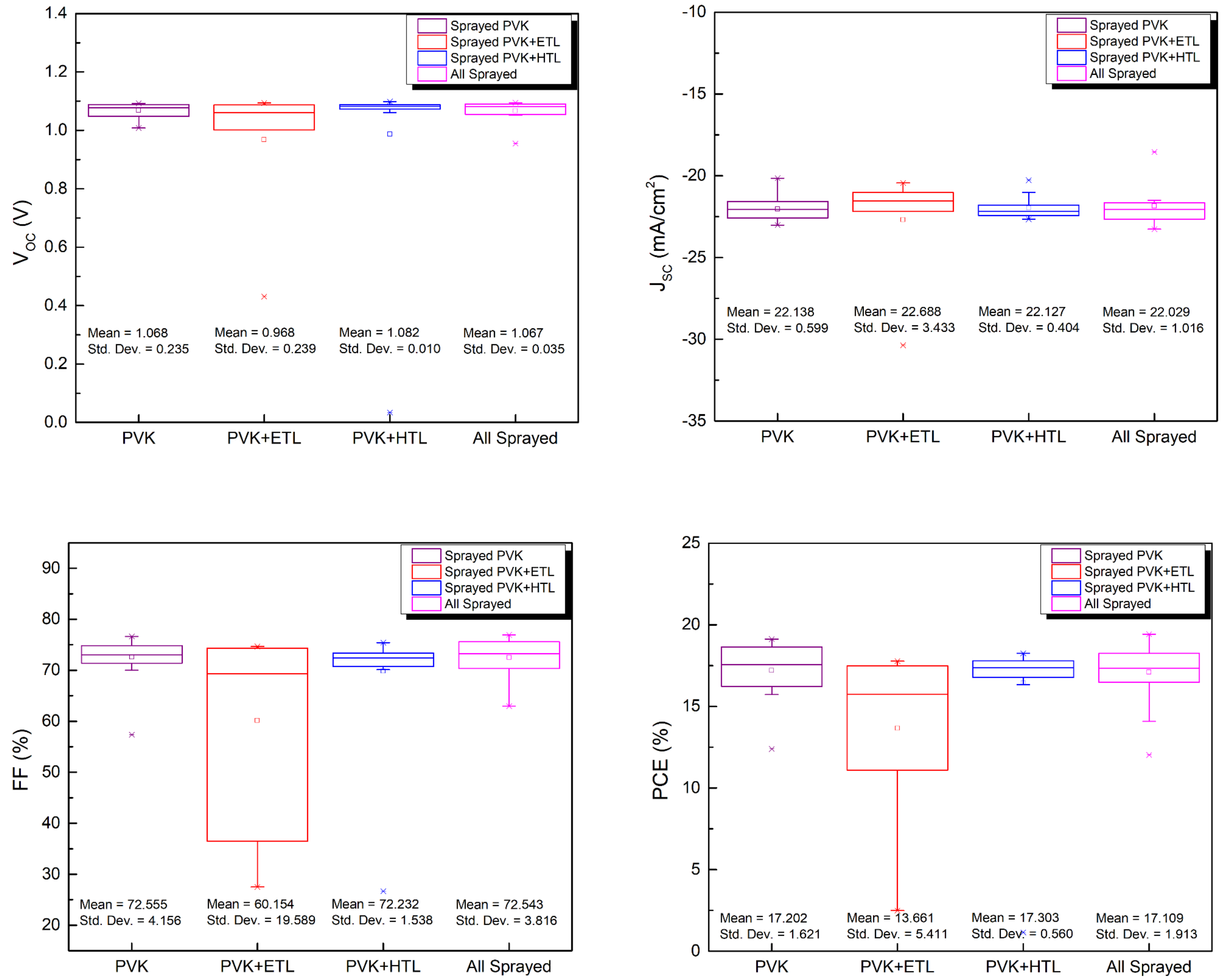

FIG. 3. Box plots of the device parameters V_{OC}, J_{SC}, FF, and PCE for the Run-9 PSC devices.

It can be reconfirmed that the ‘sprayed perovskite only’ and ‘all sprayed layers’ devices are pretty similar in terms of all device parameters, as seen in FIG. 3. The spread of both types of devices is similar in terms of mean and standard deviation. It can be particularly seen that the reliability (in terms of mean and standard deviation) of ‘sprayed perovskite+HTL’ devices is better than that of the ‘sprayed perovskite+HTL’ and even better than that of the other two device types.

The higher standard deviation and lower performance (in terms of mean) of the ‘sprayed perovskite+ETL’ devices are attributed to the lack/lower counts of data points compared to the other devices. A unique feature here is that the sprayed ETL is the bottleneck of the device's performance while the sprayed HTL is not the bottleneck as the average performance (PCE) of the ‘sprayed perovskite+HTL’ is better than the rest of the devices. This means that the ‘sprayed perovskite+HTL’ devices are more reliable than the rest.

Run 10 Devices

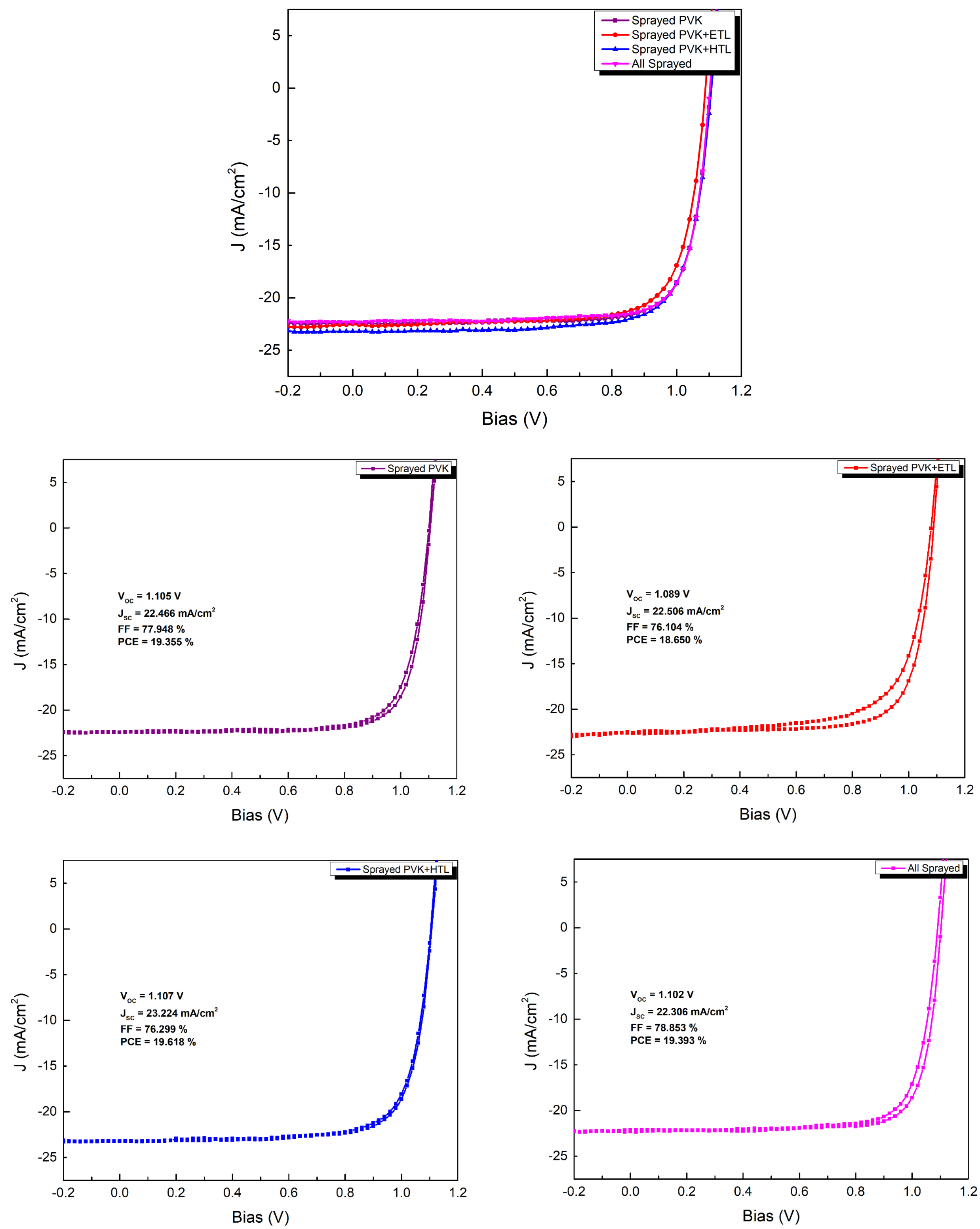

FIG. 4. Comparison of the J-V curves; full forward and reverse J-V scans for the Run-10 champion PSC devices.

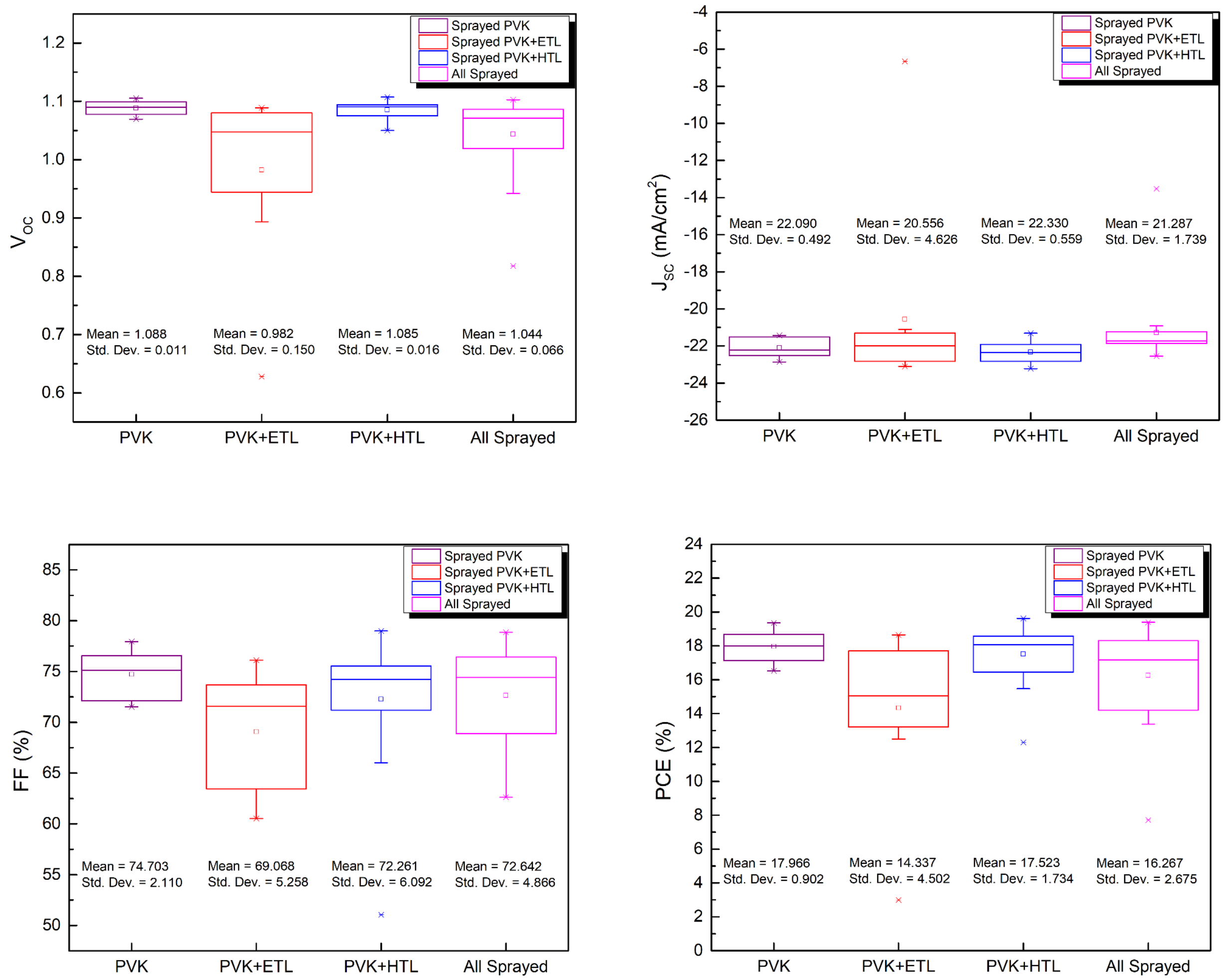

FIG. 5. Box plots of the device parameters V_{OC}, J_{SC}, FF, and PCE for the Run-10 PSC devices.

In the Run 10 devices, unlike Run 9 devices, the control over deposition of the thinner layers is taken care of, and hence the PSC devices in the Run 10 show better PCEs than that of the Run 9 PSC devices. Furthermore, the Run 10 devices show lower hysteresis losses than the Run 9 devices, as seen in FIG. 4. Uniquely, the ‘sprayed perovskite+HTL only’ PSC devices not only showcase higher champion PCE but also lower hysteresis than the rest of the Run 10 devices.

The statistics reconfirm that the Run 10 PSC devices are superior to the Run 9 devices, with the only exception being the ‘all sprayed layers’ devices. Similar to the Run 9 devices, the ‘sprayed perovskite+ETL only’ devices' data show higher standard deviation due to lower counts of data points than the rest of the devices. Moreover, the average efficiency of the ‘sprayed perovskite+ETL only’ devices, despite being better than the Run 9 ‘sprayed perovskite+ETL only’ devices, still is lower than the rest of the Run 10 device types. It remains to agree with the Run 9 devices that the sprayed ETL is the bottleneck of the device performance.

Sprayed Perovskite Thin Film and Fully Sprayed PSC Devices

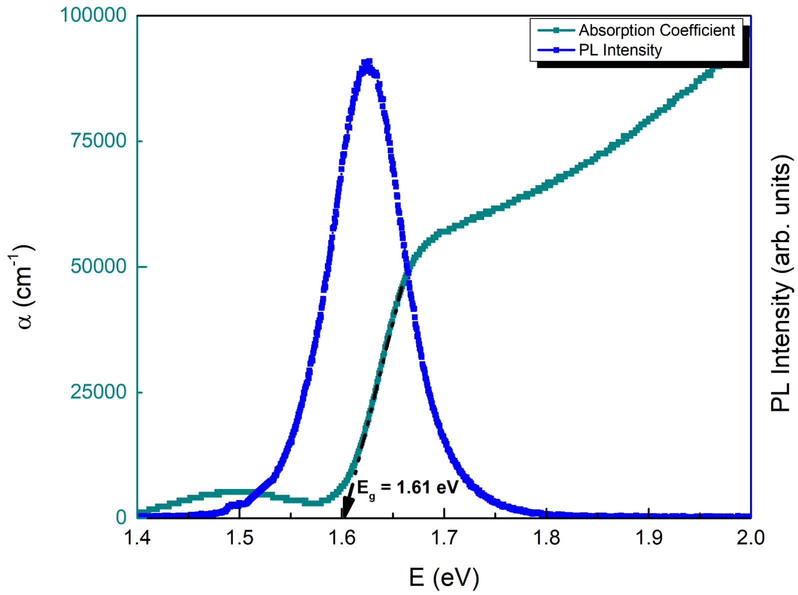

FIG. 6. Absorption spectra and photoluminescence spectra, showcasing the bandgap of a sprayed perovskite thin film.

The bandgap (E_g) of the sprayed perovskite thin film as given by the absorption spectra is 1.606 eV while that given by the PL spectra is 1.620 eV. The average bandgap from both the spectra is 1.613 eV. The EQE spectra, in FIG. 7., also shows the E_g to be 1.602 eV and the integrated photocurrent spectra give the estimated J_{SC} value for the fully sprayed device to be 20.1 mA/cm^2.

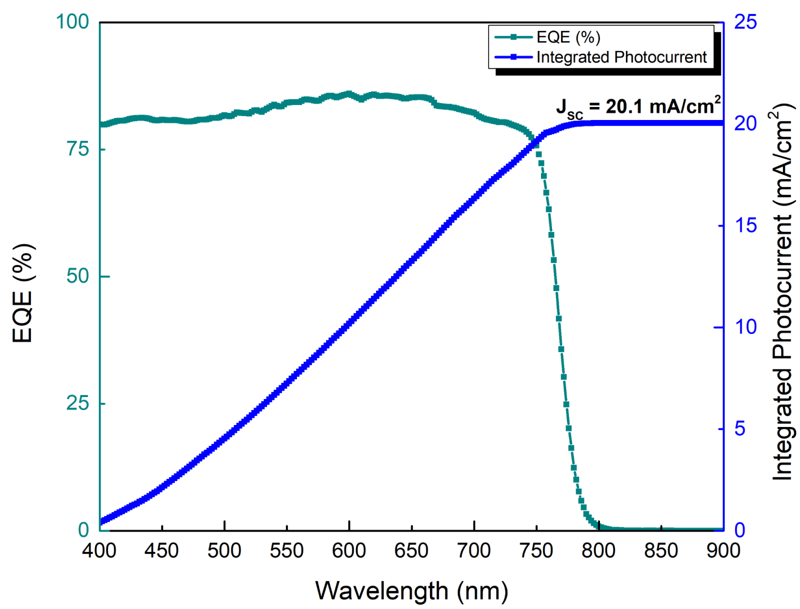

FIG. 7. EQE spectra and the integrated photocurrent spectra of the fully sprayed perovskite device.

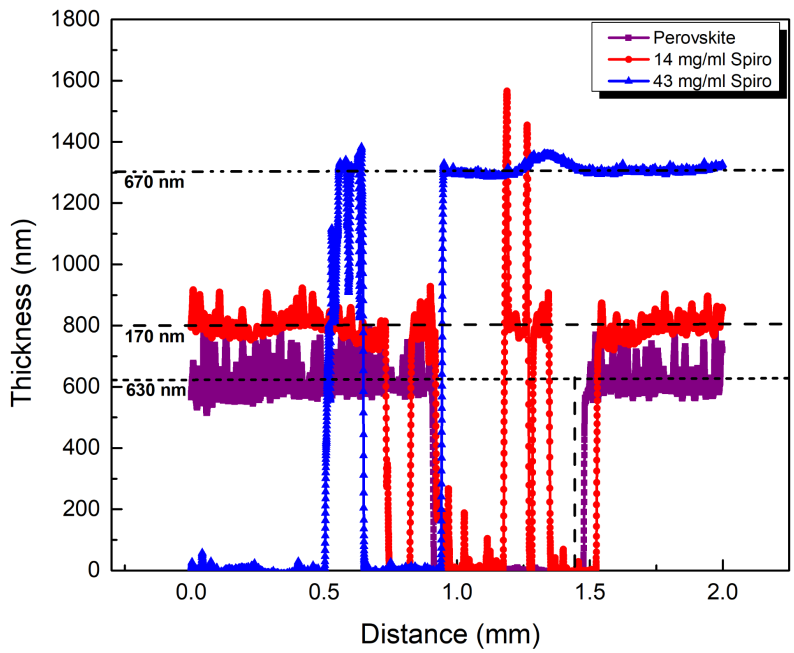

FIG. 8. Profilometry of the sprayed perovskite thin film, sprayed perovskite+HTL (14 mg/mL) thin film, and sprayed perovskite+HTL (43 mg/mL).

The thickness of the sprayed perovskite thin films is estimated to be 630 nm. That of the HTL (14 mg/mL) is 170 nm and the HTL (43 mg/mL) is 670 nm, on the perovskite layer, as per profilometry. It is in agreement with the notion that film thickness increases with concentration.

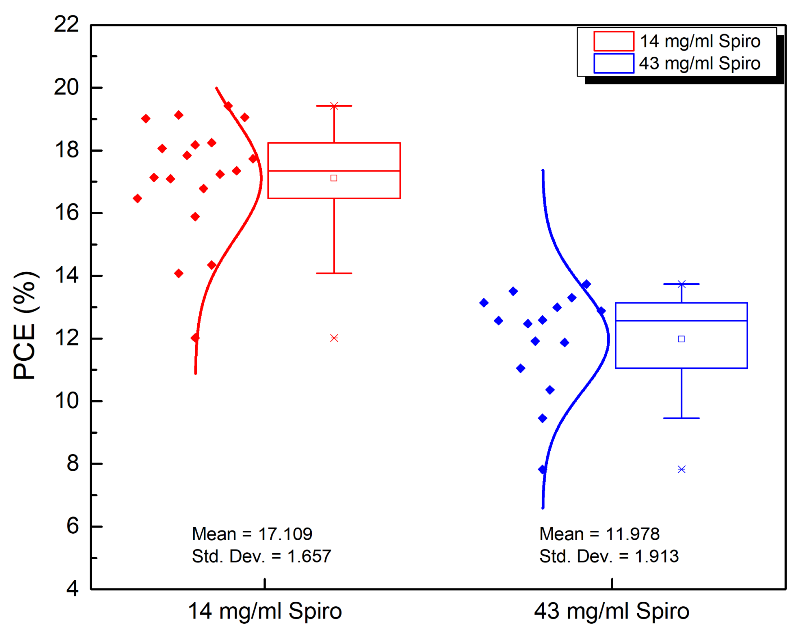

FIG. 9. Box plot of the PCE of the ‘sprayed perovskite+HTL (14mg/mL)’ and ‘sprayed perovskite+HTL (43mg/mL)’ PSC devices.

The PCEs of the 14 mg/mL HTL-based devices are superior to those of the 43 mg/mL HTL-based devices, with the average values being 17.109 % and 11.978 %, respectively. That means the thickness of the transport layer is also a bottleneck of the PSC device performance. The standard deviations of the devices are in good proximity.

CONCLUSION

Spray coating and spin coating are two prevalent methods utilized for depositing perovskite layers and charge transport layers in PSCs. Spray coating, which involves atomizing a solution containing precursors into fine droplets, which are then sprayed onto the substrate to form a thin film, is advantageous for its scalability, making it suitable for large-area deposition in industrial manufacturing, albeit with challenges in precise control over film thickness and morphology. In contrast, spin coating involves applying a solution containing precursors onto a substrate, followed by rapid spinning to spread the solution uniformly over the surface. While spin coating offers excellent control and reproducibility over film thickness and morphology, it may not be as scalable for large-scale production due to limitations in substrate size and material waste. Ultimately, the choice between these methods depends on specific application requirements, balancing factors such as scalability, control, and uniformity.[1,2]

Here in this work, the statistics and its analysis show that the mix of both deposition techniques works, in general, if the perovskite layer only is spray deposited and the rest are spin coated or all the layers are spray coated. Our statistical analysis reveals that while combining spray coating and spin coating techniques can yield promising results, the key lies in controlled deposition processes. Specifically, when the perovskite layer is spray deposited alongside either the ETL or the HTL, and the rest of the layers are spin-coated, the resulting devices demonstrate comparable performance to those where only the perovskite layer or all layers are spray coated. This suggests that judiciously incorporating spray coating alongside spin coating, particularly for selective layers, can effectively optimize device performance. These findings offer valuable insights for advancing PSC fabrication processes, emphasizing the importance of tailored deposition strategies for achieving optimal performances in perovskite PV technologies.

REFERENCES

[1] T.I. Alanazi, “Current spray-coating approaches to manufacture perovskite solar cells,” Results Phys. **44**, 106144 (2023).
[2] J.E. Bishop, C.D. Read, J.A. Smith, T.J. Routledge, and D.G. Lidzey, “Fully Spray-Coated Triple-Cation Perovskite Solar Cells,” Sci. Rep. **10**(1), 6610 (2020).