APPLICATION NOTE

Analysis of Perovskite Solar Cells via Spectral Luminescence in the 700 to 1000 nm Wavelength Range

Overview

It is by no means an exaggeration to say that solar cells based on organic-inorganic hybrid perovskites are taking the photovoltaics industry by storm.

In 2012, the first efficiency of 9.7% for a solid-state perovskite solar cell was reported.[1] Just five years later, in mid-2017, small solar cells utilizing these unique crystalline materials were fabricated with a certified power conversion efficiency of 22.1%.[2]

And already in early 2018, a multinational building firm announced its intention to be the first developer worldwide to cover office buildings with semi-transparent perovskite solar cells on a commercial scale; initial implementation tests are planned for 2018 in Poland.[3]

The rapid development trajectory of perovskite solar cells (PSCs) is attributable to a multitude of ongoing research efforts that target technological challenges associated primarily with device stability and process uniformity. The ability to detect efficiency-limiting defects, for example, is playing a particularly critical role in both PSC fabrication and performance improvements.

Luminescence Imaging Techniques

The use of photoluminescence (PL) imaging to inspect solar cells is a growing area of interest in the field of energy research.[4] Electroluminescence (EL) imaging, a complementary measurement technique, also enjoys wide use in the monitoring of solar cells.

One team of researchers in Australia, whose members are affiliated with The University of New South Wales (Sydney), Monash University (Melbourne), and BT Imaging (Sydney), has reported leveraging a combination of PL and EL to enable various quantitative methods for the detection of efficiency-limiting PSC defects.[5]

As well as performing fast camera-based PL and EL imaging measurements on PSCs (see Figure 1), the Australian researchers measured spectral luminescence using a high-resolution imaging spectrograph.

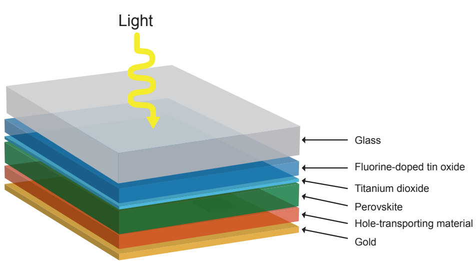


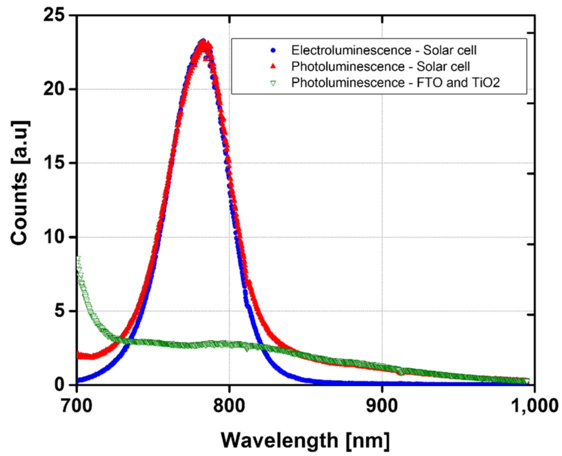
Figure 1.
Diagram of the PSC structure used in the study.

In a 2015 paper published in *Progress in Photovoltaics: Research and Applications,* the group reported employing these techniques to confirm the exponential dependence of the luminescence emission on the electrochemical potential difference in the absorber, as predicted by Planck's emission law, for PSCs. The researchers assert that this fundamental finding enables a broad range of PSC analysis techniques.

Luminescence Spectra of PSC

Figure 2 displays PL and EL spectra of a representative perovskite solar cell acquired using an IsoPlane® 160 imaging spectrograph from Princeton Instruments. The PL measurement was performed with an incident photon flux of 2.2×10^{16} cm^{-2} s^{-1}, corresponding to an electrical current density of 3.5 mA/cm^2 (about 0.1 suns). The EL measurement used a forward bias voltage of 1.4 V. For comparison purposes, the EL peak intensity was scaled to match the PL peak intensity. Significant deviations between the spectra are seen in the short (<750 nm) and long (>810 nm) wavelength ranges.[5]

Figure 2.
Luminescence spectra of a completed PSC and of the FTO-TiO_2 test structure. Data courtesy of Dr. Ziv Hameiri, The University of New South Wales. First published in Z Hameiri et al. Photoluminescence and electroluminescence imaging of perovskite solar cells. Progress in Photovoltaics: Research and Applications, 2015; 23: 1697.



To further clarify these observations, PL spectra of a test sample containing only an FTO and a TiO_2 layer were measured under the same light intensity. The relatively constant PL emission of this test structure in the 735 to 810 nm range and the long tail in the range above 810 nm explain the deviation between the PL and the EL, as the FTO-TiO_2 structure emits luminescence only under illumination and not under forward bias voltage.[5]

For more data as well as a comprehensive discussion of results, please refer to the following paper: Z Hameiri *et al.* Photoluminescence and electroluminescence imaging of perovskite solar cells. *Progress in Photovoltaics: Research and Applications,* 2015; 23: 1697.

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Enabling Technology

The Princeton Instruments IsoPlane-160 imaging spectrograph (see Figure 3) used in the Australian study of perovskite solar cells is a superb choice for this type of work. The compact 200 mm instrument, which features fast f/3.88 optics, a unique astigmatism-corrected optical design, excellent imaging performance, and spectral resolution that rivals most 1/3 meter Czerny-Turner (CT) spectrometers, provides the outstanding low-light-level sensitivity required for ultra-short-exposure signal collection.

Figure 3.
The compact IsoPlane-160 and multi-award–winning IsoPlane-320 imaging spectrographs from Princeton Instruments set new standards of performance and versatility.

Another imaging spectrograph available from Princeton Instruments, the IsoPlane-320, utilizes a unique optical design that completely eliminates astigmatism across the entire focal plane to deliver superior multichannel capabilities. This patented, multi-award–winning instrument boasts fast f/4.6 optics and exceptional image quality, ensuring maximum throughput and signal-to-noise performance.

Princeton Instruments also offers high-sensitivity CCD and InGaAs cameras (our BLAZE® and NIRvana® models, respectively) that have been specially optimized for spectroscopy applications in the near-infrared and shortwave-infrared wavelength ranges.

Resources

To learn about the latest research being conducted by Dr. Ziv Hameiri at The University of New South Wales, please visit:
https://www.engineering.unsw.edu.au/energy-engineering/staff/ziv-hameiri

For more information on IsoPlane-160 and IsoPlane-320 imaging spectrographs from Princeton Instruments, please visit:
https://www.princetoninstruments.com/products/IsoPlane

References

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3. Skanska launches first perovskite solar cell application in office buildings together with Saule Technologies. Press release, 1/17/2018, 11:45 AM CET. https://www.skanska.pl

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5. Hameiri Z, Mahboubi Soufiani A, Juhl MK, Jiang L, Huang F, Cheng Y-B, Kampwerth H, Weber JW, Green MA, Trupke T. Photoluminescence and electroluminescence imaging of perovskite solar cells. *Progress in Photovoltaics: Research and Applications,* 2015; 23: 1697.

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