



افزایش بازده در سلول‌های خورشیدی پروسکایتی با اضافه کردن لیتیوم فلوراید به لایه انتقال دهنده الکترون

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چکیده- اخیراً سلول‌های خورشیدی پروسکایتی به عنوان نسل سوم سلول‌های خورشیدی برپایه مواد پروسکایتی ظهور کرده‌اند. مواد پروسکایتی خواصی از قبیل هزینه کم، قابلیت تنظیم گاف انرژی، ساخت آسان، امکان ساخت در زیرلایه‌های مختلف و کارایی بالا دارند. تیتانیوم دی‌اکسید (TiO_2) به عنوان یک گزینه مناسب برای لایه انتقال دهنده الکترون در سلول‌های خورشیدی پروسکایتی می‌باشد. در تحقیق حاضر، لیتیوم فلوراید (LiF) به عنوان دوپینگ برای بهبود خواص الکتریکی لایه انتقال دهنده الکترون و کارایی پروسکایت بکار گرفته شد. نتایج نشان داد که دوپه کردن LiF رسانندگی TiO_2 را افزایش می‌دهد، بازترکیب الکترون-حفره را سرکوب و خواص کریستالی لایه پروسکایت را بهبود می‌بخشد. با اصلاح لایه ETL، کارایی سلول‌های خورشیدی پروسکایتی بدون لایه انتقال دهنده حفره ۴۸٪ افزایش پیدا کرد و منجر به ساخت سلول‌هایی با بازده ماکزیمم ۹/۳۳٪ شد.

کلید واژه- لیتیوم فلوراید، سلول‌های خورشیدی پروسکایتی، بازده تبدیل انرژی، تیتانیوم دی‌اکسید، لایه انتقال دهنده الکترون.

Efficiency Enhancement in Perovskite Solar Cells by Doping Lithium Fluoride in Electron Transporting Layer

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Abstract- Recently, adopted perovskite solar cells (PSCs) as the third generation of solar cells based on perovskite materials (ABX_3). PSCs have their unique properties, such as low-cost, band-gap tunability, simple fabrication, the opportunity of substrates, and high performance. Titanium dioxide (TiO_2) is an attractive choice for the electron transporting layer (ETL) in PSCs. In the current study, lithium fluoride (LiF) dopant was used to enhance electrical properties of the (ETL) and perovskite performance. The results showed that LiF -doping increased the conductivity of TiO_2 , suppressed electron-hole recombination at ETL/perovskite interface, and improved crystallinity properties of the perovskite layer. Through ETL modification, the performance of PSCs without hole transporting layer (HTL) 48% improved and endowed the devices with a champion power conversion efficiency of 9.33%.

Keywords: Lithium fluoride, Perovskite solar cells, Power conversion efficiency, Titanium dioxide, Electron transport layer.

various amounts of LiF dopant (0.5, 1, 2, 3, 5, 7.5% in v/v) were spin-coated at 4000 rpm for 30 seconds, then annealed at 100 °C for 10 min. After cooling at RT, perovskite precursor spin-coated with 4000 rpm for 30 seconds, then annealed for 10 min at 100 °C. Finally, 10 nm of the gold top electrode were sputtered under a high vacuum.

2. Results and Discussions

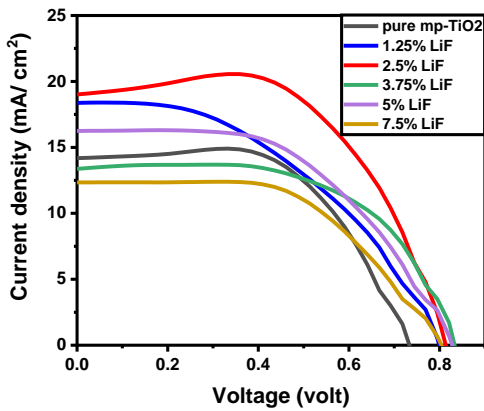


Fig. 1: J-V characteristics of PSC for different volume ratios LiF-TiO₂ as the electron transport layer.

LiF with a volume ratio (v/v) of 1.25%, 2.5%, 3.75% and 5% was doped into mp-TiO₂, and used as ETL to fabricate HTL-free PSCs. Presented that the LiF dopant to mp-TiO₂ layer affects the PV performance, electrical and optical properties of the PSCs. Solar cell performance was measured under (simulated illumination, AM 1.5). Fig. 1 shows J-V characteristics of PSCs for different volume ratios of LiF-TiO₂. PCE enhanced from 6.29% (with maximum current density J_{sc} of 14.18 mA/cm², for pure mp-TiO₂) to 9.33% (with J_{sc} of 19.02 mA/cm², for 2.5% LiF doped mp-TiO₂), see Table I. Considering LiF-dopant inducts, the conduction energy band became higher than the pure TiO₂, it meaning that a band alignment happened between the ETL and perovskite layer.

Fig. 2 illustrates the conductivity of the doped ETL layer ($\sigma = 1.44 \times 10^{-3} \text{ mS.cm}^{-1}$) was increased

by compared with undoped mp-TiO₂ ($\sigma = 1.20 \times 10^{-3} \text{ mS.cm}^{-1}$).

The optical transmittance of ETL layers with 2.5% and without the LiF dopant was studied in Fig. 3. It shows that the LiF dopant does not have a series negative effect on the transmittance of the ETL layer, and light can harvest by the perovskite layer to generate electron-hole carriers with no intense losses within ETL.

Table I. Photovoltaic parameters performance of PSC with LiF-TiO₂ as the electron transport layer.

LiF doped (v %)	Efficiency (%)		V_{oc} (v)	J_{sc} (mA/cm ²)	Fill Factor
	Max.	Ave.			
0	6.29	5.37	0.73	14.18	0.60
1.25	6.50	5.86	0.81	18.37	0.44
2.50	9.33	7.55	0.81	19.02	0.61
3.75	6.68	6.03	0.83	13.37	0.60
5.00	6.63	5.66	0.83	16.24	0.52
7.50	5.52	5.28	0.81	12.34	0.55

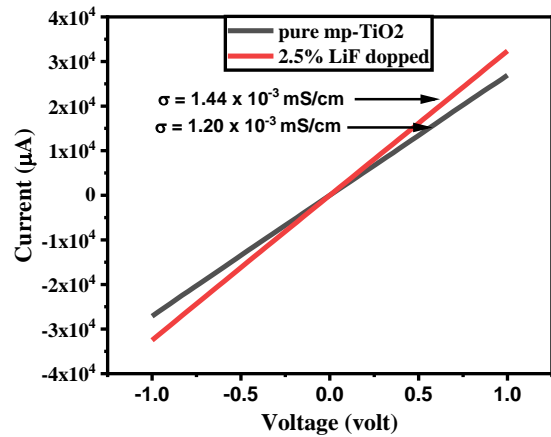


Fig. 2: I-V measurements of pure mp-TiO₂ and LiF doped to mp-TiO₂, the thickness of the mesoporous layer was (200 nm), and the area was (10 mm²).

The effect of LiF-doping on the crystallinity of the perovskite layer is confirmed by PL intensity and XRD as shown in Figs. 4a and 4b. The peak's intensity of (110) plane diffraction of LiF-doped TiO₂ increased, which means well crystallization. Notably, there was no observed shift in XRD peaks

position, suggesting that the LiF dopant in ETL does not diffuse into the perovskite layer. With the addition of LiF dopant into the ETL, the intensity of PL peak reduced, which refers to lower charge recombination at the interface of ETL/perovskite. In addition, a light blue shift was observed in the PL response of PSCs with LiF-doped ETL. It indicates ETL modification reduces band-tail state in the corresponding perovskite layer. The reduced charge recombination at ETL/perovskite, improved conductivity, and better crystallinity of perovskite layer in the LiF-doped based PSCs, altogether led to a performance improvement in PSCs.

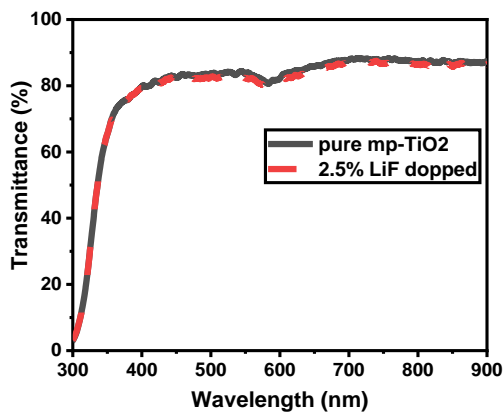


Fig. 5: Transmittance spectra of electron transport layer for pure and doped mp-TiO₂.

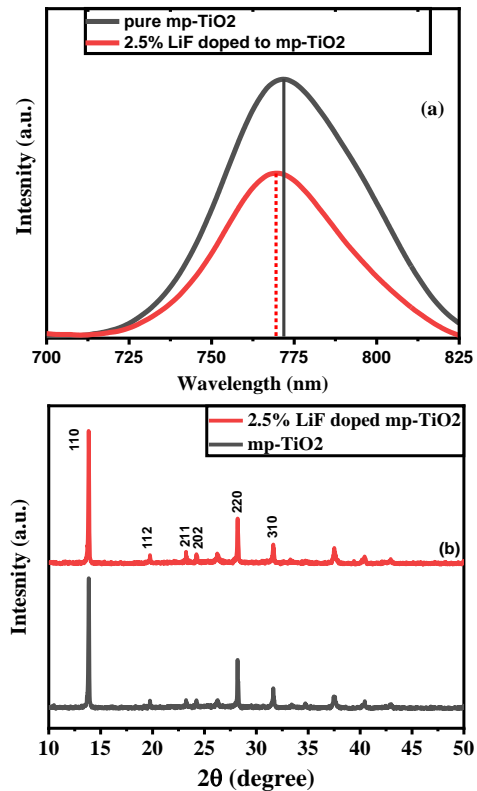


Fig. 6: (a) PL characteristics and (b) XRD patterns of perovskite films on pure and LiF-doped TiO₂.

Acknowledgments

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