Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

The temporal and spatial pinhole constraint in small molecule hole transport layers for stable and efficient perovskite photovoltaics

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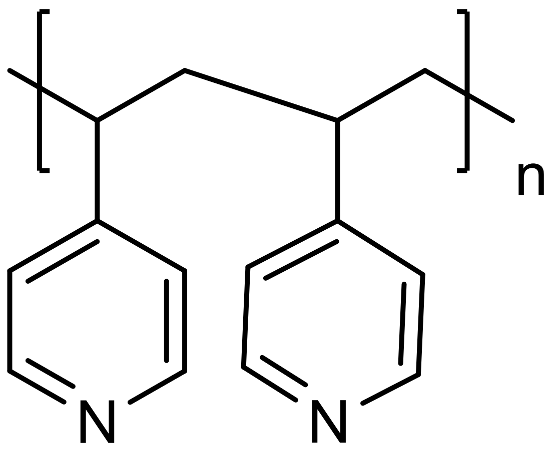

Figure S1 The chemical structure of poly(4-vinylpyridine) (P4VP).

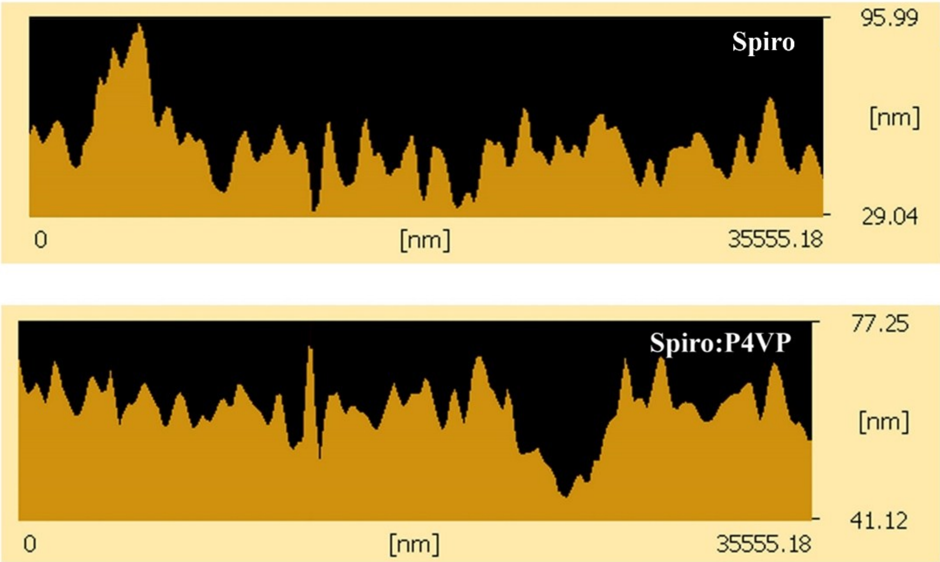

Figure S2 The RMS roughness data for Spiro and Spiro:P4VP based sample

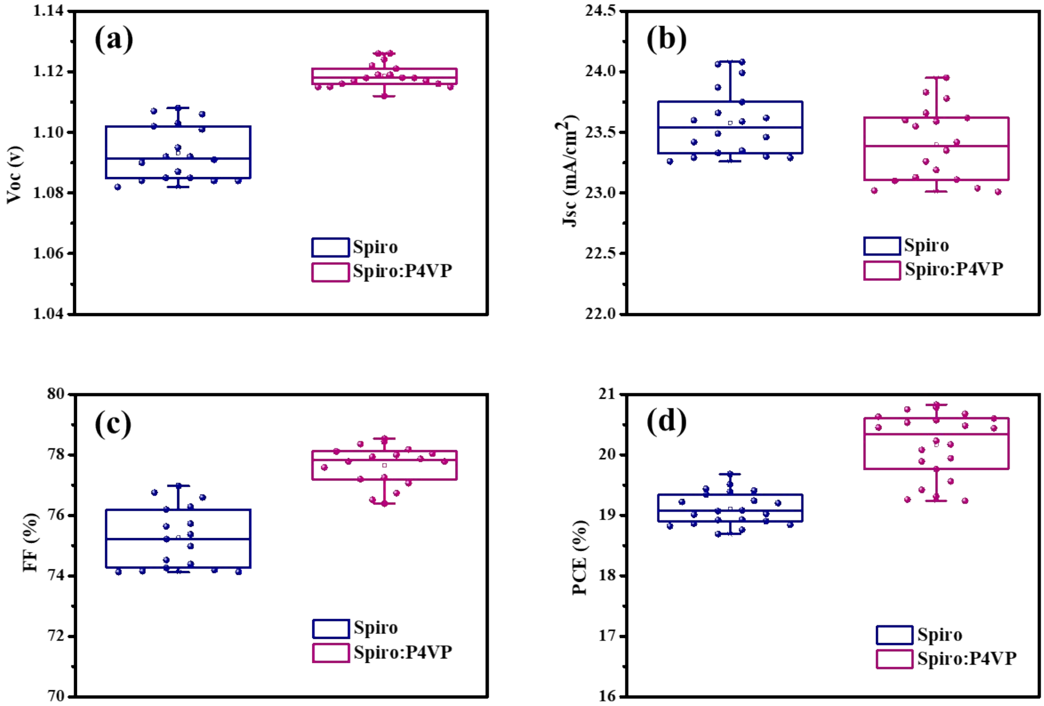

Figure S3. a) The open circuit voltage. b) The short-circuit current. c) The fill factor. d) The power conversion efficiency of multi-devices based on Spiro and Spiro:P4VP as HTLs.

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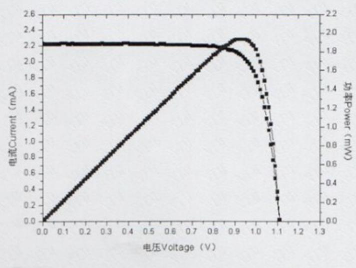
证书编号 GXtc2018-0671
Certificate No.

测试结果
Calibration Results

有效面积（mm^2）	短路电流 I_{sc}(mA)	开路电压 V_{oc}(V)	最大功率 P_{max}(mW)
9.408	2.23	1.09	1.87

最大功率电流 I_{max}(mA)	最大功率电压 V_{max}(V)	填充因子 FF (%)	转换效率(PCE) η (%)
2.03	0.92	77.0	19.8

扫描方向：反扫
Scan Direction: reverse



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测试结果
Calibration Results

有效面积（mm^2）	短路电流 I_{sc}(mA)	开路电压 V_{oc}(V)	最大功率 P_{max}(mW)
9.408	2.23	1.13	1.93

最大功率电流 I_{max}(mA)	最大功率电压 V_{max}(V)	填充因子 FF (%)	转换效率(PCE) η (%)
2.06	0.94	77.0	20.6

注 Note:
1. 测试所用 mask 的面积为 9.408mm^2（证书编号：CDjc2018-0407）。
The mask area is 9.408mm^2 (Certificate No.: CDjc2018-0407).
2. 此数据仅对被测样品当时状态有效。
The data apply only at the time of the test for the sample.
（以下空白）

测 试 员：

核 验 员：

中国计量科学研究院

证书编号 GXtc2018-0671
Certificate No.

测试结果
Calibration Results

1. 测试条件 Test Conditions:
标准太阳电池：单晶硅（81#）；
Reference Solar Cell: mono-Si（81#）；
太阳模拟器：双光源太阳模拟器，AAA 级；
Solar Simulator Classification：double-light source in AAA classification;
温度传感器/控制系统：无；
Teperature Sensor/Control System: None;
Mask（Y/N）: Y.
电压设置：-0.1V~1.2V；间隔：0.01V
Scan Parameter: From -0.1V to 1.2V with 0.01V interval
光阑 Mask（Y/N）: Y
扫描时间：39 秒 扫描点数：131

Figure S4. Certificated results by National Institute of Metrology, China (NIM, China). The forward scan is performed from −0.1 V to 1.2 V at 33 mV/s, with a PCE of 19.8% (Voc=1.09 V, Isc=2.23 mA, FF=77.0%). The reverse scan is performed from 1.2 V to −0.1 V at 33 mV/s, with a PCE of 20.6% (Voc=1.13 V, Isc=2.23 mA, FF=77.0%). The device has an active area of 0.09408 cm^2.

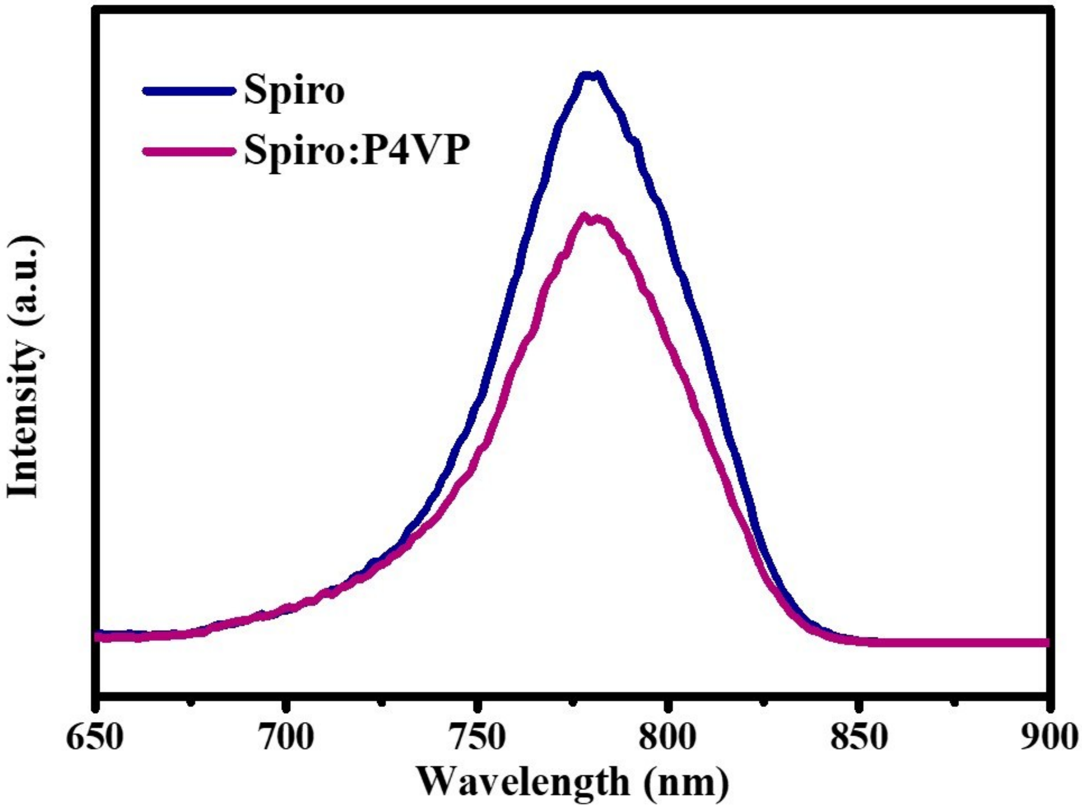

Figure S5. The steady-state photoluminescence (PL) spectroscopy based on Spiro and Spiro:P4VP as HTLs.

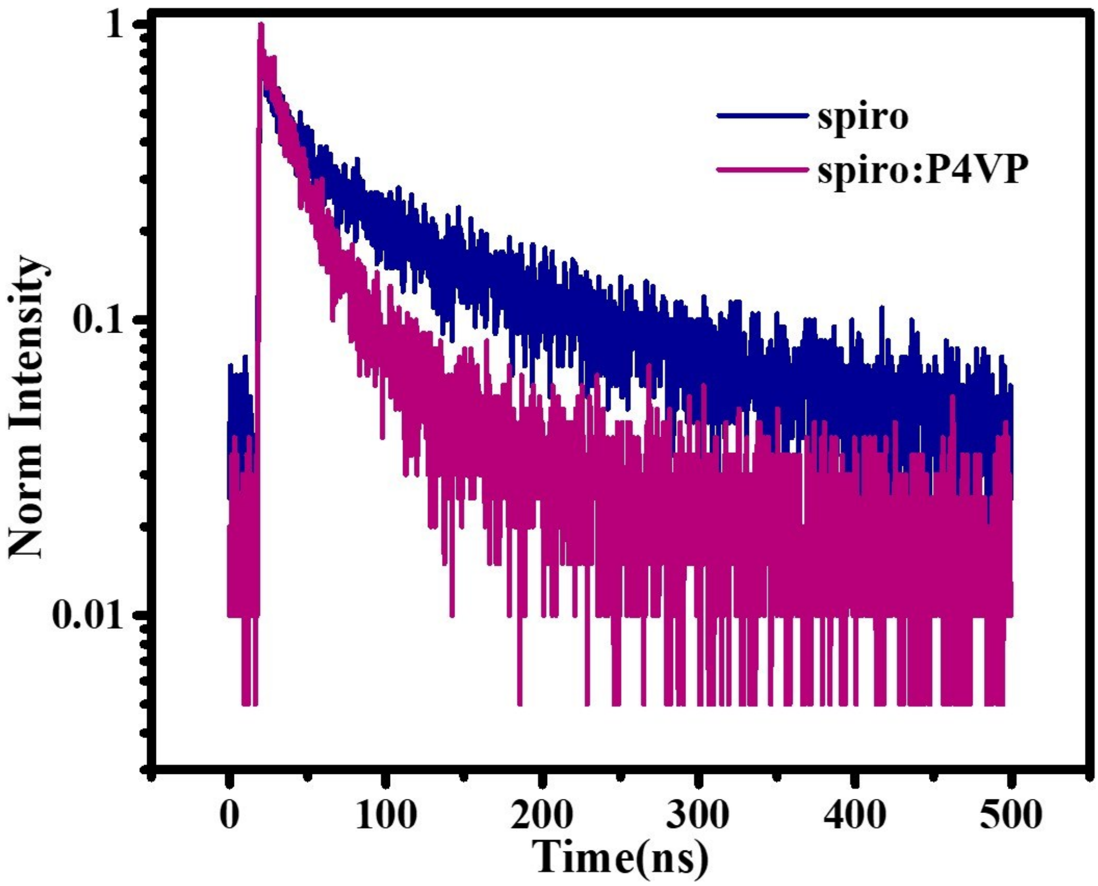

Figure S6.The normalized time-resolved photoluminescence (TRPL) spectroscopy based on Spiro and Spiro:P4VP as HTLs.

Table S1. The obtained carrier lifetimes of perovskite films based on Spiro and Spiro:P4VP as HTLs.

Sample	Spiro	Spiro:P4VP
Lifetime τ_1/ns	12.03	23.60
Lifetime τ_2/ns	112.1	100.0

Table S2. The obtained photovoltage decay time ($\tau_{recombination}$) and photocurrent decay time ($\tau_{transport}$) of perovskite solar cells based on Spiro and Spiro:P4VP as HTLs.

Sample	$\tau_{recombination}$	$\tau_{transport}$
Spiro	0.51μs	310ns
Spiro:P4VP	0.70μs	220ns

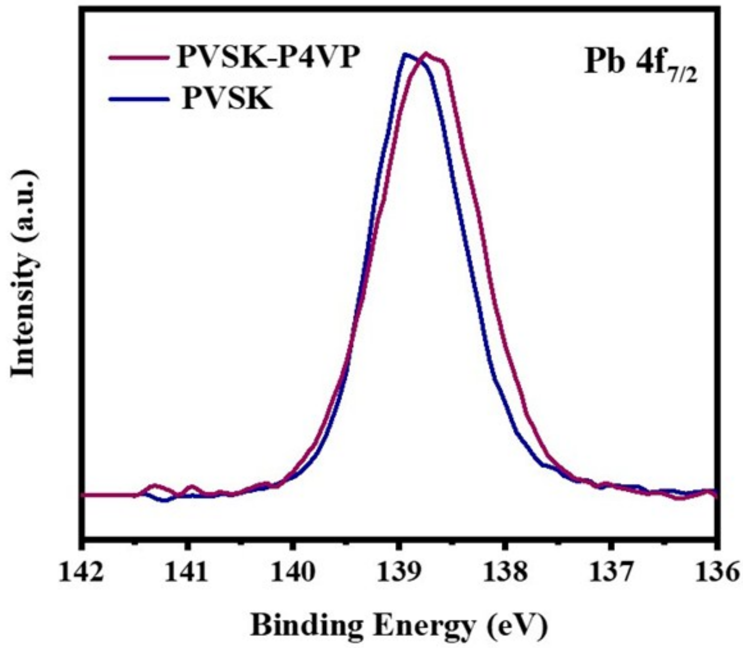

Figure S7 . XPS survey spectra of Pb atom in perovskite films without and with P4VP ($0.1\ mg\ mL^{-1}$)

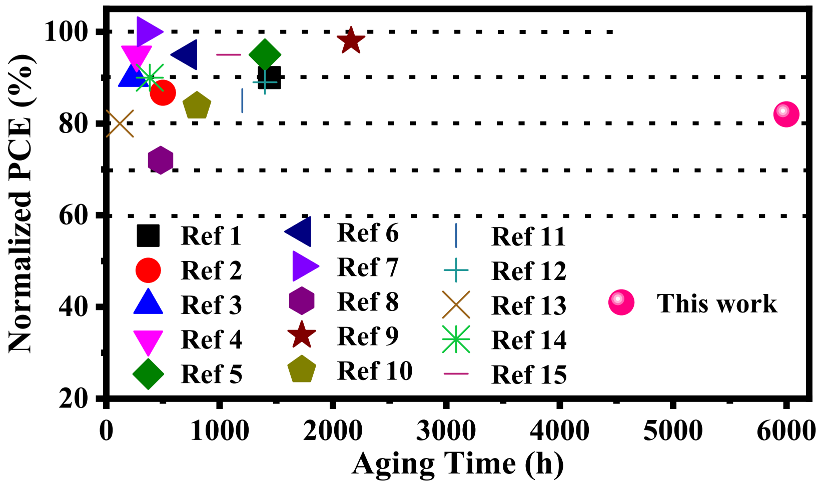

Figure S8 . The stability of this work stored in air was compared with other works.

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