

Figure S1 (a) Spray-coating equipment. (b) Copper wired bar internally fabricated for the bar-coating process.

Table S1 Optimal process conditions for surface treatment using the spray-coating technique.

Parameter	Best condition
Spray-coating runs	6
Concentration of Cleanrise	22% w/w
Solution volume per sample	1 mL
Spray-coating speed	0.8 seconds per run
Nitrogen valve	33 PSI \pm 4 PSI
Height between nozzle and sample	10 cm
Ink temperature	Room temperature
Substrate temperature while deposition	Room temperature
Curing process	10 min at 120°C

Table S2 Optimal process conditions for surface treatment using the bar-coating technique.

Parameter	Best condition
Gap	600 μ m
Cleanrise solution concentration	22% w/w
Solution volume per sample	580 μ L
Bar-coating speed	5 mm/s and 20 mm/s
Ink temperature	Room temperature
Substrate temperature while deposition	Room temperature
Curing process	30 min at 120°C

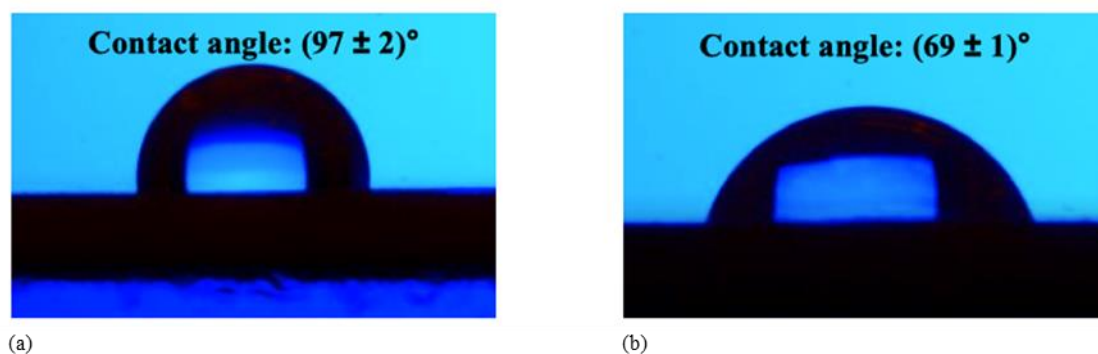


Figure S2 Contact angle recorded for water on top of a (a) barrier film treated using the spray-coating technique and a (b) non-treated film.

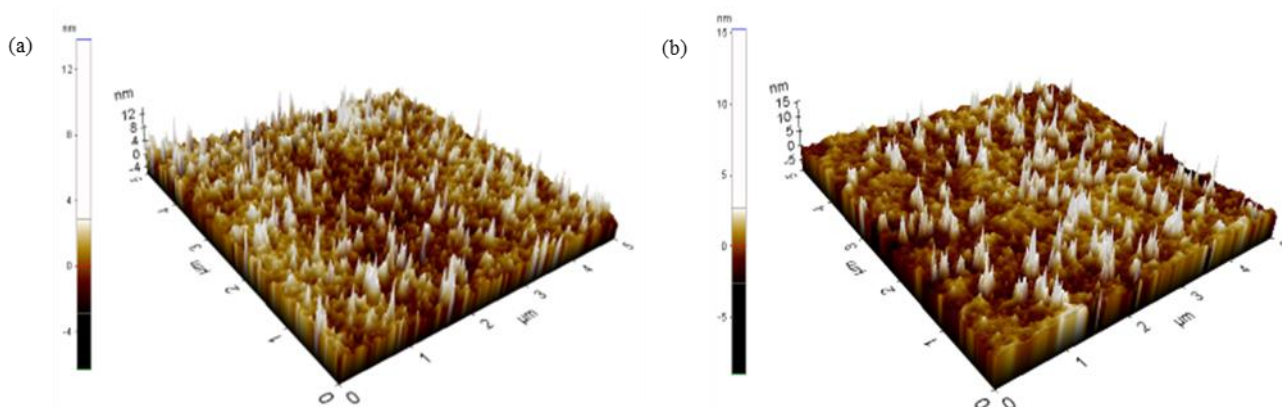


Figure S3 3D AFM Topography images of aged bar-coated barrier films processed at (a) 5 and (b) 20 mm/s.

Table S3 Photovoltaic parameters under 1000 W/m² (1-sun) before (BE) and after encapsulation (AE) for devices encapsulated with spray-coated films. The maximum values are presented within parenthesis.

Condition	V _{oc} (V)	J _{sc} (mA/cm ²)	FF (%)	PCE (%)	R _{SERIES} (ohm)	R _{SHUNT} (ohm)
Treated (BE)	4.70 ± 0.02	9.40 ± 0.04	57.32 ± 1.52	4.22 ± 0.12	33.18 ± 0.52	1625.23 ± 126.30
	(4.72)	(9.46)	(58.99)	(4.35)	(33.68)	(1814.31)
	4.61 ± 0.01	9.60 ± 0.06	56.37 ± 0.77	4.16 ± 0.05	29.45 ± 0.32	1231.77 ± 68.44
Treated (AE)	0.01	0.06	0.77	0.05	0.32	68.44
	(4.63)	(9.65)	(57.75)	(4.22)	(29.87)	(1361.34)
	4.71 ± 0.01	9.29 ± 0.20	57.67 ± 0.90	4.20 ± 0.10	33.66 ± 0.58	1617.84 ± 152.85
Reference (BE)	0.01	0.20	0.90	0.10	0.58	152.85
	(4.72)	(9.52)	(58.74)	(4.30)	(34.45)	(1875.80)
	4.61 ± 0.02	9.26 ± 0.14	56.77 ± 1.09	4.04 ± 0.04	30.23 ± 0.57	1220.56 ± 50.91
Reference (AE)	0.02	0.14	1.09	0.04	0.57	50.91
	(4.63)	(9.46)	(58.03)	(4.10)	(30.80)	(1279.99)

Table S4 Photovoltaic parameters under 1000 W/m² (1-sun) before (BE) and after encapsulation (AE) for devices encapsulated with bar-coated films. The maximum values are presented within parenthesis.

Condition	V _{oc} (V)	J _{sc} (mA/cm ²)	FF (%)	PCE (%)	R _{SERIES} (ohm)	R _{SHUNT} (ohm)
5 mm/s (BE)	4.68 ± 0.02	9.64 ± 0.17	58.92 ± 0.58	4.43 ± 0.04	30.37 ± 0.71	1685.99 ± 49.18
	(4.72)	(9.92)	(59.50)	(4.47)	(31.78)	(1734.18)
	4.59 ± 0.02	9.87 ± 0.13	56.10 ± 1.01	4.24 ± 0.06	29.11 ± 0.38	1152.60 ± 86.54
5 mm/s (AE)	0.02	0.13	1.01	0.06	0.38	86.54
	(4.61)	(10.09)	(57.10)	(4.33)	(29.41)	(1256.08)
	4.18 ± 0.01	8.32 ± 0.21	58.85 ± 0.90	4.44 ± 0.07	27.09 ± 0.45	1235.88 ± 82.12
20 mm/s (BE)	0.01	0.21	0.90	0.07	0.45	82.12
	(4.70)	(9.91)	(60.04)	(4.53)	(30.75)	(1810.91)
	4.58 ± 0.03	9.99 ± 0.18	56.02 ± 1.65	4.27 ± 0.15	29.04 ± 0.99	1208.93 ± 71.27
20 mm/s (AE)	0.03	0.18	1.65	0.15	0.99	71.27
	(4.62)	(10.18)	(58.51)	(4.54)	(30.98)	(1319.82)
	4.68 ± 0.01	9.66 ± 0.12	58.78 ± 0.73	4.43 ± 0.07	30.29 ± 0.70	1646.71 ± 69.09
Reference (BE)	0.01	0.12	0.73	0.07	0.70	69.09
	(4.70)	(9.80)	(59.83)	(4.54)	(30.91)	(1761.35)
	4.60 ± 0.04	9.52 ± 0.11	55.09 ± 2.42	4.02 ± 0.21	30.96 ± 1.39	1017.28 ± 74.88
Reference (AE)	0.04	0.11	2.42	0.21	1.39	74.88
	(4.64)	(9.64)	(58.22)	(4.34)	(33.52)	(1143.09)

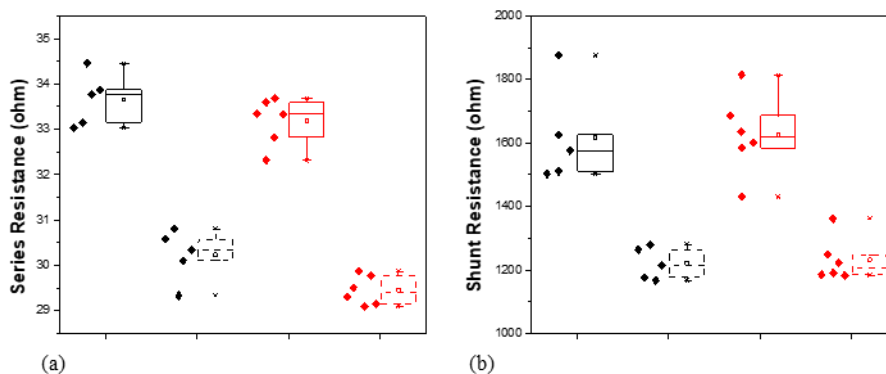


Figure S4 Photovoltaic parameters. (a) Series resistance and (b) shunt resistance corresponding to the reference and the encapsulated mini-modules with spray-coated modified barrier films. The continuous lines represent the performance of the system before encapsulation, while the dashed lines represent the performance of the system after encapsulation.

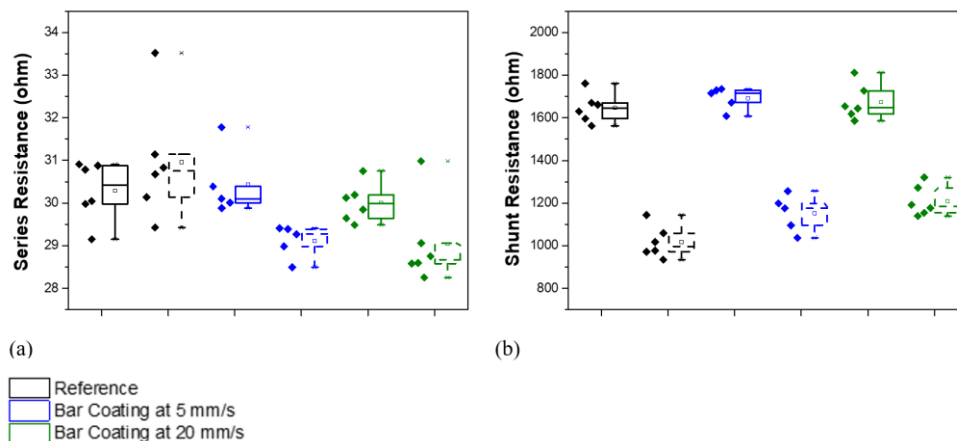


Figure S5 Photovoltaic parameters. (a) Series resistance and (b) shunt resistance corresponding to the reference and encapsulated mini-modules with bar-coated modified barrier films. The continuous lines represent the performance of the system before encapsulation, while the dashed lines represent the performance of the system after encapsulation.

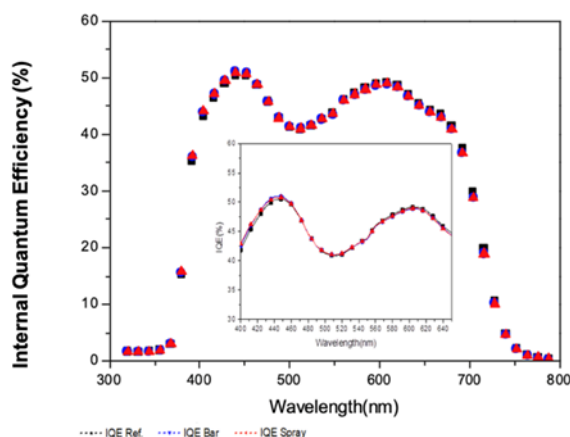


Figure S6 Internal quantum efficiency values recorded for mini-modules encapsulated with treated and non-treated films. The bar-coating condition was investigated when the speed of coating was 5 mm/s.

Table S5 Details of the thermal cure sol-gel Cleanrise CT1.C171.4 system provided by the supplier (Polyrise).

	Typical values
Appearance	Clear colorless liquid
Solids, wt%	22% ± 1%
Specific gravity at 20°C	0,85 ± 0,05
Major solvent	Ethanol (CAS 64-17-5)

Table S6 Details of the coating and curing processes conducted using Cleanrise CT1.C171.4. The sol–gel coat was designed to impart hydrophobic and oleophobic properties to the system.

	Recommendations
Relative humidity	30–60% at 22°C
Room temperature	20–25°C
Air Flow	Laminar flow, class 1000/ISO 6
Coating temperature	20°C
Coating filtration	1–5 µm absolute
Curing	10 min at room temperature (or 3–4 min at 80°C)
Recommended thickness	<2.5 µm