

Supporting Information

Highly-stable PEN as gas-barrier substrate for flexible displays via Atomic layer infiltration

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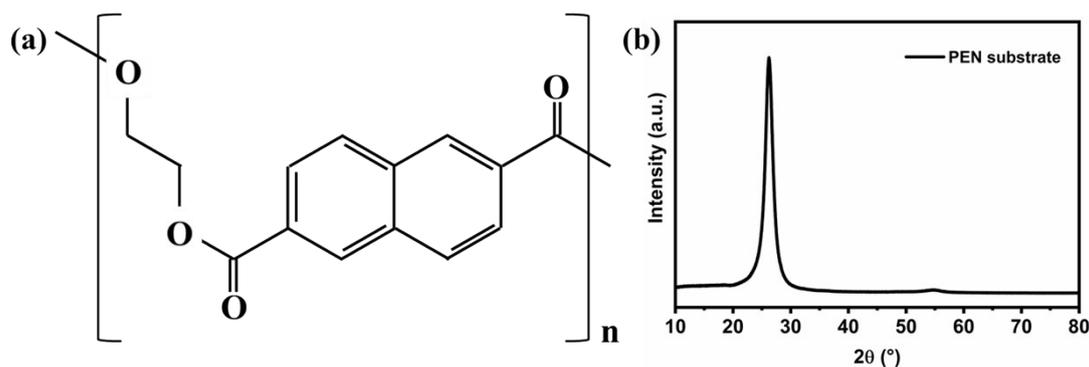


Figure S1. (a) Structure of PEN repeating units; (b) XRD pattern of the PEN substrate.

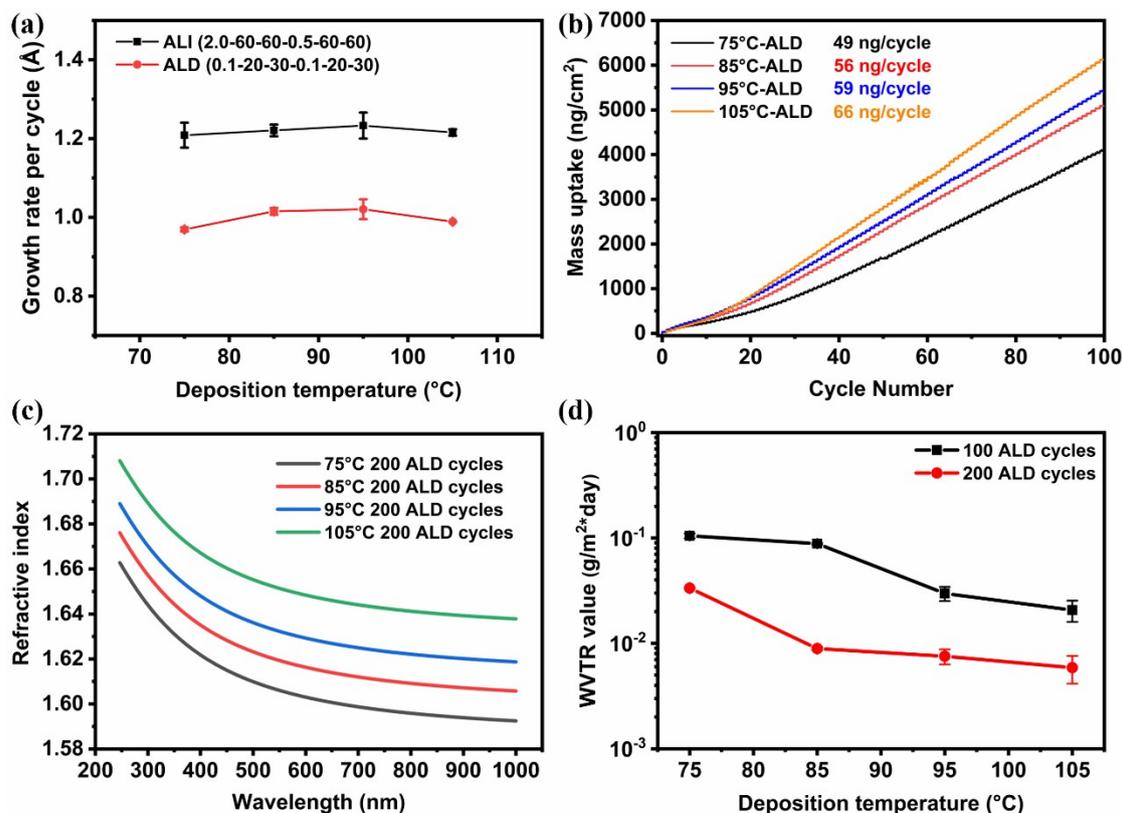


Figure S2. Characteristics of the ALD and ALI deposited Al₂O₃ films with different process temperatures; (a) growth rate per cycle; (b) mass uptake versus the cycle number on the PEN substrates; (c) refractive indexes versus the wavelength; (d) barrier properties of the PEN substrates with 100 or 200 ALD cycles with different deposition temperatures.

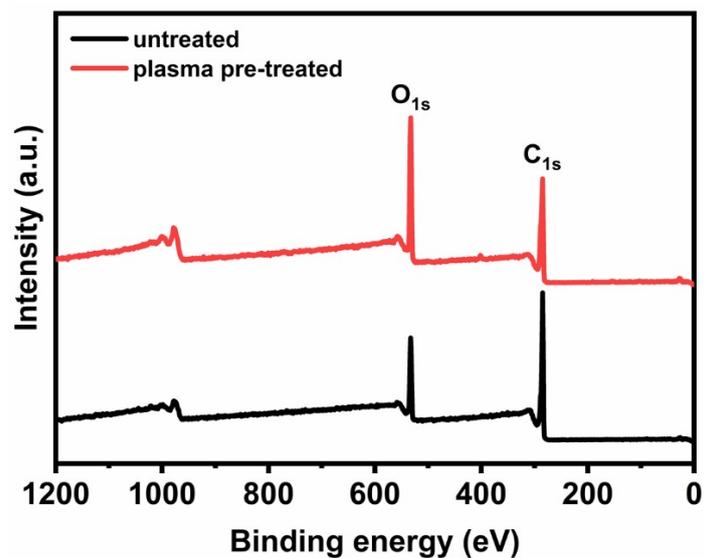


Figure S3. The full scan XPS spectra of the PEN substrate before and after the O₂ plasma pre-treatment

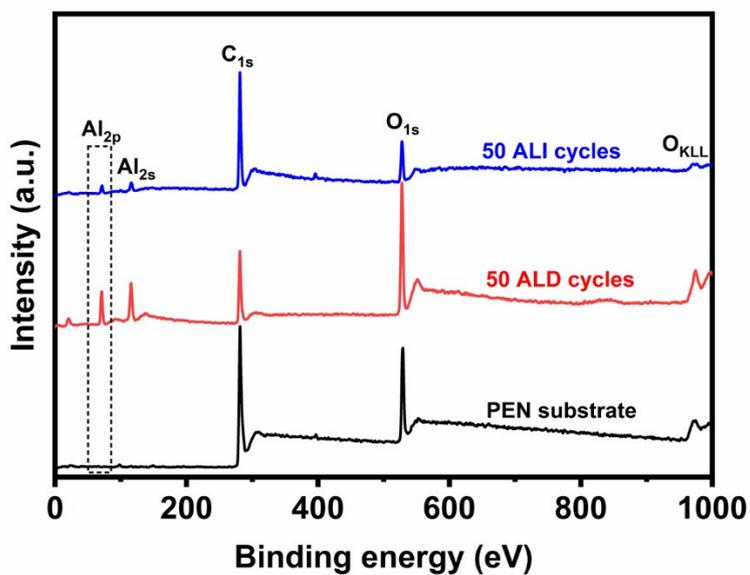


Figure S4. The full scan XPS spectra of the pristine PEN substrate, and the PEN substrates modified with 50 ALD or ALI cycles.

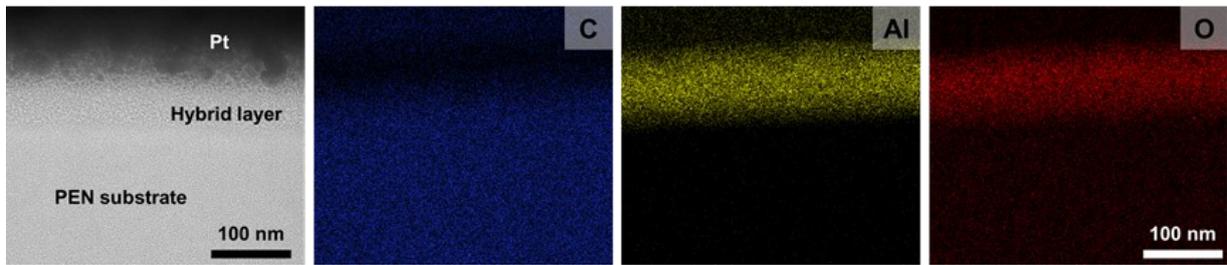


Figure S5. (a) HR-TEM cross-sectional image of the ALI-infiltrated PEN substrate; EDS mapping of the ALI-infiltrated PEN substrate: (b) carbon; (c) aluminum and (d) oxygen.

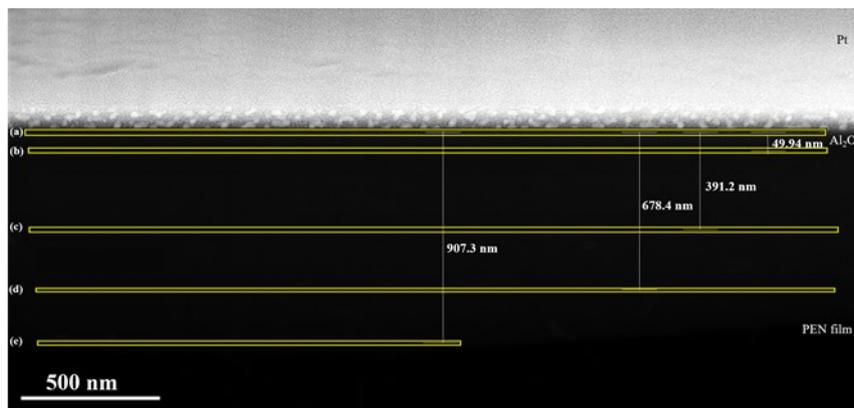


Figure S6. Schematic diagram of the different positions for the atomic fraction detection of Al element

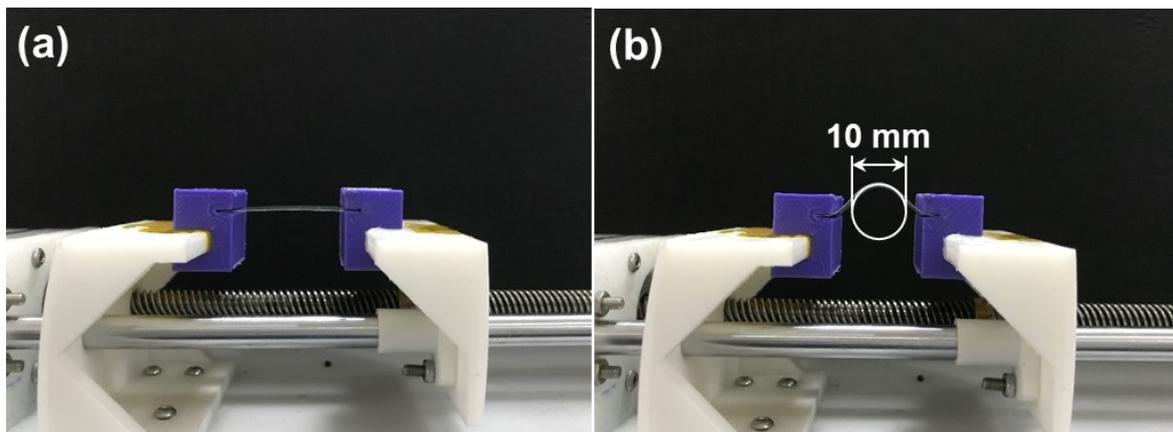


Figure S7. Photographs showing bending test of the sample with the radius of 5 mm.

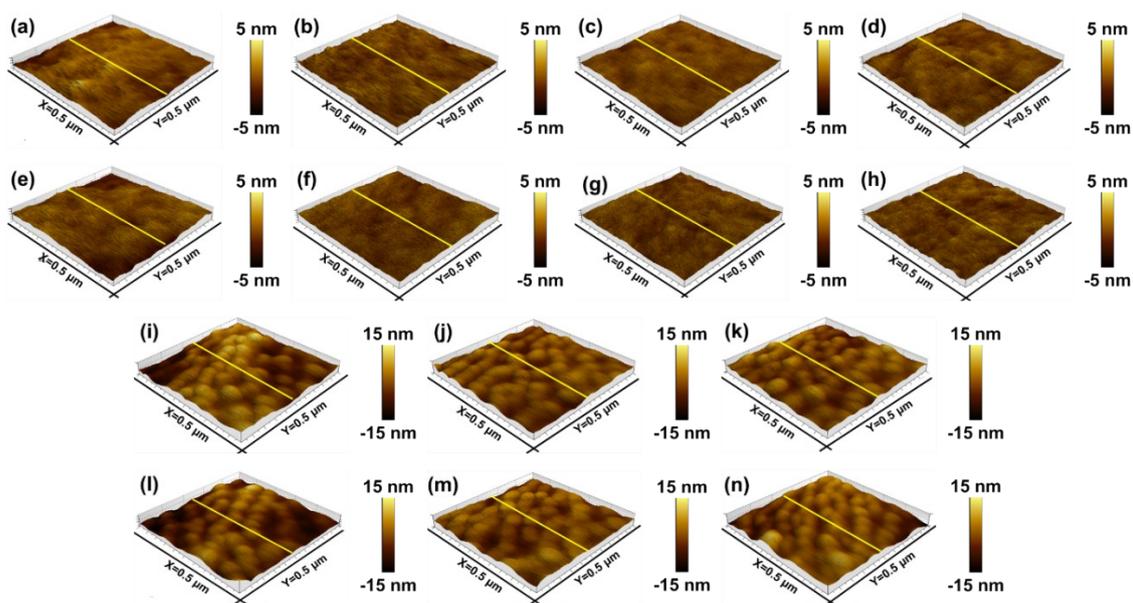


Figure S8. Surface topographies of PEN substrate (a) before and (e) after the bending test; PEN substrate coated with 100 ALD cycles (b) before and (f) after the bending test; PEN substrate coated with 200 ALD cycles (c) before and (g) after the bending test; PEN substrate coated with 100 ALI cycles (d) before and (h) after the bending test; O₂ plasma pre-treated PEN substrate (i) before and (l) after the bending test; O₂ plasma pre-treated PEN substrate coated with 100 ALD cycles (j) before and (m) after the bending test; O₂ plasma pre-treated PEN substrate coated with 100 ALI cycles (k) before and (n) after the bending test.

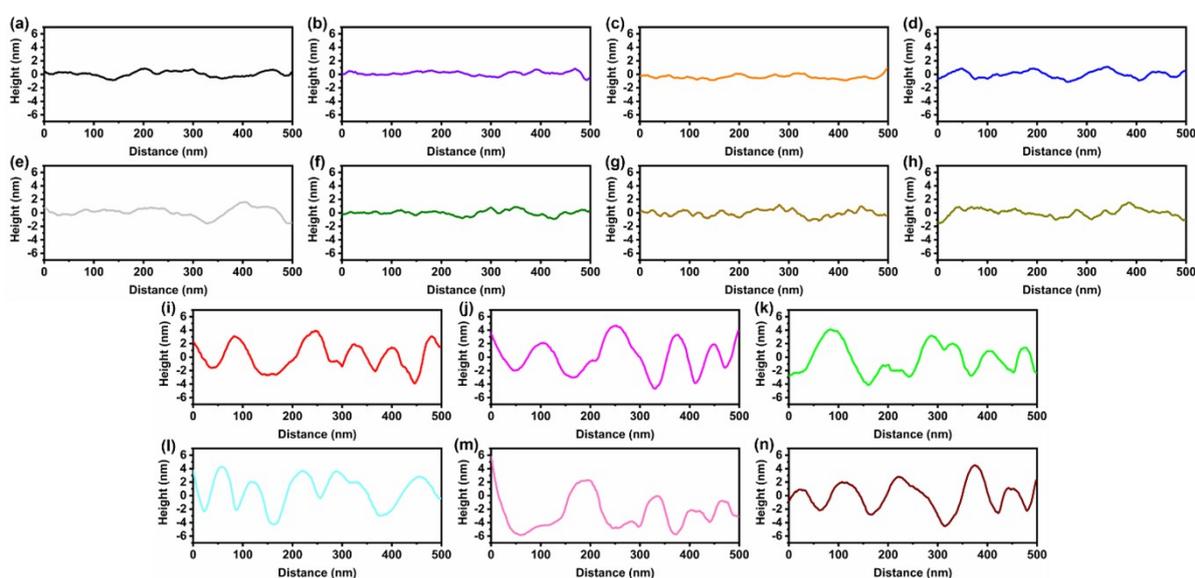


Figure S9. AFM line scan height tests of PEN substrate (a) before and (e) after the bending test; PEN substrate coated with 100 ALD cycles (b) before and (f) after the bending test; PEN substrate coated with 200 ALD cycles (c) before and (g) after the bending test; PEN substrate coated with 100 ALI cycles (d) before and (h) after the bending test; O₂ plasma pre-treated PEN substrate (i) before and (l) after the bending test; O₂ plasma pre-treated PEN substrate coated with 100 ALD cycles (j) before and (m) after the bending test; O₂ plasma pre-treated PEN substrate coated with 100 ALI cycles (k) before and (n) after the bending test.

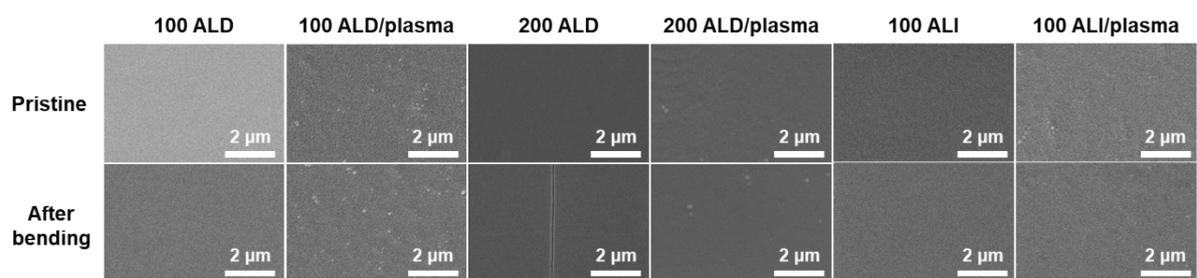


Figure S10. FE-SEM photographs of the PEN substrates modified with different processes before and after the bending fatigue tests with the radius of 5 mm.

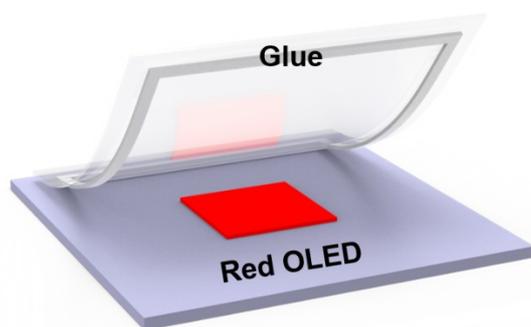


Figure S11. Schematic diagram of the encapsulation of OLED devices.

Table S1. WVTR values (g/m²/day) of ALD-modified PEN substrates in the controlled environment of 60°C/90% RH

Cycle number	O ₂ plasma Pre-treatment	Deposition Temperature (°C)			
		75	85	95	105
100	W/O	$(1.05 \pm 0.01) \cdot 10^{-1}$	$(8.83 \pm 0.19) \cdot 10^{-2}$	$(2.98 \pm 0.45) \cdot 10^{-2}$	$(2.07 \pm 0.47) \cdot 10^{-2}$
	W	$(1.99 \pm 0.20) \cdot 10^{-3}$	$(1.82 \pm 0.30) \cdot 10^{-3}$	$(1.78 \pm 0.23) \cdot 10^{-3}$	$(1.63 \pm 0.59) \cdot 10^{-3}$
200	W/O	$(3.34 \pm 0.03) \cdot 10^{-2}$	$(8.93 \pm 0.31) \cdot 10^{-3}$	$(7.54 \pm 1.22) \cdot 10^{-3}$	$(5.88 \pm 1.33) \cdot 10^{-3}$

Table S2. Atomic concentrations (%) obtained from X-ray photoelectron spectroscopy survey scans of PEN substrates before and after the O₂ plasma pre-treatment

Atomic concentrations (%)	Pristine PEN	O ₂ plasma pre-treated PEN
C 1s	81.4	68.9
O 1s	18.6	31.1

Table S3. WVTR values (g/m²/day) of PEN substrates modified with 100 ALI cycles in the controlled environment of 60°C/90% RH

	Holding time (s)	Deposition Temperature (°C)			
		75	85	95	105
	30	-	-	$(4.92 \pm 1.01) \cdot 10^{-3}$	-
	60	$(1.08 \pm 0.24) \cdot 10^{-2}$	$(6.22 \pm 2.51) \cdot 10^{-3}$	$(4.45 \pm 0.93) \cdot 10^{-3}$	$(3.82 \pm 0.50) \cdot 10^{-3}$
	90	-	-	$(3.40 \pm 0.74) \cdot 10^{-3}$	-
	120	-	-	$(3.26 \pm 0.51) \cdot 10^{-3}$	-

Table S4. Atomic fraction of Al element in different depths

Depth (nm)	Atomic fraction (%)	Error (%)
0	27.4	6.76
49.94	6.85	1.46
391.2	0.13	0.05
678.4	0.11	0.05
907.3	0.08	0.14

Table S5. Properties of modified and unmodified PEN substrates before and after the bending fatigue test

Structures	Roughness (nm)		WVTR value (g/m ² *day)	
	Before bending	After bending	Before bending	After bending
Pristine PEN	0.753	0.834	4.45±0.33*10 ⁻¹	-
PEN/P	4.195	4.250	-	-
100 ALD/PEN	0.602	0.645	2.98±0.45*10 ⁻²	-
200 ALD/PEN	0.446	0.570	7.54±1.22*10 ⁻³	1.04±0.28*10 ⁻¹
100 ALI/PEN	0.592	0.644	3.40±0.74*10 ⁻³	7.61±2.13*10 ⁻³
100 ALD/PEN/P	2.695	2.730	1.78±0.23*10 ⁻³	4.24±0.53*10 ⁻³
100 ALI/PEN/P	2.947	3.137	3.20±0.80*10 ⁻⁴	2.07±0.31*10 ⁻³

Notes: P means the “O₂ plasma pre-treatment”, all the deposition temperature was set as 95°C, and the holding time in the ALI method was set as 90 s. The WVTR values were evaluated in the controlled environment of 60°C/90% RH.