Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information for:

Ionic Dielectrics for Fully Printed Carbon Nanotube Transistors: Impact of Composition and Induced Stresses

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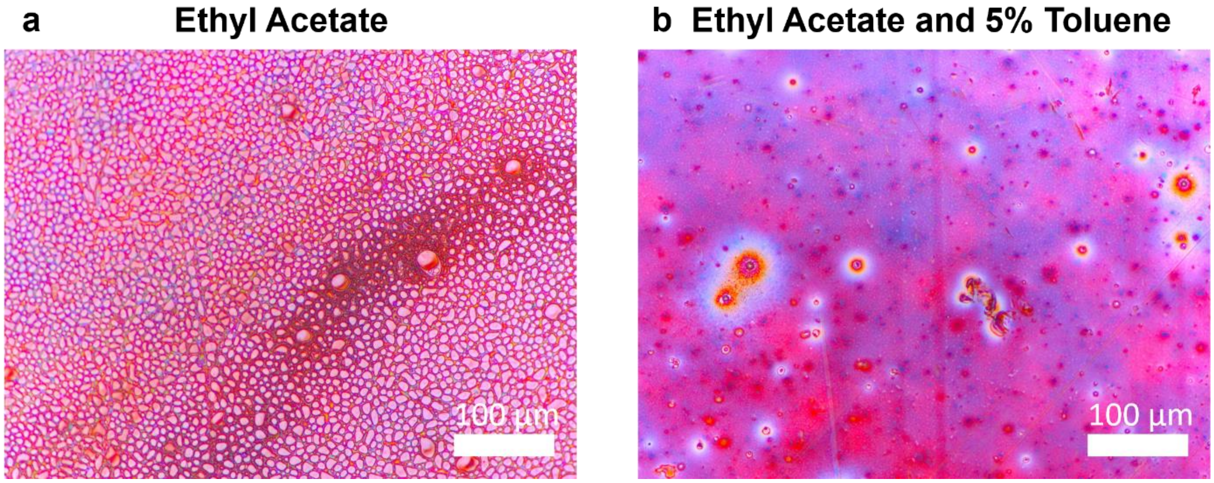

Figure S1. e-PVDF-HFP solvent optimization. Optical images of (a) e-PVDF-HFP printed with ethyl acetate as the solvent, showing large pores in the film due to bundling, and (b) e-PVDF-HFP printed with ethyl acetate and 5% toluene to create a smoother film.

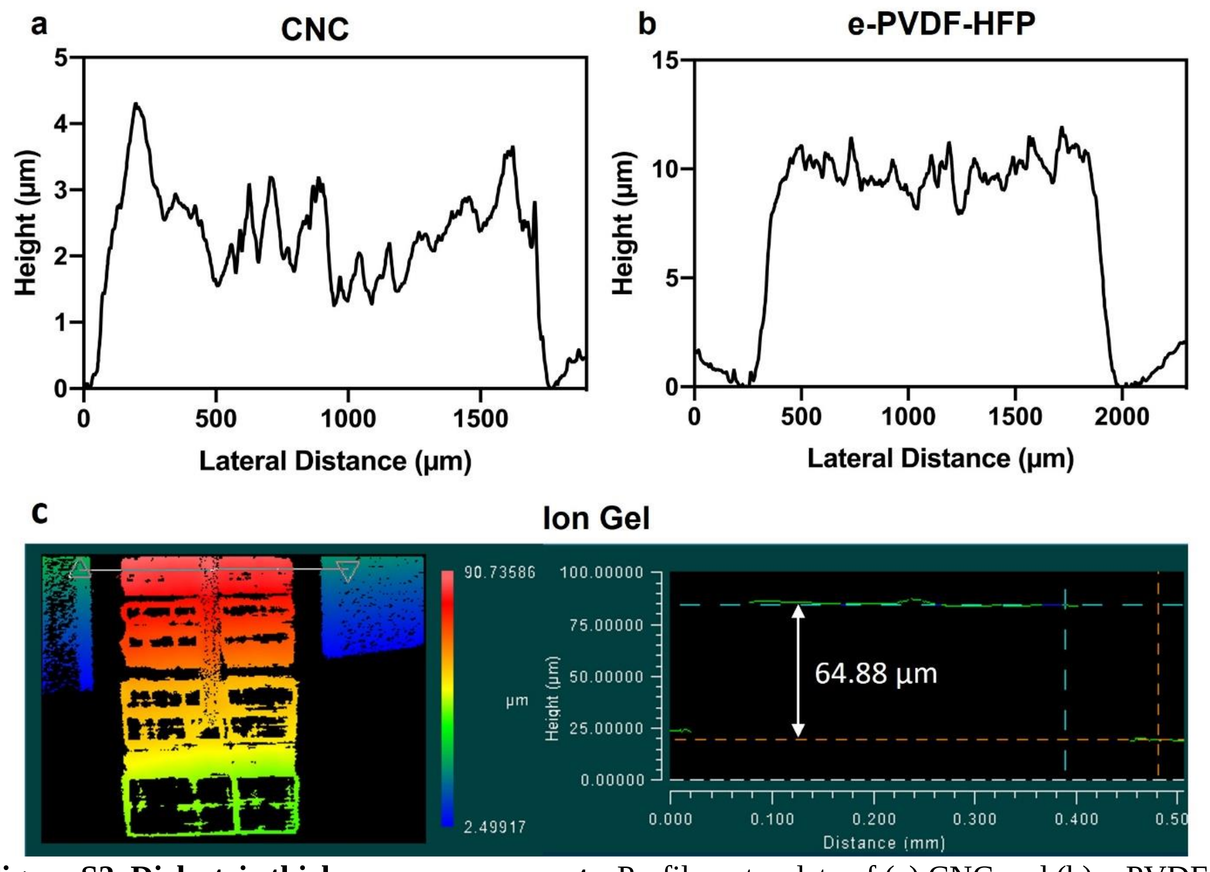

Figure S2. Dielectric thickness measurements. Profilometry data of (a) CNC and (b) e-PVDF-HFP normalized to the tilt of the platen. (c) 3D optical profiler image (left) and cross-section along line (right) of ion gel dielectric layer.

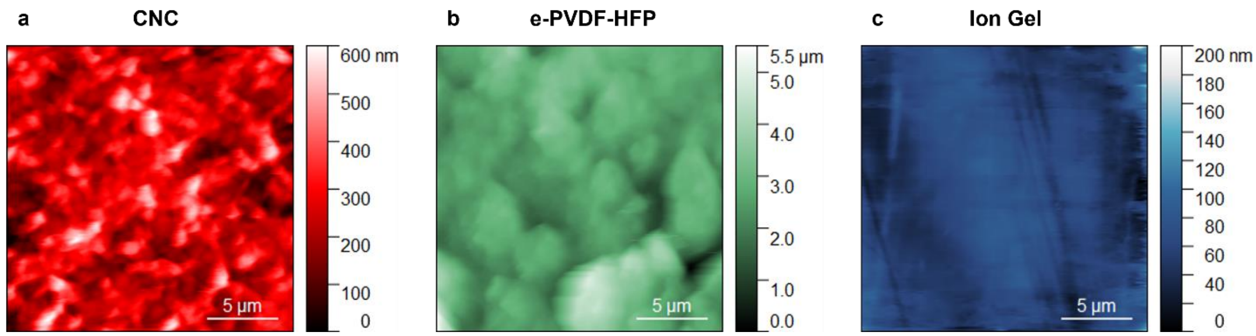

Figure S3. Atomic force microscopy of dielectrics. (a-c) AFM height maps for each dielectric showing the surface topology. The RMS roughness for CNC, e-PVDF-HFP, and ion gel are 78.82 nm, 568.2 nm, and 15.24 nm, respectively.

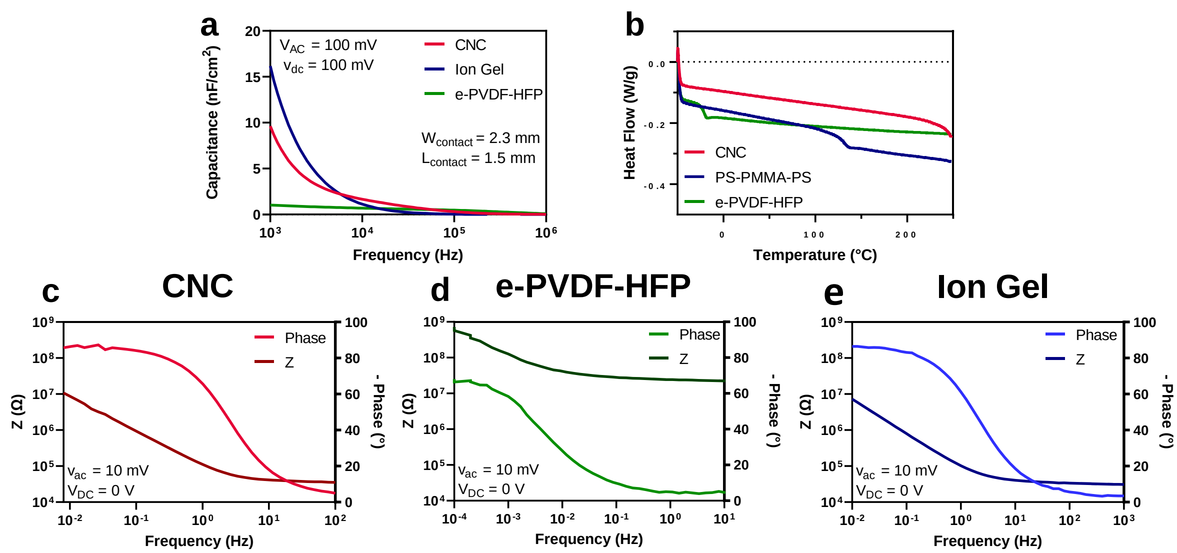

Figure S4. Characterization of the three diverse ionic dielectrics. (a) Capacitance versus frequency plot at v_{ac} of 100 mV and V_{DC} of 100 mV. (b) Differential scanning calorimetry (DSC) of each dielectric to determine glass transition temperature. (c-e) Bode plots for each dielectric showing the magnitude of impedance and phase. Top and bottom electrode of the capacitors have dimensions of 2.3 mm x 1.5 mm.

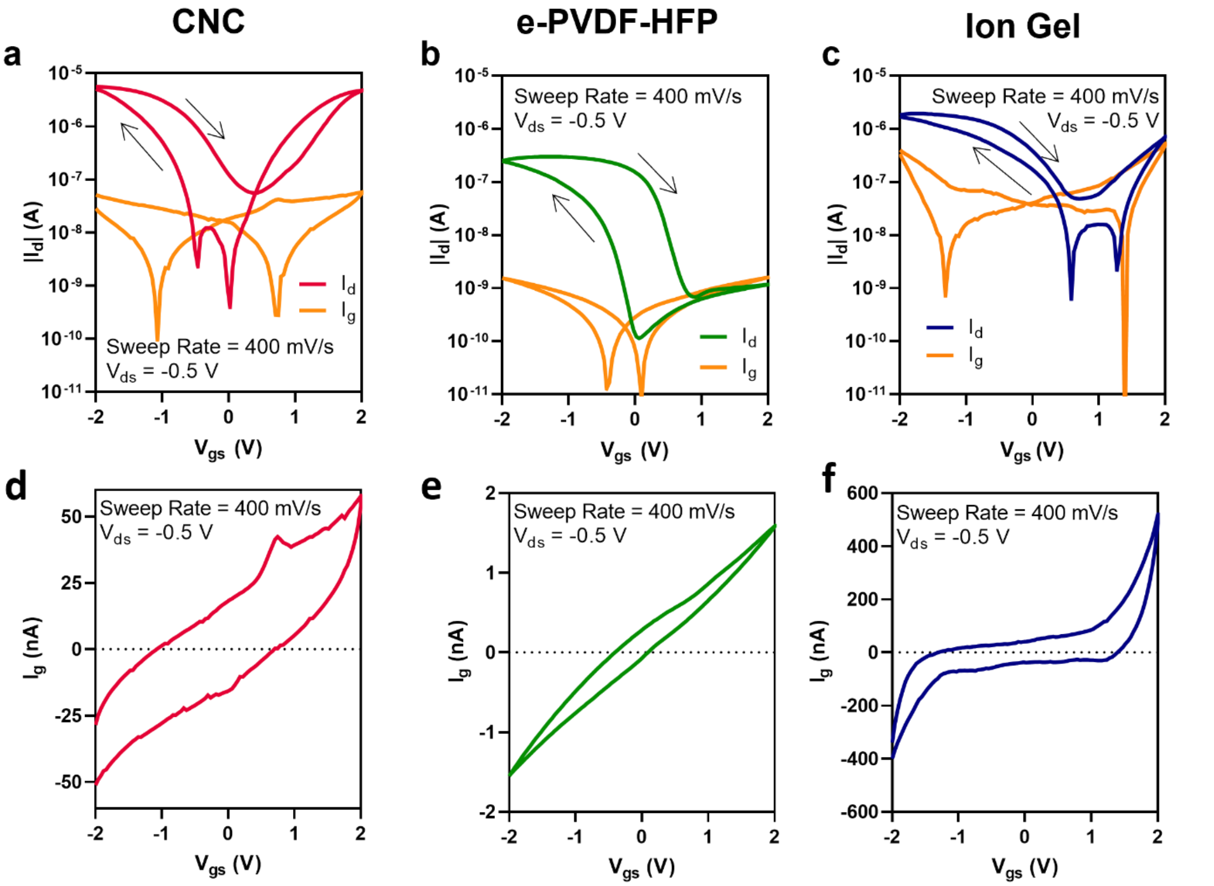

Figure S5. Representative characteristics, including gate leakage current. Subthreshold curves with gate leakage (I_g) for representative CNT-TFTs using (a) CNC, (b) e-PVDF-HFP, or (c) ion gel. Each plot includes double-sweep (hysteresis) curves, which were obtained at the same drain-source voltage and gate sweep rate. (d-f) Linear-scale gate leakage versus gate voltage for each dielectric at a V_{ds} of -0.5V and a sweep rate of 400 mV/s. For all devices, L_{CH} = 250 µm and W_{CH} = 200 µm.

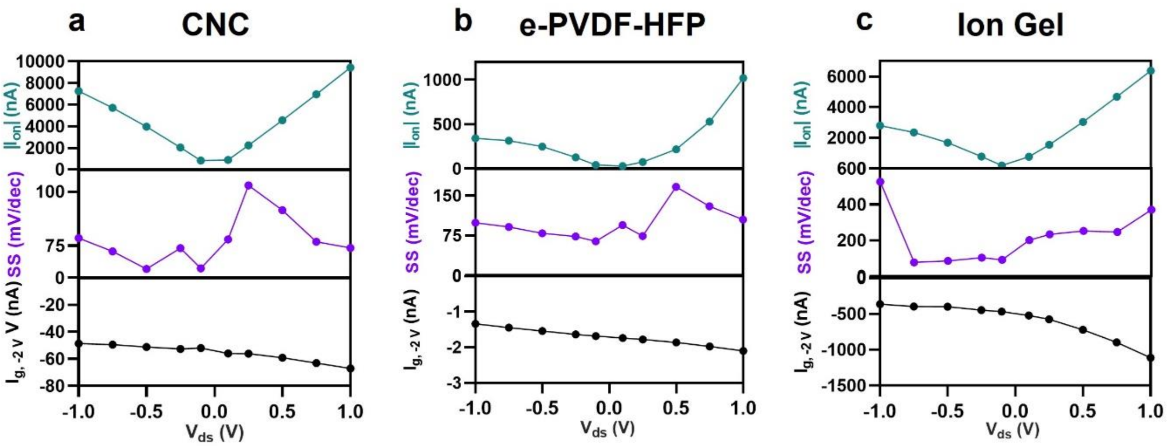

Figure S6. Drain-source voltage parameter dependence. On-current (I_{on}), subthreshold swing (SS), and gate leakage current at V_{gs} = -2 V dependence on drain-source voltage for fully printed CNT-TFTs with (a) CNC, (b) e-PVDF-HFP, or (c) ion gel ionic dielectrics.

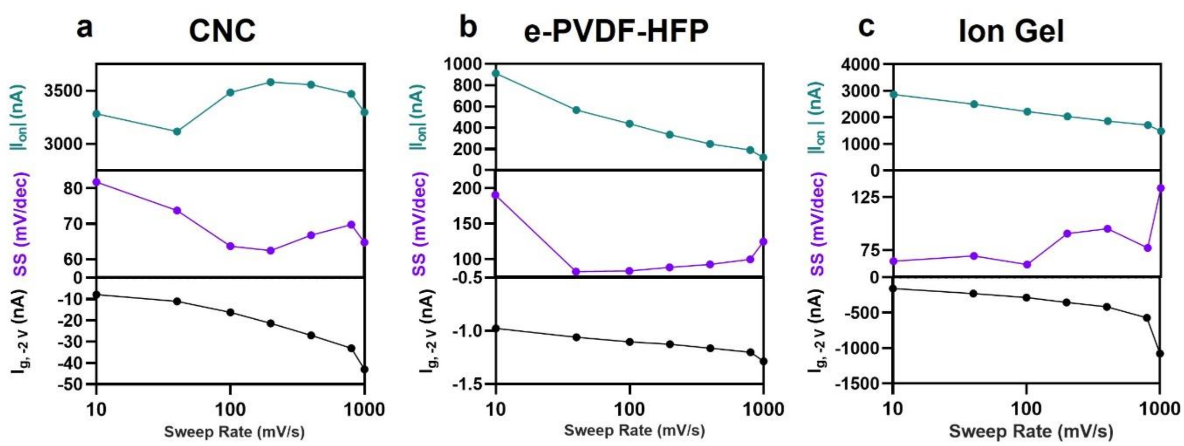

Figure S7. Sweep rate parameter dependence. On-current, subthreshold swing, and gate leakage current at V_{gs} = -2 V dependance on sweep rate for fully printed CNT-TFTs with (a) CNC, (b) e-PVDF-HFP, or (c) ion gel ionic dielectrics.

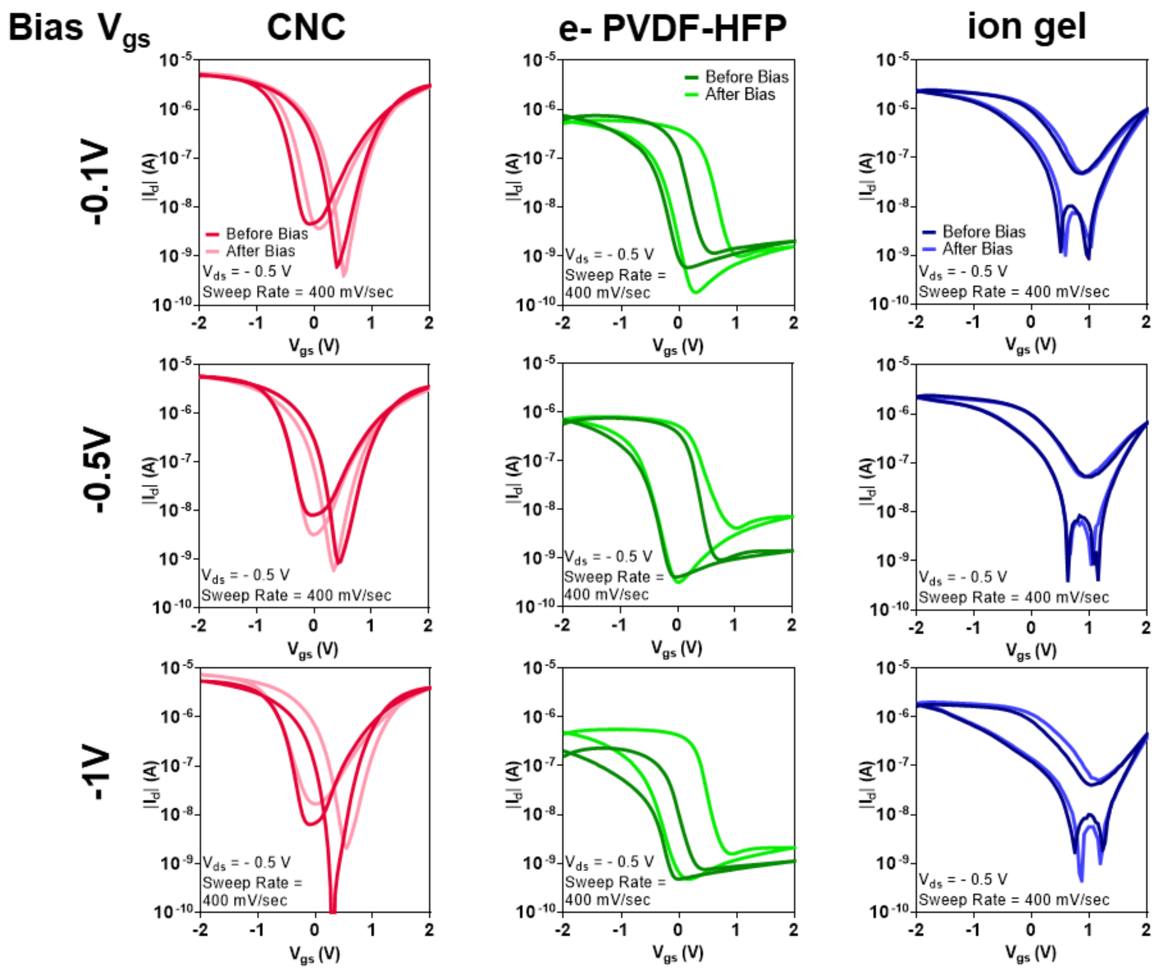

Figure S8. Subthreshold sweeps before and after bias stress. Before and after 12-hour bias stress tests of V_{gs} = -0.1 V, -0.5 V, or -1 V (with V_{ds} = -0.5 V for all cases) for fully printed CNT-TFTs with CNC, e-PVDF-HFP, or ion gel ionic dielectrics.

Table S1. Bias stress test parameter analysis. Percent change of device performance parameters after a 12-hour applied voltage stress with respect to the initial state of the device. Note, in addition to the indicated V_{gs}, there was also a V_{ds} = -0.5 V applied in all cases. * Indicates dielectric yielding best average performance for the given parameter.

Bias Stress	Parameter	CNC 0.05% NaCl	e-PVDF-HFP	Ion Gel
V_{gs} = -0.1V	I_{on} (%)	7.40	-21.87	2.54*
	$I_{g, -2 V}$ (%)	-5.39	3.92	-3.22*
	Hysteresis (%)	-15.38	81.82	0*
	SS (%)	-7.24	-7.37	-2.23*
	V_t (%)	80.00	-36.39*	57.14
V_{gs} = -0.5V	I_{on} (%)	-2.85	1.92*	-2.64
	$I_{g, -2 V}$ (%)	-43.51	9.55	-2.41*
	Hysteresis (%)	-38.46	35.00	-9.09*
	SS (%)	3.26*	4.45	-29.81
	V_t (%)	-114.29	0*	0*
V_{gs} = -1V	I_{on} (%)	34.66	137.91	5.59*
	$I_{g, -2 V}$ (%)	75.04	-17.90	-3.69*
	Hysteresis (%)	66.67	109.09	26.67*
	SS (%)	0.93*	7.95	-41.94
	V_t (%)	-1399.94	-19.05*	40.00

Table S2. Bending stress test parameter analysis. Percent change of the device performance parameters after 1,000 bending cycles with respect to the initial state of the device. * Indicates dielectric yielding best average performance for the given parameter.

	CNC 0.05% NaCl	e-PVDF-HFP	Ion Gel
I_{on} (%)	61.05	-32.20	23.95*
$I_{g, -2 V}$ (%)	-40.46	9.85	-3.13*
Hysteresis (%)	N/A	13.74*	45.83
SS (%)	188.45	5.88*	-8.96
V_t (%)	640.10	11.789*	24.06