

Supplementary Materials

Degradation by design: sequentially degradable organic transistors for sustainable electronics

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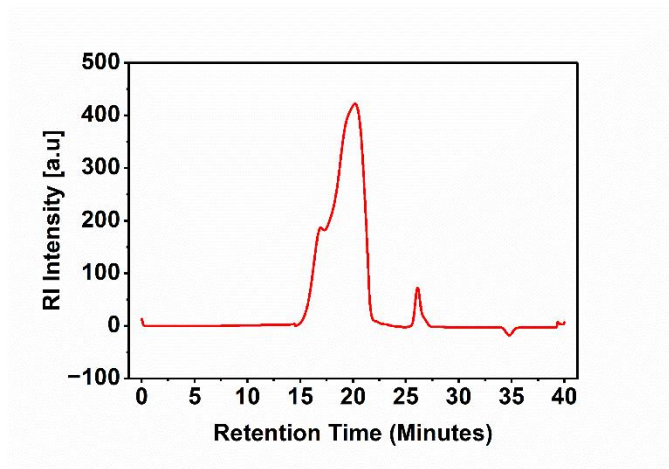
Device characterization

Our built-in autotestor made it possible to measure the source-drain current (I_{SD}), control the source-drain voltage (V_{SD}), and control the gate-source voltage (V_{GS}). While V_{GS} was adjusted between 0 and -5 V, output characteristics were obtained by sweeping V_{SD} from 0 to -5 V. For biodegradable polymer-gated devices, transfer characteristics were measured at $V_{SD} = -5$ V, while for SiO_2 -gated devices, $V_{SD} = -50$ V. V_{GS} was modulated between 0 and -50 V for the latter and between 0 and -5 V for the former.

$$I_{SD} = \frac{\mu C_i W}{2L} (V_{GS} - V_T)^2 \quad (1)$$

Equation (1)^[1] was used to extract the field effect mobility (μ_e), threshold voltage (V_T), and on/off current ratio ($I_{on/off}$) from transfer characteristics in the saturation regime. $I_{on/off}$ was derived from the ratio of the maximum to minimum I_{SD} values, whereas V_T was calculated by projecting the linear portion of the on-state transfer curve to its x-axis intercept. Using impedance spectroscopy (Methrohm PGSTAT204 potentiostat/galvanostat, Switzerland) at 10 Hz and an applied voltage sweep from 0 to 10 V, the gate dielectric capacitance (C_i) was measured. C_i was computed using equation (2),^[2] taking into account the real (Z') and imaginary (Z'') components of impedance as well as the angular frequency (ω). The active area of each device (A) was taken into account in the computation. To account for changes in channel length brought on by electrode shadowing during source-drain deposition, reported mobility values were adjusted.

$$C_i = \frac{1}{\omega A} = \frac{Z'}{Z'^2 + Z''^2} \quad (2)$$

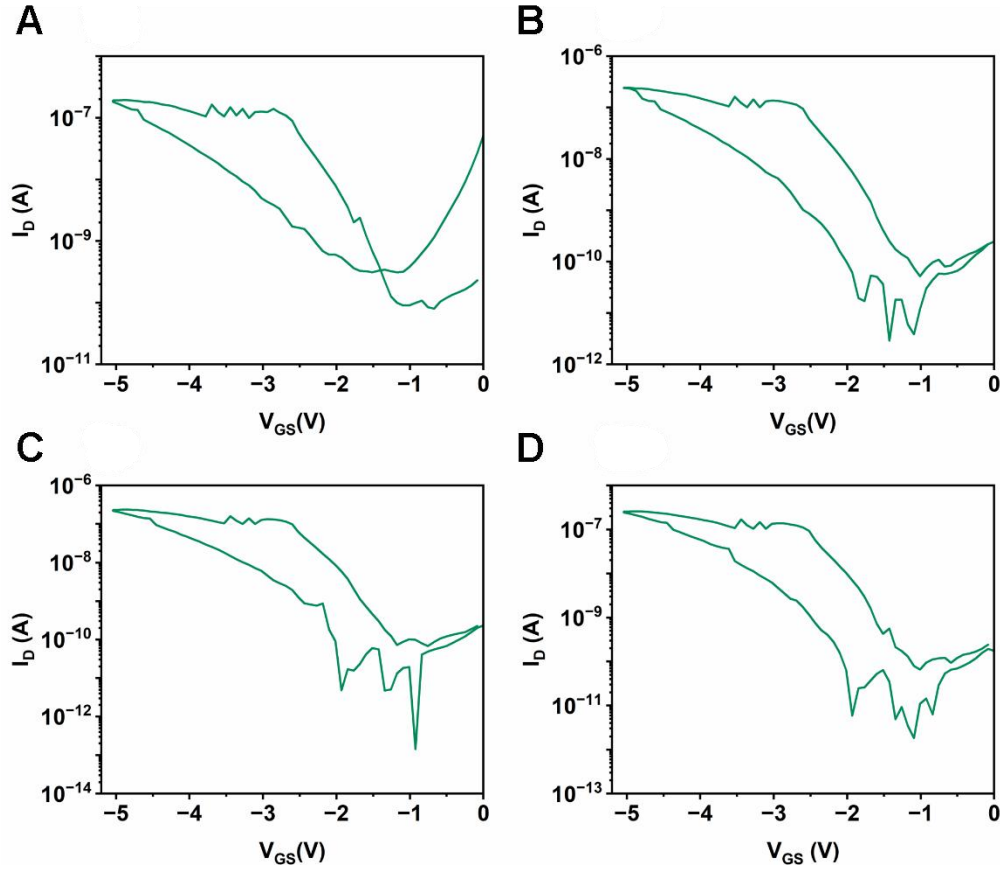


Supplementary Figure 1. High-temperature gel permeation chromatogram of P(DPP-TIT) recorded in 1,2,4-trichlorobenzene at 180 °C. Molecular weight measured against polystyrene standards.

Supplementary Table 1. Synthesis of P (DPP-TIT) polymer and its physical and optoelectronic properties

Polymer	M_n (kDa) ^a	M_w (kDa)	D_w ^b	X_n ^c	$\Lambda_{\text{film}}(\text{nm})$ ^d	$E_{g_{\text{opt}}}(\text{eV})$ ^e
P(DPP-TIT)	13085	20322	1.55	11	829.37	1.36

a) Number-average molecular weight estimated by high-temperature gel permeation chromatography in 1,2,4-trichlorobenzene at 180 °C using a polystyrene standard. b) Dispersity defined as M_w/M_n . c) Degree of polymerization defined as M_n/M_0 , where M_0 is the molecular weight of the repeat unit of each polymer. d) Absorption maxima. e) Calculated by the following equation: $\text{gap} = 1240/\lambda_{\text{onset}}$.

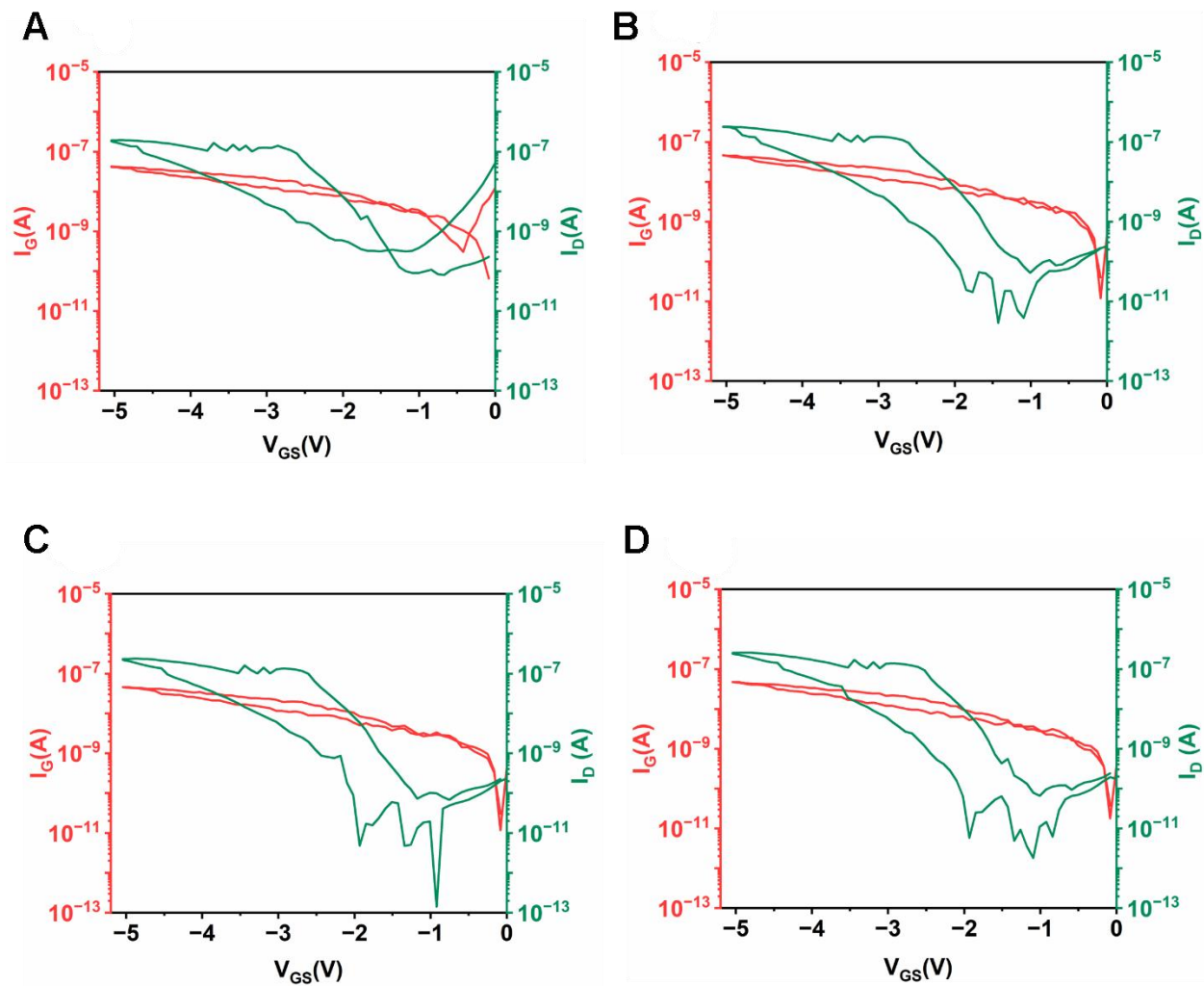


Supplementary Figure 2. Transfer curves (a-d) of a representative device run under identical bias stress ($V_{GS}=-5$)

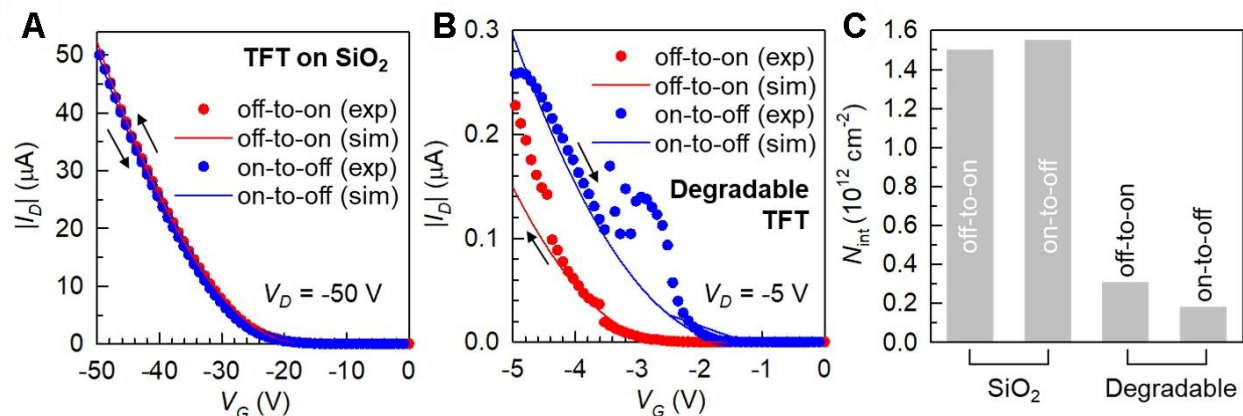
Supplementary Table 2. Summary of the field effect properties of the representative device, swept consecutively four times

Transfer Curve*	Mobility ($\text{cm}^2\text{V}^{-1}\text{s}^{-1}$)	$I_{on/off}$	V_T (V)
a	0.015	10^2	-2.0
b	0.019	10^3	-2.1
c	0.021	10^3	-2.1
d	0.031	10^3	-2.2

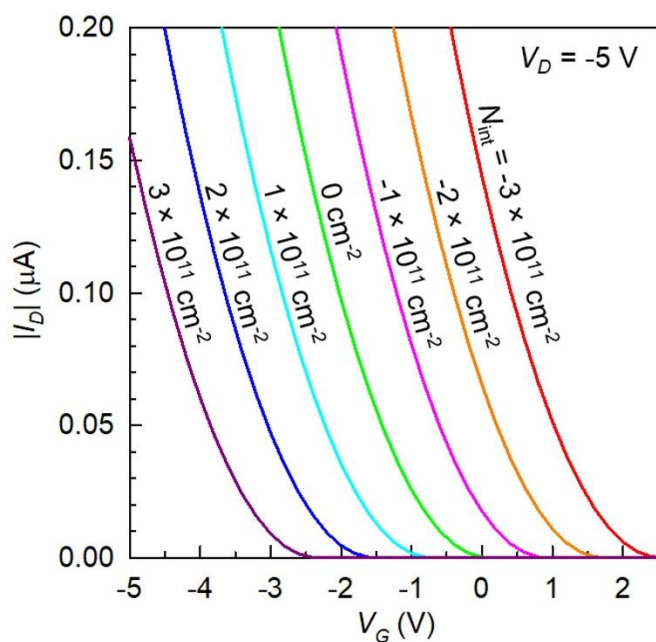
*Extracted parameters from the representative transfer curve run under identical bias conditions.



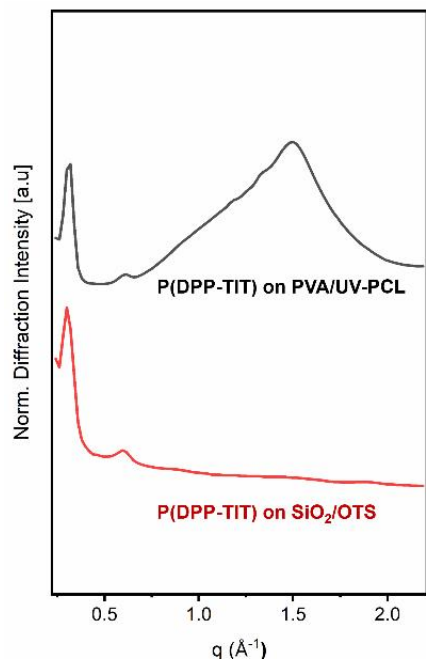
Supplementary Figure 3. Transfer curves and leakage current are plotted under identical bias conditions for four times for a representative device.



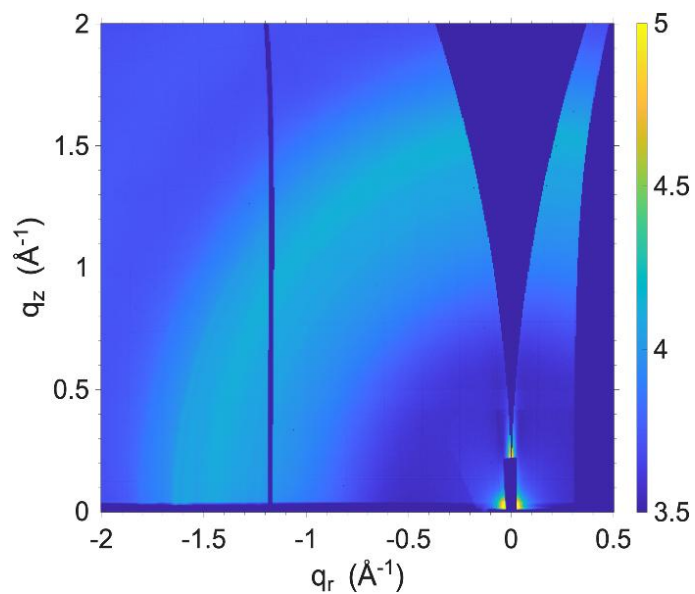
Supplementary Figure 4. Experimental and theoretically reconstructed transfer curves for (A) non-degradable and (B) degradable TFT. (C) Values of N_{int} estimated in (A) and (B).



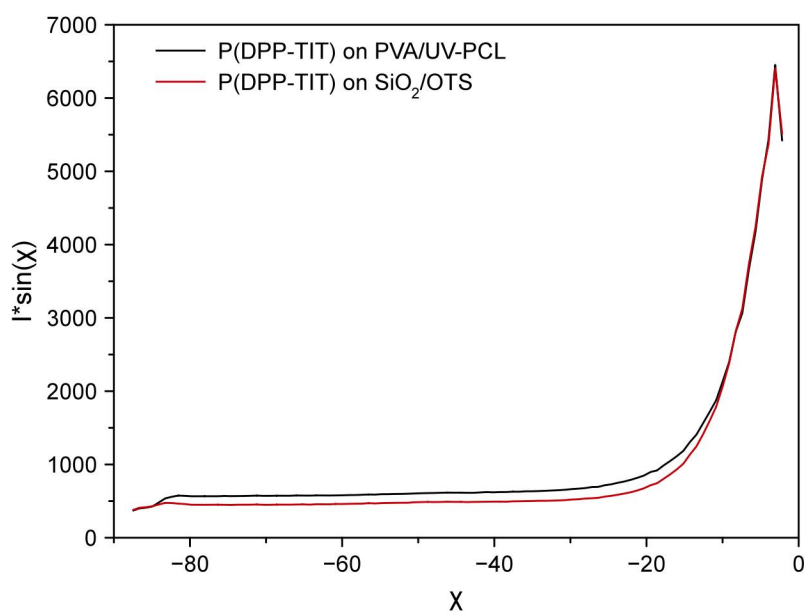
Supplementary Figure 5. Simulation results visualizing the effects of N_{int} on transfer characteristics. N_{int} is the only variable between these seven curves. All the other materials parameters were kept identical to those extracted for the degradable TFT in Supplementary Figure 4.



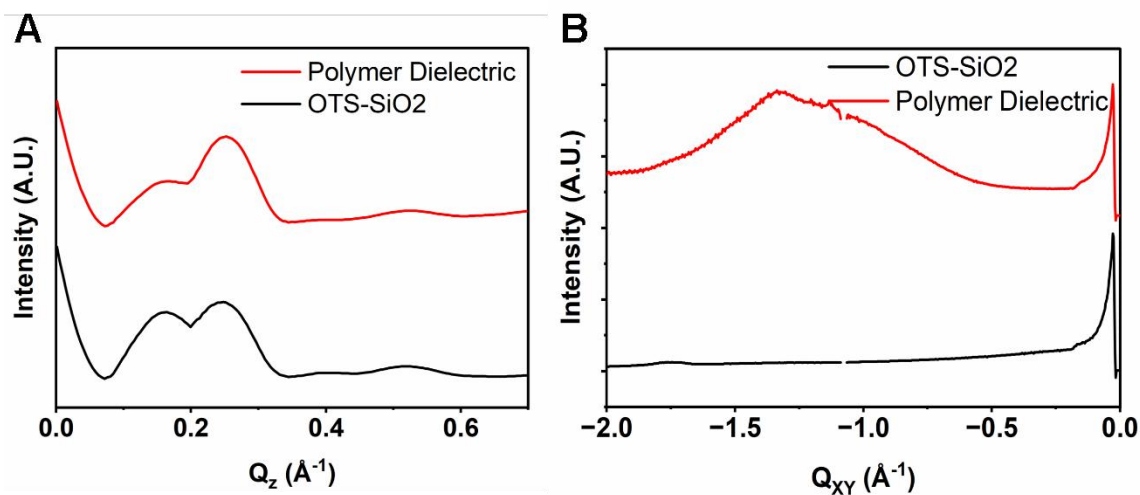
Supplementary Figure 6. Corresponding azimuthally integrated diffraction profiles of P(DPP-TIT) on PVA/UV-PCL and SiO₂/OTS.



Supplementary Figure 7. GIWAXS pattern of PVA/UV-PCL dielectric on PLA substrate

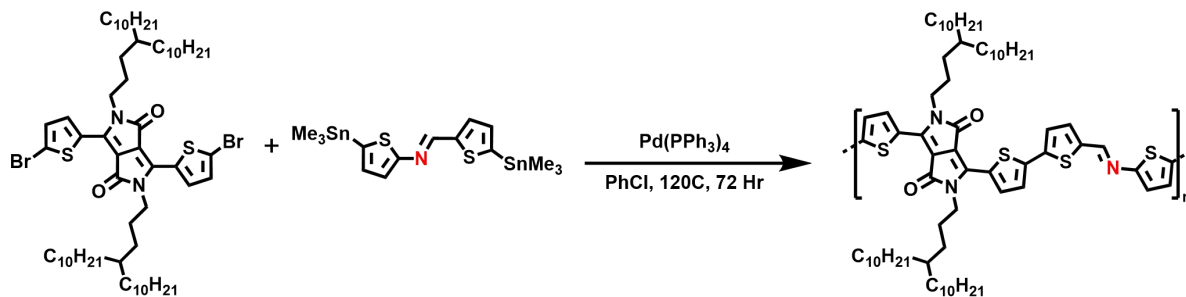


Supplementary Figure 8. χ -cuts of the (100) diffraction peak extracted from the GIWAXS patterns of P(DPP-TIT) thin films deposited on SiO₂ and on the polymer substrate. The integrated (100) intensity was normalized by film thickness



Supplementary Figure 9. 1D line profiles of P(DPP-TIT) in (A) Q_z out-of-plane vector direction and (B) Q_{xy} in-plane vector direction. Data was processed with a standard Savitzky-Golay filter for clarity.

Synthesis of a degradable semiconductor: P(DPP-TIT)



To a reaction vessel equipped with a magnetic stir bar, 150 mg of 3,6-Bis(5-bromothiophen-2-yl)-2,5-bis(4-decyltetradecyl)-2,5-dihydropyrrolo[3,4-c]pyrrole-1,4-dione (0.133 mmol) and 69 mg of (E)-N,1-bis(5-(trimethylstannyl)thiophen-2-yl)methanimine (0.133 mmol) was discharged. The reaction vessel was moved into a nitrogen atmospheric glove box anti-chamber and thrice purged with vacuum and nitrogen before being transferred into the glovebox. 2.5 mL of anhydrous, degassed chlorobenzene was discharged into the reaction vessel to solubilize the monomers and 6.1 mg of Tetrakis (triphenylphosphine) palladium (0) (0.005 mmol) was added. The reaction vessel was then sealed under the nitrogen atmosphere, removed from the glovebox, and moved to a hotplate set to 120 °C and stirred for 72 hours. The reaction vessel was subsequently unsealed, and the chlorobenzene solution was pipetted into a beaker of cold methanol to precipitate the polymer. The polymer precipitate was loaded onto a Soxhlet thimble and was subsequently washed under reflux with methanol (12 hours), acetone (6 hours), hexanes (6 hours) and subsequently collected with 100 mL of chloroform (6 hours). The chloroform solution was reduced to approximately 25 % of its original volume using rotary evaporation, upon which the solution was pipetted into a beaker of cold methanol to precipitate the purified polymer. The methanol was subsequently drained using vacuum filtration to collect the polymer as a solid blue film (127 mg).

References

- [1] M. C. Oztürk, *Veena Misra and*, **2004**, 109, <https://studylib.net/doc/27005530/the-electrical-engineering-handbook>.
- [2] M. Itagaki, S. Suzuki, I. Shitanda, K. Watanabe, *Electrochemical impedance and complex capacitance to interpret electrochemical capacitor*, **2007**, 75, 649, <https://doi.org/10.5796/electrochemistry.75.649>.