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Supplementary Materials for

High-performance transistors for bioelectronics through tuning of channel thickness

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Supplementary Materials

H3:Model for volumetric OECT operation

Here we introduce the notion of volumetric capacitance in the OECT model by Bernards and Malliaras (*1*). We start with Ohm's law applied to the channel:

$$I_D=W\cdot d\cdot e\cdot \mu\cdot p(x)\cdot [dV(x)/dx] \qquad \text{(S1)}$$

where μ is the hole mobility and $p(x)$ is the hole density, given by:

$$p(x)=SO_3^- - M^+(x) \qquad \text{(S2)}$$

where SO_3^- is the density of sulfonate groups that are compensated with holes in pristine PEDOT:PSS and $M^+(x)$ is the density of cations that enter the channel when a positive gate bias is applied. Treating the channel as a volumetric capacitor, we can write:

$$M^+(x)=(C^*/e)\cdot [V_G - V(x)]. \qquad \text{(S3)}$$

Substituting Equations S2 and S3 in S1 and integrating over the length of the channel, we get an expression for the drain current:

$$I_D=(W\cdot d/L)\cdot \mu\cdot C^*\cdot [V_T - V_G + V_D/2]\cdot V_D \qquad \text{(S4)}$$

where $V_T= e\cdot SO_3^-/C^*$. At saturation, which is achieved when $V_D=V_G - V_T$, the current is given by:

$$I_D^{SAT}=[W/(2\cdot L)]\cdot d\cdot \mu\cdot C^*\cdot [V_T - V_G]^2 \qquad \text{(S5)}$$

The transconductance in the saturation regime is the first derivative of the above equation with respect to gate voltage.

Impedance spectra and electrical characteristics of the OECTs

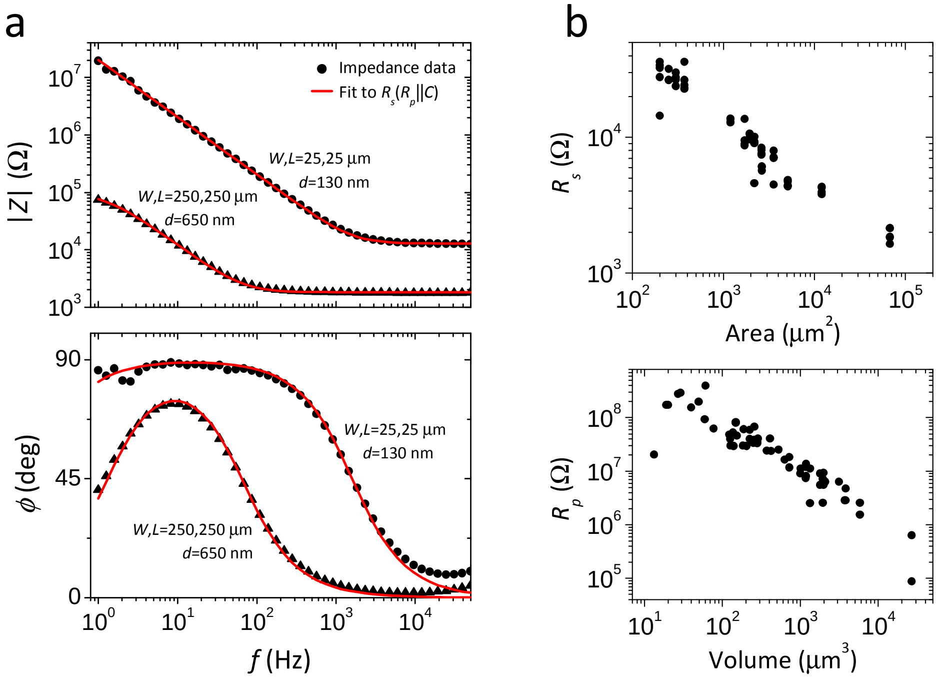

Figure S1. Impedance spectroscopy. A. Impedance spectra of two OECTs of different geometries, where the OECT is used as the working electrode with source and drain contacts connected to each other. Complex impedance data is fit to an $R_s(R_p||C)$ equivalent circuit, which was found to adequately describe the frequency dependence for all channels explored in this work. The device that is nominally 250×250 μm^2, and 650 nm thick gives fit results of (R_s,R_p,C)=(1.82 kΩ, 94.8 kΩ, 1320 nF) and the 25×25 μm^2, 130 nm thick device yields values of (R_s,R_p,C)=(12.8 kΩ, 139 MΩ, 7.79 nF). **B.** Scaling of the resistors with PEDOT:PSS film dimensions: R_s as a function of area, and R_p as a function of volume (obtained from Bode plot fits). It should be noted that the equivalent circuit provides a good fit to impedance data, but is not meant to describe transistor operation. The latter is described by the model outlined in the preceding paragraph.

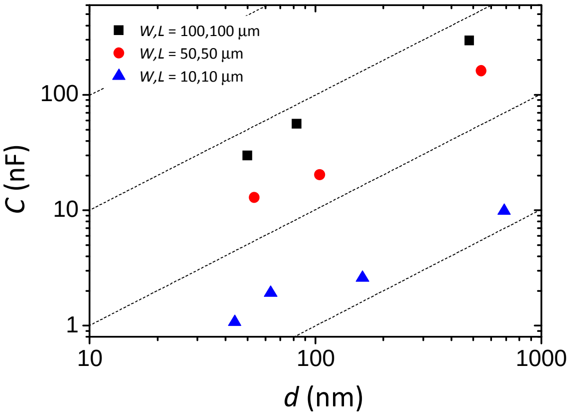

Figure S2. Thickness dependence of capacitance. Capacitance shown as a function of thickness for devices of different area.

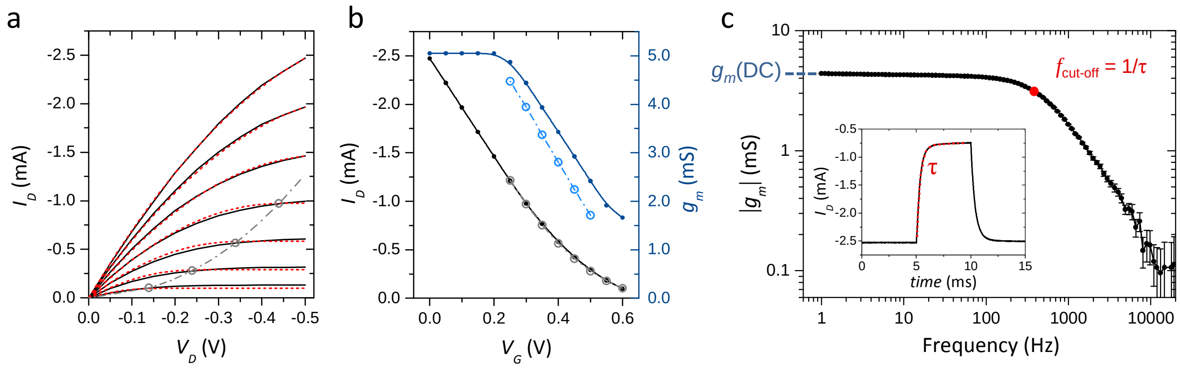

Figure S3. Device characteristics of typical OECT. A. I_D-V_D characteristics of a nominally 50×50 μm^2, 500 nm thick device (black lines), V_G = 0 to 0.6 V (top to bottom), with the corresponding fit to Suppl. Equation S4 and S5. Grey circles are the saturation values. **B.** Transfer (I_D-V_G) characteristics, and corresponding transconductance (blue) at V_D=-0.5 V, and at V_D^{SAT} for each gate voltage (open symbols, dashed line). **c.** Small signal transconductance frequency response, with labeled steady-state transconductance and -3 dB frequency cut-off value. Inset: transient response of drain current to a 5 ms V_G = 0.4 V pulse, for V_D=-0.5 V. The dotted red line is an exponential fit to extract the rise time, τ = 320 μs.

H3: Hole mobility in PEDOT:PSS

Hole mobility was obtained in a sample of OECTs by sourcing gate current I_G and measuring the drain current transient for V_D=-0.1 V. It has been shown that $\partial I_D/\partial t=-I_G/\tau_h$, where τ_h is the time-of-flight of holes across the channel.(*1*) The data are shown in Fig. S4 and are tabulated in Table S1. The average value of hole mobility obtained is 1.9±1.3 cm^2/V·s.

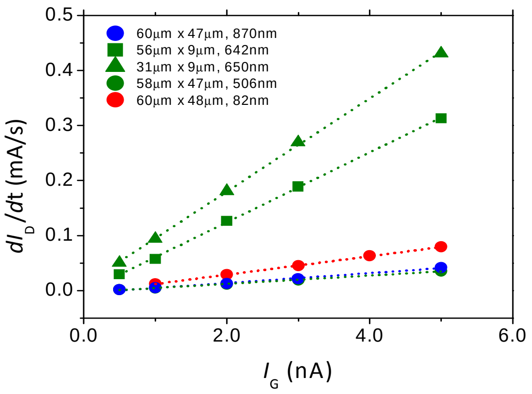

Figure S4. Determination of hole mobility from drain current transients. dI_D/dt determined from the change in the drain current upon the application of a gate current for transistors of different geometry.

Table S1. Hole mobility values for OECTs of different geometry. Channel dimensions correspond to measured (as opposed to nominal) values.

W (µm)	*L* (µm)	*d* (nm)	τ_h (µs)	μ (cm^2/Vs)
60	47	870	110	2.0
31	9	650	12	0.9
56	9	642	16	0.6
58	47	506	130	2.1
60	48	82	60	3.8