Effects influencing the transconductance of OECTs

Aneta Marková,[a] Stanislav Stříteský,[b] Martin Vala,[a] Martin Weiter,[a]
[a] Materials Research Centre, Faculty of chemistry, Brno University of Technology, Purkyňova 464/118, 612 00 Brno, Czech Republic
[b] IQS nano s.r.o., Hlavní 130, Řež, 250 68 Husinec, Czech Republic
BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF CHEMISTRY

Introduction

Organic electrochemical transistor has a potential to be used in many various biomedical devices as a sensor or actuator. The main requirements for any sensor device is a high signal-to-noise ratio. In the case of a sensor based on an organic electrochemical transistor (OECT), it is primarily a matter of maximizing the transconductance. Transconductance expresses the degree of conversion of gate voltage to output current, it depends mainly on the geometric parameters of the active channel. However, in the case of a large ratio of width and thickness to channel length (*Wd/L*), this dependence does not behave linearly. This nonlinearity results from the very low resistance of the active channel and the large parasitic resistance, which can be given either by the resistance of the contacts, the connecting wires, or by the high resistance at the interface of the semiconductor and the contacts. However, which of these parasitic resistances has the greatest influence and how it affects the resulting transconductance has not yet been fully elucidated. Therefore, this work was focused on this problematic.

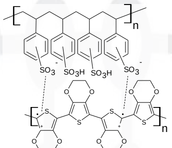
$$g_m = \frac{W}{L} d\mu C^{*}(V_{Th} - V_G)$$

$$g_m^0 = \frac{g_m}{1 - R_S g_m}$$

$$g_{mi} = \frac{g_m^0}{1 - R_{SD} g_D (1 - R_S g_m^0)}$$

Experimental

In our work, OECT devices with variable thickness and channel length of gold electrodes were prepared on quartz glass slides by physical vapour deposition technique. The active layers of poly(3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) with variable thickness were spin-coated and treated by ethylene glycol. Layers thickness and the electrical resistance of the channel and electrodes were measured. Electrical properties of OECTs were investigated by testing output and transfer characteristics in sodium chloride solution (20 mS).

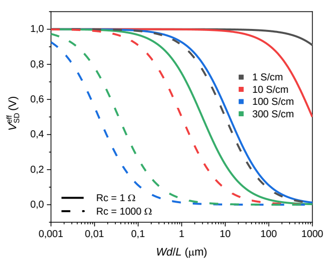


Parameters	Value
Electrodes thickness	50, 100, 150, and 200 nm
Channel length	25, 50, 75, 100 and 150 μm
Channel width	5 mm
PEDOT:PSS thickness	36, 65, 160, and 275 nm
PEDOT:PSS conductivity	300 S/cm

Results

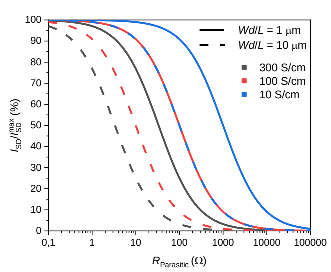
Effects of channel geometry

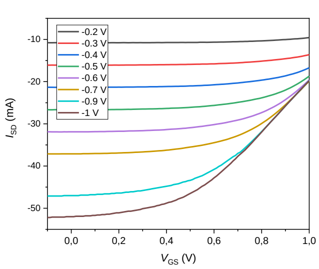
We modelled the influence of effective voltage on channel as a function of *Wd/L* for different conductivity of channel and different contact resistance. From the graph it is obvious that effective voltage relies on the voltage divider and decreases with increasing *Wd/L*. That means that the smaller the electrical resistance of the channel is, the bigger the decrease of the voltage. Based on these one can design the OECT with optimized conductivity of the channel geometry to reduce the resistance of the device.

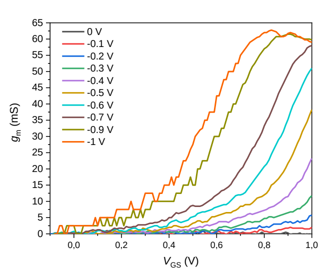


Effects of parasitic resistance

The graph shows the dependence of percentage decrease of output current on the parasitic resistance for different conductivity of channel and different ratio of *Wd/L*. When increasing *Wd/L* the parasitic resistance shifts to lower value. The same effect is observed when the channel conductivity is increased for same *Wd/L*. This determines when the parasitic resistance can be neglected and when not.

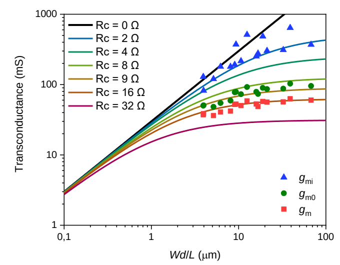






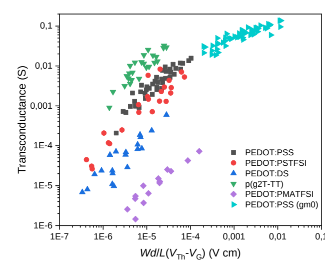
Differently expressed transconductance

As the transconductance equation expresses, the transconductance g_m should increase linearly with increasing *Wd/L*. However, as the graph shows with increasing *Wd/L* the deviation from linearity increases. The nonlinearity is probably due to the different conductivity of the individual parts of OECT. To correct the transconductance for source resistance, the g_m values were recalculate to g_{m0}, and to correct for source-drain resistance the g_m values were recalculate to g_{mi} based on the Chou model[1]. It can be seen, that small deviation still occurs due to additional series resistance.



Our OECT devices in context of published research papers

We overlaid the published values from the article of Sahika Inal[2] with our corrected values of transconductance for series resistance. Our data thus complement and extend published data by larger *Wd/L* ratios. As you can see, small deviation from linearity still occurs due to resistance of intrinsic parts of electrical circuit (ammeter, etc.). Nevertheless, this resistance can not be removed and one must always be aware of this when working with the device with high conductivity or *Wd/L*.



Conclusion

Effects influencing OECT devices' transconductance were studied, mainly the effect of the channel geometry, conductivity of semiconductor and the effect of parasitic series resistance. We showed modelled dependencies of the effective voltage on channel parameters and the decrease of current due to the parasitic resistance. Based on these models one can properly design the OECT with maximized transconductance. One should be always aware of parasitic series resistance when working with highly conductive semiconductors or with a devices with high ratio of *Wd/L*.

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1. S. Y. Chou, D. A. Antoniadis, IEEE 2, 34 (1987), DOI: 10.1109/T-ED.1987.22942
2. S. Inal et al., Nature Communications 8, 1767 (2017), DOI: 10.1038/s41467-017-01812-w