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Abstract

Electropolymerized PEDOT:PSS Thin Films for Fabrication of Vertical Organic Electrochemical Transistors †

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Abstract: This paper presents novel vertical organic electrochemical transistors (vOECTs) with thin transistor channels grown by the electropolymerization of the electrically conductive polymer PEDOT:PSS. This new fabrication method avoids the need for the further structuring of the sensitive polymer layers, which will enable the high-density integration of biosensors, e.g., on neural probes.

Keywords: OECT microfabrication; electropolymerization; PEDOT:PSS

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1. Introduction

Organic electrochemical transistors (OECTs) are excellent ion-to-electron transducers that are particularly interesting for biosensing applications due to their high transconductance and biocompatibility [1]. For example, OECTs were used to record brain activity by integrating OECTs with implantable neural probes [2]. However, the sensitive PEDOT:PSS channel layer is usually structured by a peeling process [3], which is limited in its resolution and throughput. Recently, it was shown that the PEDOT:PSS transistor channel can also be grown by electropolymerization onto lateral interdigital electrodes [4]. In this paper, the first vertical OECTs are presented, where the thin PEDOT:PSS channel layer is formed by electropolymerization.

2. Materials and Methods

For the vertical transistor design, a thin insulation layer is sandwiched between the source and drain electrodes, i.e., the channel length of the transistor is defined by the thickness of the insulator. The photolithography mask layout is shown in Figure 1a. A circular design is used for the electrodes. The transistor channel width is varied by the number of rings forming the drain electrode (ca. 95 µm for one ring and up to 1.73 mm for five rings).

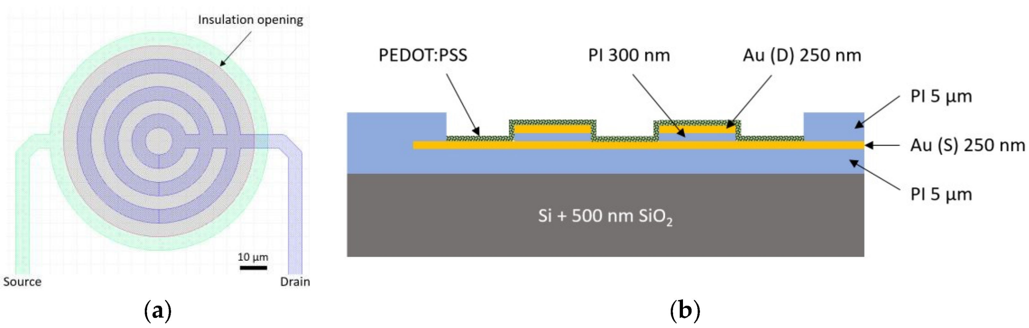


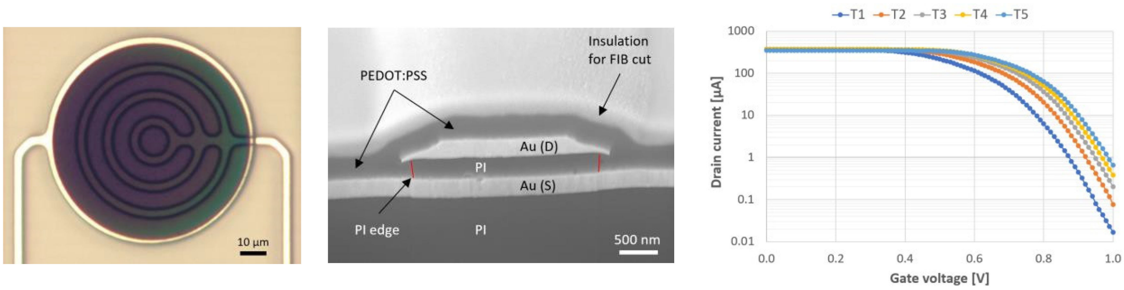
Figure 1. Design of the vertical OECT: (**a**) mask layout with 3 layers; (**b**) cross-section view.

The microfabrication process starts with an oxidized 100 mm silicon wafer. At first, a 5 µm polyimide (PI) insulation layer is spin-coated and cured. The source electrodes are made by DC sputtering, photolithography, and wet chemical etching of 250 nm gold. Next, a thin polyimide layer (300 nm) is spin-coated and cured. Afterwards, the drain electrodes are fabricated using the same processes as the source layer. A 5 µm polyimide layer is spin-coated and cured to form a top insulation layer, which is structured together with the thin PI layer using photolithography and reactive ion etching. To enhance adhesion between the PI layers, a short oxygen plasma treatment was performed directly before spin-coating PI. The cross-section of the final devices is shown in Figure 1b. After wafer dicing, a 0.5 mm pitch ZIF connector is used for all subsequent experiments.

For the electropolymerization of PEDOT:PSS, a monomer solution of 10 mM EDOT and 2 wt% NaPSS in DI water is used. The coating of the source and drain electrodes is performed simultaneously at a constant current density of 5 µA/mm^2 with a platinum counter electrode.

3. Results and Discussion

A microscope image of a PEDOT:PSS-coated vertical OECT is shown in Figure 2a. The electropolymerization process is reproducible for different coating times, and deposition rates of approx. 100 nm/min are reached. Figure 2b shows an SEM image of the cross-section of the vOECT. It can be seen that the PEDOT:PSS channel extends across and connects the source and drain electrodes. The transfer characteristic of vOECTs with an increasing number of rings measured in Ringer's solution is shown in Figure 2c. A clear modulation of the drain current can be observed. With increased channel width, the switching gate voltage and off-drain current are shifted to higher values. A maximum on/off ratio of >10^4 is reached for the smallest channel width (T1, 95 µm). The maximum calculated transconductance of 1.2 mS is reached for the largest channel width (T5, 1.73 mm) at a gate voltage of 0.65 V. These results verify the functionality of the novel vertical OECTs.



(**a**) (**b**) (**c**)

Figure 2. Microfabrication results after 180 s PEDOT:PSS coating: (**a**) microscope image; (**b**) SEM image; (**c**) transistor transfer curves for VD = −0.5 V (T1: 1 drain ring—T5: 5 drain rings).

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References

1. Nawaz, A.; Liu, Q.; Leong, W.L.; Fairfull-Smith, K.E.; Sonar, P. Organic electrochemical transistors for in vivo bioelectronics. *Adv. Mater.* **2021**, *33*, 2101874. [CrossRef] [PubMed]
2. Han, S.; Polyravas, A.G.; Wustoni, S.; Inal, S.; Malliaras, G.G. Integration of organic electrochemical transistors with implantable probes. *Adv. Mater. Technol.* **2021**, *6*, 2100763. [CrossRef]
3. Bidinger, S.L.; Han, S.; Malliaras, G.G.; Hasan, T. Highly stable PEDOT: PSS electrochemical transistors. *Appl. Phys. Lett.* **2022**, *120*, 073302. [CrossRef]
4. Lee, J.; Chhatre, S.; Sitarik, P.; Wu, Y.; Baugh, Q.; Martin, D.C. Electrochemical Fabrication and Characterization of Organic Electrochemical Transistors Using poly (3, 4-ethylenedioxythiophene) with Various Counterions. *ACS Appl. Mater. Interfaces* **2022**, *14*, 42289–42297. [CrossRef] [PubMed]