Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1097-1098

Improvement of response time in organic electrochemical transistors via reducing parasitic capacitance

Masaya Nishinaka, Wonryung Lee, Yasutoshi Jimbo, Hiroaki Jinno, Tomoyuki Yokota, and Takao Someya

Department of Electrical Engineering, University of Tokyo
7-3-1, Hongo, Bunkyo-ku
Tokyo 113-8654, Japan
Phone: +81-3-5841-6709 E-mail: nishinaka@ntech.t.u-tokyo.ac.jp

Abstract

We investigated the electrical characteristics of organic electrochemical transistors (OECTs) in changing the overlap size between electrode and channel material. The capacitance and response time increased with the size of overlap area. Therefore, we formed a passivation layer on the device to reduce capacitance. About the devices the overlap length of which is 80 μm, the passivated OECTs show the lower capacitance (2.2 nF) than the overlap exposed OECTs (4.6 nF). As a result, the passivated OECTs show higher time response compared with conventional OECTs without degradation of transconductance.

1. Introduction

Organic electrochemical transistor (OECT) [1] attracts great interests because of their high transconductance for signal amplification and flexibility, which is compatible with measuring electrocardiography (ECG) [2] and electrocorticography (ECoG) measurements [3]. In previous researches, it was shown that the capacitance of overlap between electrode and channel material is a critical factor for their fundamental characteristics including time responses [4]. OECT has been mainly used for low frequency signal detection so that fast time response was not always required. These days, target applications of OECT have been expanding, including cultured cell monitoring [5], so that its slow time response may be a main bottle neck for signal detection. Therefore it is necessary to investigate the parasitic capacitance and improve time response of OECTs.

Here we examined the overlapping effect on transconductance, capacitance and response time. Additionally, we show that overlap passivated structure can reduce their capacitance and improve their time response without decreasing their transconductance.

2. Experimental results

2.1 Fabrication of OECTs

Conventional structure OECT

A schematic of conventional structure OECT is shown in Fig. 1(a). 5 nm-thick Cr and 60 nm-thick Au were thermally evaporated on a glass substrate and patterned by lift-off process using photoresist (ZPN 1150-90).

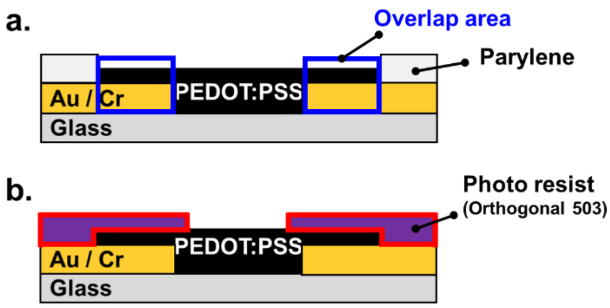

Fig. 1 Schematics of OECT structures. a) conventional structure b) overlap passivated structure

Then, 600nm-thick parylene (dix-SR), fluoride polymer (Novec1700), and another parylene (600 nm) were subsequently deposited. The first parylene is to encapsulate electrode and the latter one is a sacrificial layer. Fluoride polymer enables a sacrificial parylene layer to be removed easily. Parylene layers were deposited by chemical vapor deposition (CVD). Fluoride polymer was spin-coated as a sacrificial layer and 600 nm parylene was deposited. Then photoresist (ZPN 1150-90) was spin-coated for patterning the channel by photolithography. The patterned channel size is 10 × 10 μm. Next, for making channel, parylene was etched by using Reactive ion etching (RIE) oxygen etcher. For the channel, PEDOT:PSS (PH1000) was mixed with EG 5 vol% and GOPS 1 vol% by 10 min sonication. The liquid was spin-coated at 2000 rpm on the sample. Finally, parylene was peeled-off along the sacrificial layer. After fabricating the device, the device was annealed at 140 Celsius degrees for one hour to crosslink PEDOT:PSS.

Passivated structure OECT

The schematic of overlap passivated structure OECT is shown in Fig. 1(b). Electrode layer was patterned and PEDOT:PSS liquid was mixed in the same way of fabricating conventional structure OECT. The mixed PEDOT:PSS was spin-coated at 2000 rpm on the sample where electrode was patterned. Next, PEDOT:PSS was patterned by Orthogonal OsCOR 503 resist and RIE process. Finally, OsCOR 503 was spin-coated again and resist was used as a passivation layer.

2.2 Transconductance

Overlap length dependence of transconductance in conventional and passivated structures is shown in Fig. 2. Transconductance was measured with a parameter analyzer. The drain voltage was - 0.6 V, and gate voltage was swept from – 0.2 V to 0.4 V. Transconductance of OECT depends on the properties of channel and it is independent of overlap length in both structures (Fig. 2). In fact, there is small increase with the length of overlap area. This can be explained by the contact resistance. Basically the entire impedance of OECT affects drain current and transconductance.

2.3 Capacitance

Overlap dependence with capacitance in each structure are shown in Fig. 3. The capacitance of OECT was measured by connecting Ag/AgCl electrode which is soaked in electrolyte of OECT to the high terminal and drain of OECT to the low terminal of LCR meter. The capacitance in the conventional structure increases with the increase of overlap length. This is because PEDOT:PSS on the overlap works as parasitic capacitor. Basically, capacitance of channel is approximately proportional to the volume of PEDOT:PSS. In the new structure, overlap is insulated from electrolyte by the resist. Therefore, the stray capacitor does not affect the ionic circuit of OECT.

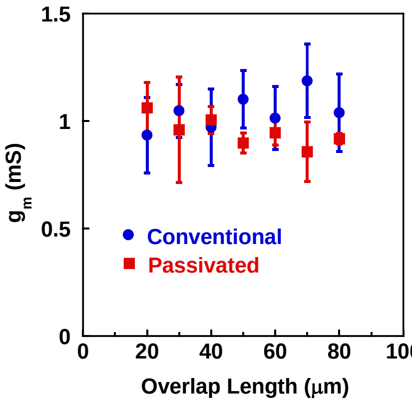

Fig. 2 Overlap length dependence of transconductance in each structure.

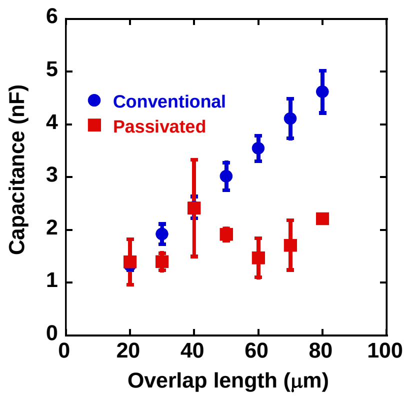

Fig. 3 Overlap length dependence of the capacitance in each structure.

2.4 Time response

Time response of conventional and passivated structure OECTs is measured by applying a gate voltage pulse (Fig. 4). In both structures, overlap length is 80 μm. Time response is improved in the passivated structure. Time response depends on the ionic current circuit and it can be expressed by the following equation. [4]

$$\tau \propto R_s * C \quad (1)$$

where R_s is the resistance of electrolyte and C is the capacitance of PEDOT:PSS.

In the conventional structure, overlap area is exposed to electrolyte, therefore, its capacitance delays response time. On the other hand, in the new structure, the overlap area is passivated and the parasitic capacitance is eliminated from the ionic circuit of OECT. Therefore, time response was improved.

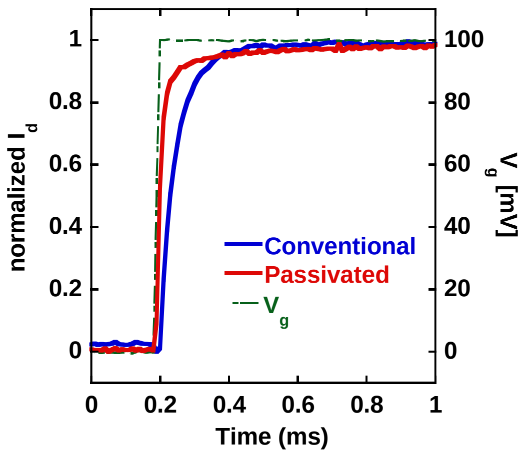

Fig. 4 Modulation of drain current is shown when gate voltage pulse was applied.

3. Conclusion

In summary, we evaluated the electronic characteristics of conventional structure OECT and demonstrated overlap passivated structure. It is shown that passivated structure can reduce the parasitic capacitor, moreover improve time response with keeping high transconductance. This result can be used for fabricating a high speed OECT sensor.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP817H06149. Yasutoshi Jimbo and Wonryung Lee are supported by the Materials Education program for the future leaders in Research, Industry, and Technology (MERIT)

References

[1] J. Rivnay et al., Nat. Rev. Mater. **3** (2018) 17086.
[2] W. Lee et al., Adv. Mater. **28** (2016) 9722.
[3] D. Khodagholy et al., Nat. Commun. **4** (2013) 1575.
[4] J. Rivnay et al., Sci. Adv. **1** (2015) e1400251.
[5] C. Yao et al., Adv. Healthcare Mater. **4** (2015) 528.