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Transparent Organic Electrochemical Transistors Connected by Low-Resistance, Ultrathin Au Wiring

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Abstract

Flexible neural interfaces are essential for less-invasive electrophysiological measurements. Organic electrochemical transistors (OECT) are a key component which can amplify the signal at the point of measurement. Here, we fabricated transparent OECTs with 14 nm-thick Au source-drain electrodes. The transparency is expected to enable microscopic observation of tissues under the OECT array. Due to the controlled growth of the Au film, the electrode sheet resistance was only 8 Ω/sq., resulting in the resistance of the connective wiring having no observable effect on OECT performance. The transconductance of the OECT was 0.9 mS, which was almost the same value as reported in previous reports using opaque metal wiring.

1. Introduction

Organic electrochemical transistors (OECT) have attracted much interest, especially in the bio-engineering field where flexible, cheap, and biocompatible local amplification devices with high transconductance are necessary. Both *in vivo*[1] and *in vitro*[2] electrophysiological measurements by OECT multielectrode array (MEA) have been demonstrated previously. For more sophisticated measurements utilizing optical methods such as fluorescence imaging or light stimulation, a transparent MEA is an indispensable component[3]. Current transparent conductors available on flexible plastic substrates are usually less conductive than opaque metals, resulting in transconductance suppression and crosstalk in the active matrix. One strategy to overcome these two effects is to develop low-resistance wiring. Previously-reported transparent OECT MEAs integrated with Au micro grids allowed optogenetic experiments[4] and featured sheet resistance low enough (3 Ω/sq.) to operate the OECT. However, the scale of the micro grid was several micrometers large and occasionally blocked the object under observation due to its size.

In this report, we fabricated transparent OECTs using 14 nm-thick Au electrodes. The Au films possessed both sufficiently low sheet resistance (8 Ω/sq.) as well as the ability to transmit light owing to their extremely low thickness. Moreover, the Au films do not need any sophisticated patterning processes, mechanically fragile materials, or chemically unstable materials.

2. Fabrication and Results

2.1 Device Structure

The device structure is shown in Fig. 1. To realize good contact between the MEA and tissue surfaces (which are soft and can sometimes even move), the OECT was fabricated on a 1.4 μm-thick parylene substrate. The film formation of ultrathin Au is strongly affected by the surface properties of the substrate on which it is deposited. Table I shows the sheet resistance of ultrathin Au deposited on various surfaces. By adding a polyimide layer on parylene, the conductivity was further improved. The channel was formed by poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS). PEDOT:PSS is highly conductive, and when cations are injected from the surrounding electrolyte, the conductivity decreases so that the voltage signal from tissues can be transduced to current.

2.2 Fabrication

For ease of handling an ultrathin device, the fabrication procedure was as follows. 1.4 μm-thick parylene substrate was first deposited on a supporting glass substrate by chemical vapor deposition. The glass was coated with diluted Novec 1700 (3M) to facilitate a later peel-off process. After the surface was coated with polyimide (spincoated at 4000 rpm and annealed at 180 °C under nitrogen atmosphere), 14 nm-thick Au was deposited by thermal evaporation with a shadow mask for patterning. The surface was then treated with O_2 plasma to enhance wettability. Next, PEDOT:PSS solution (a mixture of commercially available PEDOT:PSS solution (PH1000, Clevios), 5 vol% of ethylene glycol, 1 vol% of (3-glycidyloxypropyl) trimethoxysilane, and 0.1 vol% of dodecyl benzene sulfonic acid) was spincoated at 2000 rpm onto the surface. Subsequently, a PEDOT:PSS channel was patterned by photolithography using orthogonal resist (OSR 5001), and removed by a stripping agent designed to avoid

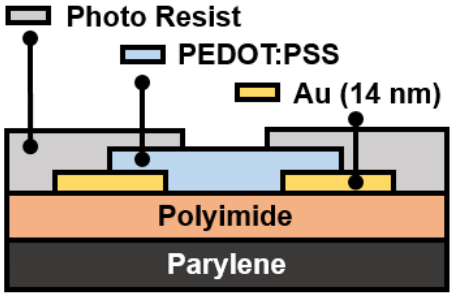

Fig. 1 The structure of fabricated transparent OECT.

Table I Sheet Resistance of 14 nm-Thick Au on Various Surfaces

Surface	Glass	Parylene	Polyimide
Sheet Resistance	>100 Ω/sq.	22 Ω/sq.	8 Ω/sq.

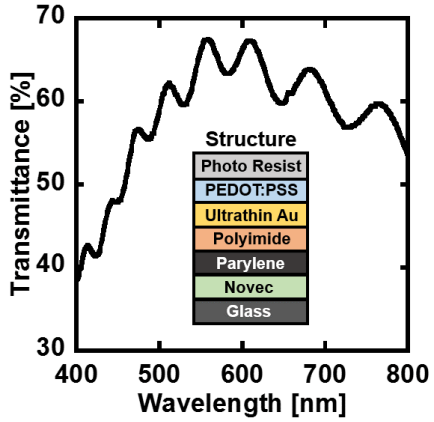

Fig. 2 Transmittance spectrum of the electrode. The inset shows the structure of measured sample.

damage to the PEDOT:PSS layer. Then, orthogonal resist was patterned a second time to encapsulate the whole device area except for the PEDOT:PSS channel. Finally, the parylene substrate was carefully peeled off from the glass, resulting in a wrap-like free-standing device.

2.3 Measurements and Results

The transmittance spectrum of the electrode is shown in Fig. 2. Although it includes all layers and the supporting substrate, the average transmittance was 53 % and the maximum was 67 %.

The mechanical durability of ultrathin Au wiring was compared with conventional indium-tin-oxide (ITO) wiring (Fig. 3). In this experiment, ultrathin Au was fabricated on a 125 µm-thick PEN film coated with polyimide, and ITO was directly fabricated on a PEN film by RF sputtering without annealing. The ultrathin Au electrodes were stable even up to a bending radius of 3 mm, which corresponds to a tensile strain of 2 %. Even at a bending radius of less than 3 mm, conductivity was preserved until the PEN substrate itself was destroyed.

The transfer characteristics of the fabricated transparent OECTs are shown in Fig. 4. For reference, OECTs connected with ITO were also prepared. Small Au interconnects were employed between ITO and PEDOT:PSS to obtain stable contact. The width / length ratio of the PEDOT:PSS channel was 1 and that of the wiring was 0.1, and the drain voltage was fixed to -0.6 V. The maximum value of the practical transconductance of ITO-connected OECTs was suppressed to 0.3 mS whereas that of ultrathin Au-connected OECTs was 0.9 mS. This value is comparable to previously reported OECTs[1]. Therefore, by using ultrathin Au-connected OECTs, we can expect more uniform and stable matrix operation.

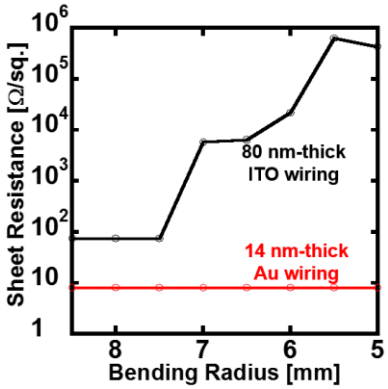

Fig. 3 Bending test for ITO and ultrathin Au. To apply precise tensile strain, 125 µm-thick PEN substrate was used instead of parylene.

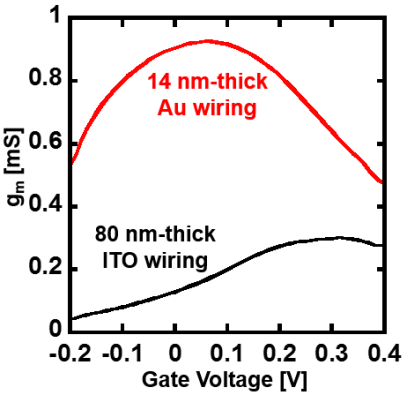

Fig.4 Transfer characteristics of transparent OECT connected by Ultrathin-Au and ITO wiring. Drain voltage was fixed to -0.6 V, Width / Length ratio of wiring was 0.1, and that of channel was 1.

3. Conclusions

In this work, we have fabricated transparent OECTs using ultrathin Au. The conductivity of ultrathin Au was enhanced by polyimide surface treatment. It showed enough transmittance and good mechanical durability. Because of the low resistance wiring, our OECT was able to demonstrate transconductance as high as 0.9 mS.

Our OECT does not have any opaque components and is fabricated without cytotoxic materials such as silver. Therefore, microscopic cell monitoring should be possible. In previous reports, biosignals from cardiomyocytes were detected by OECTs[2]. Thus, electrophysiological mapping supported by an optical method for dynamically moving cells is a promising future application.

Acknowledgements

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