論 文 の 内 容 の 要 旨

論文題目 Gas-permeable organic electrochemical transistor used as on-skin active electrode
(皮膚上のアクティブ電極として利用される通気性のある有機電気化学トランジスタ)

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Daily-life health monitoring using comfortable on-skin electronics is highly demanded for improving the life of quality. Using high-performance on-skin electrodes to acquire high-quality signals can improve the stability and accuracy of health monitoring. This study developed the gas-permeable organic electrochemical transistor (OECT) as on-skin active electrodes for acquiring and simultaneously amplifying the electrophysiological signals. The gas-permeability of the electrodes eliminated the risk of irritation to the skin caused by the accumulation of moisture between the sensor and skin. The superior electrical characteristics of the OECT were utilized to acquire high-quality signals. The fibrous organic nanomesh formed by electrospinning was used as the substrate for fabricating the gas-permeable nanomesh organic electrochemical transistor (NMOECT). Gas-permeable porous solid-state polymer electrolyte (p-SPE) was developed to be embedded with the NMOECT.

For the first time, this study developed the active elements onto the ultra-soft nanomesh substrate for the on-skin application. The NMOECT used as on-skin active electrodes to locally amplify the electrocardiographic signal was demonstrated. The superior electrical characteristics of the NMOECT enable it to acquire high-quality signals with higher amplitude and smaller output resistance was achieved. This research expanded the function of the ultra-soft nanomesh electronics, also making the OECT applicable for continuously wearing on-skin.

In Chapter 1, the background of the on-skin gas-permeable electrodes and the active electrodes for electrophysiological signal acquiring are presented and discussed. The basic knowledge of the OECT is also introduced.

In Chapter 2, the development of the fibrous nanomesh organic electrochemical transistor

(NMOECT) is discussed. The process of fabricating the device on the ultra-thin nanomesh substrate is discussed. The spray coating was utilized to coat the PEDOT:PSS polymer as the channel of the NMOECT. The thickness of the PEDOT:PSS could be controlled to several hundreds of nanometers. The process was optimized to maintain the gas-permeability of the nanomesh substrate. The steady-state and dynamic electrical performance of the NMOECT were characterized. The maximum transconductance of the NMOECTs can be controlled from 0.38 to 0.88 mS, with a fast response time of less than 1 ms, and these values are comparable to those of previously reported film-type OECTs. We demonstrated the NMOECT is robust against mechanical bending, rendering it suitable for the on-skin application. The model used to better fit the electrical characteristics of the NMOECT was also proposed.

In Chapter 3, the demonstration of using the NMOECT as the on-skin electrocardiographic (ECG) electrode is investigated. The setup to make the signal read by NMOECT readable by the conventional equipment is designed. The ECG signals read by NMOECT electrodes are presented and analyzed. The amplifying characteristics of the NMOECT with various supply voltages and loading resistors were characterized. The locally amplified electrocardiography (ECG) signals acquired by the NMOECT electrodes was demonstrated, and analog filters were utilized to cut the DC voltage in amplified signals for the first time. The high signal-to-noise ratio (SNR) of 25.896 dB was achieved in the ECG signals acquired by the NMOECT. A feasible setup for wireless reading the electrophysiological signals acquired by the NMOECT is also proposed.

In Chapter 4, the porous chitosan based electrolyte was developed to be embedded with the NMOECT, to make the gas-permeable electrolyte embedded OECT. The natural polymer chitosan based porous SPE is developed using the freezing dry process. The composition of the SPE was optimized We discussed the development of the fabrication process to form the porous structure of the SPE and the NMOECT embedded with the porous SPE, enabling the gas-permeability on-skin active electrodes. The composition of the p-SPE was optimized to form the porous structure, at the same time maintaining sufficient ion conductivity. The p-SPE embedded NMOECT fully utilizes the high humidity environment of the skin surface to achieve sufficient response speed for ECG signal acquiring.

In Chapter 5, we summarized the main achievement of this research and discussed the prospect of the research on the gas-permeable on-skin active electrodes. The possible approaches to further improve the performance of the on-skin active electrodes is proposed.