Micro-Electrochemical Sensors for pH Detection: Theoretical Analysis and Experimental Study

by

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Abstract

Micro-electrochemical sensors to detect pH are widely used in microfluidics, medical diagnosis, wearable devices, environmental monitoring and biological applications. The faradaic process including electron-charge transfer and diffusion is commonly occurring at the electrolyte-electrode interface. To date, there is very few systematic studies of quantitative normalized parameter to distinguish the dominant process in the electrochemical reactions. This thesis, for the first time, proposes a normalization method with dimensional analysis based on the equivalent circuit model of electric double layer and the impedance spectroscopy technique. With the help of Buckingham Pi Theorem, two dimensionless parameters: normalized impedance ($Z^*$) and reaction-diffusion-frequency parameter ($N^*$) were identified to distinguish these two processes. The experimental study conducted with H$^+$ selective polymer membrane is in good agreement with the theoretical analysis.

Besides the electrochemical analysis, dimensional analysis was also applied to extended gate field effect transistor (EGFET) for amperometric pH sensing. A systematic study of the EGFET performance was conducted in different working regimes: weak inversion, moderate inversion and strong inversion. The normalized sensor sensitivity was divided into normalized electronic sensitivity and electrochemical sensitivity. The $g_m/I_D$ was characterized as the normalized electric sensitivity. The experimental measurement was conducted with polymer membrane and ITO electrodes. The experimental results from the electrochemical and electric characterization indicate that the optimized working regime is consistent with theoretical analysis (error rate <22.5%). We demonstrated that within the moderate inversion regime, the pH sensitive EGFET can achieve multiple objectives: higher normalized sensor sensitivity, higher sensor output response and lower power consumption. A new design based on through silicon via technology was proposed to decrease the noise induced by coupling effect of the electrolyte and electronic device which is promising for new pH sensor system integration with signal processing circuit in commercial foundries.

Date: 14 Jan 2019 (Monday)
Time: 2:30 pm
Venue: Room 5583 (Lifts 27-28)

Examination Committee:
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All are welcome!