UNIVERSITI TEKNOLOGI MARA

EGFET-BASED SENSOR FOR PH AND NITRATE SENSING APPLICATIONS

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ABSTRACT

Ensuring soil health is crucial for sustainable agriculture and optimal crop yield. However, conventional laboratory soil tests face substantial limitations, including high costs, complicated sampling procedures, and lengthy processing times. Commercial on-site soil sensors present a practical alternative, yet their adoption is hindered by reliability and selectivity challenges, primarily due to interference from unwanted soil ions. To address these issues, this study aimed to develop highly sensitive, selective, and reliable pH and nitrate sensors using Extended-gate Field Effect Transistor (EGFET) configuration. The EGFET configuration involves an extended sensing film connected to a commercial MOSFET, provides advantages such as improved stability, reduced cost, and simplified fabrication. Titanium dioxide-polyaniline (TiO_2-PANI) composite thin films and titanium dioxide/nitrate ionophore-dibutyl phthalate (TiO_2-NI6/DBP) thin films were selected based on their superior performance. The TiO_2-PANI composite demonstrated outstanding performance as a pH sensor, achieving a super-Nernstian sensitivity of 66.1 mV/pH with linearity ($R^2 = 0.9931$), low hysteresis, excellent reproducibility, repeatability, and stability. Additionally, its low nitrate sensitivity (12.9 mV/dec) confirms its high selectivity toward pH detection. Conversely, the TiO_2-NI6/DBP thin film exhibited exceptional nitrate sensitivity (129.1 mV/dec) and linearity ($R^2 = 0.9994$), combined with minimal drift rates at low nitrate concentrations, ensuring sensor stability. Its low pH sensitivity (24.7 mV/pH) indicated high nitrate selectivity. The effects of interference from common fertilizer ions (nitrogen, phosphate, and potassium—NPK) were investigated, revealing minimal interference in pH sensing but notable interference in nitrate sensing. This highlights the need for further optimization of nitrate-selective sensing films. A correlation study comparing MARDI laboratory analytical results and EGFET-based soil measurements validated the practical applicability of the developed sensors. Results showed that the TiO_2-PANI composite film had minimal deviation from MARDI laboratory reference values, confirming its reliability for direct soil pH measurements.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

The development of an Extended-gate Field Effect Transistor (EGFET) sensor is derived from the fabrication of an ion sensitive FET (ISFET) sensor. The EGFET consists of a sensitive film and metal oxide semiconductor field effect transistor (MOSFET) device. The extended sensitive film is connected to the gate electrode of a commercial MOSFET device. This configuration has better long-term stability because the MOSFET is protected from the harmful ionic solution when the sensitive film is immersed [1], [2]. Furthermore, the EGFET structure offers several advantages such as low cost, ease of fabrication, insensitivity to temperature and light, and high sensitivity [3]–[6]. The operating principle of EGFET is the process that occurs at the interface of the sensor layer and the electrolyte containing the target analyte results in a measurable electrical signal. The electrical signal is often caused by binding interactions, electrochemical reactions, or structural changes to the sensing layer, which result in a change in surface potential. Surface potential changes affect the threshold voltage (V_T) of the FET transducer, which is determined by its structure. The threshold voltage is the lowest gate-to-source voltage (V_{GS}) that allows a significant drain current (I_D) to flow through the semiconducting channel [6].

This configuration has been applied in many different areas of research, such as pH sensors, nitrate and ion detection, biological sensors, environmental monitoring, chemical sensing and food safety and processing [7]–[12]. On the other hand, both pH and nitrate detection are critical in agriculture for maintaining soil health and nutrient levels. Regular soil testing is needed to ensure soil health and thus improve crop yield. This can be done either by sending soil samples for laboratory tests or using the commercialized sensor. Inconvenient soil sampling procedures and high cost made the soil lab test unattractive although very much needed for sustainable plantation management. On-site testing with commercialized sensors is an alternative to laboratory soil testing. However, the main obstacle to farmers and plantation owners using on-site soil testing is the problems with cross-sensitivity, in which sensors react to unwanted stimuli, resulting in inaccurate readings, in addition to reliability issues. Thus, the