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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Volatile organic compounds (VOCs) are the main components of odors that have been widely employed in a broad range of detection applications. This study explores a novel strategy for olfactory receptor (OR) mimetic peptide screening and its application for the development of bioelectronic sensors for VOC detection.

This dissertation consists of six chapters. In Chapter 1, the overview of the study's background, focusing on VOCs and their importance in detection applications, limitations of the conventional strategies for detecting VOCs, and the research objective were described. VOCs carry valuable chemical information related to their origin and serve as non-invasive biomarkers for diverse detection applications. Conventionally, gas chromatography-mass spectrometry (GC-MS), is considered a gold standard for VOC analysis; however, are hindered by costly equipment, lengthy operation, and lack of mobility. To address these limitations, a graphene field effect transistor (GFET) emerges a promising sensor platform combining advantages of a high surface-to-volume ratio, zero band gap, and high electron mobility from two-dimensional graphene with responsive and simple detection in portable size from FET platform. Nevertheless, GFET typically lacks specificity in which encourage the usage of peptide as a target-specific recognition molecule. Peptides are one of the most suitable VOC recognition molecules owing to their simplicity, functional tunability, chemical-based synthesis, and small size, which enables the sensitive VOC detection within the Debye's length. Moreover, peptides offer the potential to replicate specific VOC recognition developed in the olfactory system. As animals and insects heavily rely on their olfactory system to ensure their survival, their ORs can precisely detect and distinguish a broad range of VOCs. Thus, peptides mimicking OR can enhance the sensitivity and specificity of the sensor. Herein, the OR-mimetic peptides were screened and modified onto GFET to overcome the conventional limitations and promote the development of peptide-based bioelectronic sensors for rapid, sensitive, specific, and portable VOC detection.

In Chapter 2, limonene, a characteristic VOC from citrus, was employed as a pilot target for the strategy development. Limonene binding peptide (LBP) was isolated from fruit fly's OR19a, known for its precise limonene detection, by a novel screening technique utilizing peptide array and GC-MS. Through the screening, the limonene binding ability of the entire OR was evaluated and the key factors for limonene binding were identified. The selected LBP displayed a high affinity for limonene with dissociation constants (K_d) of 32.04 nM and high specificity. The nuclear magnetic resonance analysis revealed the peptide structural transformation upon binding with limonene, indicating crucial amino acids involved in limonene capture. These findings demonstrated the success of the developed peptide screening technique to mimic and miniaturize the VOC binding function of OR into peptides.

In Chapter 3, the LBP probe was bifunctionalized via linkage with graphene-binding peptide, enabling a simple one-step immobilization on GFET. The peptide functionalization was evaluated using electrical properties alterations and atomic force microscopy images which revealed a uniform peptide sensing layer that covered the graphene surface. Next,

the limonene detection abilities of the LBP-modified GFET sensor were demonstrated. The sensor displayed a rapid and sensitive limonene detection with K_d of 13 pM and a limit of detection (LOD) of 8 pM (1.7 ppt) with exceptional specificity for limonene. The peptide sensing layer not only improved the specificity but also enhanced the consistency of limonene detection. Furthermore, the practical application of the sensor was demonstrated by successfully detecting limonene from a citrus sample.

In Chapter 4, the applicability of the established peptide screening and GFET functionalization strategy was demonstrated through the development of OR-mimetic peptide-modified GFETs for skatole, a signature VOC from boar taint. The skatole binding peptides (SBPs) were screened from the mosquito's OR and functionalized onto GFET using identical approach. The SBP-modified GFET sensor exhibited a high affinity for skatole detection with K_d and LOD at picomolar level. The sensor displayed good specificity by differentiating skatole from its analogs, despite having just one functional group difference. This chapter highlighted the potential of the developed strategy as a proof-of-concept for the advancement of OR-mimetic peptide-modified GFETs for diverse VOC targets.

In Chapter 5, the development of a bioelectronic nose system using an array of multiple OR-mimetic peptide-modified GFET sensors and principal component analysis (PCA) for the discrimination of VOCs was described. The sensors were exposed to the set of VOCs including limonene, skatole, and other test VOCs to generate the response patterns and then analyzed using PCA for a pattern recognition system. The bioelectronic nose effectively distinguished all the VOCs, while obtaining important analysis parameters for the discrimination. These findings highlighted the promising potential of the strategy for OR-mimetic peptide-modified GFET-based bioelectronic nose for the detection and discrimination of diverse VOC targets.

Chapter 6 concludes and summarizes the key findings, implications, and potential future research. The present findings suggest that the proposed strategy for OR-mimetic peptide screening, their utilization with GFET and their bioelectronic nose application is a promising approach to overcome the limitations of conventional VOCs detection techniques.