Fully Inkjet-printed Chemiresistive Gas Sensor Array Based on Molecularly Imprinted Sol-gel Materials

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論 文 名：Fully Inkjet-printed Chemiresistive Gas Sensor Array Based on Molecularly Imprinted Sol–gel Materials
（全インクジェット印刷と分子鋳型ゾルゲル材料を用いたガスセンサアレイに関する研究）

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論 文 内 容 の 要 旨

Chemiresistive gas sensors, which are based on changes in electrical conductance caused by interactions between the analytes and the sensing materials, are particularly attractive because of their simple working principle, affordable transducers, and micro-stimuli detection capability. To date, the widespread adoption of portable, wearable, and implantable smart devices has sparked the evolution of chemiresistive gas sensors towards flexibility and miniaturization. Inkjet printing, one of the attractive techniques, has shown versatility and potential for large-scale fabrication of flexible sensors with low-cost, non-contact processing, efficient material utilization, and high-quality advantages. The combination of chemiresistive gas sensors and inkjet printing presents a compelling prospect for the next generation gas sensors. However, simultaneously realizing high sensitivity and selectivity at room temperature is still a big challenge.

Over the past few decades, molecular imprinting technology has generated significant attention from both the scientific and industrial community due to its unique properties. Molecularly imprinted sol–gels (MISGs) are defined as well-established synthetic materials to design specific recognition sites complementary to target molecules in shape, size and functional groups. One important advancement of MISG materials is their ability to achieve molecular-scale selectivity in complex environments. In addition, they have been integrated into many sensing platforms for the detection of various target molecules. This dissertation investigates the use of inkjet printing for depositing MISG materials to fabricate chemiresistive gas sensor arrays. The dissertation consists of four chapters and a summary of each chapter is as follows:

Chapter 1 provides the background and motivation of this dissertation. The outline of the dissertation is also presented.

Chapter 2 provides a brief overview of chemiresistive gas sensor array, inkjet printing technology, and MISG materials. Firstly, the definition and gas–sensing performance parameters of chemiresistive gas sensors are presented, and the recent progresses in the development of chemiresistive gas sensor array are provided. Secondly, we focus on the thin-film fabrication methods, especially inkjet printing technology, to fabricate flexible chemiresistive gas sensors. Thirdly, MISG materials, as highly selective materials, are introduced.

Chapter 3 describes a fully inkjet-printed MISG sensor array for volatile organic acids (VOAs) detection. In this chapter, a ketjen black (KB) ink and MISG inks were formulated to support the fabrication of a fully inkjet-printed chemiresistive gas sensor array, enabling the highly accurate recognition of VOAs on the molecular level. The MISG/KB sensor array was prepared on glossy photographic paper with a three-layer structure: a circuit layer by a commercial silver ink, a conductive layer by a KB ink, and a highly selective layer by MISG inks imprinted by different templates. Hexanoic acid (HA), heptanoic acid, and octanoic acid, were used as templates to prepare the MISG materials and as targets to evaluate the detection and discrimination performance of the sensor array. Three resultant MISG/KB sensors exhibited high sensitivity and selectivity to VOA vapors. The limit of detection (LOD) and imprinting factor were 0.018 parts per million (ppm) and 7.82, respectively for HA-MISG/KB sensors to the corresponding target. With linear discriminant analysis of the gas responses, the MISG/KB sensor array can realize high discrimination to VOAs in single and binary mixtures. Furthermore, the proposed sensor array showed strong sensor robustness with excellent consistency, durability, bending and humidity resistance.

Chapter 4 presents the conclusions of this dissertation and provides potential future work, including the potential of sensitivity enhancement by fabricating fully inkjet-printed chemiresistive gas sensor array using molecularly imprinted metal–organic framework materials and the potential of device miniaturization for portable and wearable applications.