Chapter 9

Development of Highly Sensitive Compact Chemical Sensor System Employing a Microcantilever Array and a Thermal Preconcentrator

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ABSTRACT

The authors developed a highly sensitive compact chemical sensor system employing a polymer-coated microcantilever sensor array and a thermal preconcentrator with an airpump. The theory, design, structure, fabrication, and experiment results are reported here. This sensor system had 1) sub-ppb detection limit enhanced by a carbon-fiber filled preconcentrator with an air pump and 2) analysis function by thermal desorption of the adsorbed VOCs in the preconcentrator and multiple cantilevers (acting as mass sensors) with different polymers. Eight silicon microcantilevers in one silicon chip fabricated by Micro Electro Mechanical Systems (MEMS) technology were driven by a PZT actuator plate mounted in the package, and four of them were wire bonded.

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Using the 4th vibration mode (resonant frequency: 764 kHz) of a polybutadiene (2.52 μm thick)-coated cantilever, the sensitivity was 514 Hz/ppm for toluene and 850 Hz/ppm for p-xylene with a 5 min preconcentration time. The estimated detection limit of the sensor system was 0.6ppb for toluene and 0.4ppb for p-xylene with a 5 min preconcentration time, which was good enough for application to environmental monitoring. Separate detection of the mixed toluene and p-xylene was achieved as different time peaks. The authors also estimate the concentration of mixed acetone and 1-propanol by the method of the fitting of two Gaussian curves model.

INTRODUCTION

The development of a chemical sensor system to detect Volatile Organic Compounds (VOCs) species has been receiving much attention for environmental monitoring and ultrafast medical diagnostics, which are strongly demanded to a safety and aged society. To date, the widely used sensor to detect VOCs has been Metal Oxide Semiconductor (MOS) sensor; however, it was difficult to analyze the VOC elements owing to the relatively poor selectivity of compounds. Quartz Crystal Microbalance (QCM) and Surface Acoustic Wave (SAW) devices with sensing films have also been widely investigated; however, it was also difficult to integrate with electronic devices as a smart sensor and mass-productive sensor chip. New highly sensitive micromass sensors using a microcantilever have been developed recently including first optical detection (Maute, et al., 1988; Battiston, et al., 2001; Kim, et al., 2001) an integration with electronic devices (Lang, et al., 1999; Lange, et al., 2002) and sensing analysis (Dufour & Fadel, 2003). However, previous investigations show a not so high sensitivity, such as 0.01 Hz/ppm for ethanol and 0.1 Hz/ppm for toluene.

We have been developing an integrated chemical analysis system with focus on the resonant micromass sensor made by MEMS technology for this purpose. We have reported the studies on the mass sensitivity of the silicon microcantilever with high resonant modes (Ikehara, et al., 2007; Lu, et al., 2006), sensing films using copolymer-based elastic polymers (Liu, et al., 2007), and the first prototype sensor system including preconcentrator (Mihara, et al., 2008). We consider that silicon micromass sensors including cantilever are potential smart and flexible used sensors because they can be easily integrated with electronic devices to install intelligent functions in a chemical sensor system and many different kinds of sensing materials can be used on the MEMS resonators. To increase the sensitivity, we used a preconcentrator. To obtain the analysis function, we utilized the desorption characteristics of adsorbed VOCs from a preconcentrator and cantilever arrays with different sensing materials (Mihara, et al., 2009, 2008). We also reported the estimation of concentration factors and system efficiencies using basic formulas on the cantilever-type chemical sensor system (Mihara, et al., 2010, 2011). Several previous investigations to combine a preconcentrator with SAW devices and QCM-type sensors have been reported to date. By using the TENAX-TA (polymer beads based on 2.6 diphenyl-p-phenylene oxide by Teijin)-filled preconcentrator and 433 MHz SAW sensor, the detection limit for toluene was reported to be 0.08 ppm and that for ethanol was 33 ppm after 3-min concentration (Groves, et al., 1998; Bender, et al., 2003). Another report showed the separation of the components with the thermal preconcentrator combined with QCM devices (Nakamoto, et al., 2005).

In this study, we report the theory, design, fabrication and evaluation results of a newly developed sub-ppb-detectable sensor system possessing a preconcentration and analysis functions at the same time. This book chapter is an expanded version of a previous report submitted to Sensor