DOI 10.5162/IMCS2018/ME.2

Miniaturized Gas Analysis System for Detection of Trace-level Volatile Organic Compound Mixtures

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Abstract:
This paper reports an integrated miniaturized gas analysis system (iSAAC; Integrated System for Analysis of Assorted Chemicals) for the analysis of volatile organic compounds (VOCs), which contains three components: 1) a micro preconcentrator (μ-PC), 2) a micro gas chromatography (μ-GC) and 3) a thermal conductivity detector (μ-TCD). All three components were fabricated using microelectromechanical systems (MEMS), and these were finally assembled into a 10×10×10 cm^3 system platform. The iSAAC was demonstrated the successful preconcentration, separation and detection for eleven-chemicals from thirteen-VOCs mixture including non-polar alkanes (C_1–C_9), benzene, toluene, ethylbenzene and o-xylene (BTEX) in less than 30 mins.

Key words: Volatile Organic Compounds, Gas Analysis System, Micro Gas Preconcentrator, Micro Gas Chromatography, Micro Thermal Conductivity Detector

Introduction

Volatile organic compounds (VOCs) analysis has been an increasing area of interest for the field of environmental monitoring and non-invasive diagnosis of various diseases by measuring their gases [1]. Currently, these analyses are usually carried out by conventional bench-top instruments such as gas chromatography-flame ionization detector (GC-FID) and GC-mass spectrometry (GC-MS). However, these methods are bulky, expensive, require high power consumption and need highly trained technicians to operate [2]. Miniaturization of analytical instruments using microelectromechanical systems (MEMS) technology can resolve some of the aforementioned issues and can lead into small, energy efficient and less expensive systems.

This work reports a miniaturized gas analysis system (iSAAC; Integrated System for Analysis of Assorted Chemicals), which integrates a micro preconcentrator (μ-PC), separation column embedded micro gas chromatography (μ-GC) and a thermal conductivity detector (μ-TCD), all components developed using MEMS technology for the analysis of VOCs. Thirteen-VOCs including non-polar alkanes in the range of C_1-C_9, benzene, toluene, ethylbenzene and o-xylene (BTEX) were analyzed through the preconcentration, separation and detection processes of the developed iSAAC.

Microfabrication and Assembly

The fabrications of the three components, which contain the μ-PC, μ-GC and μ-TCD, were performed by MEMS processing technologies such as components oxide deposition, silicon etching, metal deposition and anodic bonding. In particular, carbon nanotube (CNT) foam with a large gas adsorption capacity and low pressure drop was packed in the μ-PC to improve preconcentration efficiency, and the μ-GC column with internal bump structure was designed for high separation performance. Fig. 1 summarizes the fabrication processes for all the three MEMS components. The fabricated three components were arranged in a core analytical printed circuit board (PCB) and serially connected by micro adapters from each other.

The iSAAC platform architecture includes two PCB modules, the core analytical module and the control module consisting of microprocessor, micro pump and several electrical elements, as shown in Fig. 2. The whole system was finally integrated into a 10×10×10 cm^3 size by the assembly of two PCB modules and LCD display showing the analysis results.

Experimental Results

Operating processes of the iSAAC are widely classified into the preconcentration, separation and detection steps. Trace level gas mixtures are preconcentrated in the μ-PC for a period of time, and then they are transferred to the μ-GC separation column. The individual gas

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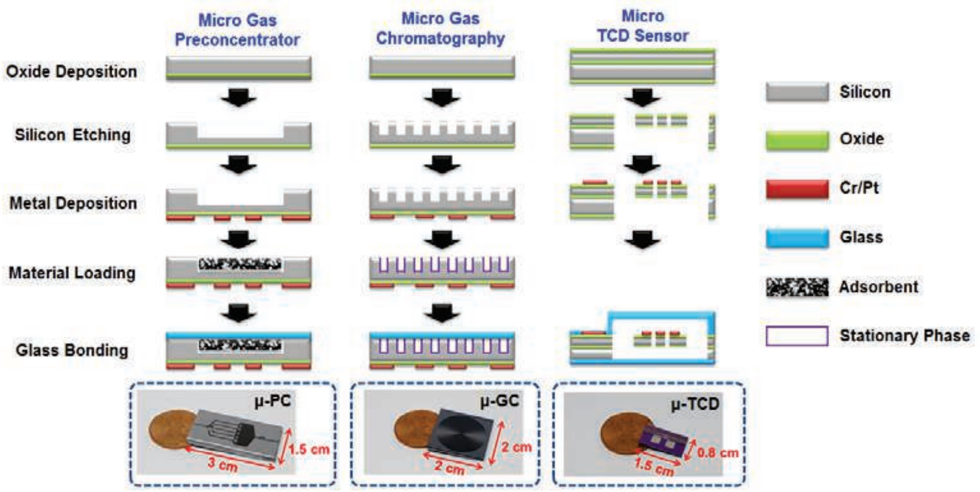

Fig. 1. Fabrication procedure for μ-PC, μ-GC and μ-TCD using MEMS technologies. The photographs shows fabricated three components.

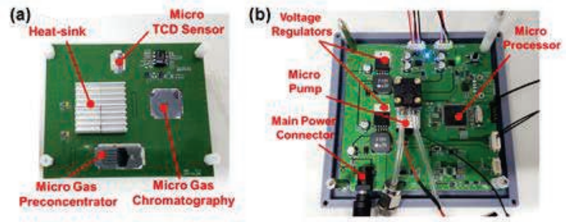

Fig. 2. Optical images of fabricated (a) core analytical PCB module and (b) control PCB module.

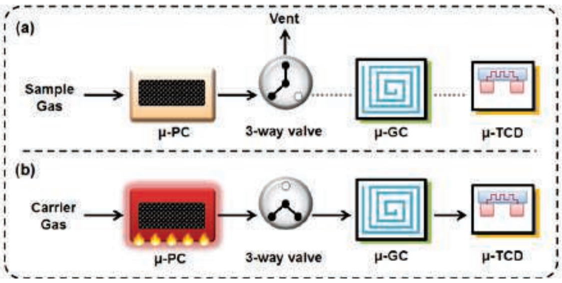

Fig.3. Schematic diagram of iSAAC operating configuration for (a) the preconcentration of sample compounds collecting with the valve set in the adsorption position and (b) thermal desorbing and transferring to series of μ-GC and μ-TCD with the valve set in the desorption position.

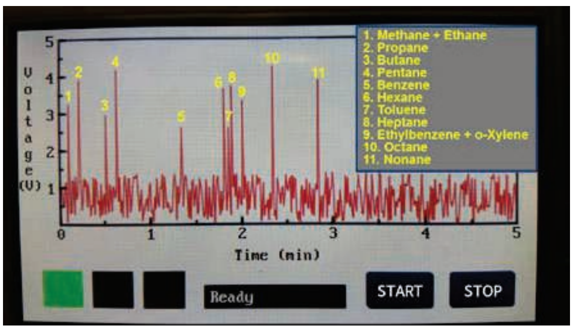

Fig. 4. The resulting chromatograms for trace level thirteen-VOC mixtures through the iSAAC operating processes.

components separated through the column are finally detected by the μ-TCD. Fig. 3 shows a block diagram explaining the proposed iSAAC operating processes. Thirteen-VOCs, which include non-polar alkanes (C_1-C_9) and BTEX mixtures with a concentration of 100 ppb, and pure nitrogen gases were prepared into the tedlar bag as test sample and carrier gas, respectively. The iSAAC was demonstrated preconcentration, separation and detection for eleven-chemicals from thirteen-VOCs mixture in less than 30 mins, as shown in Fig. 4. The lone exceptions were between methane and ethane, ethylbenzene and o-xylene, respectively, because the molecular weights of these gases are very close.

Conclusion

In this work, an integrated miniaturized gas analysis system called iSAAC for the analysis of VOCs was developed. The iSAAC was demonstrated the successful analysis for eleven chemicals from thirteen-VOCs mixture in less than 30 mins.

The proposed iSAAC platform is a promising development towards a miniaturized system that can replace commercial analytical instruments.

Acknowledgements

This research was supported by the National Research Foundation of Korea (NRF) funded by the Ministry of Science (Grant numbers: 2017M3A7B4041987 & 2015M3A9E2029267).

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