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Diffusion-based humidity control membrane for microfluidic-based gas detectors

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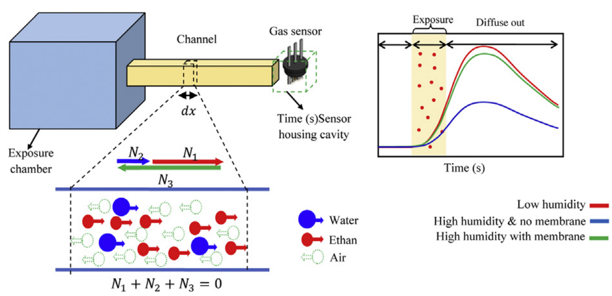
HIGHLIGHTS

- A cost effective diffusion-based humidity removal membrane is developed for microfluidic-based gas analyzers.
- A 3D-printed microfluidic gas sensor is used to test four different volatile organic compounds (VOCs) including three alcohols and one ketone in different relative humidity levels ranging from 15% to 80%.
- It is shown that the sensor fails to differentiate between different VOCs or even between different concentrations of the same gas when there is a slight change (as small as 5%) in humidity.
- A humidity control and removal membrane is developed in order to minimize the effect of humidity. The selectivity of the sensor with and without the use of the humidity removal membrane is compared and shown to be 36% more in the case of utilizing the humidity removal membrane.
- The developed low-cost humidity control system successfully removes the effect of humidity on the response pattern of the sensor and can be used for different applications such as breath analyzers.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents a cost-effective and reliable diffusion-based humidity removal membrane for microfluidic-based gas analyzers. The developed humidity control device reduces the relative humidity of a gas chamber and also stabilizes the humidity using inexpensive inorganic salts. A 3D-printed microfluidic gas sensor is used to test four different volatile organic compounds (VOCs) including three alcohols and one ketone in different relative humidity levels ranging from 15% to 80%. To study the

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Feature extraction

effects of humidity on different features of the transient response of the sensor, two different feature extraction methods are used. These methods are (i) normalization method, removing the effect of any changes in the response level for identifying the nature of the gas, and (ii) integration method, which differentiates between different response levels due to different concentrations or humidity levels. The results show that the sensor fails to differentiate between different VOCs or even between different concentrations of the same gas when there is a slight change (as small as 5%) in humidity. In essence, the device is vulnerable to the errors occur due to the presence of humidity even after the post processing analysis (feature extraction). Thus, a humidity control and removal membrane is developed in order to minimize the effect of humidity. The selectivity of the sensor with and without the use of the humidity removal membrane is compared and shown to be 36% more in the case of utilizing the humidity removal membrane. The proposed humidity control system successfully removes the effect of humidity on the response pattern of the sensor and can be used for different applications such as breath analyzers for which lowering the level of humidity of the exhaled breath is crucial before analyzing the VOCs of interest.

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1. Introduction

Gas analyzers have the potential to detect and monitor different volatile organic compounds (VOCs) as well as to reduce the corresponding costs of processing while significantly reducing discomfort and danger to operators [1,2]. Gas analyzers have been recently used in several applications such as environmental monitoring [3], food and beverage quality assessment [4], and medical and diagnostic devices [5,6]. For instance, in breath analysis (one of the applications involving the use of medical monitoring devices), the health status of the patient can be determined by examining the composition and the concentration of exhaled VOCs [7]. A certain level of specific VOCs in the breath, also known as biomarkers, can indicate the biological or physiological malfunction as a result of progression of a disease [8].

Bulky laboratory-based gas analyzers such as gas chromatography/mass spectrometry (GC/MS) are still used to detect VOCs in low ppbv (parts per billion by volume) levels [9,10]. However, these methods are not cost effective and time efficient, and their maintenance and recalibration are always expensive and involve time-consuming processes. Therefore, these devices are not suitable for many applications in which a user needs a frequent use of the device in a portable and disposable fashion [11]. Thus, electronic noses (e-noses) have recently been introduced as an alternative to these conventional devices [12,13]. E-noses work based on evaluating the overall response patterns of an array of sensors, indicating a “fingerprint” (also known as “smellprint”) of a specific odor. E-noses use pattern recognition software and feature extraction methods to differentiate among different gas components [14,15]. The drift of the components of the sensor array, however, results in faulty signals and malfunction of these devices [16]. Moreover, the high number of sensors used in e-nose devices increases the overall cost of fabrication, maintenance and calibration [1].

Single sensor gas detectors, which use a single gas sensor (with

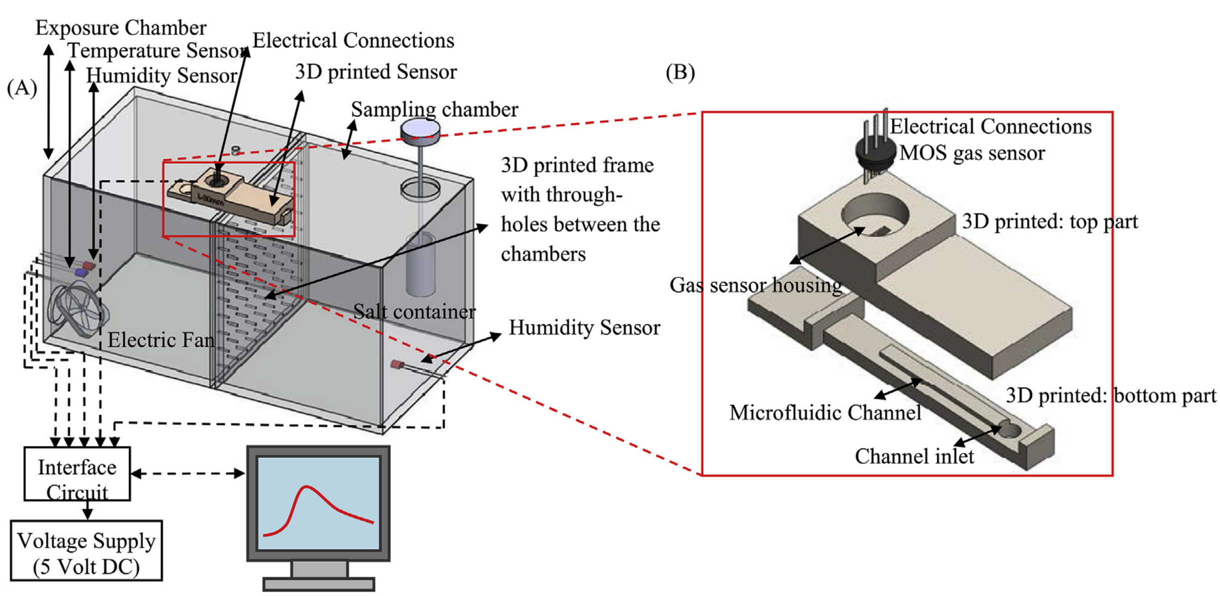

Fig. 1. (A) The schematic of the experimental setup. The sensor is mounted on the 3D-printed chambers. The sensor can rotate over the exposure chamber (exposure stage), and can rotate back to the clean air for recovery. (B) the schematic view of the 3D-printed sensor.

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