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Development of Human Breath Acetone Detector Based on Gas Chromatographic Technology

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Abstract:
Breath acetone is a characteristic biomarker of diabetes. Breath acetone concentration of diabetic patients' breath is higher than that of the normal people. A breath acetone detector based on gas chromatography and semiconductor gas sensor is presented in this paper. The breath collected from diabetic patients is pushed to the gas chromatography separation channel and accelerate flowing by an acceleration pump, then separated using a serpentine gas chromatographic separation channel fabricated by silicon oxide. Carbon dioxide, breath acetone, and ethanol are separated through the stationary phase in the 26th s, 162th s and 324th s, respectively. Separated carbon dioxide, breath acetone, and ethanol will enter the three branches gas detection channel by a time-sharing conversion switch at the end of the serpentine gas chromatographic separation channel, respectively. Then, breath acetone and ethanol were detected by their respective embedded semiconductor gas sensor based on Y-Zeolite/SnO_2 and SnO_2, respectively. The test results show that the method achieves the separation and quantitative detection of carbon dioxide, breath acetone, and ethanol, the separation accuracy is 99.7% and the accuracy is 99.2%.

Key words: Breath acetone, Gas chromatography, Time-sharing conversion switch, Gas sensor

1 Introduction

In recent years, with the improvement of people's living standards, advance changes in diet structure and lifestyle have led to various diseases[1]. Diabetes is one of the rapidly increasing diseases. A national survey conducted in 1994, involving 224,251 Chinese residents, 25 to 64 years of age, from 19 provinces, showed that the prevalence of diabetes and impaired glucose tolerance were 2.5% and 3.2%, respectively[2]. Human breath contains water vapor, carbon dioxide, oxygen, nitrogen, volatile organic compounds (VOCs) produced by metabolism in the body. It shows that a person maybe attacking a disease if the concentration of metabolites produce exceeds a normal range[3]. Breath acetone is the biomarker of diabetes[4]. The concentration of acetone in the exhaled breath of diabetes patients is higher than 1.8 ppm, whereas it is lower than 0.8 ppm for those without diabetes[5, 6].

A breath acetone detector based on gas chromatography (GC) and semiconductor gas sensor is reported in this manuscript. The human breath is separated by GC separation channel with time-sharing conversion switch, then the separated breath acetone and ethanol are measured by the gas sensor based on Y-Zeolite/SnO_2 and SnO_2. This detector realized the gas separation of breath and quantitative detection of breath acetone in diabetic patients.

2 The design of the breath acetone detector

The detector includes three parts: the GC separation channel, gas sensor unit based on semiconductor and SCM detection and display system. The structure principle schematic of breath acetone detector is shown in the Fig.1.

As we can see from the Fig.1 that the GC separation channel is composed of stationary

phase, GC column, and time-sharing conversion switch. The separated gas is detected quantitatively by gas sensors embedded in different gas channels. The SCM detection and display system is composed of A/D conversion, temperature and humidity detection unit, power supply and LCD display screen.

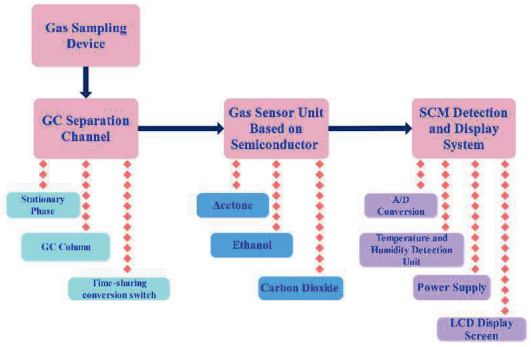

Fig.1. The structure principle schematic of breath acetone detector.

The structure parameters of the GC separation channel are calculated according to Theoretical Plate[7, 8], Rate Theory[9] and pipe inner diameter formula.

The plate number is declared to be 1600 using Formula (1) by Theoretical Plate, where N is the plate number, t_R is the retention time and $W_{h/2}$ is the peak width at half height.

The length is calculated with 2m by Formula (2), and (3) according to Rate Theory where H is the plate height, L is the length, A is the eddy diffusion, B is the longitudinal diffusion, C is the mass transfer resistance and $\bar{v}$ is the average velocity.

And pipe inner diameter is 2mm calculated by Formula (4). Where Q is the flow, V is the velocity of the flow. The structure sketch of the GC separation channel is shown in the Fig.2.

$$\mathrm{N} = 16(\frac{t_R}{W})^2 = 5.54(\frac{t_R}{W_{h_{/2}}}) \quad (1)$$

$$\mathrm{L} = \mathrm{N} * \mathrm{H} \quad (2)$$

$$\mathrm{H} = \mathrm{A} + \frac{B}{\bar{v}} + C\bar{v} \quad (3)$$

$$\mathrm{d} = 2 * \sqrt{\frac{Q}{\pi * 3600V}} \Big/ 0.001 \quad (4)$$

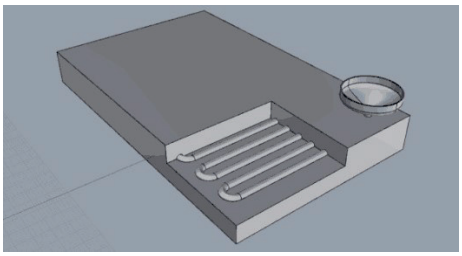

Fig.2. The structure sketch of the GC separation channel.

Gas sensors based on Y-Zeolite/SnO_2 and SnO_2 materials are used to test the concentration of breath acetone and ethanol. The gas sensors are placed at the exit of the channels to detect the contention of breath acetone and ethanol, respectively.

3 Result and discussion

The distribution volume fraction of breath acetone is simulated by COMSOL based on the turbulence model and the volume fraction slice diagram of flow phase acetone is shown in the Fig.3.

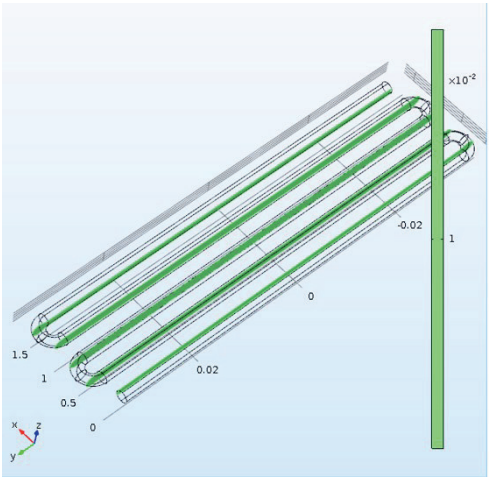

Fig.3. The volume fraction slice diagram of flow phase acetone.

The separation time of carbon dioxide, breath acetone and ethanol are measured by a GC separation channel at the temperature of 40℃. Carbon dioxide, breath acetone, and ethanol are separated in the 26th s, 162th s and 324th s. Subsequently, a time-sharing conversion switch will operate to convert at 120th s and 300th s.

Gas sensing properties of Y-Zeolite/SnO_2 sensor and SnO_2 sensor are shown in the Fig.4, Fig.5 and Fig.6. It can be seen from the Fig.4 that the optimal operating temperature of Y-Zeolite/SnO_2 sensor and SnO_2 sensor are 275℃ and 200℃, respectively. Transient responses curves of the Y-Zeolite/SnO_2 sensor to acetone with the concentration of 1~100 ppm at the operating temperature of 275℃ are illustrated in

the curve (a) of the Fig.5. Meanwhile, transient responses curves of the SnO_2 sensor to ethanol with the concentration of 1~100 ppm at the operating temperature of 200℃ are shown in the curve (b) of the Fig.5. The Fig.6 (a) and (b) show the response times of Y-Zeolite/SnO_2 sensor and SnO_2 sensor to acetone and ethanol are the 40s and 20s, the recovery times are the 30s and 40s, respectively.

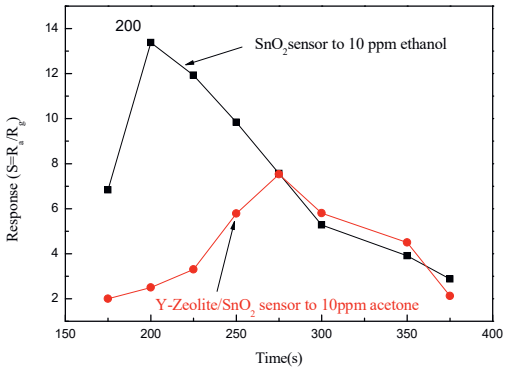

Fig.4. Responses of Y-Zeolite/SnO_2 sensor to 10 ppm acetone and SnO_2 sensor to 10 ppm ethanol as a function of operating temperature.

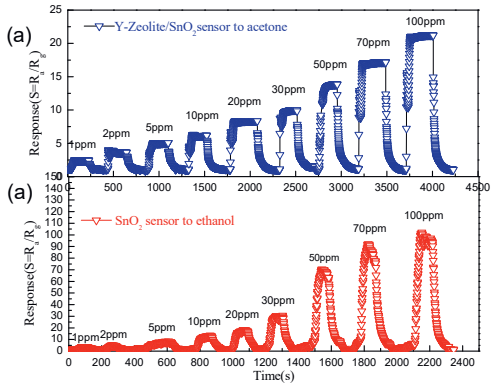

Fig.5. Transient responses curves of Y-Zeolite/SnO_2 sensor and SnO_2 sensor to acetone and ethanol with the concentration of 1~100 ppm at the operating temperature of 275℃ and 200℃.

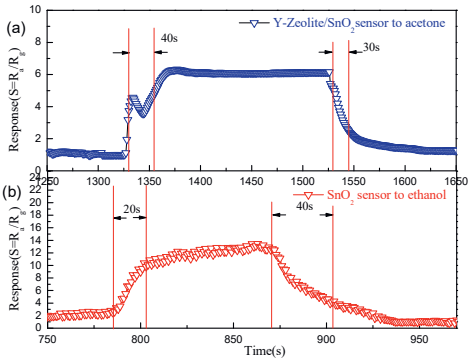

Fig.6. The response and recovery time.

Conclusion

The human breath acetone detector based on GC separation channel is designed and developed in manuscript. And diabetic patients' breath is sampled and separate effectively by GC separation channel. Carbon dioxide, breath acetone, and ethanol are separated in time-sharing conversion switch, the concentration of breath acetone and ethanol are measured by Y-Zeolite/SnO_2 sensor and SnO_2 sensor, respectively. Test results show that carbon dioxide, breath acetone, and ethanol of diabetic patients can be separated successfully and measured accurately by the human breath acetone detector. Separated time are 26s for carbon dioxide, 162s for breath acetone and 324s for ethanol. The separation accuracy is 99.7% and the accuracy is 99.2%.

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