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A portable embedded drug precursor gas detection and identification device based on cataluminescence-based sensor array

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ABSTRACT

A battery-operated, low-cost and portable embedded gas detection device consisting of a cataluminescence (CTL)-based sensor array was developed for the determination and identification of drug precursor gas. A total of 16 nanomaterials, including nano-sized metal oxides, decorated nanoparticles, and carbonates have been carefully selected as sensing elements of 4 × 4 sensor array. Dynamic and static analysis methods were utilized to characterize the performance of the portable gas detection device to 6 kinds of drug precursor gas. Each compound gave its unique CTL pattern after interaction with the sensor array, which can be employed for the detection and identification of drug precursor gas. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) were used to analyze the CTL patterns. The PCA plots showed that the groups of 6 types of drug precursor gas were well classified. In addition, the patterns obtained at different working temperature and the quantitative determination of the portable device was investigated. The results showed that the linear ranges and detection limits of the portable device for the analytes were excellent. Illegal drug detection is of great importance for public security, our study demonstrated the portable gas detection device shows promising perspective for the recognition and discrimination of drug precursor gas.

1. Introduction

Ether, acetone, chloroform, toluene, 2-butanone and acetic anhydride are common volatile organic compounds (VOCs), which have been received much attention in recent years [1–6]. These types of gases are usually important auxiliary materials utilized by drug trafficker even though they are not drugs of their own. The analytical tests and sensor devices for reliable detection and identification of multiple drug precursor gas are still very rare. Obviously, there is an obvious pressing need for the rapid, sensitive and highly portable detection and identification of drug precursor gas.

Semiconductor metal oxide sensor or surface acoustic wave quartz crystal sensor are commonly used to detect VOCs [7–9]. However, the metal oxide sensors require high working temperatures, and their response base-lines are easily drifted. Meanwhile the conducting polymer sensors have the difficulties in the arrangement of material, and they are easily disturbed by humidity. In comparison, the development of cataluminescence-based sensors offers new opportunities for gas analysis, mainly because of its high sensitivity, long-term stability, and simplicity [10]. Persistent efforts have been made to develop the CTL analytical method for the detection of volatile organic compounds such as acetaldehyde [11], benzene [12], benzaldehyde [13], formaldehyde [14] and ethanol [15].

For the recognition of complex and similar mixtures, a single sensing element is limited, therefore a sensor array based on CTL sensing mode is desired [16]. When sensor array binds to each analyte, it creates various signals and provides unique pattern for the identification of individual analyte. The method has been emerged as a powerful approach toward the detection of diverse chemical analytes with rapid and continuous measurements. In recent years, although sensor array technology has been applied successfully in gas detection, multiple sensing elements are not beneficial to the stability of the instrument [17–21]. The CTL method provides a novel sensing strategy for the detection and identification of the analytes. Furthermore, the development of nanoscience and nanotechnology also brings great opportunities for the advancement of CTL sensor array [22]. For example, Zhang et al. developed

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a CTL-based sensor array with nine sensing elements to recognize alcohols, amines and thiols [23].

In our previous work [1,24], nanosized Au/La_2O_3 were used for detecting benzene, enhanced CTL performance of ether on nanosized SiO_2/Fe_3O_4 was observed compared with pure Fe_3O_4. In the present study, a battery-operated, low-cost and portable embedded gas detection device is fabricated with ARM11 S3C6410 core as the main application processor. This device shows how the discriminatory capacity of sensor arrays utilizing pattern recognition is operating in environments. It collects images of cataluminescence sensors after exposing to the drug precursor gas, and then processes those images to extract the unique characteristic for each gas. The collected testing data of drug precursor gas are further processed using hierarchical cluster analysis (HCA) and principle component analysis (PCA) methods in order to illustrate the selectivity of this portable device. With a fully functional database, the excellent linearity and stability indicates the feasibility of this portable embedded device for drug precursor gas determination.

2. Experiment

2.1. Reagents

All chemicals (ether, acetone, chloroform, toluene, 2-butanone and acetic anhydride) used in the experiment had the high purity ($\geq$98.5%) of analytical grade or even higher and were purchased from Shanghai Chemical Reagents Company. Thus they could be used in our experiment without further purification.

2.2. The cross-responsive sensor array

The composition and preparation of the cross-responsive sensor array were similar with the array described in our previous work [25], which utilized nanosized oxides (La_2O_3, Y_2O_3, MgO, Al_2O_3, ZrO_2, CeO_2, ZnO, Fe_3O_4), decorated nanoparticles (Au/SiO_2, SiO_2/Fe_3O_4, CeO_2/TiO_2, Au/La_2O_3, ZrO_2/MgO, Al_2O_3/PtO_2) and carbonates ($BaCO_3$, $SrCO_3$) as the sensor elements. Nanomaterials were spotted orderly onto the surface of a ceramic chip to form a 4×4 array (about 0.2 mm in thickness and 4 mm in diameter for each sensing element). The arrangement of nanomaterials spots on the sensor array is shown in Fig. 1. The interactions of each sensor unit are different when exposing to different analytes. These different interactions make each sensor unit have different intensity and CTL pattern.

2.3. System composition

The schematic diagram of detection flow of the portable device is presented in Fig. 2. It can be divided into four parts: the gas system, temperature control system, MCU system, and embedded ARM11 system. The gas system includes cylinder, gas pump, flow meter, and waste gas treatment. The cylinder is used to dilute analyte to achieve trace gas samples. The air flow was supplied by a pneumatic pump and a precision flow meter was employed for the measurement of the gas flow rate. The electromagnetic valve controls waste gases treatment to avoid the leakage of drug precursor gas into the atmosphere and prevent environmental pollution.

A digital temperature controller was used to control the temperature of the ceramic chip. The final image was recorded by a camera closely placed to the ceramic chip. MCU system receives commands from the host computer embedded ARM11 to control the peripheral modules, including pump speed control module, temperature control module and image acquisition module, and finally returns the monitored data to the embedded ARM11. The embedded ARM11 system is the master platform of the drug precursor gas detection device. It collects images of CTL-based sensor arrays from the image acquisition module, and then extracts the feature color information of the CTL-based sensor arrays.

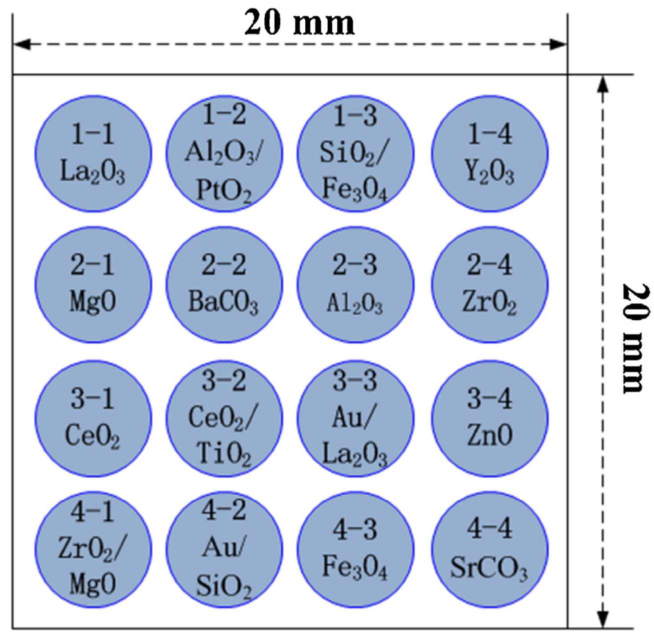

Fig. 1. Arrangement of nanomaterials spots on the sensor array.

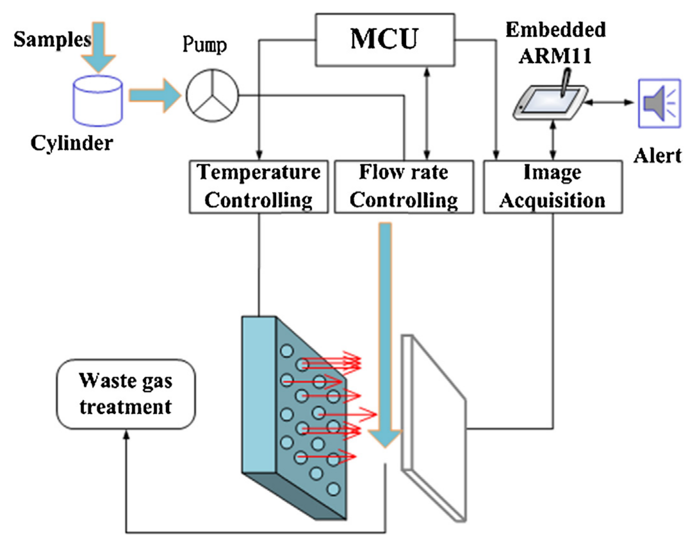

Fig. 2. Schematic diagram of detection flow of the embedded portable device.

3. Results and discussion

3.1. CTL-based sensor array response to drug precursor gas

The cross sensitivity responses are crucial for discrimination using nonspecific response patterns [26,27]. In order to analyze the cross sensitivity of the sensor array, six types of drug precursor gas including ether, acetone, chloroform, toluene, 2-butanone and acetic anhydride were examined in our study. The gases reacted with CTL-based sensor array under the concentration of 1000 ppm and six feature images are shown in Fig. 3. The results indicated that the CTL response and the gray level of each images were discriminative for different target gases. It suggested that there was a correspondence relationship between the image feature and the different target drug precursor gas.