Ammonia quantitative analysis model based on miniaturized Al ionization gas sensor and non-linear bistable dynamic model

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Keywords: ammonia, Al plate sensor, gas sensor, gas ionization, non-linear

In this paper, ammonia quantitative analysis based on miniaturized Al ionization gas sensor and non-linear bistable dynamic model was proposed. Al plate anodic gas-ionization sensor was used to obtain the current-voltage (I-V) data. Measurement data was processed by non-linear bistable dynamics model. Results showed that the proposed method quantitatively determined ammonia concentrations.

Introduction

Ammonia is widely utilized in industrial occasions. It is an odorous hazardous gas emitted from various sources. Ammonia presents a very strong smell. The permissible maximum concentration for human being is 50 ppm. It is dangerous to breathe ammonia at 2500–6500 ppm for over 2 h. Thus, development of reliable gas sensors for ammonia detection is of great importance.\(^1\)-\(^3\) Many researchers develop novel materials to fabricate ammonia gas sensors.\(^4\)-\(^13\) Since the discovery of the catalytic effect of SnO\(_2\) in 1962, many studies have been conducted to improve sensor’s functions.\(^14\),\(^15\)

Since proposed by Benzi in 1981 for the earth ice age disciplinarian explanation,\(^16\) bistable dynamic model has been widely applied in fields, such as signal detection, electrical circuits, biological modeling, neural systems, et al.\(^17\)-\(^20\) It is interesting that, under certain circumstances, an extra dose of noise can actually help the performance of some devices, by eliminating the internal noise in the system. When used properly, bistable dynamic model gives out an exciting improvement in coherence index. This unique characteristics help to establish the applications of this method as a mathematical tool in lots of scientific research fields. A number of bistable dynamic models have been proposed till now.

In this paper, ammonia quantitative analysis based on miniaturized Al ionization gas sensor and non-linear bistable dynamic model was studied. Al plate anodic gas-ionization sensor was used to obtain I-V measurement data. Recorded data was processed by non-linear bistable dynamics model. Results showed that the proposed method quantitatively determined ammonia concentrations.

Results and Discussion

Non-linear bistable dynamics model 3-D coherence index calculation method

The non-linear bistable dynamics model and 3-D coherence index calculation principle blocks were shown in Figure 1. The experimental data transferred to the computer was input into the bistable dynamic model along with the white noise. Then coherence index information was calculated in calculation block, and output on the computer screen.

Ammonia detecting results

Ammonia detecting results were shown in Figure 2. The coherence index curves reached their eigen peaks at noise intensity of 360, and different concentrations could be marked by maximums of the coherence index peaks. The lower gas concentrations possessed higher coherence index peak maximums (see Fig. 2b). Figure 2a displayed the concentration grads more clearly. The maximums of the coherence index peaks decreased with the increase of the ammonia concentrations. Platform of the 3-D coherence index plotting provided us a useful gas concentration quantitative analysis way for ammonia.

In Figure 2c, the color distributions of the lower concentrations of ammonia gas presented “wider range” than the higher concentrations. A possible explanation of this phenomenon lies in the electrical characteristics of ammonia gas. Ammonia is chemically special, so it is widely used in chemical compound. When in lower concentrations, ammonia molecules possess a lower density, which made the gas mixture more easily ionized. So at the same interelectrode voltage, a lower concentration
ammonia gas presented a higher discharge current, as the Figure 2c shows.

For determination of ammonia concentrations, maximal values of coherence index eigen peak values (see Fig. 2b) were selected to develop ammonia concentration predicting model. In Figure 2d, non-linear fitting regression between coherence index eigen peak values and concentrations was conducted. The regression model was displayed in Equation (1). After one step transform, Equation (2) was used to predict ammonia concentration.

\[ y = -57.15062 + 29.37685e^{-\frac{x + 85.60626}{29.37685}} \]

\[ R^2 = 0.97355 \]  

\[ Ammonia = -404.72854 \ln \left( \frac{Value_{peak} + 57.15062}{29.37685} \right) - 85.60626 \]

**Methods**

**Sensor and experimental setup**

Experiments in this paper were conducted using anodic Al plate ionization gas sensor (shown in Fig. 3). The gas-ionization sensor included Al plate electrodes and polyimide thin film. Polyimide insulation film was used between the Al electrodes. Inter-electrode distance could be adjusted by the thickness of polyimide film. The areas of 2 electrodes are 2.5 cm × 4.5 cm, and the effective area between MWNT electrode and Al electrode was 2 cm × 2.5 cm.
Experimental setup was shown in Figure 4. Gas flowed into gas chamber with ionization gas sensor. The peripheral circuit board increased the interelectrode voltage, and gathered the discharge current and the voltage data, which were transferred to the computer for further analysis.

Non-linear bistable dynamics model
Non-linear bistable dynamics model has been tremendously paid attention in fields. Non-linear bistable dynamics model possesses 3 basic elements: a bistable model, a weak coherent input, and outer stimulation:

\[
\frac{dx}{ds} = \sin(2\pi f_0 t + \varphi) + 2D\xi(t)
\]  

(3)

\(\xi(t)\) is a outer stimulation, \(\varphi\) is the input signal amplitude and \(f_0\) is the modulation frequency, and \(D\) is stimulation intensity. The most common quantifiers for non-linear bistable dynamics model are the spectral amplification \(\eta\) and the output coherence index. Here we adopt coherence index method, which leads the following definition:

\[
\text{Coherence index} = 2 \lim_{\Delta \omega \to 0} \left( \frac{\int_{\Omega - \Delta \omega}^{\Omega + \Delta \omega} S(\omega) d\omega}{S_N(\Omega)} \right)
\]

(4)

\(S(\omega)\) is the signal power spectral density, and \(S_N(\Omega)\) is outer stimulation in signal frequency range.

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Experiments
7 concentrations of ammonia (500 ppm, 600 ppm, 700 ppm, 800 ppm, 900 ppm, 1000 ppm, and 2000 ppm) experiments were accomplished to obtain measurement data. Then the measurement data was input into the non-linear bistable dynamics model block, and coherence index was calculated to give the results. All the tests were all conducted under room temperature, 80% relative humidity, and zero gas-flow.

Conclusions
In this paper, ammonia quantitative analysis based on miniaturized Al ionization gas sensor and non-linear bistable dynamic model was proposed. Al plate anodic gas-ionization sensor was used to obtain the I-V data. Measurement data was processed by non-linear bistable dynamics model. Results showed that the proposed model

\[
\text{Ammonia} = -404.72854 \ln \left( \frac{\text{Value}_{\text{out}} + 0.15062}{29.37865} \right) - 85.6026
\]

(R^2=0.97355) quantitatively determined ammonia concentrations.

Disclosure of Potential Conflicts of Interest
No potential conflicts of interest were disclosed.
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