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RESEARCH ARTICLE

SnO2 Thick Film Gas Sensor Fabricated by Screen Printing Method for Airplanes

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HIGHLIGHTS

> From the beginning of aviation history, the fire has been a serious problem for aircraft.
> It was observed that dozens of aircraft changed their planned flights, due to the high level of false warnings given by the smoke detectors used in the airplanes and this resulted in financial losses.
> The CO2 gas sensor can be used simultaneously with the smoke detectors to increase the detection reliability and reduce the alarm time.

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ABSTRACT

Since the beginning of aviation history, fire has been a serious problem for aircraft. Smoke detectors act as fire detectors in passenger aircraft serving today. In the researches, it has been observed that as a result of the high rate of false warnings given by the smoke detectors used in the aircraft, dozens of aircraft changed their planned flights and this resulted in financial losses. Within the scope of this study it is planned to use a carbon dioxide detector simultaneously with smoke detectors in order to increase the detection reliability and reduce the alarm time in case of a potential fire, and it is planned to produce a gas detector that will react to carbon dioxide gas. The samples produced were examined under the carbon dioxide gase with specified gas detecting properties, and it was concluded that they can be used simultaneously with smoke detectors in order to increase the detection reliability and reduce the alarm time with the smoke detectors currently used in today's passenger aircraft.

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1. Introduction

Fire has been a serious problem since the beginning of aviation history. The first fatal accident of aviation occurred as a result of a fire in 1785 during an uncontrolled flight (the hydrogen balloon of Jean-François Pilâtre de Rozier caught fire and burned over the English Channel) [1].

Crash data show that flight fires are the fourth highest accident category with fatalities and the seventh highest overall [2].

The formation of smoke or fire on commercial aircraft during flight is a dangerous situation and may result in disaster if not effectively responded by the aircraft crew [1].

For many years, commercial aircraft operated on the principle of not leaving enough oxygen in the environment to control the risk of cargo compartment fires under the main passenger cabin. A cargo fire that caused body loss in a commercial passenger plane caused the thought that the risk of fire that may occur in the cargo section should be perceived [1].

Federal Aviation Rules (FAR) required fire detectors in B, C and E cargo compartments. According to FAR 25.857, 25.858 certification standards, the fire must be detected within 1 minute after it starts. This determination is made with smoke sensors in cargo compartments of type B, C and E [3].

Fire detectors must be able to operate reliably in environmental conditions to prevent false alarms. The cargo compartments on aircraft have only a single source fire sensor which is smoke sensors. It is known that most of the warnings given by the smoke detectors are false alerts and there are financial losses due to flight delay, flight cancellation and emergency landing situations, therefore, it is necessary to use multi-source sensors on new generation aircraft [4].

Very different substances coexist in burning environments and different gases are released as a result of combustion. Fires involving all organic fuels produce carbon monoxide (CO), carbon dioxide (CO_2) and water vapor. In recent years, CO and CO_2 sensors have become popular to monitor the atmosphere in building applications for general health or environmental control. Some of the multiple fire detectors developed recently include CO and CO_2 detectors [5].

Adoption of recommendations to prevent fires that may occur in flights could help reduce the risk of future flight fires. Aviation will continue to experience in-flight fires in the future as in the past. The recommendations made within the scope of this study are designed to help prevent the progression of fires that may occur in flight and to reduce the likelihood that any flaming fire are uncontrollable.

The aim of this study is to provide a reference document on current risks and proposed reductions for smoke and fire incidents in commercial transport aircraft. For this purpose, metal oxide carbon dioxide detector was produced with the screen printing technique in order to detect CO and CO_2 gases from the sensors required to observe the occurrence of a fire that may occur in the aircraft and to make the necessary controls.

The purpose of choosing the screen printing technique as the sensor construction technique is to synthesize the smallest size films for gas sensor applications and to convert them into gas detectors. It is also closely related to the mechanical and electrical properties of sensitive layers which vary depending on ambient conditions.

Therefore, economical and effective production methods should be selected. In addition to being one of the most economical methods for the production of gas detector components, the screen printing technique has various advantages such as the production of perfectly homogeneous semiconductor oxide structures and the addition of high purity additives [6].

When the electrical characteristics of the sensor made were examined, it was observed that it meets the requirements of the Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) standards (the fire should be detected within one minute) and the false alarm situation experienced in the smoke sensors used today can be eliminated.

2. Materials and Method

In the SnO_2 thick film gas sensor fabrication made within the scope of this study, the screen printing method was used and the planar structure of the thick film to be produced is given in Figure 1.

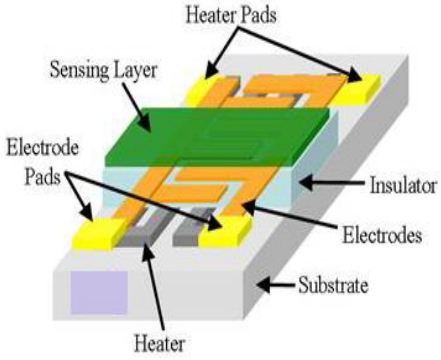

Figure 1 Thick film gas sensor structure [6]

While this technique is applied, at each stage (heater, electrode and sensitive layer making), the selected material is screened on the substrate and the heat treatment of the created structure is performed. Alumina (Al_2O_3) is used as a substrate in this technique.

The application order in the screen printing process is as follows;

- Screen printing of the heater on the substrate and heat treatment of this layer
- Screen printing of electrodes on the substrate and heat treatment of this layer
- Screen printing of active layer on the substrate and heat treatment of this layer

2.1. Preparation of Binder and Paste

Both of the bonding preparation techniques described in the screen printing method were used for comparison. The rates encountered in the literature study [6–9] to determine the proportions of chemicals to be used in the compounding were tested one by one, and the rates decided to be used in this study are as given in Table 1.

Table 1 Chemicals and ratios used in binder preparation

Binder made with linseed oil		**Binder made with ethyl cellulose**	
	wt(%)		wt(%)
linseed oil	85	ethyl cellulose	10
m–xylene	12,5	α–terpineol	90
α–terpineol	2,5		

For the preparation of the binder, first, linseed oil and m–xylene were mixed and they subjected to magnetic stirring at 40 °C on hot plate. The stirring process was continued for about 4 hours.

After that α–terpineol was added then the temperature of was decreased to 30°C. The stirring was continued for about 2 hours to obtain a sticky liquid form binder.

Thick film gas sensor pastes usually comprise a semiconducting metal oxide powder, inorganic additives and organic binders.

In this research, tin oxide (SnO_2) was used as the base sensitive metal oxide powders.

Sensitive powder (SnO_2) was mixed with 40 wt% and binder was mixed with 60 wt% and they subjected to magnetic stirring at 40 °C on hot plate for 24 hour.

2.2. Film Preparation

The screen printing process, which has given its name to the method in this technique, consists of masks designed according to the type of gas to be detected and the metal oxide to be used.

The base to be used during the screen printing process is placed on the screen printing machine used in the screen print technique shown in Figure 2. and the pattern to be used in the mask is placed on the base. The reason for using the screen printing machine is to prevent the base from sticking to the mask while screen printing, since it has a vacuum feature.

Figure 2 Screen printing machine

The SnO_2 thick films were prepared by screen print technic using Al_2O_3 substrate. Silver was used when making electrodes due to its superior conductivity, chemical stability, and low price. Silver electrodes were printed on an Al_2O_3 substrate. After printing the electrodes, it was kept at room temperature for 10 minutes. After these electrodes were kept at 125 °C for 10 minutes for drying. Finally, electrodes were kept at 350 °C for 20 minutes for firing. Sensitive layer was printed with sensitive paste on electrodes. After printing the sensitive layer, films were left at room temperature for 20 min to insure the paste is leveled off and settled and then the films are subjected to a drying and firing process.

The sensitive layer was dried in three steps: first it was subjected to 50°C for 5 minutes and then temperature was increased to 100 °C for another 5 minutes, and finally it was dried at peak temperature of 125 °C for last five minutes. Finally film was kept at 450 °C for 30 minutes for firing [8].

2.3. The Gas Sensor Measurement System

The gas sensor measurement system is designed to make gas sensitive resistance measurements depending on the temperature. The amount of gas entering the cell is opened and closed at the desired level and with high precision in terms of parts per million (ppm), while the current voltage system can measure. The designed gas detector measurement system is shown in Figure 3.

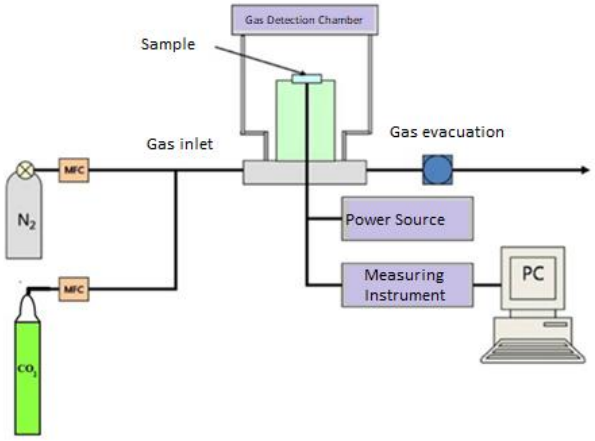

Figure 3 Gas sensor measuring system

The experimental setup consists of 3 main parts. These are:

- Heating the system
- Gas flow control
- Observing electrical change

3. Results and Discussion

3.1. XRD Analysis of Samples Produced With SnO2

The structure of the made with SnO_2 based sample produced by the screen printing method was examined by the XRD technique and is shown in the figure below.

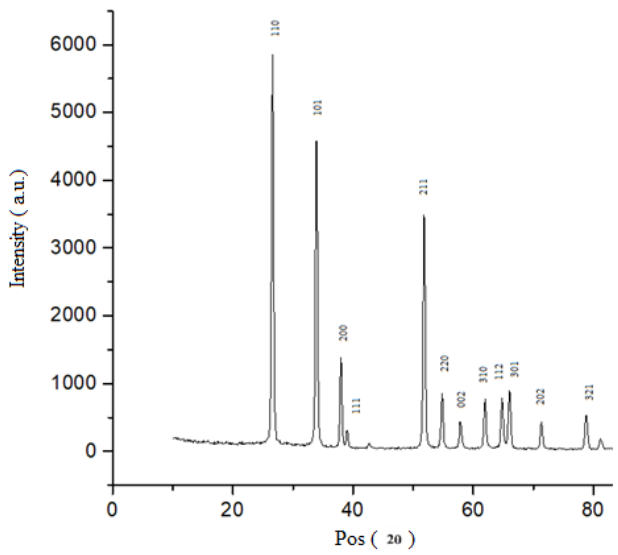

Figure 4 XRD graph of the SnO_2 sample

In the graphic shown in Figure 4. It has been observed that it gives reflection. When these planes are compared with other studies [10–14] and with the JCPDS 71-0652 card number XRD database phases, it was observed that they are reflective peaks of pure SnO_2.

3.2. Measurements of SnO_2 Based Gas Sensor

The values used during the measurement of the SnO_2 sample measured at 300 ℃ temperature are given in Table 2.

Table 2 Values used during the measurement of the SnO_2 sample

Temprature	300 °C
Time to measure	400 seconds
External gas sweeping time	800 seconds
Gas measured	CO2
External gas	Nitrogen (N2)
Period (Per Ppm)	1
PPM list	5000
Voltage source level	1 V

In order to clean the environment from various gases, nitrogen gas was sent to the environment for 90 seconds during the measurement process number 1 of the SnO_2 sample. Then, measurements were taken by giving the carbon dioxide gas to be measured together with nitrogen gas at the rate of 5000 ppm in the 90th second and the current increased from 9.08 nA in 90th second to 37.211 µA in 152nd second. This measurement is shown in Figure 5.

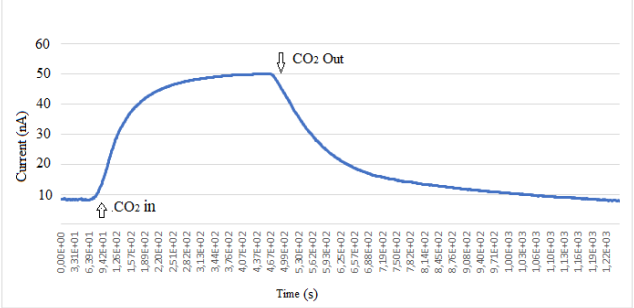

Figure 5 Gas sensor measurement chart of SnO_2 sample under 5000 ppm CO_2

In the literature search, Wang et al. Subjected the sensors they produced in their pure SnO_2 thick film gas detector study to approximately three heat treatments at different periods between 400 and 950 ° C. They made the gas sensor measurements of their samples in the temperature range of 240 ℃ - 600 ℃ and 500 ppm - 30000 ppm, and they made measurements for different ppm levels at different temperatures, and measured the resistance change depending on time [15].

The measurements of the SnO_2 sample used in this study were made at various CO_2 concentrations and measurement temperatures, and similar and better results were obtained with the data in this range. When the response times of the measurements were examined, it was observed that it was between 50 and 65 seconds. This observed value has been observed to meet the requirement for a fire detector that can be used in commercial aircraft, to react within 60 seconds from the start of the fire.

3.3. SEM analysis of SnO_2 Sample

SEM images of SnO_2 thick film are given in Figure 6.

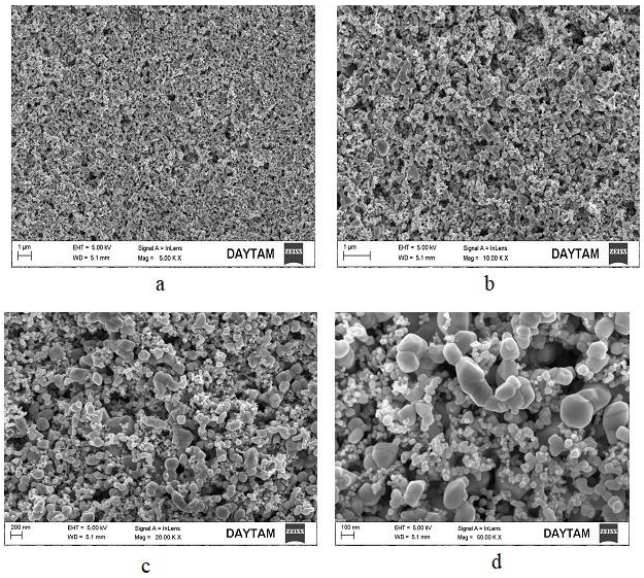

Figure 6 SEM images of 5.00 KX (a), 10.00 KX (b), 20.00 KX (c) and 50.00 KX (d) of the SnO_2 sample

In order to have information about the surface morphologies of the SnO_2 sample enlarged by the screen printing method, images of the SnO_2 sample were taken at different magnifications and shown in Figure 6. When we look at Figure 6. it is clearly seen that the samples grow in a homogeneous structure in the SEM photograph, which is magnified by 5,000 times. This shows that the samples are adapted to the base material and thus there is no clumping and nucleation in certain areas on the base material. In order to examine the effect of SnO_2 on the morphology of the samples, larger magnifications were made and are shown in Figures b, c and d. In Figure d, SEM photographs of the specimens at 50,000 times magnification show that large and small nanotopes were formed in SnO_2 samples. This situation is compatible with the literature [16].

It was determined from the SEM images that the particles in the SEM images were spread in a homogeneous pattern, but there were size differences between the particle sizes and the

porous structure of the surface. It was observed that the SEM images of SnO_2 in the screen printing study of Miskovic et al [17].

4. Conclusions

The main purpose of the study is to produce a CO_2 thick film gas detector that can be used to detect CO_2 gas that will arise in case of a fire in aircraft that can be used with smoke detectors used in aircraft, in line with the need to use multi-source sensors in aircrafts.

Conflict of Interest

Authors declare that they have no conflict of interest with any person, institution, or company.

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