FLIGHT EVALUATION OF A COMPACT AIRBORNE TRACE GAS ANALYSIS SENSOR PROOF-OF-CONCEPT

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Abstract

The National Research Council of Canada (NRC), in partnership with The Armstrong Monitoring Corporation (AMC), undertook the development of a compact, airborne, trace gas analysis system - CATGAS - based on conductometric sensors.

In this work, conductometric CO_2 sensing materials were investigated with the goal of integrating these materials into sensor devices which are small enough to be incorporated into a future UAV. A conductometric thin film sensor was developed at NRC and evaluated in flight on-board the NRC Twin Otter atmospheric research aircraft. The details of the flight test evaluations are presented in this paper and the sensor response findings are discussed.

1 Introduction

Conductometric film sensors work on the principle that the gas coming in contact with the sensor film changes the conductivity of the film, thus providing the basis for the sensor response.

Conductometric gas sensors have certain advantages including low cost, simple design, good sensitivity and fast response which make them amenable to device miniaturization. Miniaturization permits gas sensors to be used in applications where larger detection systems are not feasible. This includes sensors which can be mounted in unmanned air vehicles (UAVs) for gas detection.

1.1 The CATGAS Sensor

After developing and evaluating several different film sensors, a composite thin film, comprised of 98% $BaTiO_3$ and 2% CuO phases, was selected as the most promising for the final design [1].

A pulsed laser deposition (PLD) technique was used to create this film; the success of which demonstrated that composite ceramic materials, whose constituent phases are distributed on a scale less than 1 micron, can be developed using PLD for selective CO_2 sensors and adapted for miniaturized device applications. This film was packaged into a compact sensor (Fig. 1).

Fig.1 The CATGAS Conductometric Gas Sensor

The sensor package was integrated with plumbing, power supply, gas flow control and a heating circuit. The CATGAS sensor was then evaluated for its sensitivity to CO_2, first on the bench in the lab; next it was installed and integrated in the NRC Twin Otter atmospheric research aircraft and tested in the hangar.

Finally, the experimental system was packaged to make it flight worthy and then evaluated in flight on board the NRC Twin Otter. The NRC Twin Otter aircraft was chosen for this evaluation because of its well documented capability for airborne measurement of atmospheric CO_2 concentration using an airborne LiCor LI-7000 CO_2 analyzer.

2 The NRC Twin Otter Research Aircraft

The NRC Twin Otter atmospheric research aircraft (Fig. 2) is often used for the measurement of fluxes of greenhouse gases (GHG), in the earth's boundary layer, usually at low altitudes (as low as 100 feet above ground or vegetation), but also up to altitudes of 10,000 feet.

Fig.2 The NRC Twin Otter Research Aircraft

2.1 Twin Otter Instrumentation (Fig. 3)

The instrumentation suite on board the NRC Twin Otter (Fig. 3) allows us to measure gaseous fluxes of CO_2, H_2O and O_3 in real-time, and N_2O and CH_4 via post-flight spectrographic analysis in the lab.

3 Laboratory Testing of CATGAS

The first task was to package the sensor in a small volume enclosure (black box in Figs. 4 & 5), with plumbing to get the test gases flowing into and out of the box in such a manner as to fully expose the sensor to the gas flow. The enclosure had an approximate internal volume of one liter.

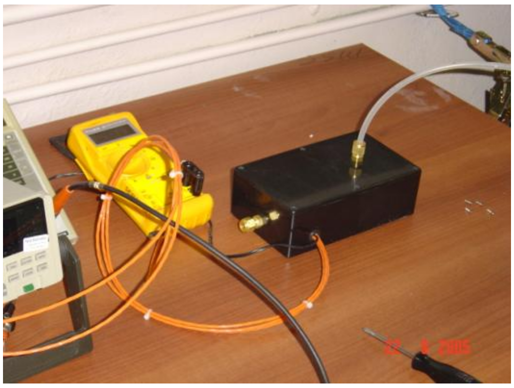

Fig.4 The Packaged CATGAS Sensor

Several gas compositions were used for testing and calibration. They were selected to span and encompass the ambient atmospheric value of 380 ppm, as follows: 0, 100, 350, 1000 ppm CO_2.

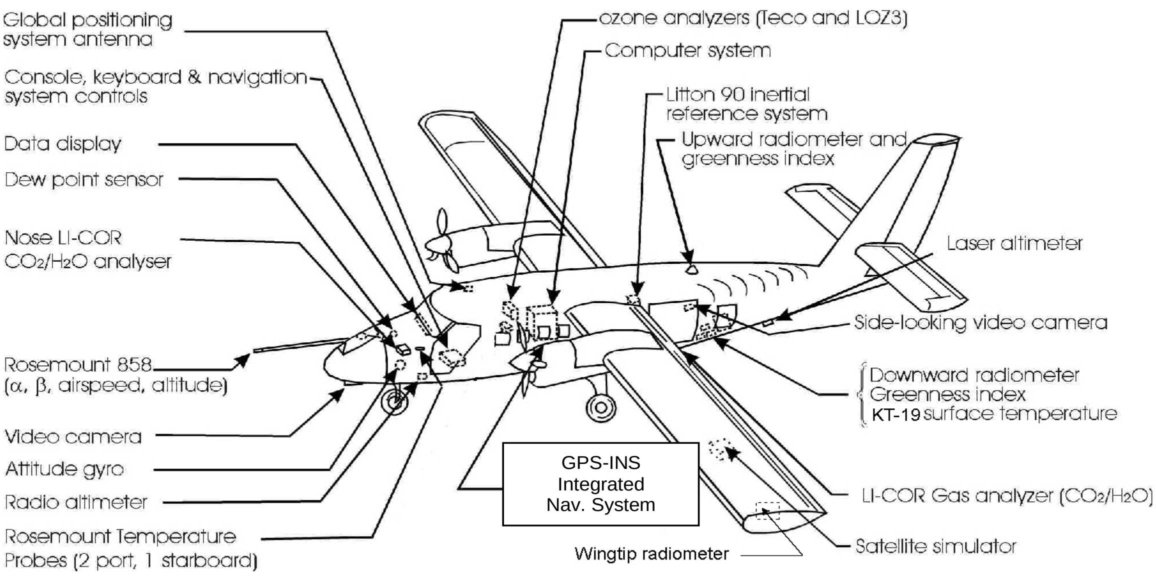

Fig. 5 The Experimental Test Setup

Figure 6 shows the sensor response to a step change in the gas composition from 0 to 1000 ppm CO_2. On the Y-axis, approximately 7 Volts represents 1000 pm while approximately 5.5 Volts represents 0 ppm. The sample gas concentration is switched from 0 to 100 pm at about the 105 second mark on the X-axis and switched back to 0 ppm at about the 255 second mark.

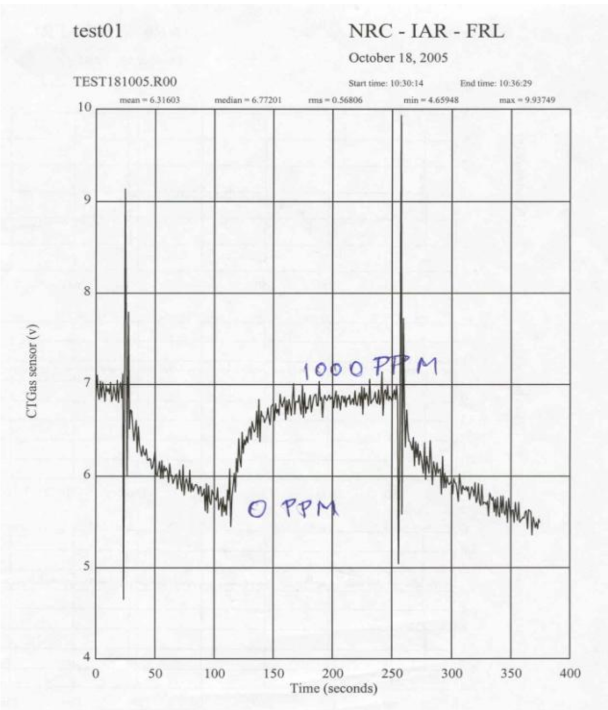

Fig. 6 Sensor Response to Step Changes in CO_2 Concentration

Even after subtracting the transport delays of the gas flow in the plumbing, as well as the diffusion in the enclosure, the large time constant of the sensor is evident.

This was the first indication that this sensor would not be fast enough for airborne flux measurement work. Also evident is the differences in the shape of the curves when going from 0 to 1000 ppm and vice-versa. This is typical of the inherent hysteresis characteristics of gas absorption sensors.

4 Flight Trials of CATGAS

In order to truth the experimental data - i.e. to compare the experimental data to some known benchmark data - the Twin Otter's on-board LiCor LI-7000 CO_2 analyzer would be used. The LI-7000 is a commercial system based on IR absorption technology, with a resolution of less than 10 ppm. The CATGAS package was installed on top of the rear rack in the cabin of the aircraft (Figs. 7 & 8).

Fig. 7 The On-board LiCor LI-7000 CO_2 Analyser

Fig. 8 CATGAS installed atop the LI-7000 rack

The first flight with CATGAS on board the NRC Twin Otter was designed to be a shakedown flight, both to evaluate the function of the sensor and to identify any airworthiness issues. In this case, the bench tests, hangar tests and EMI/EMC tests performed earlier were all vindicated by a successful, no-snags first flight.

During this flight, a second objective was also undertaken - to investigate the suitability of the Thurso paper mill's smoke stack (Fig. 9) as a CO_2 emitting target. This was done by overflying the stack and tracking the plume, while the aircraft sampled the gases and the on-board LiCor LI-7000 analysed and indicated the concentration of CO_2 in the air.

Fig. 9 Overflying the Thurso Paper Mill Smoke Stacks

The results, however, proved rather disappointing, in that the LiCor data showed that the stack was putting out a very small amount of CO_2 - causing only a 20-30 ppm increase from the ambient atmospheric CO_2 concentration of 380 ppm. It was clear that this would not be detectable by the CATGAS sensor; so a different CO2 target would have to be found.

Fig. 10 Trailing the NRC Harvard's Exhaust Fumes

The next flight was planned as a chase flight, trailing the exhaust emitted by the NRC's Harvard aircraft, a piston-prop with radial I.C. engines (Fig. 10).

5 Flight Trial Results

The sensor response was found to be remarkably – and somewhat surprisingly - good (Fig. 11).

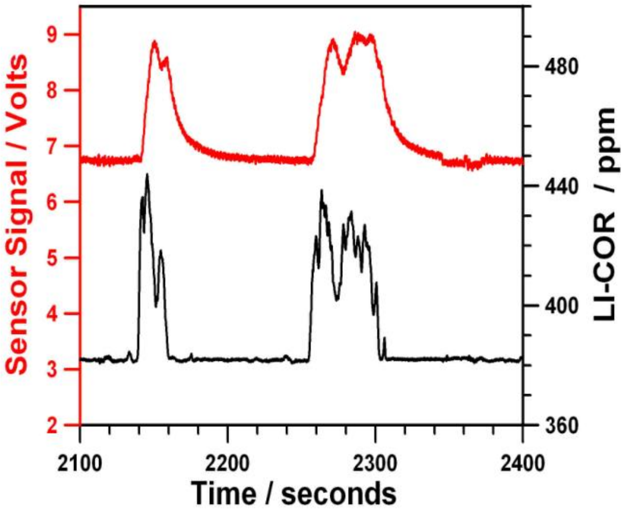

Fig.11 Harvard Chase Sensor Response Results

The two peaks in CO_2 concentration represent time segments when the Twin Otter "found" and sampled the Harvard's exhaust plume. The CATGAS sensor signal is fairly well correlated with the LiCor signal, albeit with a small time lag.

This suspiciously strong correlation between the LiCor and CATGAS sensor data led us to consider the possibility of "poisoning" of the sensor (by Pb, S, Si, …) and cross-sensitivity (to CO, hydrocarbons, NOx, …) to species commonly found in I.C. engine exhaust gases.

In order to rule out and prevent poisoning and cross-sensitivity issues, the sample gas itself would have to be controlled; this would require a method of releasing a controlled sample from the aircraft itself [2] (Fig. 12).

Fig. 12 Rooftop Gas Discharge-Inlet System

The next three flights were used to test this setup. Unfortunately, the sensor did not appear to be responsive to CO_2 and the earlier results could not be reproduced.

This lends further credence to the suspicion of poisoning and/or cross-sensitivity to other gases (besides CO_2) on the previous flight. Indeed, post-mortem testing of the sensor film by X-Ray Photoelectron Spectroscopy (XPS) confirmed the presence of sulphur and lead contaminants at the surface.

6 Conclusions

The CATGAS project had demonstrated that composite ceramic materials, whose constituent phases are distributed on a scale less than 1 micron, can be developed using PLD for selective CO_2 sensors and adapted for miniaturized device applications.

The sensor technology developed had exploited the chemical-physical properties of novel metal oxide nano-composites.

The results also indicate that further work is required to:

- Increase the speed of the sensor response for atmospheric flux measurement.
- Improve the stability of the sensor, to allow for accurate and repeatable calibration.
- Improve the sensor's robustness and reduce its susceptibility to poisoning.
- Reduce the sensor's cross-sensitivity to other chemical species.

6.1 Future Work

Further work could investigate the use of adsorbing pre-concentrators to provide a means of amplifying the levels of some alternate target gas species to those that can be detected using conductometric methods to ppm resolutions.

This approach might offer the potential of developing a micro-sensor system of the type reported here, to detect and quantify target species which are typically at ppb or ppt levels in the atmosphere – such as methane and nitrous oxide. This work would include laboratory testing and subsequent in-flight trials, making use of the on-board hardware and systems already developed in this project.

References

[1] Kunkel M, Tunney J, Post M, Srinivasan R, Marcotte D and Segall D. Conductometric CO_2 Sensing Using $BaTiO_3$-CuO Composite Thin Films Grown by Pulsed Laser Deposition. *Electrochemical Society Conference*, Quebec City, 2005.

[2] Srinivasan R, Marcotte D, Tunney J, Post M and Segall D. Development of CATGAS. NRC Internal Report No. LTR-FR-277, October 2007.

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