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Impedance Spectroscopy: A Key to More Selective and Reliable Chemoresistive Gas Sensors

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Summary: This proceeding explores the usage of impedance spectroscopy to enhance the performance of chemoresistive gas sensors. By employing and studying a frequency dependent response across various concentration of two gases, Hydrogen and Methane, we were able to identify distinct impedance signatures. Preliminary results suggest improvement regarding the time of response, limit of detection, sensitivity and selectivity compared to a more conventional approach by using the resistive readouts. Moreover, impedance leads into a richer dataset for sensor characterization integrating data analysis techniques to support both gas classification and quantification.

Keywords: Impedance Spectroscopy, Chemoresistive Gas Sensor, Selectivity, Reliability, Electrical Characterization

Introduction

The increasing interest in hydrogen as a clean energy carrier brings new challenges related to its safe distribution and monitoring. Hydrogen, while versatile and sustainable, is highly flammable and difficult to detect at low concentrations, especially when mixed with methane in existing natural gas infrastructures. Methane itself is a potent greenhouse gas, and even minor leaks in the distribution system have significant environmental implications.

To address these challenges, we propose a novel sensing approach based on impedance spectroscopy applied to metal oxide (MOX) gas sensors. Traditional chemoresistive sensors often struggle to distinguish between hydrogen and methane due to their similar interaction mechanisms at the sensor surface. By leveraging the frequency-dependent electrical response of the sensors, impedance spectroscopy provides a richer set of information, potentially allowing both enhanced sensitivity and selectivity [1]. This work aims to enable accurate detection and quantification of hydrogen and methane leaks, supporting a safer and more sustainable energy transition. The study leverages known information about the potential of impedance spectroscopy for enhancing the performance of chemoresistive gas sensor [2].

Materials & Methods

A custom test bench was developed to evaluate the performance of various MOX-based sensors under controlled gas exposure. The sensors were exposed to different concentrations of hydrogen and methane, both separately and in mixture, within a gas mixing chamber equipped with calibrated mass flow controllers. The impedance spectra were measured using a Keysight E4990A impedance analyzer over a defined frequency range (200 Hz to 500 kHz).

The sensing elements included lab-fabricated MOX sensors, based on SnO_2:Pd materials. The impedance was recorded in dry air conditions.

Preliminary Results

This study examines the relationship between the imaginary part of the impedance and the concentration of gases, specifically hydrogen and methane, at varying frequencies. The impedance measurements reveal a clear correlation with gas concentration, indicating the potential use of impedance spectroscopy for gas sensing applications.

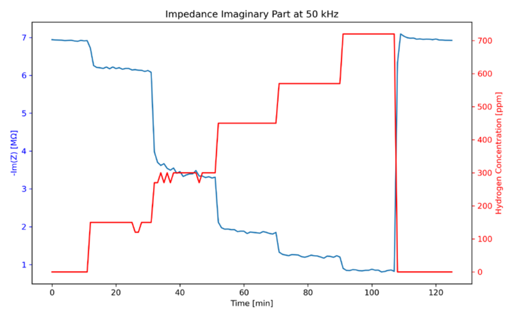

Fig. 1: Imaginary part of the sensor impedance at various concentration of Hydrogen fluxed inside the test chamber.

In presence of Hydrogen at a frequency of 50 kHz, the data demonstrate a stepwise increase in the imaginary part of the impedance as it can be seen in Figure 1. This behavior suggests a strong and reliable relationship between

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the impedance response and the gas concentration with a time of response that is close to one minute. A similar trend is observed for Methane at 300 kHz in Figure 2; however, at this higher frequency, the fluctuations in the impedance data become more pronounced. In this case the results obtained are also closer to a linear trend between the imaginary part of the impedance of the sensor and the concentration of the gas. For Methane the preliminary results mimic the one obtained and presented in literature [2].

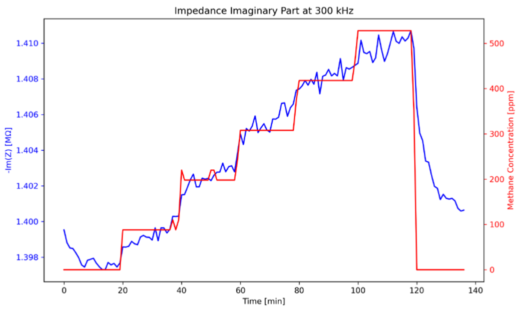

Fig. 2: Imaginary part of the sensor impedance at various concentration of Methane fluxed inside the test chamber.

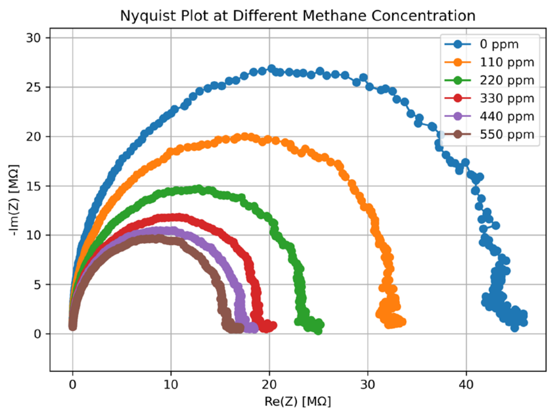

Fig. 3: Nyquist Plot of the SnO_2:Pd sensor at different concentrations of Methane.

Moreover the Nyquist plots in Figure 3 obtained in the different conditions further support these findings, displaying the characteristic semicircular arcs typically observed in impedance spectroscopy. These arcs shift in response to changes in gas concentration, providing visual evidence of the impact of the gas. This observation underscores the utility of impedance-based measurements for distinguishing between different gas concentrations, which is essential for applications in environmental monitoring and industrial processes.

In conclusion, the preliminary results highlight the strong potential of impedance spectroscopy for gas detection, with both the imaginary part of the impedance and the Nyquist plot providing valuable information on gas concentration and composition.

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