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Abstract

Optimization of Dielectric Excitation for Metal Oxide Sensors: Simulation and Experimental Results †

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Abstract: This study assesses the agreement in terms of linearity errors between simulated and experimental data from MOX sensors operated in dielectric excitation mode. Both simulated and experimental reactance spectra exhibit high linearity with respect to gas concentration in the high-frequency shoulder of the relaxation peak. The results demonstrate strong agreement between simulated and experimental 95% CI of absolute linearity errors as a function of frequency. As expected, the empirical errors are slightly bigger compared to the simulation prediction, since the latter only considers the linearity errors. The good correspondence between simulations and empirical results supports the use of simulation to optimize the tuning capacitor and the selection of the optimal operating frequency.

Keywords: metal oxide sensor; dielectric excitation; error analysis; calibration; linearity

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1. Introduction

Dielectric excitation is a promising technique for operating metal oxide sensors (MOXs), offering several benefits over conventional approaches, such as linear response to gas concentration, a large dynamic range of gas detection, high baseline stability, and low cross-sensitivity to ambient factors. Specifically, n-type sensors exhibit a highly linear response to gas concentration in the high-frequency shoulder of the relaxation peak. Incorrect selection of the operating frequency can lead to a non-optimal linear response and a decrease in the signal-to-noise (SNR) ratio. In this study, we aimed to assess a simulation approach in predicting the experimental behavior of the sensors operated in dielectric excitation mode to optimize the tuning capacitor and select the best operating frequency.

2. Materials and Methods

The measurements reported in this study comprised four days of measurements. On the first day, we measured the resistance responses of four TGS8100 sensors (FIGARO Engineering Inc., Osaka, Japan) for six linearly spaced ethanol gas concentrations (ranging from blank to 27.7 ppm) using a permeation tube (Owlstone, Cambridge, UK) as a calibration gas source [1] The relative error in concentration was estimated to be lower than 3%. A dynamic gas humidification system was used to keep relative humidity at 50% [2]. The tuning capacitors were optimized by simulation using the resistance responses to lower the optimum frequency to the desired frequency band. The remaining three days were devoted to measuring both the resistance (DC) and the reactance (10–1000 Hz) spectra. Both the experimental and simulated responses at each frequency were fitted to concentration using simple linear regression, and then the measurement errors were evaluated at each operating frequency. The agreement between simulated and experimental results to the reference concentrations was assessed by comparing the evolution of the 95% confidence intervals (CI) of the absolute errors vs. frequency.

3. Discussion

The simulated and the experimental reactance responses demonstrate high linearity ($R^2 > 0.996$) with respect to gas concentration in the high-frequency shoulder of the relaxation peak, as illustrated in Figure 1 (left), confirming the results of Potyrailo et al. [3]. The 95% confidence interval (CI) of the absolute errors in the empirical and simulated responses show a very good match (Correlations $0.988 < r < 0.999$), indicating a strong agreement in the evolution of the error vs. frequency. The empirical errors are always slightly higher than the simulation results, due to the presence of additional sources of error beyond linearity. The obtained results confirm previous findings and offer support for the use of simulation to optimize dielectric excitation for MOX chemical sensors. Studies regarding sensor tolerances and time stability of the optimum operating frequency will be reported in the extended abstract.

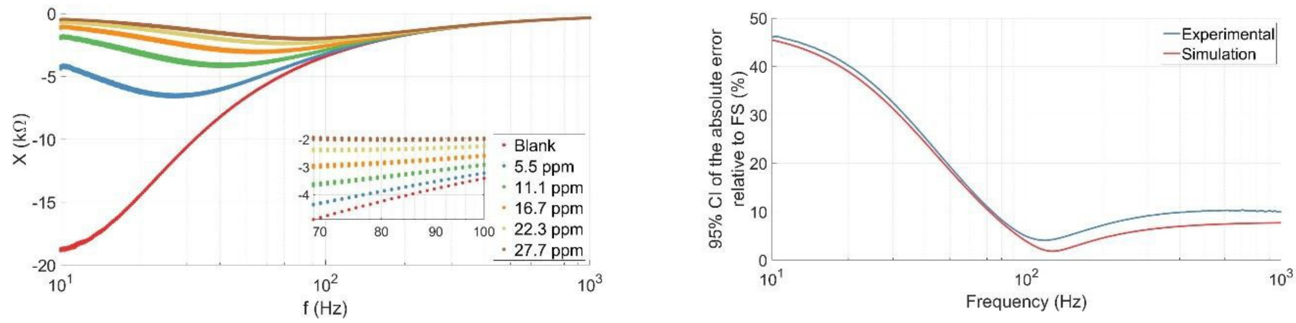

Figure 1. (**Left**) Reactance spectra of a single sensor during an experimental day, with different colors indicating varying ethanol gas concentrations. The close-up highlights the region where the reactance response demonstrates maximum linearity with respect to the gas concentration. (**Right**) The 95% CIs of the absolute error relative to the full scale are shown as a function of the operational frequency, comparing experimental and simulated data for the same sensor during the same experimental day.

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References

1. Mitchell, G.D. A review of permeation tubes and permeators. *Sep. Purif. Methods* **2000**, *29*, 119–128. [CrossRef]

2. Nelson, G. *Gas Mixtures: Preparation and Control*; CRC Press: Boca Raton, FL USA, 1992.
3. Potyrailo, R.A.; Go, S.; Sexton, D.; Li, X.; Alkadi, N.; Kolmakov, A.; Amm, B.; St-Pierre, R.; Scherer, B.; Nayeri, M.; et al. Extraordinary performance of semiconducting metal oxide gas sensors using dielectric excitation. *Nat. Electron.* **2020**, *3*, 280–289. [CrossRef]