proceedings

Proceedings

Temperature Cycled Operation and Multivariate Statistics for Electronic-Nose Applications Using Field Effect Transistors †

Guillem Domènech-Gil *, Marius Rodner, Jens Eriksson and Donatella Puglisi

Sensor and Actuator Systems, IFM, Linköping University, 58183 Linköping, Sweden; marius.rodner@liu.se (M.R.); jens.eriksson@liu.se (J.E.); donatella.puglisi@liu.se (D.P.)

* Correspondence: guillem.domenech@liu.se

† Presented at the 4th International Conference nanoFIS 2020—Functional Integrated nano Systems, Graz, Austria, 2–4 November 2020.

Published: 31 December 2020

Abstract: Gas sensitive iridium-gated field effect transistors based on silicon carbide were used to study the response towards formaldehyde, ammonia, carbon monoxide and nitrogen dioxide at concentrations ranging from parts per million to parts per billion diluted in dry synthetic air and under 50% of relative humidity. The sensor performance was studied using temperature cycled operation mode from 270 to 390 °C to investigate the capability of these devices to discriminate between the studied gases under different background conditions via pattern recognition algorithms.

Keywords: gas sensor; SiC-FET; dynamic operation; temperature cycled operation

1. Introduction

Metal-insulator-semiconductor field-effect-transistors (MIS-FETs) have been studied as gas sensors for several decades [1] leveraging the catalytic properties of the gate electrode to promote the dissociation of hydrogen species into protons. The absorption of these protons through the metal to the metal-insulator interface influences the width of the depletion region in the semiconductor and, thus, the capacitance of the MIS-FET [2]. Using a porous metal gate, in this case iridium, the sensitivity of these devices is extended to gas species such as carbon monoxide (CO) or nitrogen dioxide (NO_2), removing negative charges from the surface.

Chemical gas sensors suffer from poor selectivity. This obstacle can be overcome using the well-known electronic-nose configuration, defined as a heterogeneous group of sensors that is used to produce different finger prints for each studied gas from the combined acquired signals [3] or, using a single sensor, via an array of virtual multi-sensors using, in this case, the temperature cycled operation (TCO) mode. The latter opens the possibility to study the response from the target gases at a broad range of temperatures around the temperature corresponding to the maximum sensitivity for each gas. At the same time, the unique transient response patterns of each studied compound can be used to improve the selectivity of the gas sensor. This methodology has been demonstrated to allow discrimination between gases that in static mode cannot easily be distinguished [4].

In this study, increasing and decreasing temperature cycles were compared. The sensors were exposed to CO, NO_2, formaldehyde (CH_2O) and ammonia (NH_3) at concentrations in the parts per million to parts per billion range. The exposures were performed in backgrounds of dry synthetic air and 50% of relative humidity. The two temperature cycles were compared in their discriminating power using multivariate statistical tools.

2. Gas Sensing via Signal Processing

The amount of information acquired from a gas sensor operating in dynamic mode is considerably large and, for this reason, the signal processing is a fundamental step. This procedure concerns three main parts: pre-processing, feature extraction, and modeling. The signal pre-processing consists in the reduction of noise and drift by smoothing and normalizing the signal. The extracted features in this study are the mean values computed from the three last seconds of each temperature plateau depicted in Figure 1a, resulting in five virtual sensors. Also, the slope of the averaged cycle corresponding to each exposure. Finally, the relative response from the quasistatic plot shown in Figure 1b. These features are later used for a principal component analysis or linear discriminant analysis, followed by model validation using 10-fold cross validation and classification via k-nearest-neighbors algorithms.

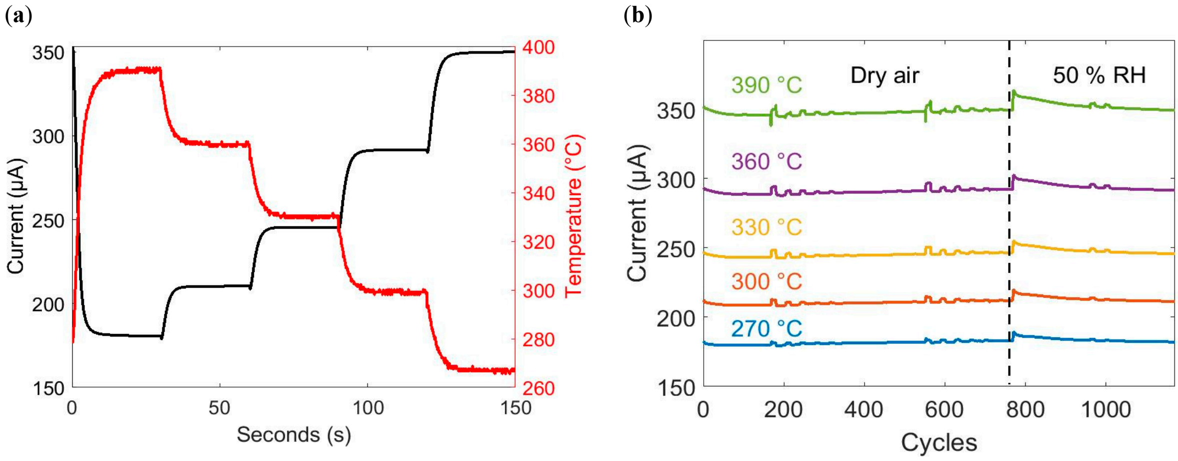

Figure 1. (**a**) Temperature cycle and resulting sensor signal. (**b**) Virtual sensors working at different temperatures extracted from the sensor signal.

Funding: This project has received funding from the EU's H2020 research and innovation program under grant agreement No. 814596 (SensMat).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lundström, I.; Sundgren, H.; Winquist, F.; Eriksson, M.; Krantz-Rülcker, C.; Lloyd-Spetz, A. Twenty-five years of field effect gas sensors research in Linköping. *Sens. Actuators B Chem.* **2007**, *121*, 247–262, doi:10.1016/j.snb.2006.09.046.
2. Andersson, M.; Lloyd-Spetz, A.; Puglisi, D. Recent progress in silicon carbide field effect gas sensors. In *Semiconductor Gas Sensors*, 2nd ed.; Jaaniso, R., Tan, O.K., Eds.; Matthew Deans: Duxford, UK, 2020; pp. 309–346. ISBN: 978-0-08-102559-8.
3. Hrachowina, L.; Domènech-Gil, G.; Pardo, A.; Seifner, M.S.; Gràcia, I.; Cané, C.; Romano-Rodríguez, A.; Barth, S. Site-specific growth and in situ integration of different nanowire material networks on a single chip: toward a nanowire-based electronic nose for gas detection. *ACS Sens.* **2018**, *3*, 727–734, doi:10.1021/acssensors.8b00073.

4. Bastuck, M.; Puglisi, D.; Möller, P.; Reimringer, W.; Schütze, A.; Lloyd-Spetz, A.; Andersson, M. Low-cost chemical gas sensors for selective formaldehyde quantification at ppb-level in the field. In Proceedings of the AMA Conferences 2017—SENSOR 2017 and IRS2 2017, Nuremberg, Germany, 30 May–1 June 2017; pp. 702–707, doi:10.5162/sensor2017/P5.4.