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Evaluation of MOX Sensor Characteristics in Ultra-Low Power Operation Modes: Application to a Semi-Passive RFID Tag for Food Logistics †

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Abstract: Most of the battery powered systems with integrated sensors need low power consumption modes to enlarge the operation time. In the case of the fruit logistic chain, the fruit quality may be controlled by the detection of some gases as ethylene, acetaldehyde and ammonia, that are related to maturation, oxygen stress and refrigeration leakage. We report the integration of an ultra-low power (ULP) metal oxide (MOX) sensor array inside a Radio Frequency IDentification (RFID) 13.56 MHz ISO/IEC 15693 compliant tag with temperature, humidity and light sensors and data logging capabilities. Pulsed Temperature Operation (PTO), which consists in switching on and off the sensor heater, was used to reduce power consumption more than three orders of magnitude, from 14 mW down to 7 µW. The sensor behavior was characterized in terms sensitivity for ammonia.

Keywords: RFID; battery powered systems; food quality; Ultra-low-power MOX sensors; power consumption reduction; logistics

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1. Introduction

Battery power systems with sensors are needed in the food logistic chain for traceability and advanced monitoring. In the case of the fruit logistic chain, the stage of ripening of climacteric fruits can be detected by monitoring the concentration of ethylene, ammonia and acetaldehyde. In this scenario, a portable low-power device is required to monitor the gases. The power consumption of MOX sensors needs to be reduced to reach the battery life levels required by the logistic applications. In this work, we present the integration of an ULP MOX sensor array [1,2] in a semi-passive flexible RFID tag, which functionalities in the food logistic chain were already reported [3,4] for the detection of these target gases. The tag implements a 25 mAh small battery to power all the sensors. Since the power consumption of one MOX sensor is 14.5 mW, the battery life time is limited to only 7.2 h. Thus, a method to reduce the power consumption of the MOX sensors is needed. PTO, which is usually applied to increase the selectivity of MOX sensors [5], was used here to reduce the power consumption of four MOX sensors.

Traditionally, SnO_2 based MOX sensors have been controlled by temperature modulation techniques to enhance the selectivity of the sensors to specific gases. The sensitivity to a gas is affected by the working temperature and by the materials in the active layer of the sensor. PTO consists in periodically activating and deactivating the heater of the sensor to increase the sensitivity and selectivity to the desired gases [6–8].

PTO can also be used to reduce the power consumption of MOX sensors.

2. Materials and Methods

2.1. The Sensor Matrix and Pulsed Temperature Control

Four ULP MOX-based sensors (three of them made of Ag-doped SnO_2 and another one made of SnO_2, with dimensions $120 \times 6\ \mu m^2$ each) were implemented in a matrix, each one including its own integrated micro mechanized heater. The matrix was integrated in a RFID tag (see Figure 1). The whole matrix had an active window of $1140 \times 400\ \mu m^2$. The sensors were designed to work at 400 °C and had a thermal time constant of approximately 1.5 ms. The sensor resistance was 1.5 MΩ in clean synthetic air and 100 kΩ in synthetic air with 0.1 ppm benzene, both measurements taken at 30% RH.

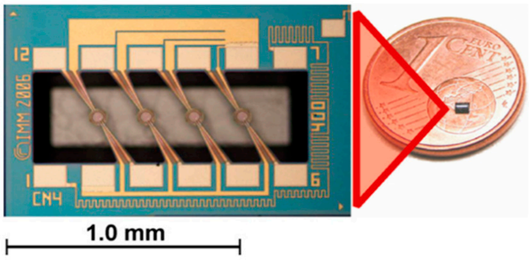

Figure 1. ULP MOX-based sensor matrix integrated into the RFID tag.

2.2. Operation Mode

Several tests were performed varying T_{on} from 2 s to 32.5 ms and T_{off} from 1 to 120 s. The experiment duration was 11.5 h, divided in 40 min of exposure to synthetic air followed by 40 min of exposure to one of the target gases, repeated 8 times. The heaters were operated sequentially and controlled by a demultiplexor (see Figure 2).

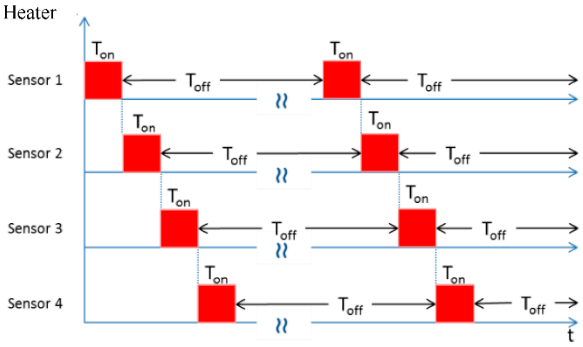

Figure 2. Sequential behavior of the heaters in the sensor matrix.

3. Results and Discussion

The results shown in Table 1 indicate that the LOD of ammonia remained invariant to the PTO mode whereas the power consumption was reduced. Using the most aggressive PTO mode (0.0325/69) the battery life could be extended to more than 3 months and achieve the same detection limits than more power demanding operating modes.

Figure 3 shows that the sensitivity to ammonia of the four sensors was significantly reduced only in the lowest power consumption operating mode (PTO 0.0325/69). Compared to the PTO mode with highest sensitivity (PTO 2/120), the PTO 0.065/75 can extend the battery life from 7 to 84 days at the cost of a reduction of 23% in sensitivity (0.5 vs. 0.65). The SnO_2 sensor without Ag doping only improved the sensitivity of the SnO_2 + Ag sensors for the PTO mode with the highest power consumption (PTO 2/20). In summary, extending the life time of the battery through PTO is possible but has negative effects in the sensitivity and the LOD of ethylene and acetaldehyde.

Table 1. Power consumption, battery life and LOD of ammonia as a function of the PTO mode.

PTO Mode	Power Consumption (µW)	RFID Tag Operation Time (Days)	LOD Ammonia (ppm)
2/20	1450	1.2	2
2/40	725	2.4	2
2/80	362	4.5	2
2/120	241	6.7	2
1/120	120	12.7	2
0.5/120	60	23.3	2
0.25/120	30	39.3	2
0.125/120	15	60.9	2
0.065/75	12	83.8	2
0.0325/69	6.83	103.2	2

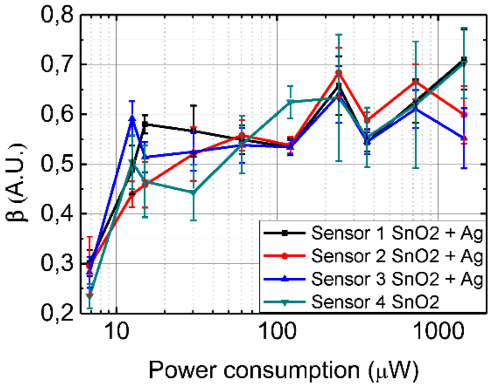

Figure 3. Sensor sensitivity to ammonia.

4. Conclusions

The preliminary results shown here reveal that the sensitivity to ammonia increased with power consumption but the LOD was stable at 2 ppm. The PTO mode 0.065/75 was a good tradeoff between battery life and sensitivity, for the detection of ammonia. However, an optimal behavior requires a compromise between the detection level and the fruit transportation duration. Thus, the operation mode should be selected according to the transportation type and the battery type.

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