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# Integration of an Oxygen Indicator Sensor with a Passive UHF Band RFID Tag

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**Abstract**

For the creation of smart RFID tags, we have developed an oxygen indicator sensor based on a metal cell that both changes color and generates electrical signals depending on the oxygen concentration, and integrated the colorimetric oxygen sensor with a passive UHF band RFID tag. The resulting integrated system was used for the online monitoring of oxygen concentration in a plastic package containing oxygen scavengers, and it was found to function well as a smart RFID tag.

**Keywords:** Oxygen Indicator Sensor, Self-Powered Sensor, Methylene Blue, Passive UHF band RFID Tag, Smart RFID Tag, Integrated System

## 1 Introduction

Oxygen is indispensable for our life, but it can decrease the quality of food. Visual oxygen indicators change color in the presence of oxygen and thus give information about the quality and safety of food without tearing the food packaging [1],[2],[3]. Radio-frequency identification (RFID) technology has been recognized as a basic technology being a part of the Internet of Things (IoT) and has been drawing attention and interest in various fields. Recently RFID has been developed in combination with sensors to create smart RFID tags [4] [5]. In this respect, the connection of an oxygen indicator with a passive UHF band RFID tag is certainly required in various fields in addition to food distribution [6][7].

For the creation of smart RFID tags, we develop a new oxygen indicator sensor which not only changes color in the presence of oxygen but also generates electrical signals (voltage and current) in proportion to the oxygen concentration levels. This colorimetric oxygen sensor is integrated with a passive RFID tag in the UHF band [6][8]. Our system consists of a colorimetric oxygen sensor, a UHF band RFID tag, an interface circuit, a reader, and a server. In order to demonstrate this new system, the system has been used for the online monitoring of oxygen concentration in plastic packaging containing oxygen scavengers.

## 2 Experimental

### 2.1 Oxygen Indicator Sensor

The oxygen indicator sensor was invented based on a cell and composed of zinc foil with a diameter of 0.7 cm (Sigma-Aldrich, USA) and carbon paper with a diameter of 0.7 cm (JNT40, Korea) used as anode and cathode, respectively. These two electrodes were placed in a sodium acetate buffer (0.1 M, pH 4.5) containing methylene blue (MB, 0.02mM) as a redox dye and connected to an external circuit. To test the half cell, a multi-channel potentiostat/galvanostat (PARSTAT MC, Princeton Applied Research, USA) was used with a conventional three electrode configuration: the carbon paper as a working electrode, platinum wire as a counter electrode, and Ag/AgCl (3 M KCl) as a reference electrode. Electrochemical reduction of MB was carried out in a sodium acetate buffer (0.1 M, pH 4.5) at a constant potential of –0.7 V (vs. Ag/AgCl) under argon, air, or oxygen conditions for 1.5 hr. The full cell of the oxygen indicator sensor was supplied with mixed gases containing different concentrations of oxygen using an automatic gas mixing system (Sehwa Hightech, Korea) and the oxygen concentrations were measured and verified using an oxygen gas analyzer (CheckPoint II, PBI-Dansensor, Denmark). The cell voltage and current density were measured using the multi-channel potentiostat/galvanostat [6] [8].

### 2.2 The Passive Type UHF Band RFID Tag

A block diagram describing the passive type UHF band RFID tag is shown in Figure 1 [7], [9]. The passive type UHF band RFID tag consisted of a UHF band antenna, matching network and power harvester, demodulator, modulator, power management, and MSP430. In this system the power harvester supplies power to the MSP430. The demodulator transmits converted RF data to the MSP430 using the ASK method. The modulator transmits a digital signal of MSP430 to the reader using the backscatter method. Finally, the MSP430 processes the sensor data and converts it to digital data [6], [10]. Due to the loss of signal strength over transmission distance, there is potentially very little power available for the tag. For this reason, the efficient conversion of incoming RF energy into DC power for the tag is an important design consideration. A matching network facilitates maximum power transfer from the antenna to the rectifier, and a 5 stage voltage doubling circuit converts the incoming power to voltage. Low threshold RF Schottky diodes were used to maximize the voltage output of the rectifier. Finally, this rectified DC voltage was stored in a large capacitor and supplied to a 1.8V regulator to power the smart RFID tag [9][10].

Figure 2 shows the manufactured passive type UHF band RFID tag. This passive type UHF band RFID tag is both a sensing and computing device that is powered and read by off-the-shelf UHF RFID readers. This tag has on board microcontrollers that can sample a variety of sensing devices, creating a wirelessly-networked sensor device.

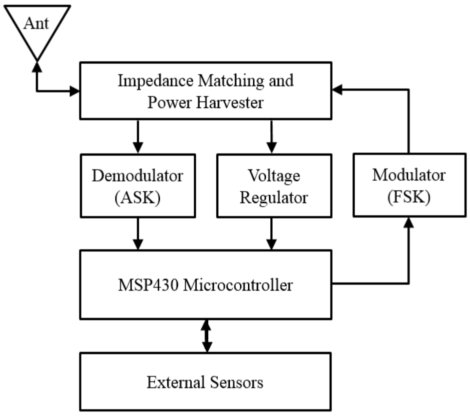


Fig.1. Block diagram of the UHF band RFID tag

Fig. 2. Manufactured RFID tag

## 3 Results and Discussion

For the integration of oxygen indicators with RFID tags, we have developed an electrochemical sensor-type oxygen indicator that not only changes color but also generates electrical signals in the presence of oxygen. The oxygen indicator sensor is based on a cell and made up of zinc foil, carbon paper, and a buffer solution containing MB. The oxidized form of MB is blue, but its reduced form (leuco-MB) is colorless. In the presence of oxygen, leuco-MB is readily oxidized to the colored form. Initially, electrochemical reduction of MB was tested under argon, air, or oxygen gas conditions. As shown in Figure 3, MB was reduced and bleached under anaerobic conditions, and retained its color under aerobic conditions. In addition, the cathodic currents were very sensitive to the concentration of oxygen [8]. These results indicate that the half-cell system can function as an electrochemical sensor-type oxygen indicator. The full cell of the oxygen indicator sensor was assembled and examined under the conditions with different oxygen concentrations. Depending on the oxygen concentration, the oxygen indicator sensor showed different colors and generated a voltage and current proportional to the concentration of oxygen [6][8].

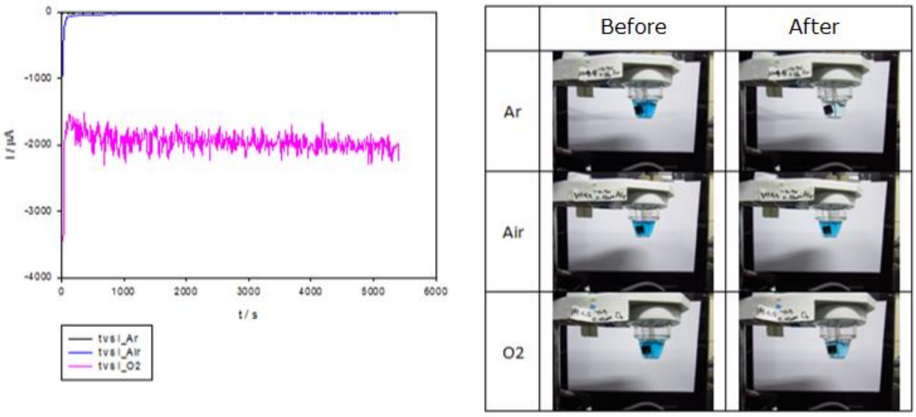


Fig.3. Electrochemical reduction of MB

Figure 4 is a photograph of the combined system including the oxygen indicator sensor and the passive RFID tag. The block diagram of the complete integrated system composed of the colorimetric oxygen sensor, the RFID tag, an interface circuit, a RFID reader, and a server is shown in Figure 5.

Fig.4. Photograph of the integrated system

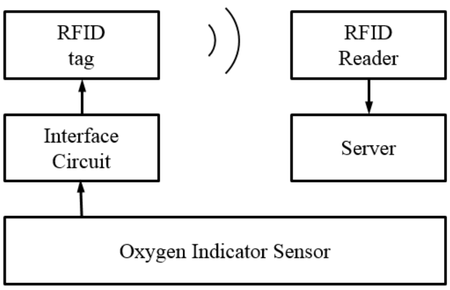


Fig.5. Block diagram of the complete system

The interface circuit of the oxygen indicator sensor is shown in Figure 6, consisting of a low pass filter and a storage capacitor. The interface circuit is a passive type, and the storage capacitor can be used as an auxiliary power source for the passive RFID tag.

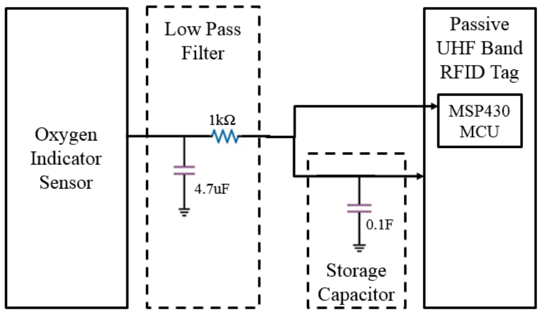


Fig.6. Interface circuit

The measured voltage is converted to a digital signal through an analog-to-digital converter (ADC), and this digital data is transmitted to a reader in the RFID tag and stored in the server. The Speedway revolution UHF RFID reader was used for monitoring. By running Speedway, it connects on the reader and configures it to export tag readings over a TCP/IP port (the specifications are shown in Table 1 [11]).

Table 1. Specifications of the RFID reader

| **Characteristics** | **Content** |
|---|---|
| Interface protocol | EPC global UHF Class 1 Gen 2 / ISO 18000-6C |
| RF frequency | 900Mhz ~ 930Mhz |
| RF range | 10 cm ~ 10 m |
| Transmit power | +10.0 ~ 30.0dBm |
| Power consumption | 24 V |
| Operating temperature | -20°C ~ +50°C |

In order to test this new system, we have monitored online the oxygen concentration in a plastic package containing oxygen scavengers (HNS 30-LiPmen). The colorimetric oxygen sensor and nine oxygen absorbers were placed in a closed plastic box. The environmental conditions were a temperature of 25°C, a humidity of 50%, and the distance was 2 m. Figure 7 is a photograph of the experimental device used.

Fig.7. Photograph of experimental device

Figure 8 shows changes in the sensor response over 12 hr during which the voltage decreased rapidly in the first 1-2 hr and then decreased slowly. This change is caused by the oxygen absorbers decreasing the oxygen concentration in the box. The box was opened after 10 hr, giving a jump in the voltage back to the initial value because the surrounding air rushed into the box. This clearly demonstrates that our new integrated system functions well as a smart RFID tag.

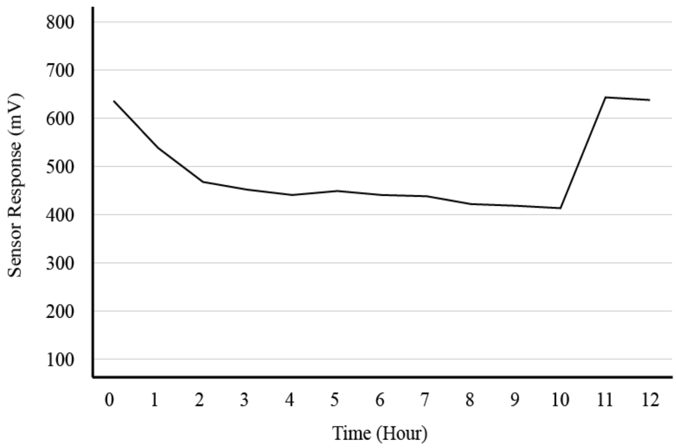


Fig.8. Change in sensor response over time

## 4 Conclusions

Recently, RFID technology has received increasing levels of interest and has been widely applied to various fields, leading to the development of smart RFID tags integrated with sensors. Oxygen degrades the quality of food inside food packages. Oxygen indicators are able to help determine the conditions inside food packaging without the need to tear or open the packaging by simple color changes.

It is beneficial to combine an oxygen indicator with a passive UHF band RFID tag for checking food safety.

In this study, we have invented an oxygen indicator sensor and combined this with a passive UHF band RFID system. This new integrated system consists of the electrochemical sensor-type oxygen indicator, the RFID tag, an interface circuit, an RFID reader, and a server. In order to test the useful benefits of this new system, we performed experiments to measure oxygen concentrations in a plastic packaging with oxygen absorbers. When oxygen was present, the sensor showed a color change from colorless to blue. There was a linear increase in voltage with increasing oxygen concentrations, and the voltage from the sensor was as high as about 1.0 V. Oxygen concentration in the plastic packaging with oxygen scavengers decreased rapidly in the first 1-2 hr and then decreased slowly until the package lid was opened after which the concentration returned to the initial value.

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