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A Screen-Printed and Light-Activated Copper Oxide Sensor for Acetone Detection

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Abstract:

In this work, we report on the design, fabrication, and investigation of a low-power screen-printed Cu_2O/CuO chemiresistive sensor. Typically, copper oxide sensors are fabricated either using microfabrication technologies or by directly depositing copper oxide through solution processes. In contrast, we thermally oxidized commercially available copper ink to develop chemiresistive sensors. This process paves the way for an additive and scalable production of copper oxide-based gas sensors. The sensors were activated with a blue light emitting diode and tested with acetone vapor at room temperature. Based on the evaluated repeatability and linearity, we consider this sensor to be a promising candidate for use in power efficient chemical sensing applications like breath analyzers.

Keywords: Printed gas sensor, Acetone sensor, Metal oxide semiconductor (MOS) sensor, Light-activated sensors, Room temperature sensor

Introduction

Chemiresistive gas sensors based on metal oxide semiconductors (e.g., ZnO, CuO, Cu_2O, SnO_2) can detect various harmful volatile organic compounds (VOCs, e.g., acetone, methanol, ethanol) by monitoring changes in electrical resistance upon interaction with the analyte gases [1 - 3]. These MOS sensors require high temperature for activation which leads to elevated power consumption [4]. Light activation offers a viable alternative, not only addressing this issue but also potentially enhancing sensor sensitivity and selectivity, as studies suggest [5].

Screen printing has been widely used for fabricating sensors, enabling additive manufacturing, and the use of various substrates, such as PET, glass, and paper [6]. In this work, we present a fully screen-printed Cu_2O/CuO-based chemiresistive sensor, activated by blue light, for acetone detection operable at room temperature.

Materials and methods

Regular microscopic glass slides were used to provide mechanical stability for the sensors. The Loctite ECI 1006 E&C silver ink was used for printing interdigitated electrodes (IDEs, 14.8 mm long, 300 μm wide, and 500 μm spacing) on the glass substrates followed by curing at 120 °C for 15 minutes in the regular oven. Saral Copper 200 screen printable ink was mixed with Saral curing agent A and curing agent B (in the specific ratio) and a blanket layer of copper was screen printed on top of the silver IDEs followed by curing in an oven at 150 °C temperature for 5 minutes. The entire printed structures were thermally oxidized at 450 °C for 1 hour on a hot plate under ambient conditions.

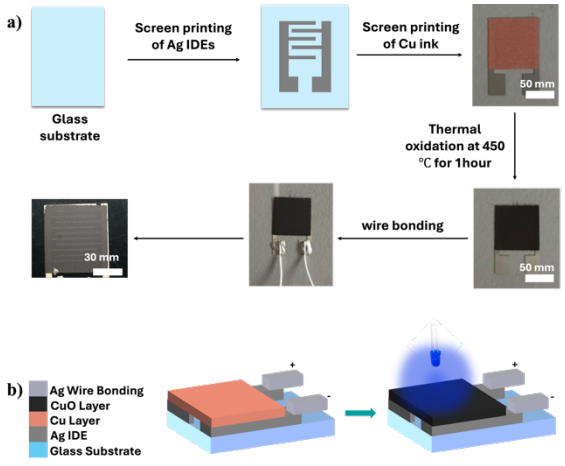

Fig. 1 a) A schematic diagram of the process flow for the sensor fabrication including images of the fabricated devices. b) Cross-section schematics of the fabricated sensors.

The sensor was tested with acetone in a VOC gas testing chamber [7] at room temperature. The sensor was activated with a commercially available blue LED which remained on

throughout the entire experiment. For a p-type semiconductor, like copper oxide, an increase in resistance indicates a response to acetone (reducing gas) [8] and the relative response was calculated by

$$S = \frac{R_g - R_0}{R_0} \times 100\%, \quad (1)$$

where R_g represents the sensor resistance in the presence of acetone and R_0 represents the sensor resistance in air.

Results

The XRD patterns (Fig. 2a) confirmed that the screen-printed copper layer has been oxidized leading to the formation of both phases of copper oxides, i.e., cuprous oxide (Cu_2O) and cupric oxide (CuO). It can also be qualitatively said that Cu_2O is present in a higher proportion than CuO along with a trace of unoxidized copper. Fig. 2b demonstrates the sensor's response to repeated cycles of exposure to acetone vapor, in the fixed time range of 5000 seconds for each cycle.

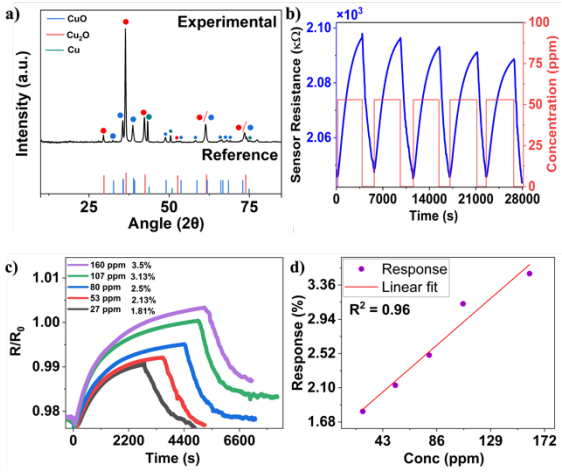

Fig. 2 a) XRD result of screen-printed and thermally oxidized copper oxide b) Sensor response to cyclic acetone exposure c) Normalized response towards different concentrations of acetone d) Response vs. concentration.

This copper oxide-based chemiresistive sensor detects acetone through surface adsorption and desorption that modulate the hole concentration, altering the resistance of copper oxide. The slight drift (Fig. 2b) in response may be due to the irreversibility during surface adsorption and desorption. Fig. 2c presents the normalized sensor's response to different concentrations of acetone, showing that the responsivity increases with increasing acetone concentration and from Fig. 2d, a sensitivity of 5% per 100 ppm of acetone was estimated.

Conclusion

In this work, we have introduced a copper oxide-based acetone sensor by screen printing copper ink and converting it to copper oxide by thermal oxidation. XRD confirmed the formation of copper oxide, and the sensor responded to acetone under blue light activation at room temperature. This method is suitable for large-scale production of copper oxide sensors for power-efficient acetone detection.

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