

Printed and Light-activated CuO/Cu₂O-Based Chemiresistive Acetone Sensors with Carbon Electrodes

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Summary:

Printed metal-oxide gas sensors commonly rely on thermal activation and metallic interdigitated electrodes (IDEs), typically silver, which increases cost and raises sustainability concerns. In this work, as a step toward more sustainable and cost-effective sensor fabrication, carbon-based IDEs were employed in place of conventional silver electrodes together with light activation. Carbon electrodes were screen-printed onto the glass substrates, followed by the deposition of copper layer on the carbon electrodes, and subsequently thermally oxidized to form CuO/Cu₂O sensing devices. Owing to the strong optical absorption of CuO/Cu₂O in the yellow spectral region, yellow light was used for sensor activation. The fabricated devices demonstrated repeatable room-temperature sensing of acetone, achieving a sensitivity of approximately 0.0264 %/ppm with efficient light-assisted recovery. These results highlight the potential of fully screen-printed, carbon-electrode-based platforms for developing cost-effective and more sustainable gas sensing systems.

Keywords: Carbon interdigitated electrodes (IDEs), Gas sensors, Light-activated sensors, Printed sensors

Introduction

Metal-oxide chemiresistive gas sensors widely use interdigitated electrodes (IDEs) to convert changes in the sensing layer's resistance into measurable electrical signals. Common IDE materials include conductive metals such as Ag, Au, Pt, and Pd owing to their high conductivity, low contact resistance, and compatibility with microfabrication or printing processes [1]. However, metallic electrodes can present drawbacks, including high material cost, electromigration, thermal diffusion, and dependence on precious metal resources [2]. Therefore, alternative electrode materials are interesting for low-cost and sustainable gas-sensor platforms. Carbon-based conductive inks offer low cost, abundance, chemical stability, corrosion resistance, lightweight nature, and compatibility with large-area printed electronics [3]. Screen-printed carbon IDEs have recently been explored in humidity, strain, and emerging gas-sensing devices, highlighting their promise as functional electrode alternatives.

In our previous work, we demonstrated light-activated CuO/Cu₂O-based acetone sensors; however, these devices employed silver electrodes [4]. In this work, screen-printed carbon IDEs are investigated as a sustainable and cost-effective alternative to conventional metallic IDEs for CuO/Cu₂O-based acetone sensors. Mixed-phase copper oxide sensing layers were

fabricated on carbon electrodes via screen printing and thermal oxidation, followed by structural, optical, and acetone-sensing characterization under room-temperature, yellow-light-assisted operation.

Materials and methods

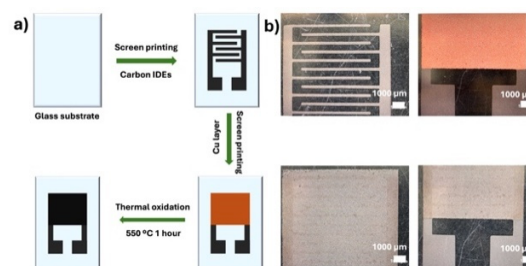


Fig 1. (a) Fabrication of the CuO/Cu₂O sensor on carbon IDEs. (b) Optical microscope images of the printed carbon IDE, Cu-coated device, and final oxidized sensor.

CuO/Cu₂O chemiresistive sensors were fabricated via a screen-printing and thermal oxidation route adapted from our previously reported process [4], employing a slightly increased oxidation temperature. Carbon IDEs were screen-printed onto glass slides (Sigma-Aldrich, 24 × 50 mm) using a carbon paste (DM-CAP-4402S, DYCOTEC MATERIALS) and cured at 120 °C for 10 min. A 1 × 1 cm² copper layer was then screen-printed over the IDE area using Cu ink (SARAL Cu 200, SARALON GmbH) and cured at 120 °C for 15 min. The printed Cu films were

subsequently oxidized in ambient air at 550 °C for 1 h on a hot plate to obtain mixed-phase CuO/Cu₂O sensing layers. A schematic of the fabrication process is shown in Fig 1. Structural characterization was performed by X-ray diffraction to determine the crystallographic phases of the CuO/Cu₂O sensing layer and to evaluate the structural state of the carbon IDEs before and after annealing. Optical absorption properties of the copper oxide layer were investigated using UV–Visible spectroscopy. Gas sensing measurements were conducted in a static VOC test chamber using acetone as the target analyte. Prior to exposure, the sensor was pre-activated under yellow LED (5mm commercial) illumination (350 μW optical power). Acetone was then introduced while the light source was simultaneously switched off to probe the sensing response under dark conditions, followed by light-assisted recovery through re-illumination. The sensor response was defined by:

$$\frac{\Delta R}{R_0} = \frac{R_g - R_0}{R_0} \times 100\%. \quad (1)$$

Results

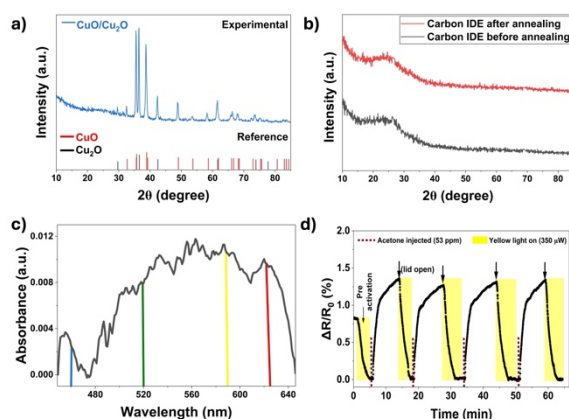


Fig 2. (a) XRD pattern of the CuO/Cu₂O-coated carbon IDE. (b) XRD of bare carbon IDE before and after annealing. (c) UV–Visible spectrum of the CuO/Cu₂O layer. (d) Repeated response/recovery cycles to 53 ppm acetone under yellow-light-assisted operation (350 μW) at room temperature.

Fig 2a shows the XRD pattern of the CuO/Cu₂O layer on carbon IDEs, where reflections matching CuO and Cu₂O confirm successful formation of mixed-phase copper oxides after thermal oxidation. Such phase coexistence may favor sensing through interfacial charge modulation [5]. Fig 2b presents the bare carbon IDE before and after annealing, both showing broad humps rather than sharp peaks, indicating a predominantly amorphous, thermally stable nature. The absorbance spectrum in Fig 2c reveals broad visible-light absorption with enhanced intensity in the yellow region, supporting the use of yellow light for activation. Sensing performance to an exposure to 53 ppm acetone is shown in Fig 2d.

The carbon IDE-based CuO/Cu₂O sensor exhibits its repeatable response/recovery cycles under the yellow-light-assisted protocol, reaching a maximum response of ~1.4%. The sensor signal fully recovers upon re-illumination. Additionally, the CuO/Cu₂O layer uniformly covers the carbon electrodes, minimizing their direct exposure to the environment and restricting their role to electrical interfacing for resistive measurements. This configuration enables stable room-temperature operation and demonstrates that carbon IDEs can effectively replace metallic electrodes, offering a lower-cost and more sustainable alternative.

Conclusion

Screen-printed carbon interdigitated electrodes were successfully demonstrated as a viable platform for CuO/Cu₂O chemiresistive acetone sensors. The fabricated device showed stable room-temperature operation, repeatable light-assisted sensing behavior, and a sensitivity of ~0.0264 %/ppm to acetone. These results highlight carbon electrodes as a promising route toward low-cost, scalable, and sustainable printed metal-oxide gas sensors.

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