Journal of Materials Research and Technology 35 (2025) 379–391

Contents lists available at ScienceDirect

Journal of Materials Research and Technology

journal homepage: www.elsevier.com/locate/jmrt

Morphological and optical characterization of spin-coated CuO nanostructured thin films doped with V, Na, Ba, and Er for enhanced CO_2 sensing

Nihed Allouche [a,b,1], Bouzid Boudjema [a,b], Radouane Daira [a,b], Adel M. El Sayed [c], Khaled Abdelkarem [d,e,1], Inas A. Ahmed [f], Mohamed Shaban [g,*]

[a] Department of Physics, Faculty of Sciences, 20 August 1955 University of Skikda, Algeria
[b] Physical Chemistry Research on Surfaces and Interfaces, 20 August 1955 University of Skikda, Algeria
[c] Physics Department, Faculty of Science, Fayoum University, El Fayoum, 63514, Egypt
[d] Nanophotonics and Applications (NPA) Lab, Department of Physics, Faculty of Science, Beni-Suef University, Beni-Suef, 62514, Egypt
[e] Department of Physics, Chonnam National University, Gwangju, 61186, Republic of Korea
[f] Department of Chemistry, Faculty of Science, King Khalid University, Abha, 62224, Saudi Arabia
[g] Department of Physics, Faculty of Science, Islamic University of Madinah, Madinah, 42351, Saudi Arabia

ARTICLE INFO

Keywords:
V-doped CuO thin films
Spin coating
Gas sensing
Dynamic response
Sensitivity
Stability
Selectivity

ABSTRACT

Carbon dioxide sensors are crucial for industrial processes and monitoring indoor air quality, but developing low-cost, high-performance sensors that operate at room temperature remains challenging. This study explores carbon dioxide detection using copper oxide thin films doped with sodium (CuO:Na), barium (CuO:Ba), erbium (CuO:Er), and vanadium (CuO:V), which were fabricated through spin-coating and annealed at 500 °C. All the films displayed a monoclinic tenorite structure, with crystallite sizes ranging from 23.8 to 59.5 nm, and band gaps that increased from 1.7 eV for pure copper oxide to 2.1 eV for copper oxide doped with vanadium (CuO:V). Among the various sensors, copper oxide doped with vanadium (CuO:V) exhibited the best performance, with a 248.3% response to 11100 ppm carbon dioxide at 30 °C and 45% relative humidity. It also had a response time of 7.4 s and a recovery time of 7.5 s. At 25% relative humidity, the response improved to 401.2%, reaching 1220% at 140 °C and 45% relative humidity. These findings highlight the potential of copper oxide doped with vanadium (CuO:V) for energy-efficient carbon dioxide detection, offering valuable contributions to environmental monitoring and efforts to mitigate climate change.

1. Introduction

The escalation of greenhouse gas emissions and the resulting greenhouse effect, a significant factor in the heating of the Earth's atmosphere, have become central concerns in the global dialogue on environmental safety. Human activities, such as the burning of fossil fuels, solid waste management, and industrial processes like cement production, significantly contribute to the increase in atmospheric levels of greenhouse gases, including carbon dioxide (CO_2), methane, toluene, nitrous oxide, and fluorinated gases. According to the 2018 Inventory of U.S. Greenhouse Gas Emissions and Sinks, CO_2 alone accounts for 81% of these emissions. Human-caused deforestation has also increased CO_2 emissions. In the delicate equilibrium between growth and consequence, industry, transportation systems, and medical applications require reliable CO_2 detection [1,2]. Even if that follows safe limits, high CO_2 levels may harm human health. CO_2 has a greater toxicity threshold near 5000 ppm, but lower levels are necessary for occupant health and comfort. Household CO_2 levels should not exceed 1000 ppm, according to the American Society of Heating, Refrigerating, and Air- Air-Conditioning Engineers ASHRAE [3]. When indoor air quality monitors detect CO_2 levels above this threshold, "CO_2 accumulation" occurs, impacting our routines slowly. Also, CO_2 leakage from cylinders or manufacturing lines may happen unexpectedly in busy industrial environments [4–7]. Even in non-industrial environments, HVAC failures and CO_2 leaks need care.

* Corresponding author.
E-mail addresses: nihedallouche.21@gmail.com (N. Allouche), Boudjema_b@yahoo.fr (B. Boudjema), r.daira@univ-skikda.dz (R. Daira), ams06@fayoum.edu.eg (A.M. El Sayed), oldfighter.khaled123@gmail.com (K. Abdelkarem), eaahmed@kku.edu.sa (I.A. Ahmed), mssfadel@aucegypt.edu, mssfadel@iu.edu.sa (M. Shaban).

[1] Both authors equally contributed to this work.

https://doi.org/10.1016/j.jmrt.2025.01.048
Received 1 September 2024; Received in revised form 25 December 2024; Accepted 7 January 2025
Available online 9 January 2025