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Single-Atom Metal Catalysts on Flame-Made Oxide Supports for Gas Sensing

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Summary:
We demonstrate a generalizable approach for synthesizing single-atom metal catalysts (SACs) on flame-made oxide supports by leveraging high densities of oxygen vacancies. Using Co_3O_4 as a model system, atomically dispersed Cu^{2+} species were stabilized without aggregation. This strategy is being extended to other support–metal combinations, offering a versatile materials design platform for gas sensing applications.

Keywords: single-atom catalysts, oxygen vacancies, flame spray pyrolysis, metal–support interaction, gas sensor materials

Background, Motivation and Objective

Single-atom catalysts (SACs) represent a frontier of gas sensor material design due to their unparalleled surface control and maximum atom utilization.[1] However, scalable synthesis of non-noble metal SACs remains challenging, especially under high-temperature conditions typical of sensor fabrication. In this work, we use flame spray pyrolysis (FSP) to synthesize oxide supports[2-4] with abundant surface oxygen vacancies[5]—thermodynamically favorable anchoring sites for SACs. Our goal is to establish a modular synthesis platform for various SAC-support systems beyond Cu-Co_3O_4, ultimately enabling tailored redox interfaces for improved gas sensing performances such as selectivity.[6]

Description of the New Method or System

The FSP process yields nanocrystalline oxide particles with high surface defect densities, particularly oxygen vacancies, which are exploited to immobilize transition metal atoms via post-synthetic wet impregnation and annealing. We demonstrate this approach using Cu on Co_3O_4 as a model, achieving 1.42 wt% loading of atomically dispersed Cu^{2+} without aggregation. EXAFS and XANES confirm the isolated, oxidized nature of Cu in square-planar coordination. The same methodology is being extended to alternative oxides and metal precursors to create a library of SAC-functionalized sensing materials. This work establishes a scalable and tunable pathway toward next-generation gas sensing platforms via vacancy-assisted SAC design.

Results

Elemental mapping (Fig. 1) revealed a homogeneous distribution of Cu atoms across the Co_3O_4 surface, with no evidence of clustering. EXAFS analysis (Fig. 2) confirmed the absence of Cu–Cu coordination, supporting the atomic dispersion of Cu^{2+} species. Together, these results validate the successful synthesis of stable, single-atom Cu catalysts on flame-made Co_3O_4 nanoparticles. These atomically dispersed sites translated into superior formaldehyde sensing performance, enabling high sensitivity at low operating temperature and enhanced selectivity under humid conditions.

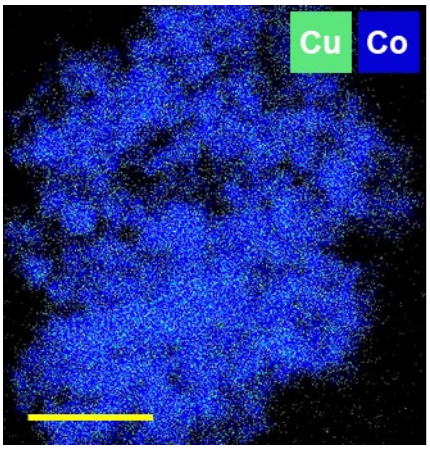

Fig. 1. EDS mapping on Co and Cu for Cu SAC-anchored Co_3O_4 (scale bar: 250 nm)

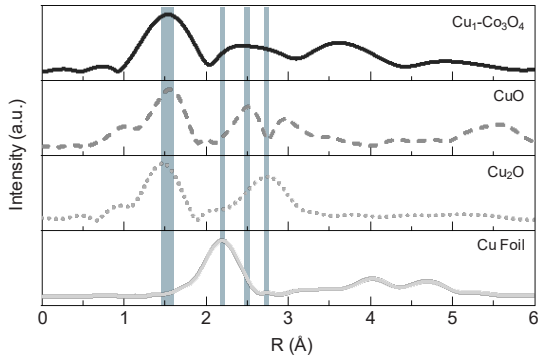

Fig. 2. Fourier transform radial distribution function of the Cu K-edge EXAFS spectra of Cu SAC-anchored Co_3O_4 and reference samples.

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