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Selective Benzene Sensing Enabled by Catalytically-Active Metastable Nanoparticles

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Summary:

Prolonged exposure to volatile organic compounds (VOCs), especially benzene, poses serious health risks due to their toxic nature. However, detecting benzene at parts-per-billion (ppb) concentrations is challenging, as it often coexists with chemically similar compounds like toluene and xylene. A catalytic packed-bed system using $CoCu_2O_3$, combined with a Pd/SnO_2 chemoresistive sensor, successfully detected benzene concentrations down to 15 ppb, even in the presence of high levels of confounders.

Keywords: benzene, chemoresistive, nanotechnology, gas sensor, aromatic volatile compounds

Prolonged exposure to VOCs remains a major occupational health risk [1]. Among them, benzene is particularly concerning due to its high biotoxicity, prompting the World Health Organization to impose stringent exposure limits [2]. Accurately detecting benzene at ppb levels is especially challenging in environments where chemically similar compounds like toluene and xylene are also present.

In this work, we introduce a sensing system capable of detecting benzene from 15 to 1000 ppm, even when toluene and xylene are present at concentrations up to 100 times higher (Figures 1a and 1b). The $CoCu_2O_3$-based catalytic packed-bed system [3] was evaluated under varying relative humidity (RH) conditions from 40% to 90% yet maintained a stable benzene response and effectively eliminated toluene and xylene with only 16 mg (Figure 1c).

Notably, tests over six months confirmed the system's operational stability, which was further supported by XRD analysis after continuous exposure to operating temperatures for over a week (Figure 1d). The system utilized a packed-bed loading optimized to remove high toluene concentrations while preserving benzene detection capability [3].

This packed bed was then integrated it with a Pd/SnO_2 [4] chemoresistive sensor – known for its sensitivity but limited selectivity. Through a combination of flow-bench experiments and catalytic performance assessments, the engineered system successfully detected down to 15 ppb benzene in the presence of 2 ppm each toluene and xylene. Furthermore, it demonstrated the ability to quantify benzene in real-world samples collected from gas stations. Overall, this strategy offers a promising pathway for miniaturized sensor platforms that comply with evolving exposure regulations.

References

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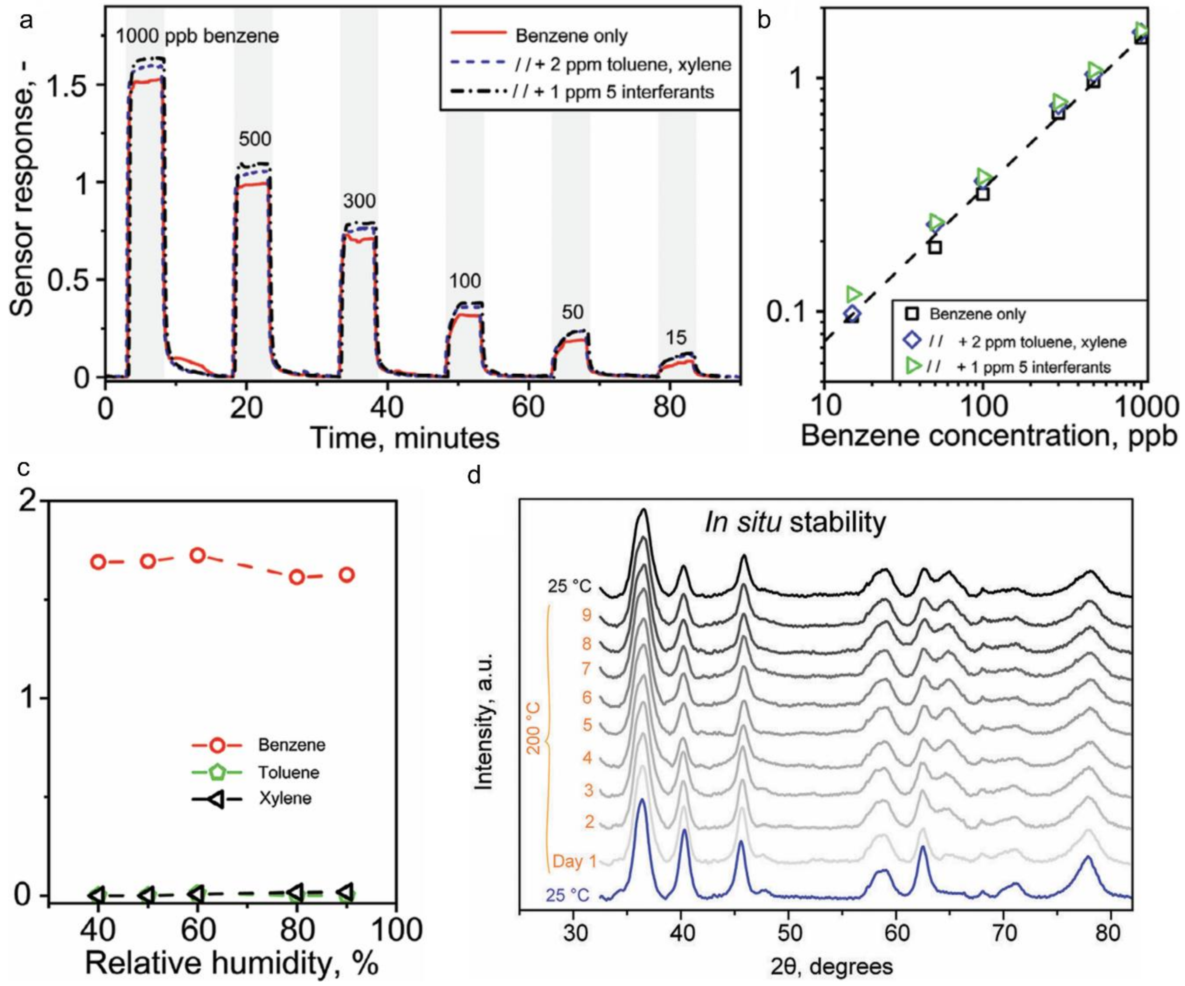

Fig 1. (a) Transient sensor response to benzene exposure (solid red line) at 50% relative humidity (RH). System robustness was assessed by co-feeding 2 ppm of toluene and xylene (dashed lines), along with 1 ppm of up to five interfering compounds (dash-dotted lines): toluene, xylene, methanol, ethanol, and acetone. (b) Corresponding sensor responses as a function of benzene concentration. (c) Sensor response to benzene, toluene, and xylene across a humidity range of 40–90% RH. (d) XRD patterns of $CoCu_2O_3$ recorded at 200 °C over a period of 9 days, demonstrating material stability. Adapted from [3].