Quantitative analysis of the synergistic effect of Au nanoparticles on SnO_2-rGO nanocomposites for room temperature hydrogen sensing

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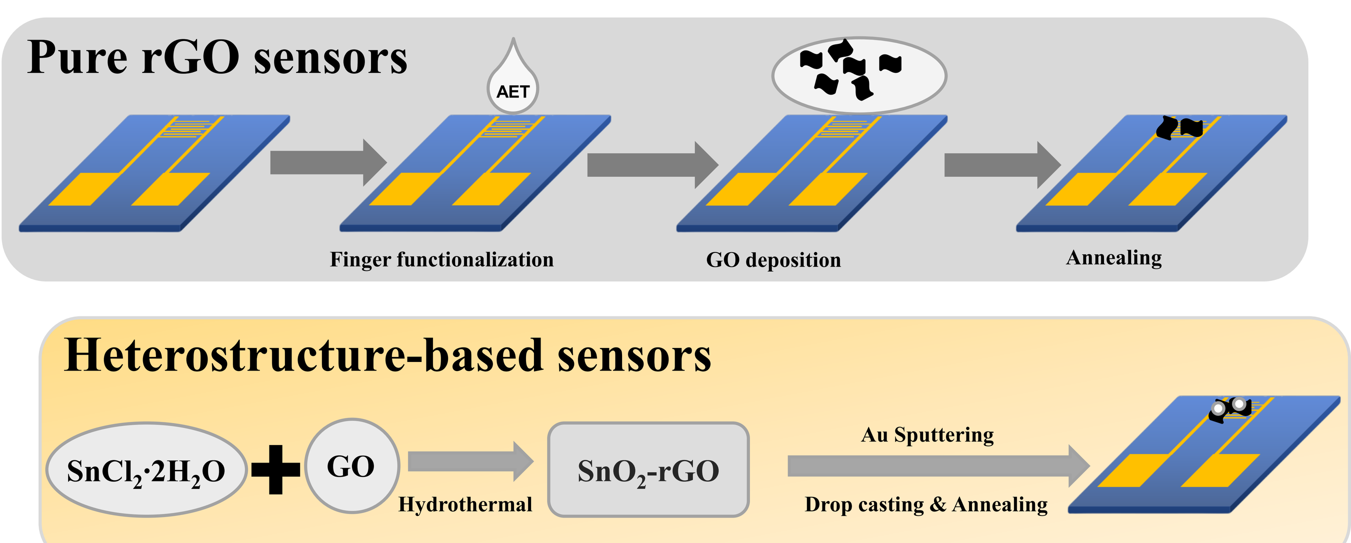
Introduction

Hydrogen is one of the most promising sustainable fuels since it produces no air pollutants in fuel cells, but very flammable and could lead to an explosion at a high concentration (4%) in the air.[1] As hydrogen is colorless, odorless, and highly flammable under ambient conditions, it must be reliably monitored in real-time during its production, delivery, storage, and utilization.

The SnO_2 nanocrystals-rGO sensing platform reported in our previous work demonstrated advantages such as tunable sensing performance and room temperature operation.[2] Gold doping indicated enhanced selectivity sensing performance against hydrogen gas.[3] However, the sensing mechanism remains unclear. It is promising to combine the gold dopant with the SnO_2-rGO sensing template to achieve desirable hydrogen sensing performance at room temperature.

Method



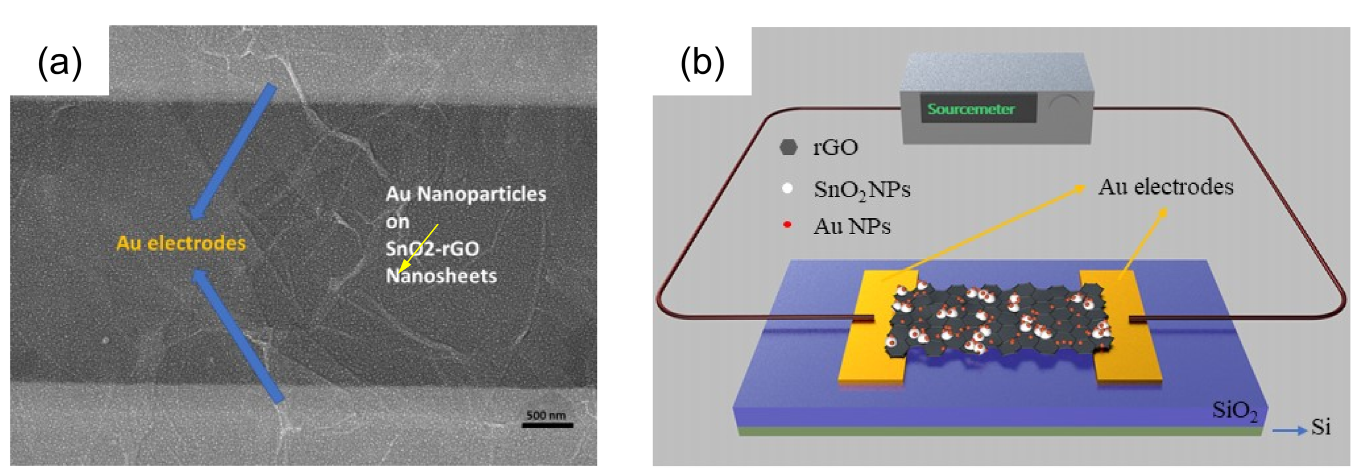
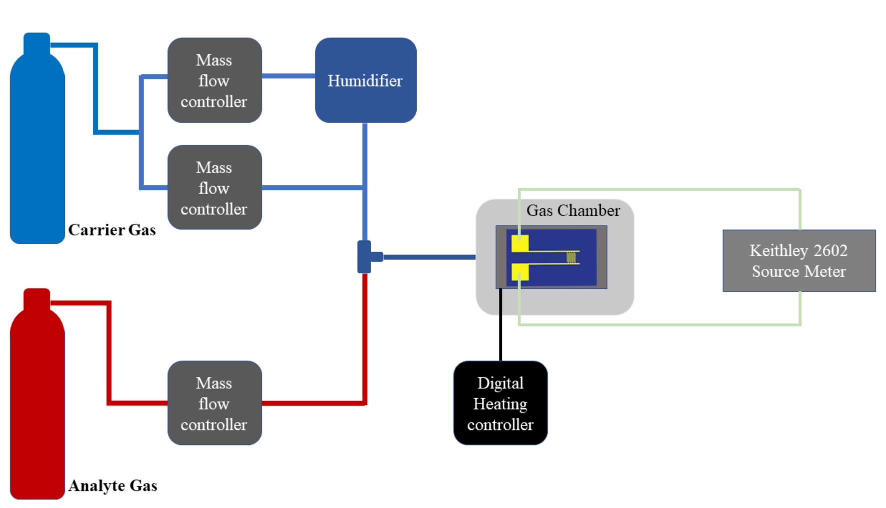


Fig. 1. (a) SEM images of Au-SnO_2/rGO sensor. The rGO nanosheets bridging two gold electrodes were modified with well-dispersed SnO_2 and Au nanoparticles on the surface (b) Schematic of the Au-SnO_2/rGO sensor device and measurement system.



Typical sensing cycle

1. Establish the baseline: 10 mins carrier gas injection
2. Sensing interval: 5 mins analyte injection
3. Sensor recovery: 10 mins carrier gas injection

Fig. 2. Schematic illustration of the current gas sensing test system

Results

- We define the sensitivity as Response (%) = $[(I_g - I_a)/I_a \times 100]$, where I_g is the current in the presence of H_2 and I_a is the base current in the air.
- The good repeatability of this device is evidenced by the multicycle sensing.
- The hydrogen concentration-related dynamic response curves and the calibration curves are well fitted by the Langmuir isotherm.[4]

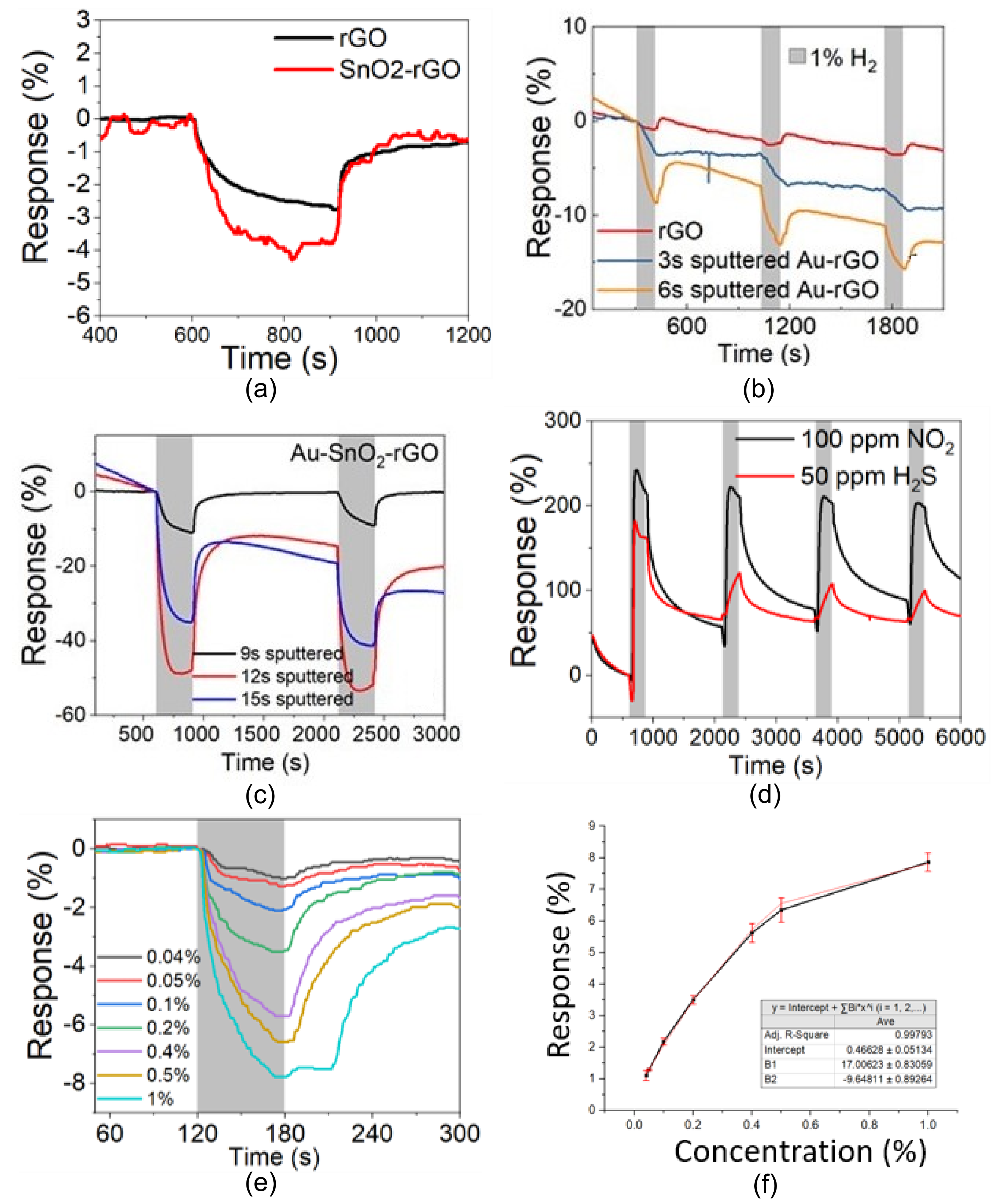


Fig. 3. Responses to 1% H_2 of (a) rGO and SnO_2-rGO. (b) rGO and Au-rGO. (c) Au-SnO_2/rGO nanohybrids with different sputtered gold thickness. (d) dynamic response curves of 12s sputtered Au-SnO_2/rGO to 100 ppm NO_2 and 50 ppm H_2S. (e) dynamic response curves of 12s sputtered Au-SnO_2/rGO to H_2 with varying concentrations from 0.04% to 1% in 1 min. (f) Calibration curves of 1 nm Au-SnO_2/rGO sensors to H_2 gas.

References

1. I. Sayago, et al. *Synthetic Met*, 2005.
2. S. Mao, et al. *Journal of Materials Chemistry*, 2012.
3. Y. Wang, et al. *Sensors and Actuators B : Chemical*, 2017.
4. S. Cui, et al. *ACS Appl Mater Inter*, 2012.

Acknowledgments

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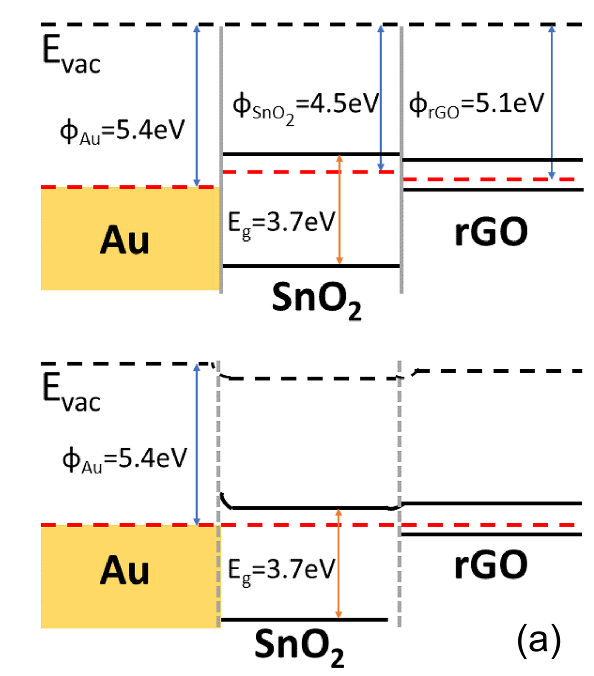
Discussion

- The better recovery performance suggests the oxygen spillover effect than the hydrogen spillover effect
- The sensors with loaded Au nanoparticles indicate reduced activation energies in both hydrogen adsorption and desorption.

$$O_2 + e^- \rightarrow O_2^-(ads)$$
$$H_2 \rightarrow 2H(ads)$$
$$O_2^-(ads) + 4H(ads) \rightarrow 2H_2O + e^-$$
$$O_2^-(ads) + 2H_2 \rightarrow 2H_2O + e^-$$



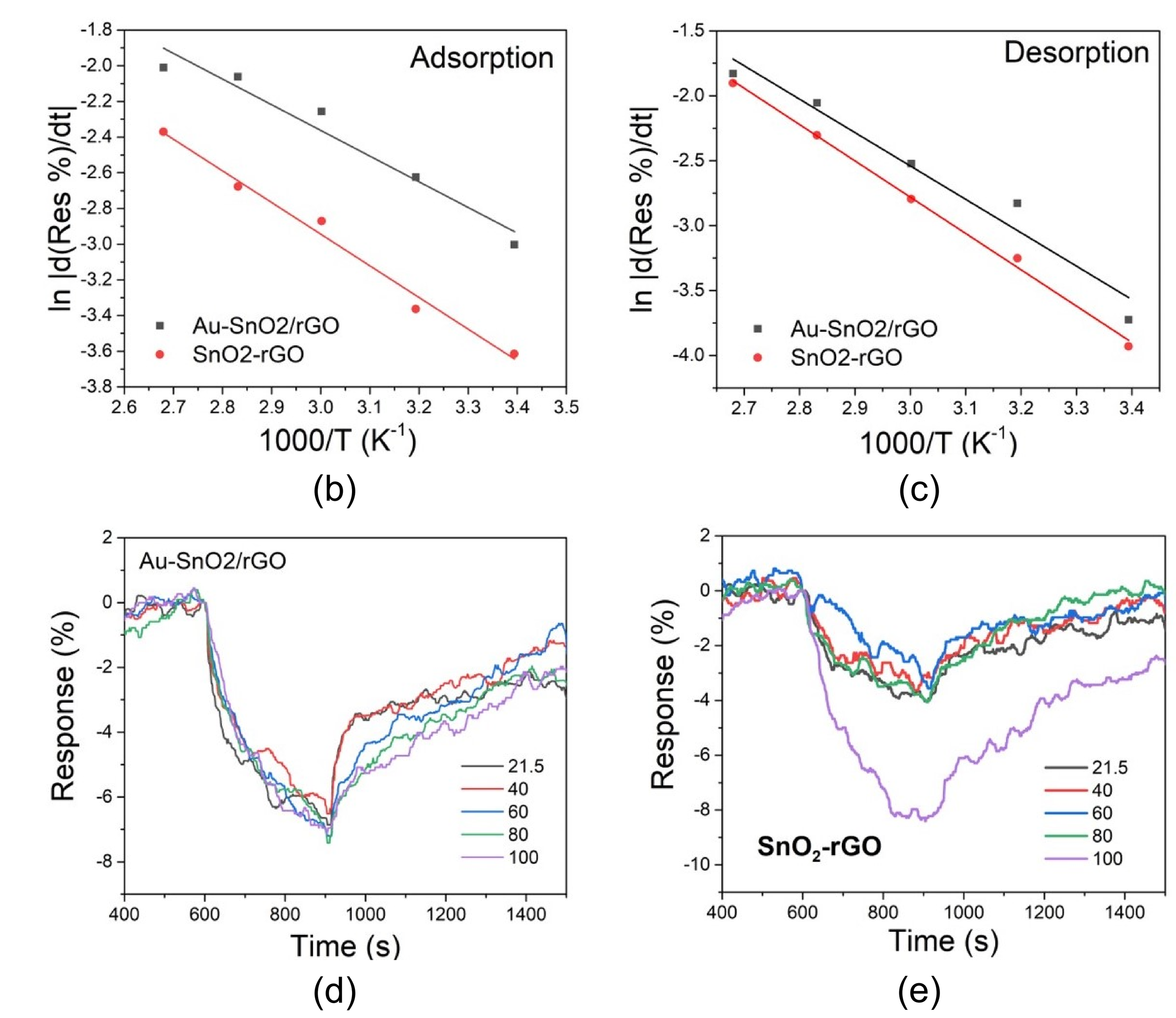


Fig. 4. (a) Schematic band diagrams of Au-SnO_2/rGO sensors (top figure) with the heterojunction formation at the interfaces (bottom figure). (b-c) The Arrhenius plot of ln |d (Res%)/dt| determined from the initial slope of the recovery cycle. Dynamic response curves of (d) Au-SnO_2/rGO and (e) SnO_2-rGO sensors to 1% H_2 in the temperature range 21.5-100 ℃.

Conclusions

- The Au-SnO_2/rGO ternary nanohybrids were designed with improved room temperature H_2 sensing performance.
- The sputtered Au nanoparticles enhanced both sensitivity and recovery of the SnO_2-rGO template.
- The catalytic effect of Au nanoparticles for hydrogen adsorption and desorption was then revealed through the temperature-dependent sensing test and Arrhenius analysis.
- The availability of such sensors will contribute to promoting a sustainable hydrogen economy, protecting public safety, and enhancing lead-acid battery safety in a wide range of applications.