UV light enhanced room temperature NO₂ gas sensors based on Au loaded organic–inorganic hybrid perovskite incorporated with tin dioxide

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Abstract:
A novel NO₂ sensing material Au/MASnI₃/SnO₂ was fabricated by coupling a light-sensitive material, Au decorated organic-inorganic hybrid perovskite (Au/MASnI₃), with a wide band gap gas sensing semiconductor materials, tin dioxide (SnO₂), via a simple calcination process. The physical and gas sensing properties of these prepared Au/MASnI₃/SnO₂ composite toward NO₂ gas at room temperature in dark and under 365 nm UV illumination were examined. The characterization demonstrates the formation of a p-n heterojunction structure between p-MASnI₃ and n-SnO₂. Due to the good synergistic effect of the ternary materials, including the high light absorption of MASnI₃, the surface plasmon resonance and the active catalytic effect of Au nanoparticles and the special interactions at MASnI₃/SnO₂ heterojunction, the Au/MASnI₃/SnO₂ sensor obtained by calcining Au/MASnI₃ at 230°C (named as MSA230) exhibits superior gas sensing performance toward NO₂ with high sensitivity (Rg/Ra=240 up to 5 ppm NO₂), ultra-fast recovery time (about 12s) and excellent selectivity as compared to the SnO₂ and SnO₂/Au counterparts at room temperature under UV illumination. All these characters make it more possible to be used as sensor material widely.

Key words: gas sensing, NO₂, CH₃NH₃SnI₃, room temperature, UV

Results and Discussion

Fig.1 (a-b) HRTEM image of MSA230 composite.

Fig.1 depicts the HRTEM images of MSA230 with different magnifications. The lattice fringes in Fig.1b was measured to be 0.33, 0.31 and 0.11 nm, which can be assigned to SnO₂, MASnI₃ and Au, respectively. It can be deduced that the Au/MASnI₃/SnO₂ was successfully fabricated and p-n heterojunctions between MASnI₃ and SnO₂ were formed in composite, which is in accord with the I-V measurement results.

Fig.2 The corresponding response of the as-prepared samples are plotted against NO₂ concentration at room temperature with UV illumination.

As shown in Fig.2, the response of the sensor using MSA230 to 5 ppm NO₂ increased from 17.2 in dark to 240.6 under UV light illumination. This illustrates that UV illumination increases the carrier density and reduces the depletion layer width, making it possible to provide more
electrons for the oxidizing gas, therefore, the sensors show high responses to NO\textsubscript{2}. Comparing to the MSA230 sensor, the responses of the others were not enhanced as dramatically as the sensor based on the MSA230. This is because that a high content of MASnI\textsubscript{3} would reduce the contact between the target gas and SnO\textsubscript{2} and a high content of SnO\textsubscript{2} also would decrease the density of the photogenerated carriers excited by MASnI\textsubscript{3}.

Fig. 3 Recovery time of the sensor based on various samples towards 5 ppm NO\textsubscript{2} with and without UV light illumination at room temperature.

As shown in Fig. 3, with and without UV light illumination, the recovery time of the sensor using MSA230 is 12s and 154s, respectively. With UV light illumination, the photogenerated electron improved the surface oxidation activity and accelerated the surface reaction and the photogenerated holes can also reacted with NO\textsubscript{2}, leading to a much faster recovery time.

Fig. 4 Selectivity of the sensor based on the MSA230 towards different gases in dark and with UV light illumination at room temperature.

Fig. 4 illustrates the selectivity of the sensors to 5 ppm NO\textsubscript{2}, 10 ppm Cl\textsubscript{2}, 50 ppm CO, H\textsubscript{2}S, acetone, ethanol, methanal and benzene at room temperature with and without UV light illumination. Among these target gases, the MSA230 sensor demonstrated a dramatically higher response to NO\textsubscript{2} than the other gases with UV light stimulation, proving that the p–n heterojunction nanostructure of the sensor based on MSA230 has a high response and selectivity to NO\textsubscript{2} gas at room temperature under UV light illumination.

In conclusion, that the Au-MASnI\textsubscript{3}/SnO\textsubscript{2} sensor possesses outstanding gas sensing property toward NO\textsubscript{2} at room temperature with UV light stimulation can be attributed to the good synergistic effect of the ternary materials, including the high light absorption of MASnI\textsubscript{3}, the surface plasmon resonance and the active catalytic effect of Au nanoparticles, and the p–n heterojunction between p-MASnI\textsubscript{3} and n-SnO\textsubscript{2}.

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Reference

