Transition-Metal Dichalcogenides Synthesized by Thermally-Assisted Conversion for Gas Sensor Applications

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Two-dimensional (2D) materials have been widely investigated for the fabrication of electronic devices, sensors, catalysis, and energy storage application because of their exotic electronic properties and large specific surface area. According to recent reports on layered transition-metal dichalcogenides (TMDs), they present excellent electronic performance with outstanding on-off ratios [1,2] and ultra-high sensitivities towards gaseous molecules [3,4]. In this study, we present various TMD thin-films grown by thermally-assisted conversion (TAC) method [5] and investigate their performance as gas sensors in a simple chemical resistor (chemiresistor) structure.

Our TMD films were produced by direct sulfurization or selenization of pre-deposited metal layers in a quartz tube furnace with two heating zones. The pristine metal layers were heated to growth temperature and S or Se powder was melted in a second upstream heating zone. Ar, as a carrier gas, delivered S or Se vapor to pre-defined metal patterns on the substrates, for converting of TMDs: MoS_2, $MoSe_2$, WS_2, and WSe_2 films. This approach is scalable and industry compatible and allows for patterned growth with good control over film thickness as shown in Figure 1.
Interdigitated electrodes were defined for electrical characterization and sensor tests using a shadow mask. The contacted samples were loaded into a custom-built chamber which kept a constant pressure with a dry N_2 flow. Mass flow controllers (MFCs) remotely mixed target gas (NH_3 or NO_2) in N_2 to control gas concentration. While the target gas was periodically introduced, the resistance was continuously monitored at a constant bias voltage. Sensor response can be depicted by percentile relative resistance. Adsorbed gas molecules onto the surface of TMD layers modulate carrier density by adjacent doping, thus conductance changes depending on majority carrier of TMDs as shown in Figure 2.

In conclusion, sub-ppm of NO_2 was empirically detectable in 2 minutes and it could be proven by a simple signal processing based on signal-to-noise ratio. The initial resistance and root-mean-square (RMS) noise of sample resistance were derived from certain data points just before the first gas introduction. From the linearity of the SNR versus gas concentration, theoretical limit of detection could be extrapolated down to sub-ppm.

References

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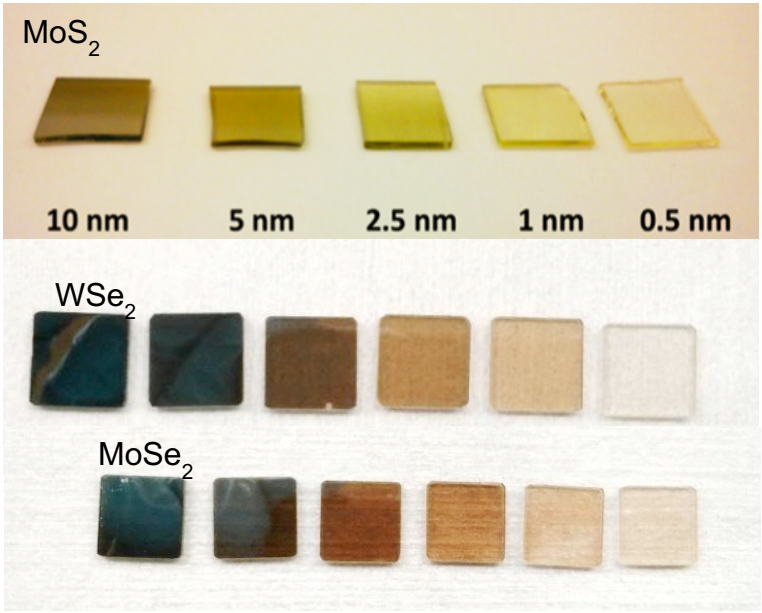

Figure 1: Synthesized TMD films on the quartz substrates show different transparency depending on film thickness.

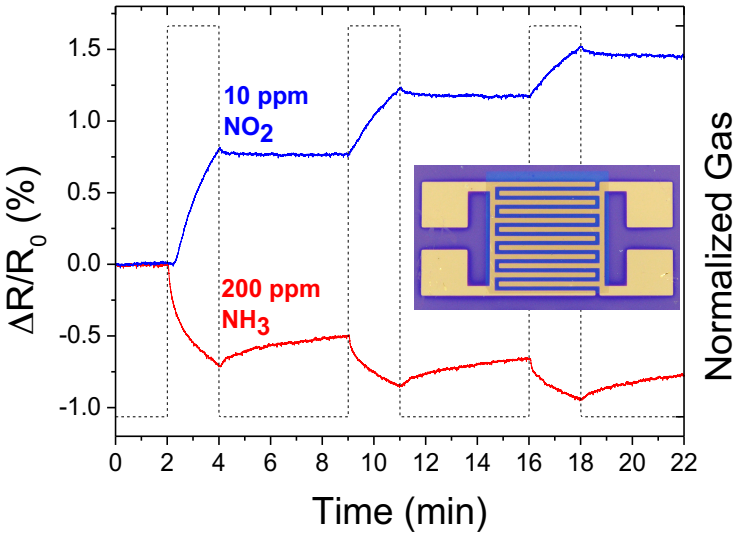

Figure 2: Sensor response curves of the $MoSe_2$ sensor at 10 ppm of NO_2 and 200 ppm of NH_3 gases, respectively. Inset: Photograph of a contacted $MoSe_2$ sensor.