CVD growth of two-dimensional semiconducting transition metal dichalcogenides for Gas Sensing application

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Summary

Recently layered inorganic material analogues to graphene such as two dimensional transition metal dichalcogenides have emerged as promising materials for the gas sensing industry as they show promising semiconducting properties, tunable band gap, large surface area and excellent gas adsorbing capacities. Herein, we report on single step synthesis of 2D thin sheets of WS_2 and MoS_2-MoO_2 using atmospheric pressure CVD technique without the assistance of hydrogen gas under inert gas environment directly on silicon oxide substrate. E-SEM, EDX and Raman spectroscopy have been used to investigate the morphology and composition of the grown material. Demonstration of one of these materials has been studied towards some of the pollutant gases in the environment such as ammonia and nitrogen dioxide. Gas sensing results shows that WS_2 is sensitive to small concentration of these gases at lower temperatures. Moreover these sensors gave significant response on exposure to these gases even at room temperature.

Motivation and Results

Two dimensional (2D) material is showing great potential in gas sensing with high sensitivity and provides interesting new possibilities for sensor processing. These next-generation material consists of a metal atomic layer sandwiched between two atomic layers of a chalcogen material where the layers are stacked one above the other by Van der waals forces of interaction. Among various 2D TMDCs materials available, MoS_2 and WS_2 have attracted major attention as they offer high compatibility for integration with conventional Si technology with superior semiconducting properties. Among the different top-down and bottom-up approaches available, CVD growth is the one chosen by researchers for the synthesis of 2 dimensional materials as they offer high surface coverage of the substrate material. Chemical vapour deposition is a technique that allows deposition of one or more material on the substrate from volatile precursors that are caused to react by heating and hence this technique is chosen here for the deposition of thin films [1].

Figure 1 depicts formation of thin films, grown at 900°C comprising of triangular domains of WS_2 with an average size of~6μm and energy dispersive X-ray analysis also confirms the presence of W with S in the deposited layers, with an atomic ratio of 72.27 and 27.73 at %, respectively. The fine triangular shape with clean surface and smooth edge indicates growth of high quality WS_2. Raman spectrum plays a key role to identify the number of layers present, figure 2 corresponds to the Raman spectrum obtained, and here the strongest peak at~419 cm^{-1} corresponds to presence of multilayers of WS_2. Next, figure 3 shows formation of rhomboidal shaped vertically aligned large assembly of MoS2-MoO2 domains which are grown at 800°C. The presence of MoS2 along with MoO2 was also confirmed by energy dispersive X-ray analysis with an atomic ratio of 5.14, 1.18 and 40.72 of Mo, S and O at % respectively. Also, Raman spectrum obtained (fig. 4) confirms the formation of MoS2-MoO2, where the peak at 406, 380 cm^{-1} corresponds to MoS2 while peaks at 125,203,228,348,361,456,493,566,740 cm^{-1} confirms the presence of MoO2 along with MoS2 [1]. Furthermore, fig 5, 6 shows the gas sensing results of WS2 sensor for detection of nitrogen dioxide and ammonia respectively. Results shows that the sensor exhibits a good sensitivity upon exposure to smaller concentrations of gases. More results will be shown and discussed during the conference.

References

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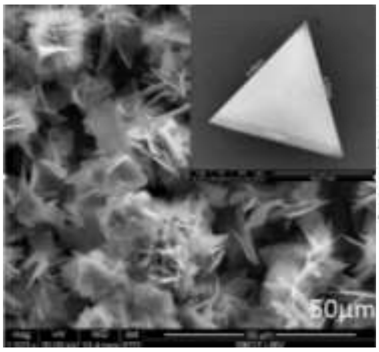


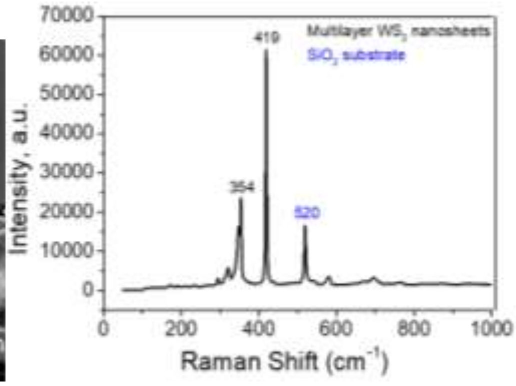
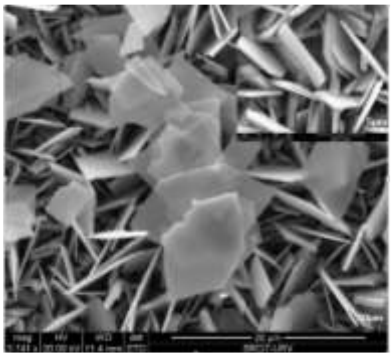


Fig. 1: *ESEM image of the WS2 thin film containing triangular domains with side length of ~5.5µm*

Fig. 2: Raman spectrum of the multilayer WS2 grown at 900°C



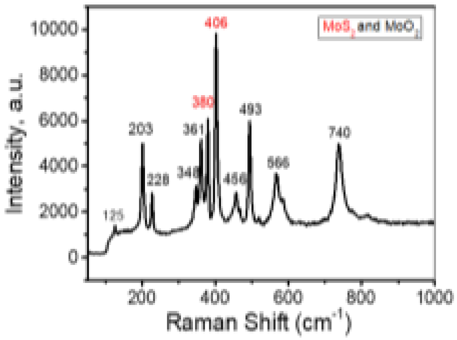
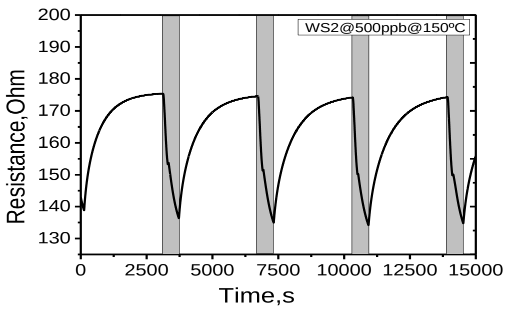


Fig. 3: ESEM image of the vertically aligned rhomboidal shaped MoS2-MoO2 domains

Fig. 4: Raman spectrum showing peaks corresponding to MoS2 and MoO2 grown at 800°C



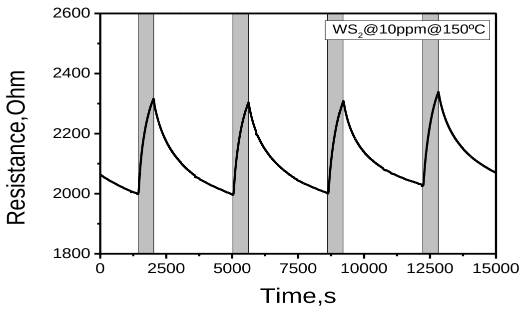


Fig. 5: WS2 sensor response and recovery cycles toward 500 ppb of NO_2 at heated temperature of 150 ºC.

Fig. 6: WS2 sensor response and recovery cycles toward 10 ppM of NH_3 at heated temperature of 150 ºC.