CHAPTER 5

CONCLUSION AND FUTURE WORK

In summary, MoO_3 nanostructures were successfully synthesized. MoO_3 nanoplates were prepared on Si substrates by vapor transport method at the temperature close to sublimation point with a short growth time. The facet of the nanoplates was in the a-c plane due to the large differences in the close−packing rate between (100) and (010) planes, whereas the close−packing rates of (100) and (001) are close to each other. The MoO_3 nanoplates had a thickness of about 60−120 nm and a width of 1−4 μm. MoO_3 nanobelts were grown on MoO_3 whiskers by using nitrogen ion implantation technique. The MoO_3 nanobelts had a width of 20−60 nm in width and a length of 300−800 nm. The MoO_3 nanobelts exhibited an orthorhombic crystal structure with preferential growth in the [001] direction. MoO_3 nanowires were grown on MoO_3 whiskers using a similar technique with the MoO_3 nanobelts but employing carbon ion instead of nitrogen ion. The MoO_3 nanowires had a diameter of 50−200 nm and a length of 280−1000 nm. The formation of the MoO_3 nanoplates and nanobelts could be explained with the kinetics of crystal growth via the 2D nucleation probability of VS mechanism. The formation of the MoO_3 nanowires could be explained with similar mechanism but the carbon ion probably acted as a catalyst which led to the formation of nanowires instead of nanobelts.

Raman scattering of MoO_3 single crystals with different crystal orientations was carried out by with polarized Ar^+ laser. The intensity of Raman peaks strongly depended on the crystal orientation, which could be explained by Raman tensors.

The effect of nitrogen ion implantation on MoO_3 whiskers using Raman spectroscopy was studied and its electrical properties were considered. The intensity of Raman peaks was decreased significantly about one order of magnitude with respect to that of the unimplanted whiskers. This could be explained based on the electronic screening of phonons in the metallic state that the electron transfers from nitrogen to Mo. In addition, the intensity ratios respecting to I_{816}, I/I_{816}, were evaluated and found that only the peaks of B_{3g} had higher ratio. This result referred to the defects existing in MoO_3 crystal structure, which led to higher conductivity comparing to that of the unimplanted whisker.

SnO_2 nanostructures were successfully synthesized on Au−coated alumina substrates and Au electrodes by using carbothermal reduction process in a closed crucible. SnO_2 nanowires decorated with nanodendrites and beaded together with nanoparticles were mostly observed. The size of the SnO_2 nanowires and nanoparticles ranged from 50 to 150 nm and 100 to 1000 nm, respectively. Carbothermal reduction process can be regarded as a carbon−assisted thermal evaporation. The formation of the nanowires could be explained by VLS mechanism. The formation of the nanodendrites and nanoparticles on the nanowires could be caused by low oxygen content in the system.

Sensors based on MoO_3 thick film, SnO_2 thick film, and SnO_2 nanostructures were fabricated using alumina as a substrate, NiCr wire as heater, gold paste as electrodes and connectors, and 8−pin IC socket as holder. The sensing properties of ethanol were characterized. The sensor response and response time of the sensor depended on the concentration of ethanol and operating temperature. The optimal sensor responses were observed at 260, 260, 340, and 360°C for MoO_3 thick film, SnO_2 thick flim, SnO_2 nanowires beaded nanoparticles, and SnO_2 nanowires mixed nanodendrites. The b−values for SnO_2 nanowires beaded nanoparticles and mixed nanodendtrites were evaluated to be 0.66 and 0.60, respectively, from the relationship of the sensitivity and the ethanol concentration. This suggested O^{-2} dominated on the sensing mechanism.

Ethanol gas sensing properties of Au-impregnated SnO_2 nanostructures were investigated. The impregnation of gold particle to the SnO_2 nanostructures improved the sensor response from about 100 to 140 at 1000 ppm of ethanol. Moreover, the optimal temperature slightly decreased from 340°C to 320°C. Table 5.1 shows the optimal temperature and the sensor response of various sensing materials for comparison

Table 5.1 Summary of the optimal temperature and the sensor response for various sensing materials

Sensing material	**Optimal temperature**	**Sensor response**	**Ethanol concentration**
MoO_3 thick film	260	11.5	200
SnO_2 thick film	250	9	200
SnO_2 NWs+NPs	340	43.2 104.8	200 1000
SnO_2 NWs+NDs	360	52.8 120	200 1000
Au-impregnated SnO_2 NWs (10μl)	320	53.2 138.5	200 1000

Study of e-nose application was carried out by fabricating array sensors based on commercial sensors and developed sensors. Commercial e-nose was also used for comparison. The responses of array sensors to ethanol, hydrogen, methanol, acetone, toluene, iso–propanol, and gasoline were studied. The classification among ethanol, hydrogen, and acetone by Bayesian analysis showed that 82.5% of samples in the training set was assigned correctly into their own class. The row–wise standardization was employed to the data matrix of acetone, ethanol, iso-propanol, and methanol. PCA result of the row-wise standardized data showed a better separation among these gases comparing to PCA of the raw data matrix. The classification among gasoline and three ethanol blended gasolines with the array sensor based on four commercial array using LDA showed that samples were separated definitely into three groups, in which samples of E10 and E20 were grouped together at the middle between E85 and B91 samples. Moreover, the array sensor based on the developed sensors also had ability to classify between ethanol and acetone. The suggested that it could be used as an device for e-nose application.

For future work, more studies can be carried on, for example, electrical and gas sensing properties of SnO_2, ZnO, TiO_2, or WO_3, by ion implantation technique, the effect of active carbon amount in the mixture to the morphology of SnO_2 nanostructures, or controlling of fabrication of SnO_2 nanostructures into appropriate substrates for gas sensor and also solar cell application. In addition, sputtering and evaporation techniques could be powerful methods to coat many types of material, such as Zn, Cu, Au, W, or Ti, to functionalize SnO_2 nanowires for using in gas sensor, solar cell, and e-nose applications.