# CHAPTER V

# CONCLUSION AND RECOMMENDATION

In this work, the ZnO/MWCNT composites were synthesized by the single-step gas phase reaction. Glycerol and ferrocene were used as sources of carbon and iron catalyst, while pure zinc powder was used as zinc source. It was found that the synthesis of the composites by the combination of the formation of ZnO nanoparticles and carbon nanoparticles was more complicated than the isolated synthesis of the ZnO nanoparticles or the isolated of the carbon nanoparticles. Therefore, the isolated synthesis of ZnO nanoparticles and carbon nanoparticles was separately studied. The MWCNTs with high purity were synthesized by CVD of glycerol and ferrocene. Meanwhile, to understand the formation of MWCNTs, parallel study on synthesis of SWCNTs by pulsed Nd:YAG laser ablation was also investigated. ZnO nanoparticles were synthesized by oxidation of pure Zn in a tubular quartz reactor. Finally, the ZnO/MWCNT composites were then investigated under designated conditions by single-step gas phase reaction.

## 5.1 Analysis of the SWCNT synthesis by laser ablation

In this part, the airborne SWCNTs were synthesized by pulsed laser ablation of C/Ni/Co rod under atmospheric pressure. The effects of Nd:YAG pulsed laser intensity and temperature on the morphology, purity and crystallinity and size distributions of the synthesized products were studied. An increase in the laser intensity resulted in an increase in the number concentration of synthesized carbon nanoparticles in aerosol. The experimental results exhibited that the formation of the SWCNTs would be negligible at temperature lower than 1000 °C although the laser intensity was increased. However, the airborne SWCNTs with high purity and crystallinity were synthesized at the temperatures of 1000 and 1080 °C. Therefore, the temperature was found to be the main parameter for the SWCNT formation.

## 5.2 Analysis of the carbon nanoparticle synthesis by CVD of glycerol and ferrocene

The MWCNTs were synthesized by CVD of glycerol and ferrocene under a condition of atmospheric pressure. The effects of the nitrogen flow rate, synthesizing temperature, glycerol to ferrocene molar ratio and deposited position on the morphology, purity and crystallinity and yield of the synthesized carbon nanoparticles were investigated. When the nitrogen flow rate was increased, the MWCNTs with smaller tube diameters and higher purity were synthesized. However, the increasing of the nitrogen flow rate revealed the decreasing of the yield. When the synthesizing temperature was increased, the MWCNTs with larger tube diameters and lower purity were synthesized. Furthermore, an increase in synthesizing temperature could lead to the increasing yields. The glycerol to ferrocene molar ratio could also exert significant effect on the MWCNTs. The higher molar ratio resulted in the synthesized MWCNTs with larger diameters and lower purity, while the yield was found to be decreased.

## 5.3 Analysis of the ZnO synthesis by oxidation of Zn

The ZnO nanoparticles were synthesized by the oxidation of pure Zn particles by a French process. The effects of the nitrogen flow rate, synthesizing temperature, oxygen flow rate and deposited position on the morphology, size and yield of the synthesized ZnO nanoparticles were investigated. When nitrogen flow rate was increased from 200 to 350 and 500 mL/min, the morphologies of the synthesized ZnO nanoparticles were changed from combination of rod-like structure, and tetrapod nanostructure to combination of rod-like structure, micro-sheets and tetrapods and only tetrapods, respectively. The increased nitrogen flow rate could lead to a significant decrease in diameter and length of the synthesized ZnO nanoparticles with tetrapod characteristics. When the synthesizing temperature was increased, the morphologies of the synthesized ZnO nanoparticles were change from tetrapods only to combination of the rod-like structure, micro-sheets and tetrapods. Increase in the synthesizing temperature would also result in a significant increase in diameter and length of the synthesized ZnO. When the oxygen flow rate was increased, the majority of the synthesized ZnO nanoparticle morphology was tetrapod. However, the diameter and length of the pod were found to be decreased significantly with the higher oxygen flow rate.

### 5.4 Analysis of the ZnO/MWCNT composites

Finally, the ZnO/MWCNT composites were synthesized by a single-step gas phase reaction. The theoretical study of thermodynamics exhibited unavoidable oxidation of C and Fe simultaneous with the oxidation of Zn over wide ranges of the synthesizing conditions. The synthesizing temperature was found to be a major parameter in this work. At the synthesizing temperature of 800 °C, the synthesized products were the ZnO/MWCNT composites. Iron oxide in form of α-$Fe_2O_3$ was found to exist in the synthesized composites. These experimental results revealed that some of the MWCNTs were oxidized, leading to the formation of $Fe_2O_3$ because the Fe catalytic nanoparticles inside were exposed to surrounding $O_2$. However, at the synthesizing temperature of 900 °C, the MWCNTs were disappeared, while some remains of Zn were clearly observed. It could be implied that the synthesizing temperature of 900 °C was excessively high for the formation of the composites of ZnO nanoparticles and MWCNTs. Therefore, in this work, the composites were synthesized under the optimal condition of the nitrogen flow rate, oxygen flow rate and synthesizing temperature of 500 mL/min, 100 mL/min and 800 °C, respectively.

### 5.5 Recommendation for future work

In a single-step synthesis process of the ZnO/MWCNT composites by gas phase reaction, $O_2$ which is strong oxidizer are significantly introduced into the system at high temperature for the formation of the ZnO nanoparticles. However, the oxidations of carbon unavoidably simultaneous occur at any high temperature. Furthermore, Fe as catalyst for the formation of the carbon nanoparticles of this work was also oxidized. Therefore, the introduced $O_2$ might be too strong oxidizer for this system. To decrease in the oxidation of undesired products, therefore, weaker oxidizer such as water vapor is considerable recommended for next study.