CHAPTER 5

Conclusions

5.1 Preparation of CuO nanostructure

5.1.1 Preparation of CuO nanowires on copper plate and copper powder

CuO nanowires were successfully prepared by an oxidation reaction. For oxidation reaction, a copper plate was heated in a furnace tube under normal atmosphere at heating temperature of 400, 500, and 600^{o}C. After heating, the color of the copper plate turned black. It was found that the black products were copper CuO and exhibited nanostructure with diameter ranging from 100–300 nm. The diameter of CuO nanowires was about 100 nm at heating temperature of 400^{o}C and about 200–300 nm at 500–600^{o}C. From cross-section of FE-SEM image, it suggested that the growth process began with the formation of thin layer of Cu_2O, then thick layer of CuO and finally, CuO nanowires. Moreover, from TEM analysis, the CuO nanowires exhibited single-crystalline property with monoclinic structure.

5.1.2 Preparation of CuO thin films on alumina substrate

CuO thin films were successfully synthesized by oxidizing copper thin films which were prepared by an evaporation method. The characterization of CuO nanostructure by FE-SEM revealed a thickness of around 1 micrometers and it depended on the oxidation reaction time and temperature. CuO and Cu_2O phases observed from XRD pattern agreed with oxidation reaction process. The CuO thin films that can be grown on substrate may found application for nanodevices such as nano gas sensor or dye-sensitized solar cells.

5.2 CuO nanowires for ethanol sensors application

Ethanol sensors based on CuO nanowires were successfully fabricated. The CuO nanowires were prepared by an oxidation reaction of copper plate. From FE-SEM, EDS and TEM characterization, CuO nanowires exhibited diameters of 100–400 nm having a monoclinic structure with a growth along [110] direction. Moreover, the CuO nanowire sensor responded to ethanol vapor, exhibiting the optimum sensitivity of 1.5 to an ethanol vapor concentration of 1000 ppm with a working temperature of 240^{o}C, the response time of 110 s, and recovery time of 120 s. The CuO nanowires could be explored for gas sensor application.

5.3 CuO nanostructure for DSSCs application

5.3.1 CuO nanostructure as photoelectrode and counterelectrode in ZnO DSSCs application

The ZnO DSSCs with different photoelectrodes-counterelectrodes of ZnO/CuO nanowire-Pt, ZnO/CuO powder-Pt, ZnO-Pt, ZnO-CuO nanowire, and ZnO-CuO powder were fabricated and investigated the effect of morphology and the effect of p-n junction photoelectrode on photoelectrochemical characteristics. It was found that CuO nanowire DSSCs exhibited higher current density and higher photoconversion efficiency than those of CuO powder DSSCs and could be explained in terms of larger available dye adsorption surface area. In addition, the increase of short current density and photoconversion efficiency in ZnO/CuO photoelectrode due to the formation of p-n junction was observed. This could be explained in terms of low back or reverse current resulting from p-type CuO layer which prevents electrons to back or reverse transfer to dye and electrolyte.

5.3.2 CuO nanostructure as a barrier layer of photoelectrode in ZnO DSSCs application

The ZnO DSSCs with different photoelectrodes were studied on the effect of CuO layer as a barrier layer toward power conversion characteristics. CuO powder, nanowire and thin film were used as a layer on the top of ZnO layer to form a blocking layer. It was found that ZnO DSSCs with CuO thin film exhibited the highest current density and the highest power conversion efficiency than those without CuO thin film. The enhancement of the power conversion efficiency can be explained in terms of the retardation of the interfacial recombination dynamics of CuO blocking layer. However, DSSCs with CuO powder and nanowire exhibited lower efficiency than that of CuO thin film and comparable to DSSCs without CuO layer. This is due to the thicker layer of CuO powder and nanowire resulting in a retardation of the interfacial recombination dynamics of CuO blocking layer which is comparable to dye excited-state decay and CuO blocking layer has almost no effect on DSSC performance.

5.3.3 ZnO passivating layer with CuO thin films as a barrier layer of photoelectrode in ZnO DSSCs application

The ZnO DSSCs with different photoelectrodes were studied on the effect of CuO layer as a barrier layer toward power conversion characteristics with ZnO sputtering passivating layer. ZnO sputtering passivating layer by difference thickness with various sputtering time of 5, 10, 20 and 40 min were used as a layer between FTO and ZnO layer to form a passivating layer. It was found that ZnO DSSCs with CuO thin films and ZnO sputtering passivating layer exhibited the highest current density and the highest power conversion efficiency than those without CuO thin films and ZnO passivating layer. The enhancement of the power conversion efficiency can be explained in terms of the retardation of the interfacial recombination dynamics of CuO blocking layer. However, DSSCs with CuO thin films and ZnO passivating layer exhibited lower efficiency than that of comparable to DSSCs without CuO layer when the thickness of passivating layer was increased. This is due to the thicker layer of CuO thin films and ZnO passivating layer resulting in a retardation of the interfacial recombination dynamics of CuO blocking layer which is comparable to dye excited-state decay and CuO blocking layer has almost no effect on DSSC performance.

5.4 Suggestion and future works

The future prospect of CuO is quite bright and interesting in DSSCs application. The possible future studies of CuO are described below:

1. Detailed studies of CuO nanostructures: the varieties morphology of CuO nanostructures can design by various techniques and the selection of growth parameters such as temperature, supersaturation ratio, substrate[41], etc. The CuO nanostructure with various morphologies such as nanowires, nanoparticles, and thin films can be further studied.

2. Studies of photoelectrode morphology and thickness: dye absorption and electron transport depend on the morphology of the semiconductor used as photoelectrode. The nanowires have recently emerged as a promising architecture for electron transport as well as dye adsorption[42]. If nanowires of semiconductor can grow and control thickness on FTO, it will improve additional performance DSSCs[43].

3. Studies thickness dependence of CuO thin films as a barrier layer: the characteristics of the CuO barrier layer with various morphologies on the nanoporous ZnO layer was investigated for its application in DSSCs. The CuO layer thickness is one condition of the power conversion efficiency of the DSSCs. Moreover, CuO thin films thickness with various thicknesses is also interesting for studied and improved additional performance DSSCs[44].

4. Studies thickness dependence of ZnO passivating layer: the characteristics of the RF sputter grown ZnO passivating layer with various thickness on the FTO electrode were investigated for its application in DSSCs. In addition, it was found that

the power conversion efficiency of the DSSCs is critically dependent on the thickness of ZnO passivating layer inserted between FTO electrode and nanoporous ZnO layer. Jeong and co-worker(45) have reported that TiO_2 DSSCs with TiO_2 passivating layer thickness of 50 nm showed highest efficiency. This suggested that the thickness optimization of theTiO_2 passivating layer is one of the important parameter to obtain high performance DSSCs.