Fluorescence Effect of ZnO Nanostructure to Improve Photovoltaic Performance of DSSCs

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Abstract

The demand for clean energy has increased significantly in the past decade, and by a series of legislative measurements and public support, the development of renewable energy has been put at the forefront of power generation. In response, solar cells have been researched extensively because solar energy is one of the most promising clean and renewable energy sources. Dye-sensitized solar cells (DSSCs) are a certain type of next-generation solar cells, with wide applications, including building integrated photovoltaic (BIPV) technology and flexible solar cells.
In this poster, we demonstrate the synthesis of 1-dimensional semiconducting zinc oxide (ZnO) nanostructures for their future application as a photoelectrode in DSSCs. By adjusting synthesis conditions, ZnO with diverse dimensions have been successfully produced. Fluorescence emission characteristics have been found on certain dimensioned ZnO nanostructures. The fluorescence could be used as a secondary light source, with the potential to improve the photovoltaic characteristics of DSSCs.

Introduction

❑ Dye-Sensitized Solar Cells

- Low cost and simple process
- High efficiency
- Aesthetically pleasant
- Suitable for BIPV
- TCO | TiO_2 : dye | electrolyte | TCO structure

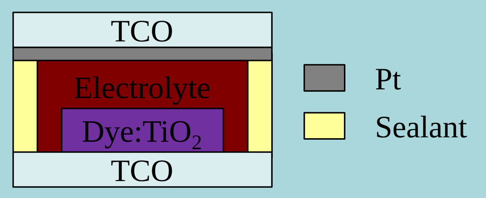


Figure 1. Structure of DSSCs.

❑ Chemical Vapor Deposition (CVD)

- High-purity, high-performance solid product
- Continuous process for hybrid system
- Flexible conditioning
- Cost-effective
- Good step coverage

❑ Zinc Oxide (ZnO)

- Wide-bandgap semiconductor
- Transparent, high electron mobility
- Hexagonal wurtzite
- Piezoelectricity, pyroelectricity characteristics

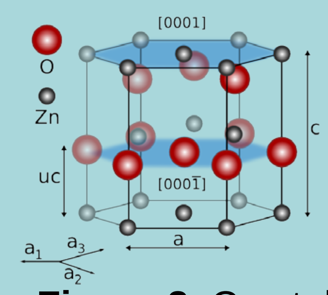


Figure 2. Crystal structure of wurtzite ZnO.
http://www.theochem.ruhr-uni-bochum.de/~joerg.behler/zno.htm

❑ Fluorescence

- Electron excited by absorbing light
- Excited electron relaxes with light emission
- Longer wavelength emission than excitation

Experimental

❑ CVD Synthesis System

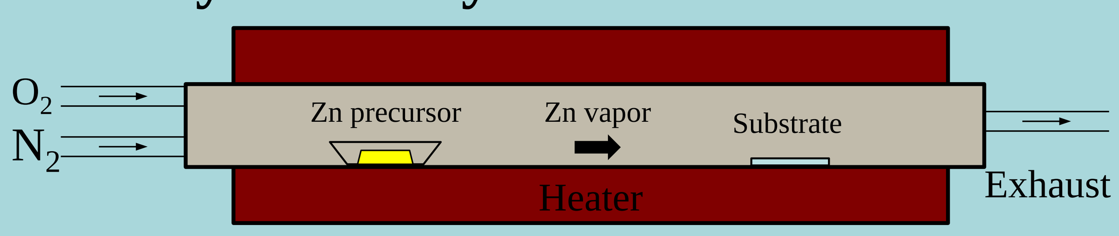


Figure 3. Schematic drawing of CVD synthesis system.

Table 1. List of controllable parameters and range of CVD synthesis.

Controllable parameters	Conditions range
Precursor temperature	400 - 600°C
Ramping/Reaction time	10 - 60 min / 30 - 120 min
Pressure	Atmospheric pressure ~ 10^{-3} torr
Carrier gas	Nitrogen (N_2)
Oxidizer	Oxygen (O_2)
Flow rate	N_2: 50 - 200 SCCM / O_2: 0 - 10 SCCM
Precursor-Substrate distance	0 - 2 cm
Substrate orientation	Parallel to gas flow

❑ Experimental condition

Table 2. List of synthesis condition and results in terms of transparency and fluorescence emission.

Sample #	Temperature (°c)	Position (inch)	N_2 rate (SCCM)	O_2 rate (SCCM)	Reaction time (min)	Transparency	Fluorescence
1	550	+1.0	90	10	30/30	NO	NO
2	550	+1.0	92	8	30/30	NO	NO
3	550	+1.0	94	6	30/30	NO	NO
4	550	+1.0	96	4	30/30	NO	YES
5	550	+1.0	98	2	30/30	NO	YES
6	550	+1.0	99	1	30/30	Slightly	YES
7	**550**	**+1.0**	**100**	**0.5**	**30/30**	**YES**	**YES**
8	550	+1.0	100	0.3	30/30	YES	NO

❑ Characterization

- SEM for physical structure and morphology
- XRD for crystal structure and crystallinity
- Fluorescence emission under 365nm UV lamp

Results and discussion

❑ Crystallinity Analysis by XRD

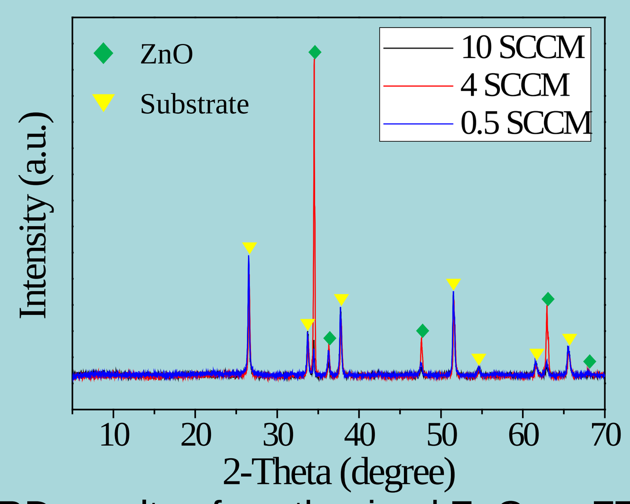


Figure 4. XRD results of synthesized ZnO on FTO substrate.

The XRD results show two different sets of peaks, one from the synthesized ZnO material and one from the FTO substrate. The peaks marked by a yellow triangle are from the substrate ($F:SnO_2$). The peaks marked by a green square are from the target material, ZnO. The XRD results confirms that the synthesized material is high crystalline wurtzite ZnO.

Results and discussion (cont.)

❑ Morphology Analysis by SEM

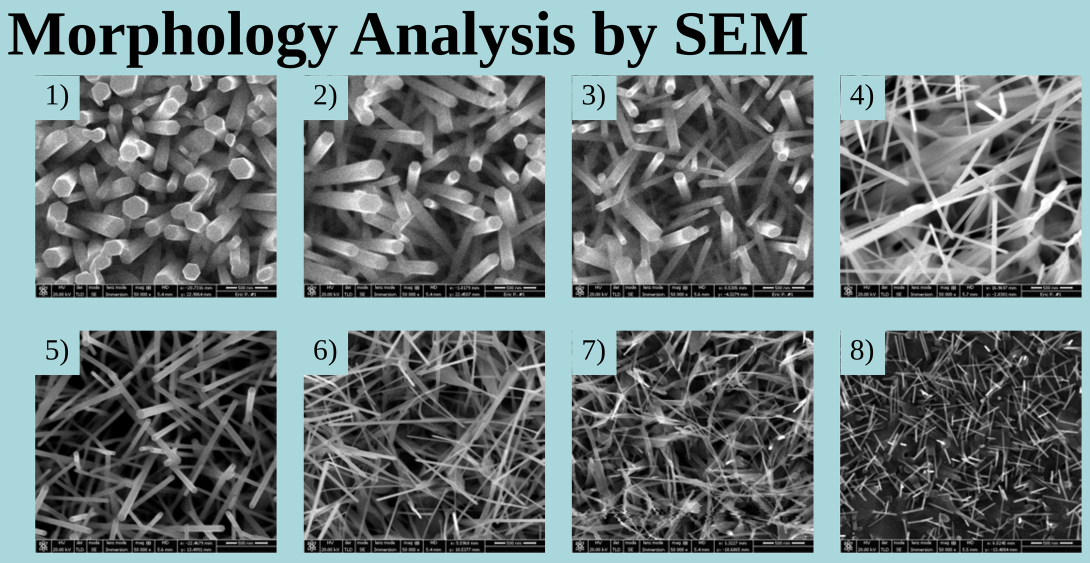
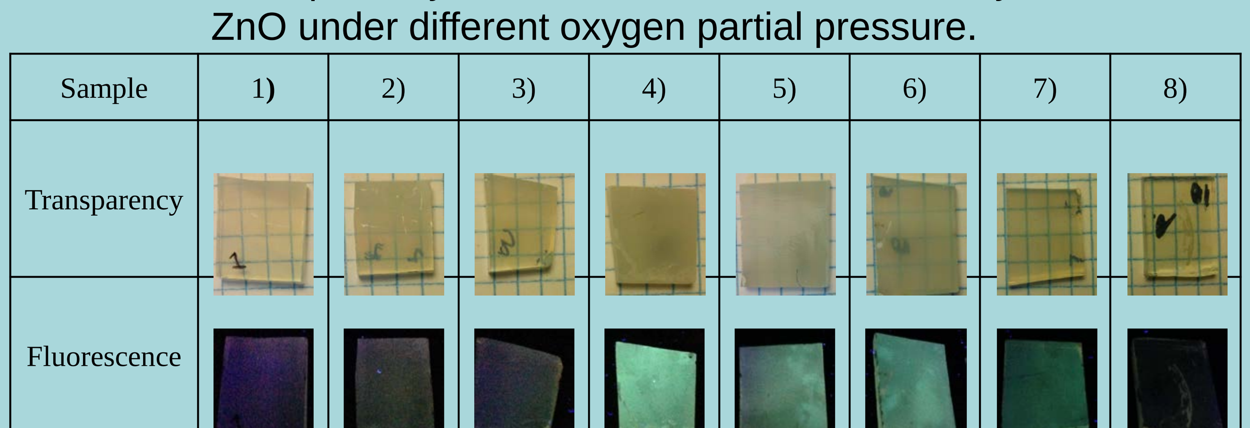


Figure 5. SEM images of ZnO synthesized under different oxygen partial pressure.

The morphology and dimensions of ZnO nanostructures synthesized under different partial pressure ratios of N_2 and O_2 are observed by scanning electron microscopy (SEM). As shown above, the partial pressure of oxygen plays a pivotal role in the shape and size of the synthesized product. Furthermore, when the oxygen ratio was too high, ZnO nanostructures were not grown on the surface, but could only grow near the edge of the substrate.

❑ Transparency and fluorescence

Table 3. Transparency and fluorescence emission of synthesized ZnO under different oxygen partial pressure.



In high oxygen conditions (samples 1-3), the ZnO layer was not evenly formed through the entire substrate surface, but rather formed on the area closest to the precursor. No fluorescence was observed in these samples. In medium oxygen conditions (samples 4-5), the ZnO layer was formed on the entire surface and the fluorescence emission was strong but the ZnO layers were not transparent. However, in low oxygen conditions (samples 6-7), the ZnO layer became more transparent while they still had fluorescence emission. Very thin ZnO layer was formed in extremely low oxygen condition (sample 8). ZnO synthesized at 0.5 SCCM oxygen rate (sample 7) is the most suitable for DSSC applications because it has both characteristics, transparency and fluorescence emission.

Summary

In this research, we have successfully synthesized 1-dimensional ZnO nanostructures exhibiting fluorescence emission excited from 365 nm UV light. By using the emission as a secondary light source, this ZnO nanostructures have the potential to improve photovoltaic characteristics of DSSCs. High crystallinity wurtzite crystal structure is confirmed by XRD characterization. Morphology and dimensional characteristics are observed by SEM. In conclusion, the synthesized ZnO nanostructures are suitable for a wide range of applications including photovoltaic devices, UV sensors, phototransistors, or photocatalysts.

Acknowledgements

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