APPENDICES

APPENDIX A

INSTRUMENT

A.1 Flame Spray Pyrolysis Reactor

Figure A.1 Flame Spray Pyrolysis Reactor at The NRL Research Laboratory Chiang Mai University.

A.2 X-ray diffractometer (XRD)

Figure A.2 X-ray Diffractometer, Rigaku, TTRAXIII, Japan.

A.3 Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectrometer (EDS)

Figure A.3 Scanning Electron Microscope & Energy Dispersive X-Ray Spectrometer, JSM-6335F, JEOL, Japan.

A.4 Transmission Electron Microscope (TEM)

Figure A.4 Transmission Electron Microscope, JEM-2010, JOEL, Japan.

A.5 Surface area analyzer (BET)

Figure A.5 Surface area analyzer, Quantachrome Autosorb 1 MP, USA.

APPENDIX B

JCPDS INFORMATION

B.1 JCPDS File No. 83−0950 of Tungsten Oxide

[83−0959]

Tungsten Oxide

WO_3

Rad.: CuKα1 (1.54060)

Filter:

d–sp: calculated

I/Icor.: 5.66

Cutoff: 17.7

Int.: calculated

Sys.: Monoclinic

S.G.: $P2_1/n$ (14)

a: 7.30084 (7) b: 7.53889(7) c: 7.68962 (8)

A: 0.9684 C: 1.0200 Z: 8 mp:

Dx: 7.278 Dm:

Ref.: Woodward. P.M., Sleight. A.W., Vogt. T., J. Phys. Chem. Solids., 56, 1305 (1995)

2Theta	Int.	h k l
16.454	1	0 1 1
16.864	1	1 0 1
16.864	1	1 1 0
20.375	1	1 1 1
20.591	1	1 1 1
23.117	982	0 0 2
23.583	956	0 2 0
24.367	999	2 0 0
25.996	10	0 1 2
26.593	190	1 2 0
28.614	170	1 1 2
28.927	167	1 1 2
28.927		1 2 1
29.698	2	2 1 1
33.261	383	0 2 2
33.565	242	2 0 2
34.167	565	2 0 2
34.167		2 2 0

2Theta	Int.	h k l
35.390	62	1 2 2
35.650	67	1 2 2
35.650		2 1 2
36.036	3	2 2 1
36.185	5	2 1 2
36.292	3	2 2 1
36.962	1	1 0 3
37.018	1	0 1 3
37.337	4	1 0 3
37.627	1	0 3 1
38.604	1	3 0 1
38.908	2	3 1 0
38.908		1 1 3
38.965	2	3 0 1
39.267	2	1 1 3
39.729	8	1 3 1
40.483	3	3 1 1
40.831	3	3 1 1
41.432	129	2 2 2
41.886	137	2 2 2
42.624	1	0 2 3
42.964	12	0 3 2

2Theta	Int.	h k l
43.697	1	2 3 0
44.270	43	3 2 0
44.270		1 2 3
44.698	35	1 2 3
44.698		1 3 2
44.912	36	1 3 2
45.384	45	3 1 2
45.384		2 3 1
45.737	3	3 2 1
46.017	41	3 1 2
46.017		3 2 1
47.250	87	0 0 4
48.247	91	0 4 0
48.858	6	0 1 4
49.933	252	4 0 0
49.933		1 4 0
50.230	48	2 3 2
50.230		3 2 2
50.336	125	1 1 4
50.726	111	1 1 4
50.816	70	3 2 2
50.816		0 3 3

2Theta	Int.	h k l
51.374	2	3 0 3
51.374		1 4 1
51.471	2	1 4 1
51.471		4 1 0
52.195	1	3 0 3
52.330	1	3 3 0
52.330		1 3 3
52.615	1	1 3 3
52.745	1	4 1 1
52.847	1	3 1 3
53.467	106	0 2 4
53.467		2 0 4
53.590	59	3 3 1
54.153	80	0 4 2
54.235	60	2 0 4
54.772	91	2 4 0
54.962	54	2 1 4
55.344	75	4 0 2
55.621	65	1 4 2
55.804	88	1 4 2
55.933	161	4 2 0
56.074	133	4 0 2

2Theta	Int.	h k l
56.074		2 4 1
56.259	40	2 4 1
56.785	2	4 1 2
56.888	1	2 3 3
57.131	1	4 2 1
57.635	15	3 3 2
58.170	14	3 3 2
59.238	33	2 2 4
59.933	42	2 2 4
60.055	53	2 4 2
60.402	39	2 4 2
60.601	30	0 3 4
60.979	63	0 4 3
60.979		4 2 2
61.667	67	4 2 2
61.885	59	1 3 4
62.264	124	3 4 0
62.264	124	3 1 4
63.282	47	4 1 3
63.282		3 1 4
63.424	25	3 4 1
64.215	1	1 5 1

2Theta	Int.	h k l
64.215		4 1 3
64.338	1	4 3 1
64.756	1	5 0 1
64.846	1	3 3 3
65.172	1	5 0 1
65.505	1	0 2 5
65.979	13	2 3 4
66.249	6	3 2 4
66.414	4	2 4 3
66.638	17	2 3 4
66.638	17	1 2 5
67.099	29	3 4 2
67.099	29	1 2 5
67.235	18	3 2 4
67.589	30	3 4 2
67.589	30	4 3 2
68.031	6	1 5 2
68.272	4	4 3 2
68.272	4	2 5 1
68.437	2	2 5 1
68.915	9	5 2 0
69.594	11	5 1 2

2Theta	Int.	h k l
69.835	24	0 4 4
70.397	11	5 2 1
70.397		5 1 2
70.548	21	4 0 4
70.548	11	2 2 5
71.029	14	1 4 4
71.348	14	1 4 4
71.348		2 2 5
71.822	24	4 0 4
71.822	24	2 5 2
71.965	42	0 3 5
71.965		4 4 0
72.182	27	2 5 2
72.641	22	3 3 4
72.641		0 5 3
73.077	2	4 1 4
73.077	2	3 4 3
73.380	7	3 1 5
73.380	7	5 2 2
73.587	23	4 3 3
73.587		3 3 4
73.806	11	3 4 3

2Theta	Int.	h k l
74.165	7	5 2 2
74.165	7	5 0 3
74.876	14	2 4 4
75.141	9	0 1 6
75.552	24	2 4 4
75.552		4 2 4
76.224	38	5 3 1
76.224		1 1 6
76.434	41	4 4 2
76.690	49	1 1 6
76.794	31	4 2 4
76.794	31	2 3 5
76.936	57	1 6 0
77.054	36	3 2 5
77.054		4 4 2
77.611	1	2 3 5
78.153	1	1 6 1
78.392	3	2 5 3
78.562	19	6 0 0
78.853	12	0 2 6
78.853		3 5 2
79.109	2	5 2 3

2Theta	Int.	h k l
79.536	5	5 3 2
79.536		2 0 6
79.780	3	6 1 0
79.907	3	1 2 6
79.907		2 1 6
80.302	8	5 3 2
80.302	8	1 2 6
80.558	4	0 4 5
80.837	7	2 1 6
80.837		2 6 0
80.979	13	0 5 4
81.245	15	6 1 1
81.245		3 4 4
81.543	26	1 6 2
81.696	28	1 4 5
81.696	28	1 6 2
81.925	15	2 6 1
82.160	13	1 5 4
82.160	13	3 4 4
82.421	12	1 5 4
82.768	14	6 0 2
82.874	8	4 3 4

2Theta	Int.	h k l
83.049	8	4 5 0
83.049		4 4 3
83.127	5	3 3 5

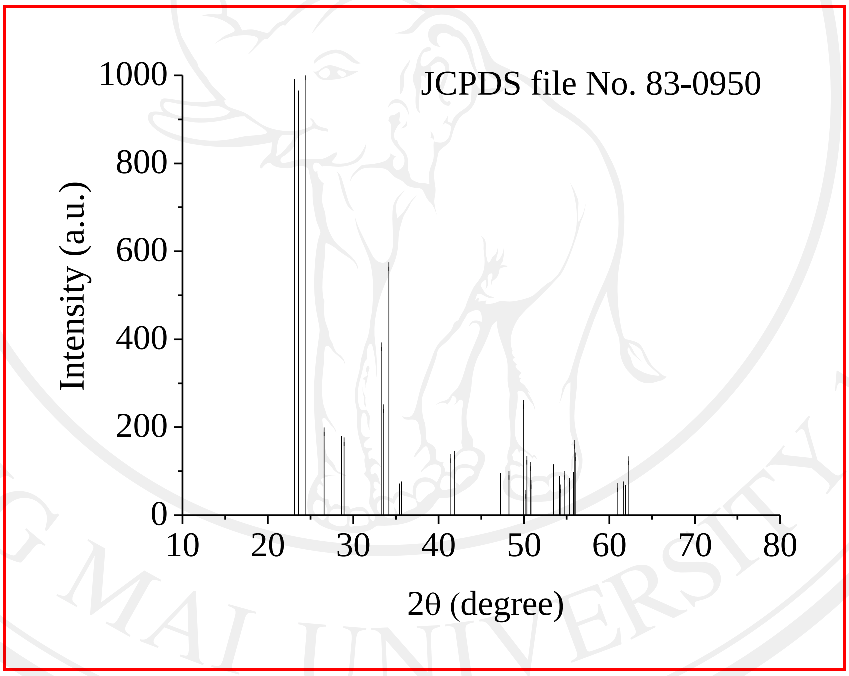

Figure B.1 JCPDS file No. 83−0950 of X-ray diffraction pattern of tungsten oxide.

B.2 JCPDS File No. 04−006−7123 of Tungsten Oxide

[04−006−7123]

Tungsten Oxide

WO_3

Rad.: CuKα1 (1.5406)

Filter:

I/Icor.: 5.59

Sys.: Monoclinic

S.G.: $P2_1/c$ (14)

Ref.: Zhang O., Dahn J.R., Colbow K. Phys. Rev. B: Condons. Mater. Phys., v46 p2554 (1992)

2Theta	Int.	h k l
16.447	0.1	0 1 1
16.846	0.1	1 1 1
16.846	0.1	1 0 2
20.575	0.1	1 1 2
23.101	98.2	0 0 2

2Theta	Int.	h k l
23.580	95.4	0 2 0
24.336	100	2 0 2
25.981	1	0 1 2
26.304	0.7	0 2 1
26.582	19.2	1 2 1
28.593	16.1	1 1 1
28.906	16.4	1 2 0
28.906	16.4	1 1 3
29.362	0.6	2 1 1
29.667	0.2	2 1 3
33.246	37.8	0 2 2
33.531	24.3	2 0 0
34.142	55.6	2 0 4
34.142	55.6	2 2 2
35.371	6.3	1 2 1
35.630	6.8	1 2 3
35.630	6.8	2 1 0
36.010	0.4	2 2 1
36.151	0.5	2 1 4
36.265	0.4	2 2 3
36.993	0.1	0 1 3
36.993	0.1	1 0 2

2Theta	Int.	h k l
37.306	0.3	1 0 4
37.619	0.1	0 3 1
38.556	0.2	3 0 2
38.916	0.3	3 0 4
38.916	0.3	1 1 2
39.237	0.1	1 1 4
39.716	1	1 3 2
40.436	0.2	3 1 2
40.783	0.2	3 1 4
41.402	12.5	2 2 0
41.854	13.1	2 2 4
42.601	0.2	0 2 3
42.950	1.1	0 3 2
43.674	0.1	2 3 2
44.227	4.1	3 2 3
44.227	4.1	1 2 2
44.679	3.2	1 2 4
44.679	3.2	1 3 1
44.893	3.4	1 3 3
45.335	4.1	2 3 3
45.335	4.1	3 1 1
45.693	0.3	3 2 2

2Theta	Int.	h k l
45.693	0.3	3 2 2
45.966	4.1	3 1 5
45.966	4.1	3 2 4
47.214	8.7	0 0 4
48.239	8.8	0 4 0
48.823	0.5	0 1 4
49.370	0.3	2 2 1
49.865	17.5	4 0 4
49.865	17.5	1 4 1
50.183	4.8	2 3 4
50.183	4.8	3 2 1
50.298	11.7	1 1 3
50.687	10.3	1 1 5
50.687	10.3	3 2 5
50.823	6.3	0 3 3
51.276	0.2	3 0 0
51.361	0.2	1 4 0
51.457	0.2	1 4 2
51.457	0.2	4 1 4
52.138	0.1	3 0 6
52.304	0.1	1 3 2
52.304	0.1	3 3 3

2Theta	Int.	h k l
52.588	0.2	1 3 4
52.678	0.2	4 1 3
52.793	0.2	3 1 0
53.055	0.2	4 1 5
53.433	11.0	2 0 2
53.433	11.0	0 2 4
53.673	6.1	3 1 6
53.673	6.1	3 3 2
54.138	8.8	0 4 2
54.138	8.8	2 0 6
54.749	8.7	1 2 3
54.749	8.7	2 4 2
54.915	5.2	2 1 2
55.274	6.9	4 0 2
55.602	6.2	2 1 6
55.602	6.2	1 4 1
55.784	9.5	1 4 3
55.869	14.7	4 2 4
56.003	12.8	4 0 6
56.003	12.8	2 4 1
56.233	3.9	2 4 3
56.717	0.2	4 1 2

2Theta	Int.	h k l
56.852	0.2	2 3 1
57.066	0.1	4 2 3
57.175	0.1	3 2 0
57.519	1.3	3 3 1
58.123	1.3	3 3 5
59.192	3.2	2 2 2
59.889	3.9	2 2 6
60.026	5.3	2 4 0
60.373	3.6	2 4 4
60.567	2.9	0 3 4
60.912	5.8	0 4 3
60.912	5.8	4 2 2
61.598	6.2	4 2 6
61.747	4.1	1 0 6
61.848	4.3	1 3 3
62.203	11.6	3 4 3
62.203	11.6	3 1 1
63.218	4.3	3 1 7
63.218	4.3	4 1 1
63.383	2.3	3 4 2
63.635	0.2	3 4 4
63.941	0.1	4 3 3

2Theta	Int.	h k l
64.200	0.1	4 3 5
64.200	0.1	1 5 2
64.666	0.1	5 0 4
64.793	0.1	3 3 6
64.926	0.1	5 1 5
65.081	0.1	5 0 6
65.458	0.1	0 2 5
65.934	1.1	5 1 4
65.934	1.1	2 3 2
66.189	0.7	3 2 1
66.379	0.4	2 4 1
66.379	0.4	5 1 6
66.590	1.8	2 3 6
66.590	1.8	1 2 4
66.692	1.0	2 1 3
67.055	2.7	4 2 1
67.055	2.7	3 4 1
67.171	1.6	3 2 7
67.543	2.7	3 4 5
67.543	2.7	4 3 2
68.010	0.5	1 5 3
68.204	0.4	4 3 6

2Theta	Int.	h k l
68.204	0.4	2 5 1
68.411	0.2	2 5 3
68.828	0.9	5 2 5
69.502	0.9	5 1 3
69.801	2.1	0 4 4
69.801	2.1	5 2 4
70.302	1.0	5 2 6
70.302	1.0	5 1 7
70.468	2.1	2 2 3
70.468	2.1	4 0 0
70.992	1.4	1 4 3
71.310	1.4	2 2 7
71.310	1.4	1 4 5
71.738	1.8	4 0 8
71.738	1.8	4 1 0
71.904	4.1	0 3 5
71.904	4.1	4 4 4
72.152	2.3	2 5 4
72.582	1.9	3 3 1
72.993	0.2	4 1 8
72.993	0.2	1 3 4
73.289	0.6	4 4 5

2Theta	Int.	h k l
73.289	0.6	5 2 3
73.524	2.0	3 3 7
73.524	2.0	4 3 1
73.753	1.0	3 4 6
74.072	0.7	1 5 4
74.072	0.7	5 2 7
74.831	1.3	2 4 2
74.831	1.3	3 5 2
75.080	0.8	0 1 6
75.080	0.8	5 3 5
75.472	2.6	4 2 0
75.472	2.6	2 4 6
75.608	1.5	0 6 0
76.161	3.4	1 1 5
76.161	3.4	5 3 4
76.369	3.7	4 4 2
76.625	4.5	4 2 8
76.625	4.5	1 1 7
76.919	5.1	1 6 1
76.919	5.1	4 4 6
77.712	0.1	2 5 1
78.134	0.2	3 2 8

2Theta	Int.	h k l
78.134	0.2	1 6 2
78.444	1.7	6 0 6
78.444	1.7	3 5 1
78.617	1.0	2 0 4
78.617	1.0	0 2 6
79.013	0.2	5 2 2
79.446	0.4	2 0 8
79.446	0.4	5 3 3
79.663	0.2	6 1 6
79.835	0.3	2 1 4
79.835	0.3	1 2 5
80.209	0.5	5 2 8
80.209	0.5	5 3 7
80.308	0.4	0 6 2
80.308	0.4	1 2 7
80.599	0.3	0 4 5
80.599	0.3	6 1 5
80.811	0.6	2 1 8
80.811	0.6	2 6 2

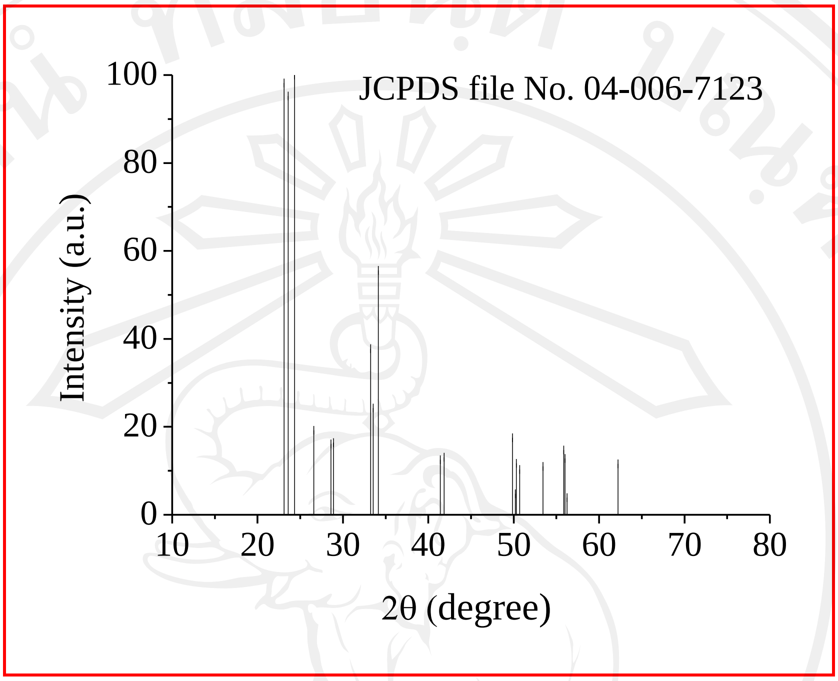

Figure B.2 JCPDS file No. 04−006−7123 of X-ray diffraction pattern of tungsten oxide.

APPENDIX C

CALCULATION

Particle Size (d_{BET})

The average BET equivalent particle size (d_{BET}) was calculated using

$$d_{BET} = \frac{6}{SSA_{BET}\,\rho_{sample}}$$

where:

SSA_{BET} is specific surface area

ρ_{sample} is the density of sample

1. Unloaded WO_3 and Pt-loaded WO_3 nanoparticles synthesized by FSP

1.1 Unloaded WO_3

The specific surface area of unloaded WO_3 is 84.12 m^2/g and ρ_{WO3} is 7.16 x 10^3 kg/m^3

$$d_{BET} = \frac{6}{84.12\ m^2/g\ x\ 7.16x10^3\ kg/m^3}$$

$$= 9.96\ \text{nm}$$

1.2 0.25 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.25 wt.% Pt-loaded WO_3 nanoparticles is 96.57 m^2/g

$$d_{BET} = \frac{6}{(96.57\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.75 wt.\% WO_3/100) + (96.57\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 0.25 wt.\% Pt/100)}$$

= 8.70 nm

1.3 0.5 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.5 wt.% Pt-loaded WO_3 nanoparticles is 94.92 m^2/g

$$d_{BET} = \frac{6}{(94.92\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.5 wt.\% WO_3/100) + (94.92\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 0.5 wt.\% Pt/100)}$$

= 8.87 nm

1.4 0.75 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.75 wt.% Pt-loaded WO_3 nanoparticles is 97.11 m^2/g

$$d_{BET} = \frac{6}{(97.11\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.25 wt.\% WO_3/100) + (97.11\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 0.75 wt.\% Pt/100)}$$

= 8.69 nm

1.5 1.0 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 1.0 wt.% Pt-loaded WO_3 nanoparticles is 96.19 m^2/g

$$d_{BET} = \frac{6}{(96.19\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.0 wt.\% WO_3/100) + (96.19\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 1.0 wt.\% Pt/100)}$$

= 8.80 nm

2. Unloaded WO_3 and Pt-loaded WO_3 nanoparticles synthesized by the hydrothermal method

2.1 Unloaded WO_3

The specific surface area of unloaded WO_3 is 9.94 m^2/g and ρ_{WO3} is 7.16 x 10^3 kg/m^3

$$d_{BET} = \frac{6}{9.94\ m^2/g\ x\ 7.16x10^3\ kg/m^3}$$

$$= 84.30 \text{ nm}$$

2.2 0.25 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.25 wt.% Pt-loaded WO_3 nanoparticles is 12.39 m^2/g

$$d_{BET} = \frac{6}{(12.39\ m^2/gx7.16\ x\ 10^3\ kg/m^3x99.75wt.\%WO_3/100)+(12.39\ m^2/gx21.45\ x\ 10^3kg/m^3x0.25wt.\%Pt/100)}$$

$$= 67.80 \text{ nm}$$

2.3 0.5 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.5 wt.% Pt-loaded WO_3 nanoparticles is 12.66 m^2/g

$$d_{BET} = \frac{6}{(12.66\ m^2/gx7.16\ x\ 10^3\ kg/m^3x99.5wt.\%WO_3/100)+(12.66\ m^2/gx21.45\ x\ 10^3kg/m^3x0.5wt.\%Pt/100)}$$

$$= 66.52 \text{ nm}$$

2.4 0.75 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 0.75 wt.% Pt-loaded WO_3 nanoparticles is 15.07 m^2/g

$$d_{BET} = \frac{6}{(15.07\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.25 wt.\% WO_3/100) + (15.07\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 0.75 wt.\% Pt/100)}$$

$= 56.03$ nm

1.5 1.0 wt.% Pt-loaded WO_3 nanoparticles

The specific surface area of 1.0 wt.% Pt-loaded WO_3 nanoparticles is 15.04 m^2/g

$$d_{BET} = \frac{6}{(15.04\ m^2/g x 7.16\ x\ 10^3\ kg/m^3 x 99.0 wt.\% WO_3/100) + (15.04\ m^2/g x 21.45\ x\ 10^3 kg/m^3 x 1.0 wt.\% Pt/100)}$$

$= 56.28$ nm

CURRICULUM VITAE

Name	Miss Thanittha Samerjai
Date of Birth	April, 24^{th}, 1985
Education Background	B.Sc. (Chemistry), Department of Chemistry, Faculty of Science, Chiang Mai University, Thailand, 2003–2007 M.S. (Chemistry), Department of Chemistry, Faculty of Science, Chiang Mai University, Thailand, 2007–2009
Scholarship	The Center of Excellence for Innovation in Chemistry, (PERCH-CIC), Thailand, 2007–2009 The Office of the Higher Education Commission, under the program Strategic Scholarships for Frontier Research Network, Thailand for the Ph.D., 2009–2012.
Working experience	Work as a teaching assistant in the Chemistry Laboratory courses, Department of Chemistry, Faculty of Science, Chiang Mai University, Thailand, 2007.

Publications and Presentations

Journal Article

1. **Samerjai T.**, Liewhiran C., Phanichphant S., Characterization of ZnO/MgO Nanocomposites Synthesized by Flame Spray Pyrolysis, Journal Microscopy Society of Thailand, 2009, 87−90.

2. **Samerjai T.**, Liewhiran C., Phanichphant S., Synthesis of MgO/ZnO Nanocomposites by Flame Spray Pyrolysis. Advanced Materials and Nanotechnology Conference (AMN-4), 2009, 17−20.

3. **Samerjai T.**, Liewhiran C., Wisitsoraat A., Phanichphant S., Hydrogen Sensors Based on Zinc Oxide Nanoparticles, Nano/Micro Engineered and Molecular Systems (NEMS), 2010, 34−37.

4. Janmenee R., **Samerjai T.**, Liewhiran C., Phanichphant S., Pd-doped SnO_2 Nanoparticle Synthesized by Precipitation/Thermal Decomposition Methods, Nano/Micro Engineered and Molecular Systems (NEMS), 2010, 38−42.

5. **Samerjai T.**, Tamaekong N., Liewhiran C., Wisitsoraat A., Tuantranont A., Phanichphant S., Selectivity towards H_2 Gas by Flame-made Pt-loaded WO_3 Sensing Films, Sens. Actuators B: Chem., 2011, 290−297.

6. Wetchakun K., **Samerjai T.**, Tamaekong N., Liewhiran C., Siriwong C., Kruefu V., Wisitsoraat A., Tuantranont A., Phanichphant S. Semiconducting metal oxides as sensors for environmentally hazardous gases, Sens. Actuators B: Chem., 2011, 580−591.

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