APPENDICES

APPENDIX A

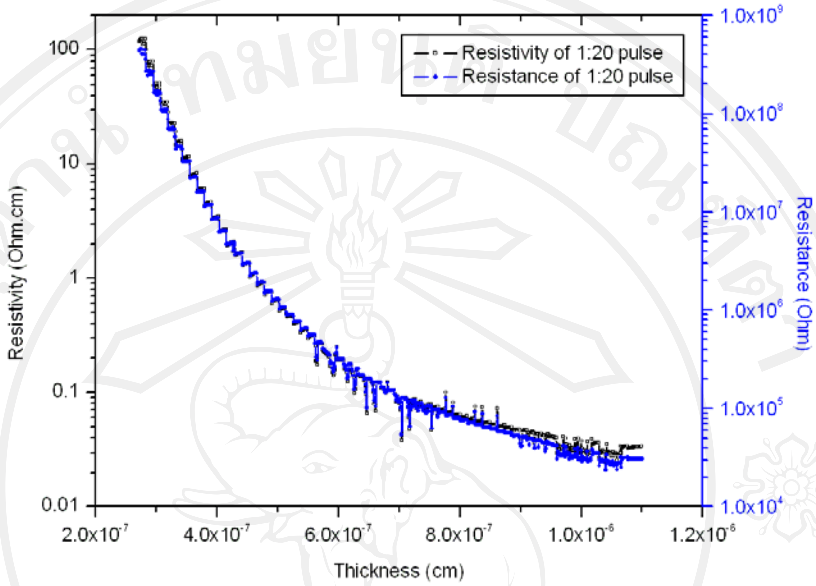
a-C:Mo Thin Film

Appendix A-1 : Additional data of a-C:Mo experiment.

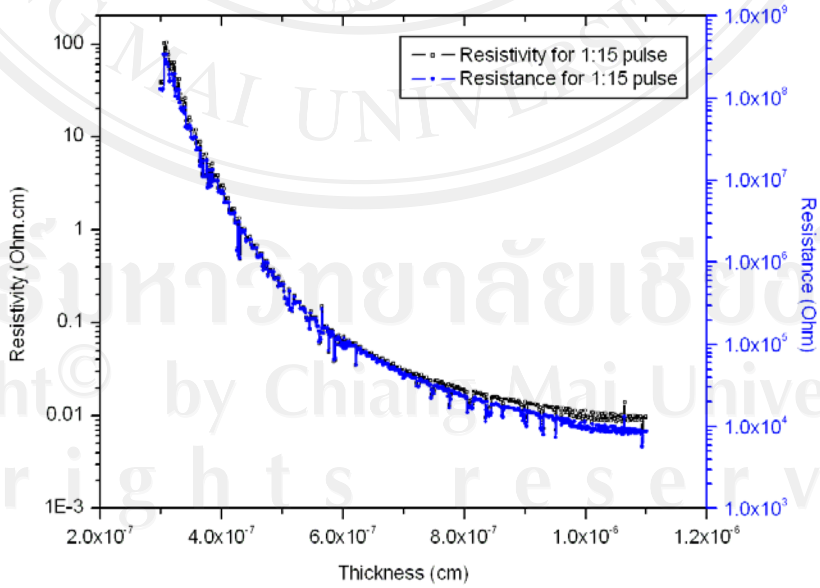
Additional data for Molybdenum doped amorphous carbon film deposited on micro glass slide. Each sample deposited with 2,000 arc total pulse. Sheet resistance were measured by two terminal configuration technique.

Sample	Mo:C pulse ratio	Date processed	Pressure (Torr)	Thickness (nm)	Sheet resistance (Ω)					
					At the date processed	Jan 25	Jan 30	Jan 31	Feb 8	Feb 14
Ex 011	1:15	Jan 20,2006	1.3×10^{-6}	11	8.44 k	8.66 k	8.72 k	8.73 k	8.80 k	8.81 k
Ex 012	1:20	Jan 20,2006	2.4×10^{-6}	11	32.24 k	34.1 k	34.6 k	34.7 k	35.2 k	35.1 k
Ex 013	1:10	Jan 23,2006	2.4×10^{-6}	13	2723	2.74 k	2.758 k	2.761 k	2.769 k	2.767 k
Ex 014	1:5	Jan 24,2006	1.3×10^{-6}	11	622	627	632	632	637	638
Ex 015	3:10	Jan 24,2006	3.0×10^{-6}	12	230.0	234.2	238.0	238.5	241.5	242.8
Ex 016	1:20	Jan 24,2006	4.8×10^{-6}	11	31.90 k	33.5 k	34.1 k	34.1 k	34.3 k	34.2 k
Ex 017	2:5	Jan 25,2006	1.3×10^{-6}	11	206.04	206.9	212.1	212.7	215.9	217.0
Ex 018	0:1	Jan 26,2006	1.3×10^{-6}	8	> 500 MΩ	> 500 MΩ	> 500 MΩ	> 500 MΩ	> 500 MΩ	> 500 MΩ

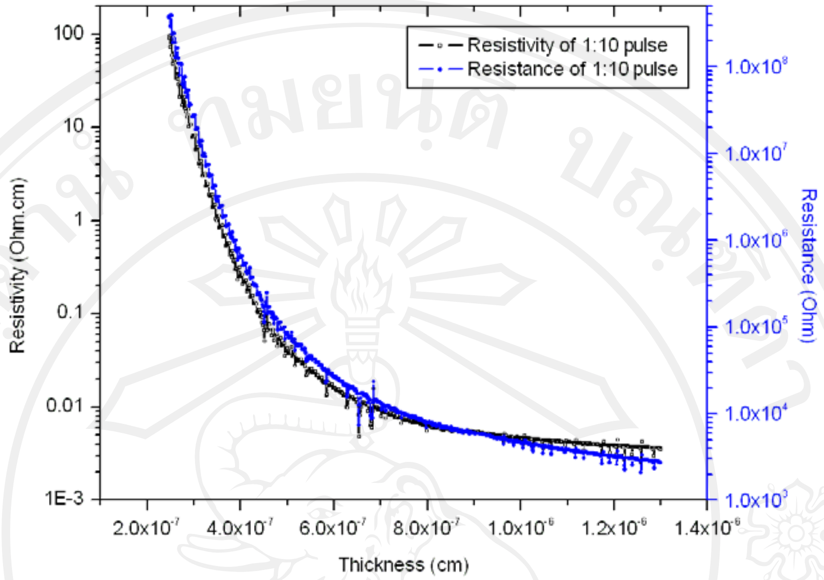
Appendix A-2 : Film resistance during deposition



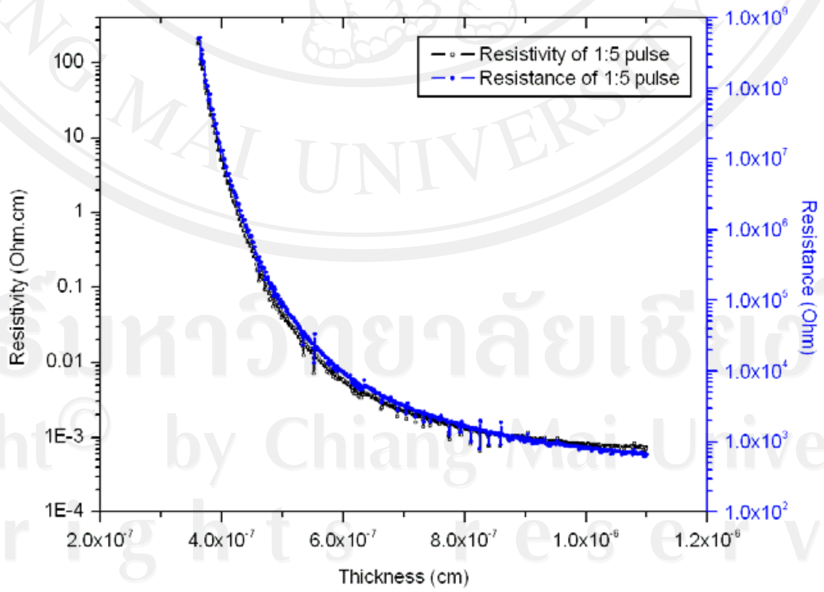
Resistance and resistivity during deposition of Sample Ex 012 (no bias).



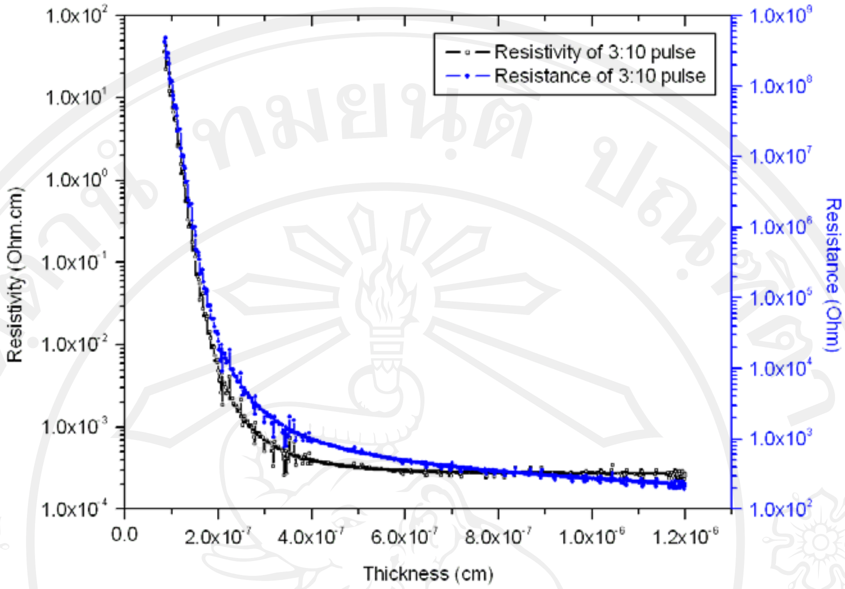
Resistance and resistivity during deposition of Sample Ex 011 (no bias).



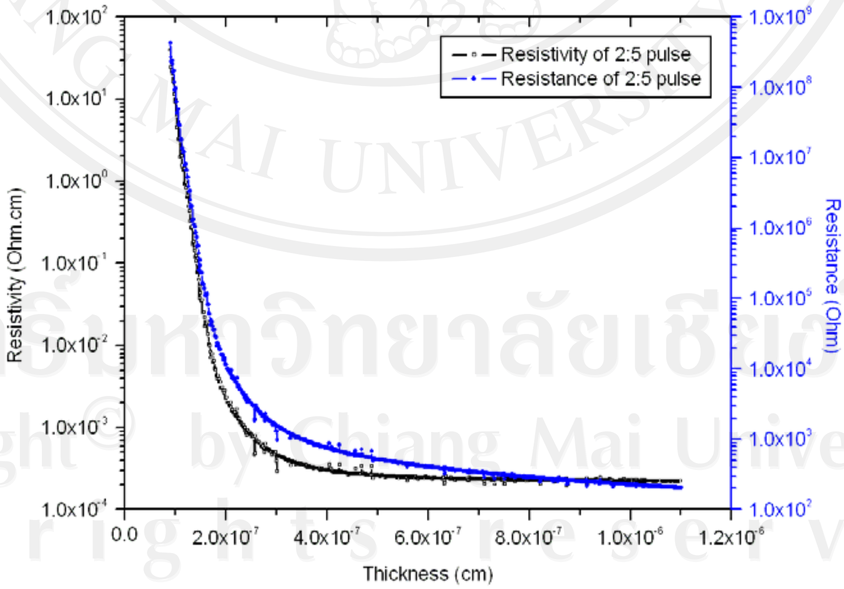
Resistance and resistivity during deposition of Sample Ex 013 (no bias).



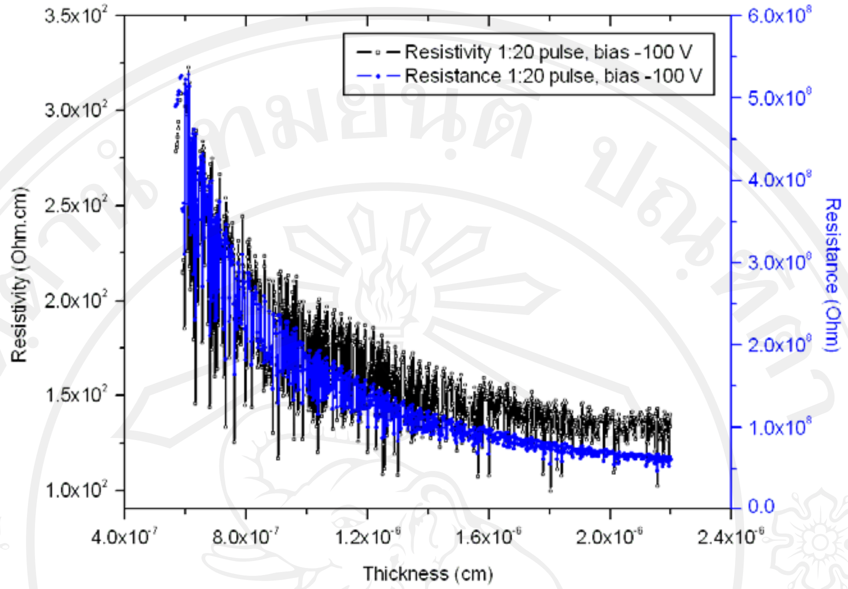
Resistance and resistivity during deposition of Sample Ex 014 (no bias).



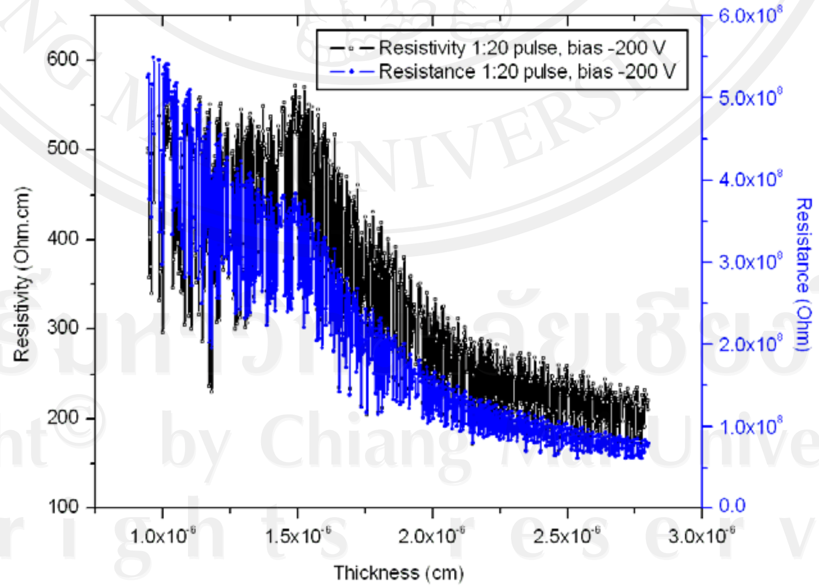
Resistance and resistivity during deposition of Sample Ex 015 (no bias).



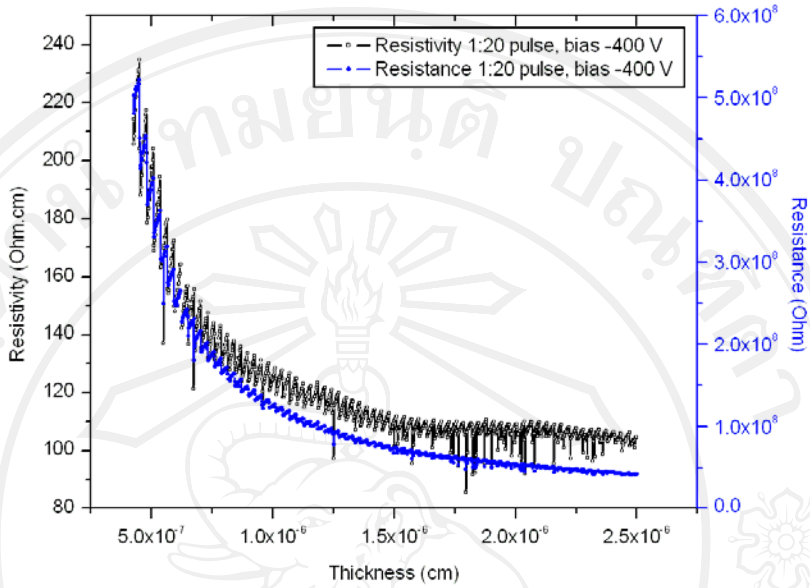
Resistance and resistivity during deposition of Sample Ex 017 (no bias).



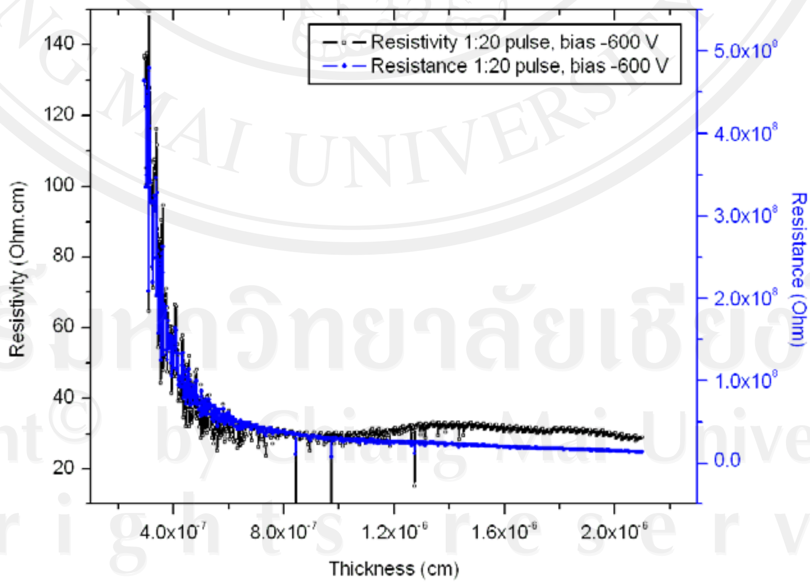
Resistance and resistivity during deposition of Sample Ex 037.



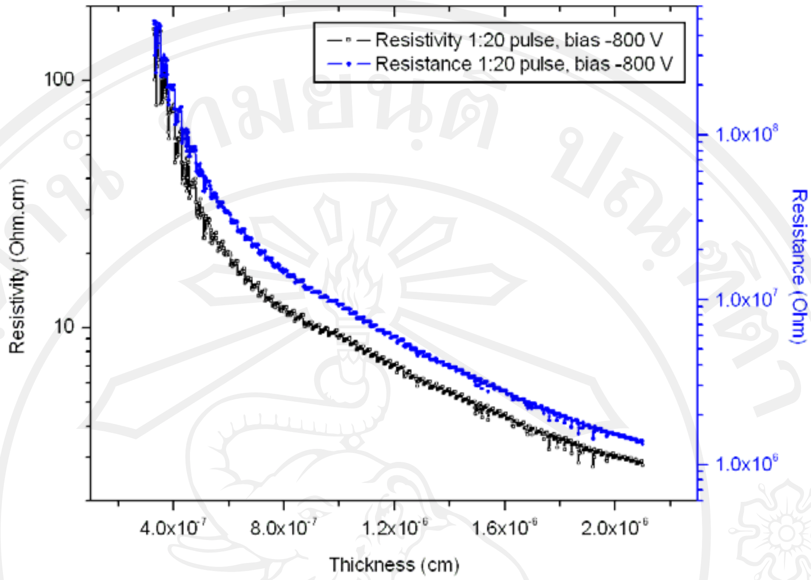
Resistance and resistivity during deposition of Sample Ex 038.



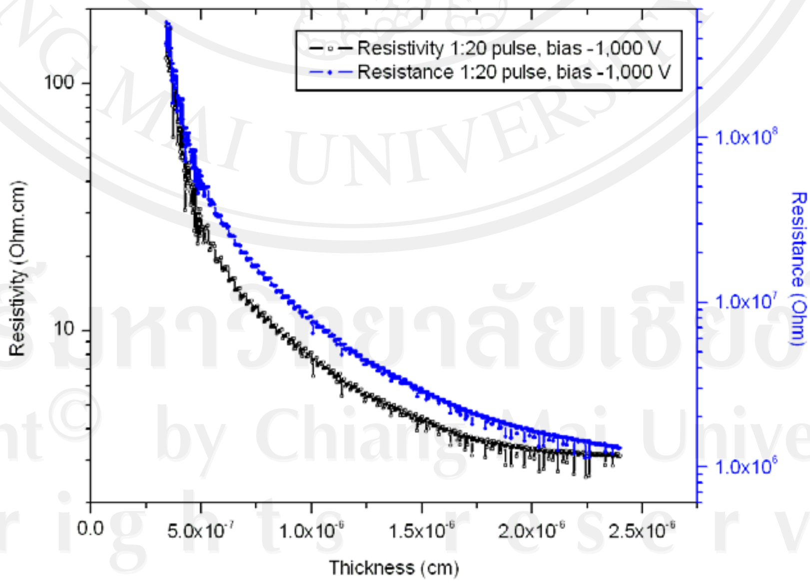
Resistance and resistivity during deposition of Sample Ex 039.



Resistance and resistivity during deposition of Sample Ex 040.



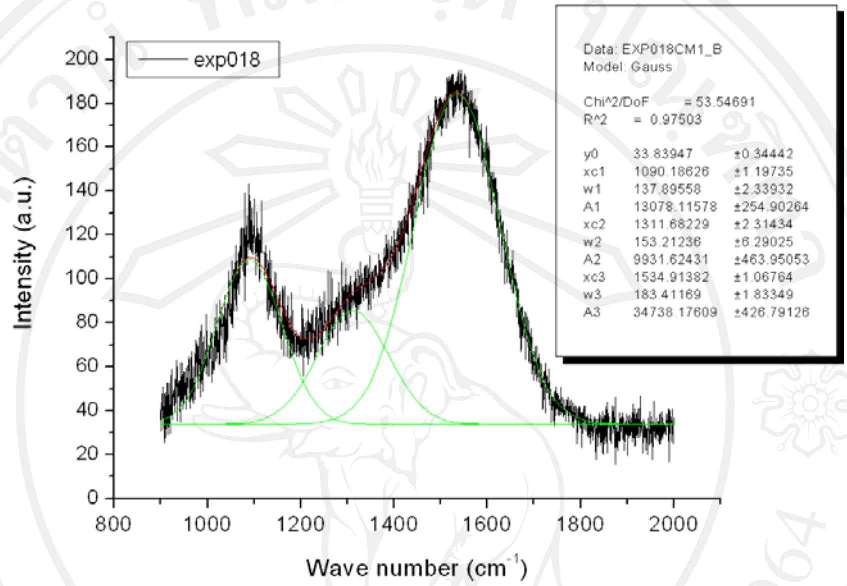
Resistance and resistivity during deposition of Sample Ex 041.



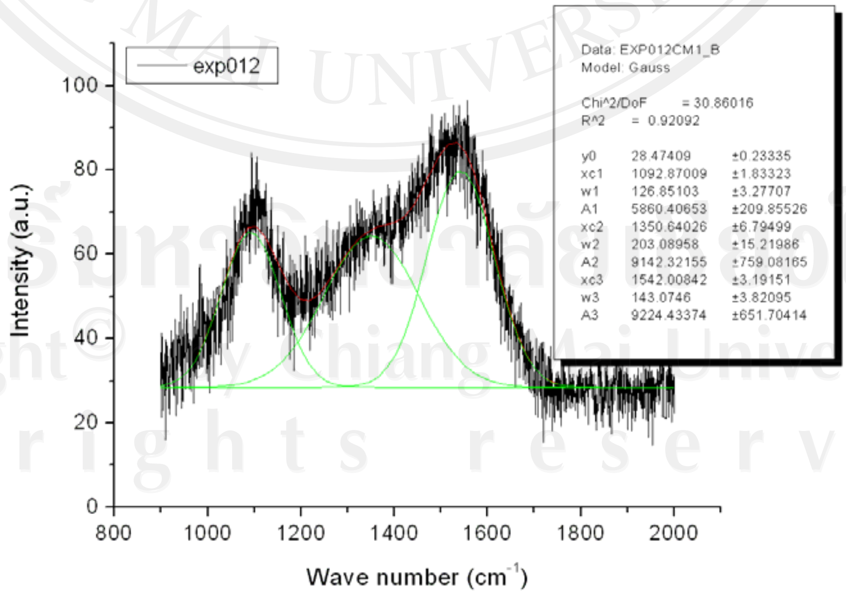
Resistance and resistivity during deposition of Sample Ex 042.

Appendix A-3 : Raman spectra Gaussian fit.

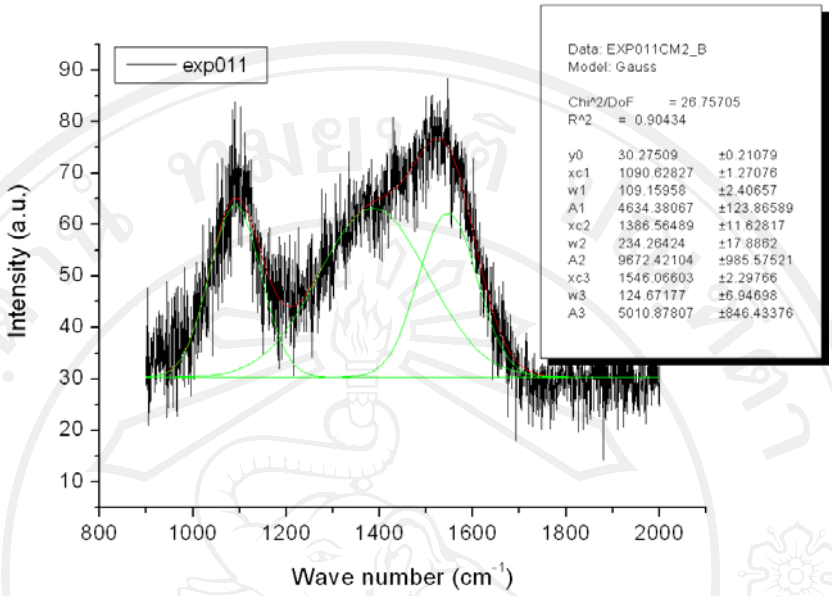
There are three peaks in the Raman spectra ; SiO_2 from substrate, D-peak and G-peak from the diamond like carbon film.



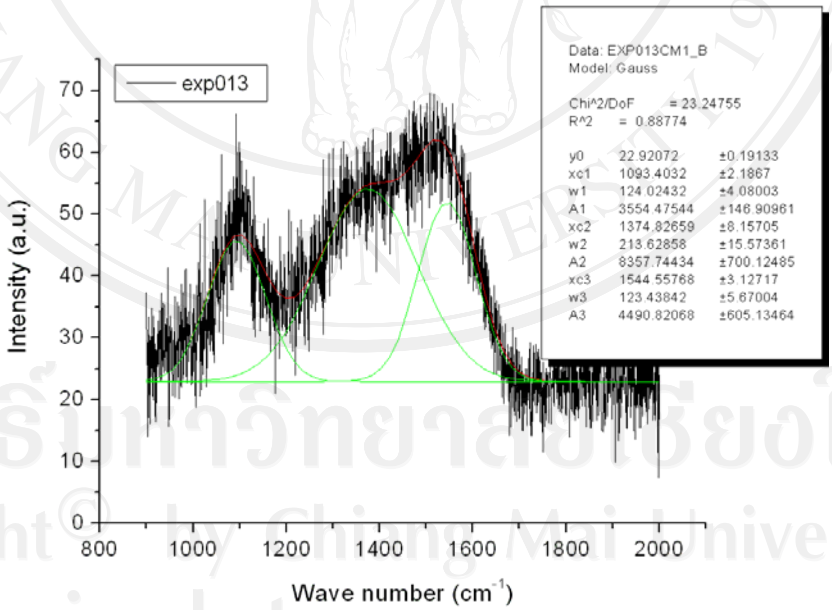
Raman spectra of Exp018 with Gaussian fit.



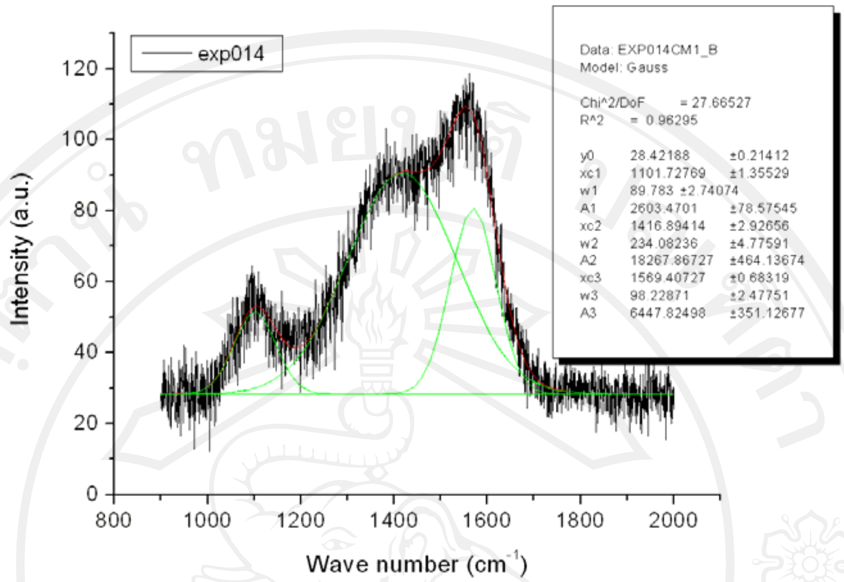
Raman spectra of Exp012 with Gaussian fit.



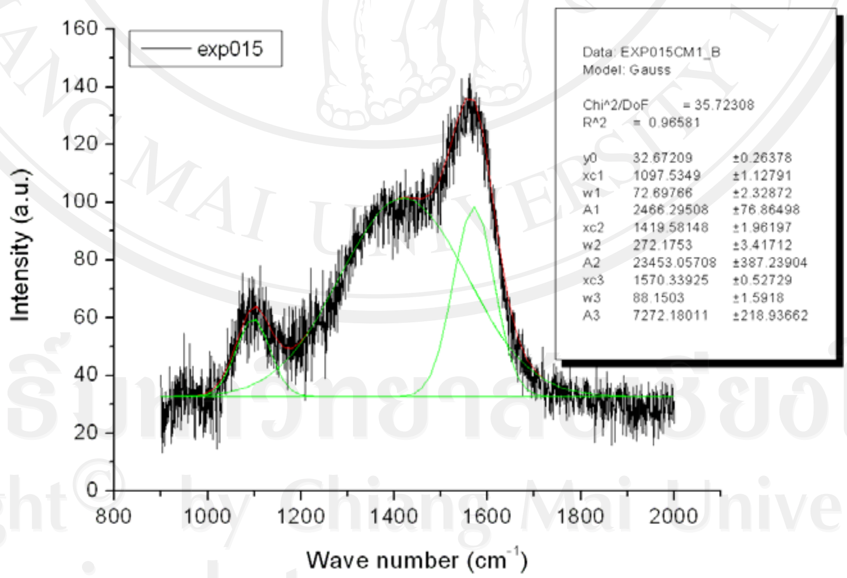
Raman spectra of Exp011 with Gaussian fit.



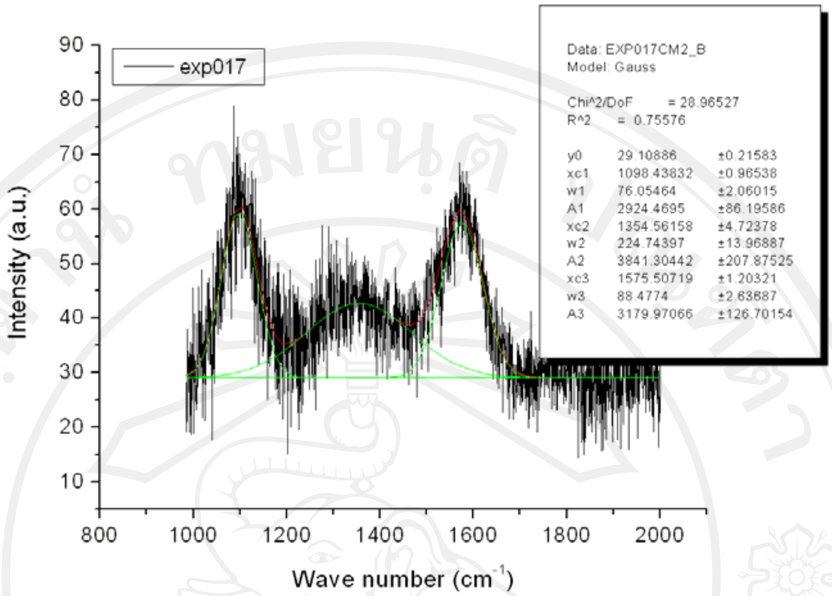
Raman spectra of Exp013 with Gaussian fit.



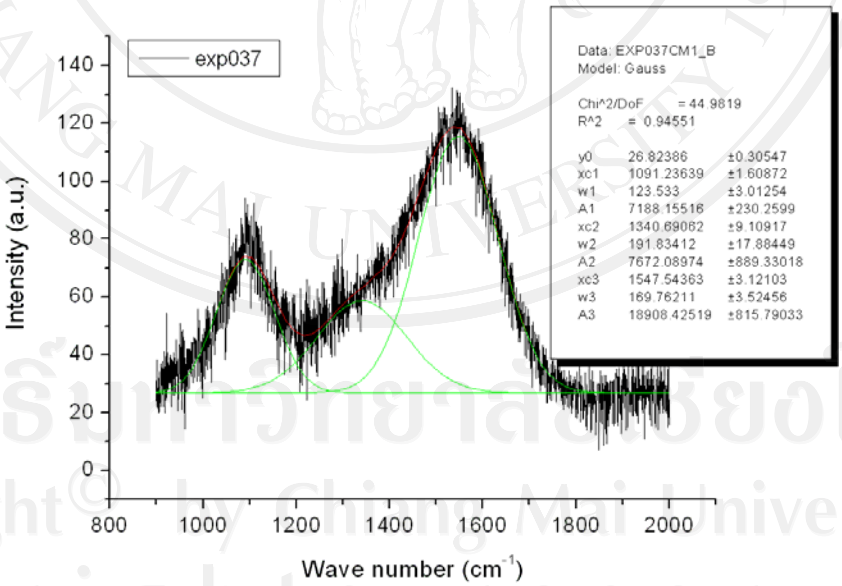
Raman spectra of Exp014 with Gaussian fit.



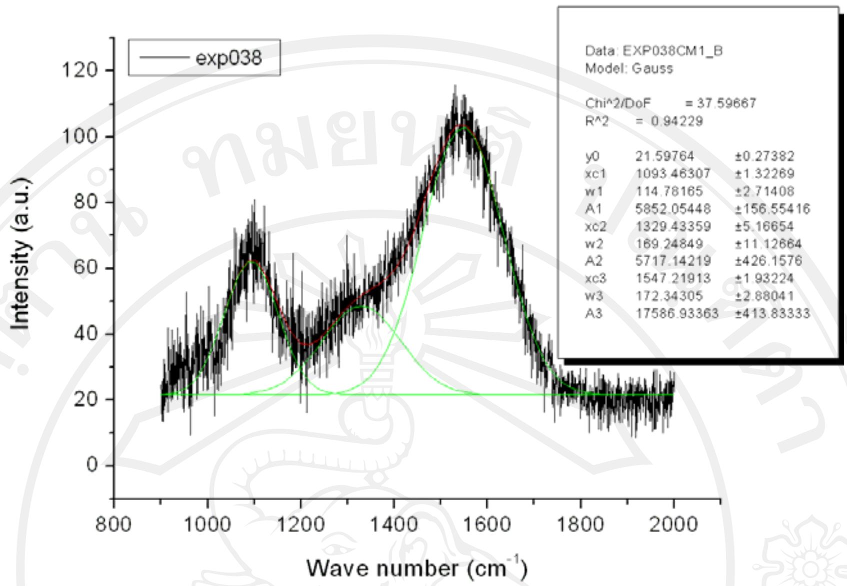
Raman spectra of Exp015 with Gaussian fit.



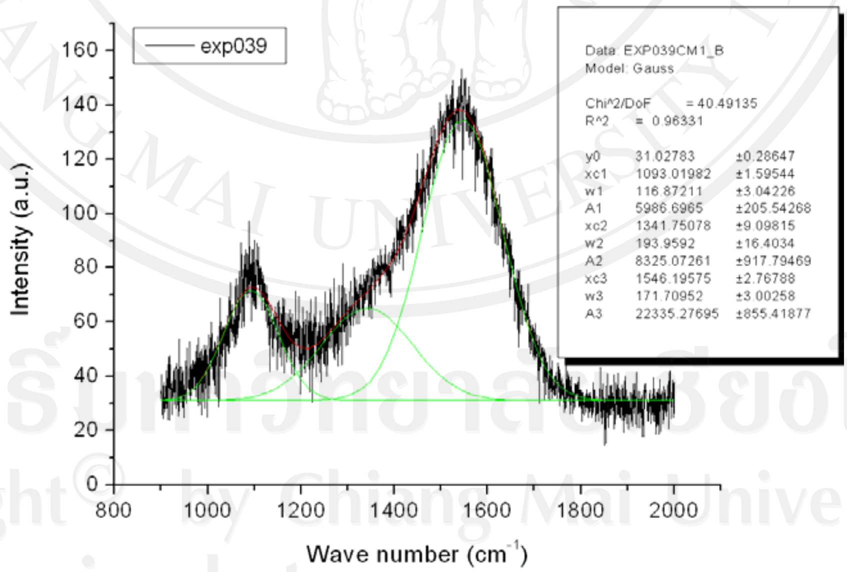
Raman spectra of Exp017 with Gaussian fit.



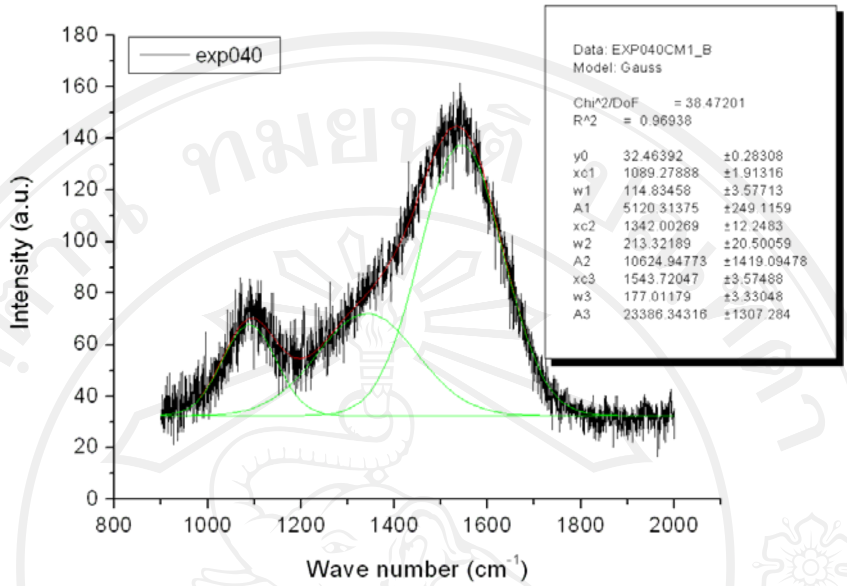
Raman spectra of Exp037 with Gaussian fit.



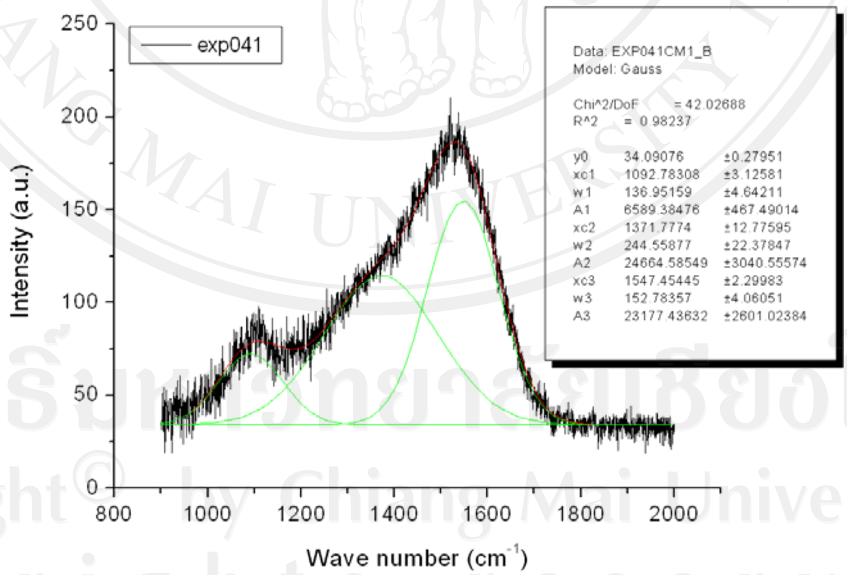
Raman spectra of Exp038 with Gaussian fit.



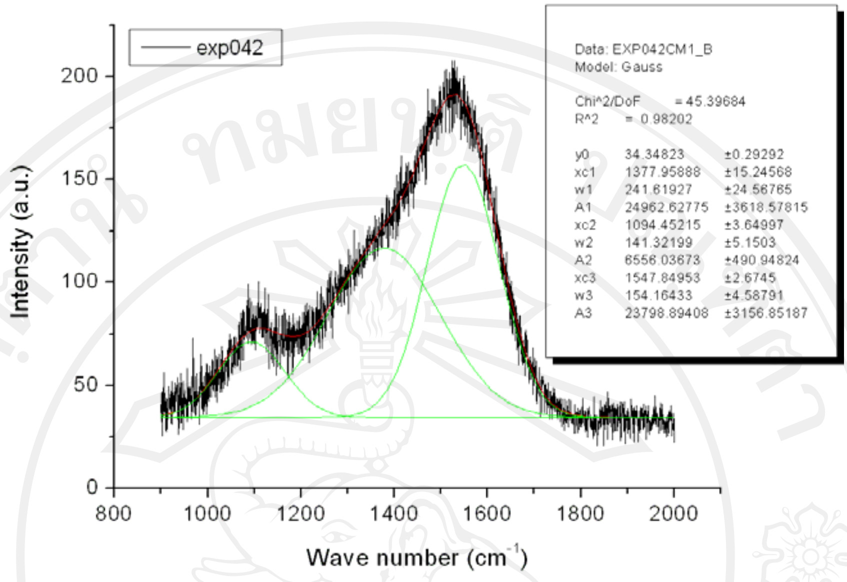
Raman spectra of Exp039 with Gaussian fit.



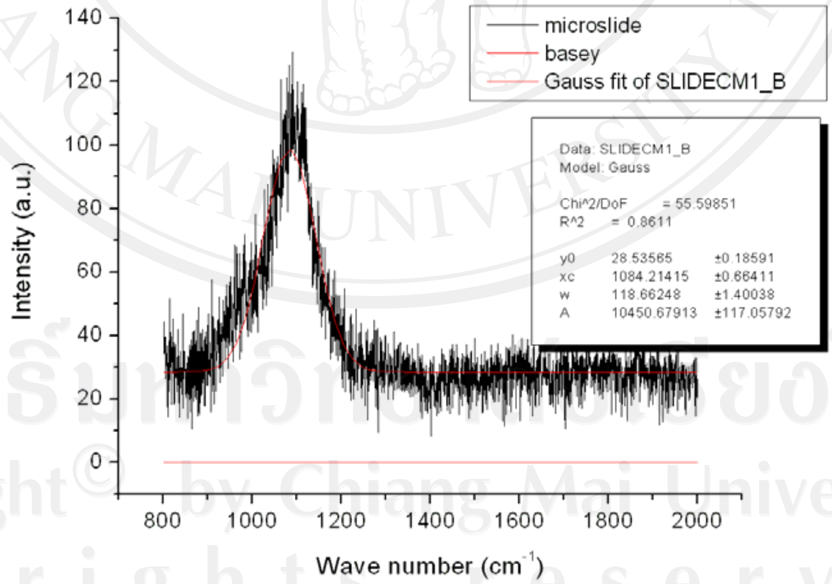
Raman spectra of Exp040 with Gaussian fit.



Raman spectra of Exp041 with Gaussian fit.



Raman spectra of Exp042 with Gaussian fit.



Raman spectra of the substrate.

APPENDIX B

Bipolar Plates

Appendix B-1 : Photo of contact angle.

Graphite

Bare SS304

ZnO

ZnO:Al

Nitride

Nitride+Carbide

Photo of water droplet on specimen surface.

Appendix B-2 : DOE bipolar plates technical targets.

<u>Technical Barriers</u>

(A) Durability

Improved corrosion resistance.
Decrease weight and volume

(B) Cost

Lower material & production costs.
Increased power density due to decreased thickness

(C) Performance

Improved gas impermeability.
Improved electrical and thermal conductivity.

<u>Technical Targets</u>

The targets are listed in following table (Adrianowycz et al., 2008) is the DOE high temperature performance and low cost manufacturing targets for 2010 and beyond.

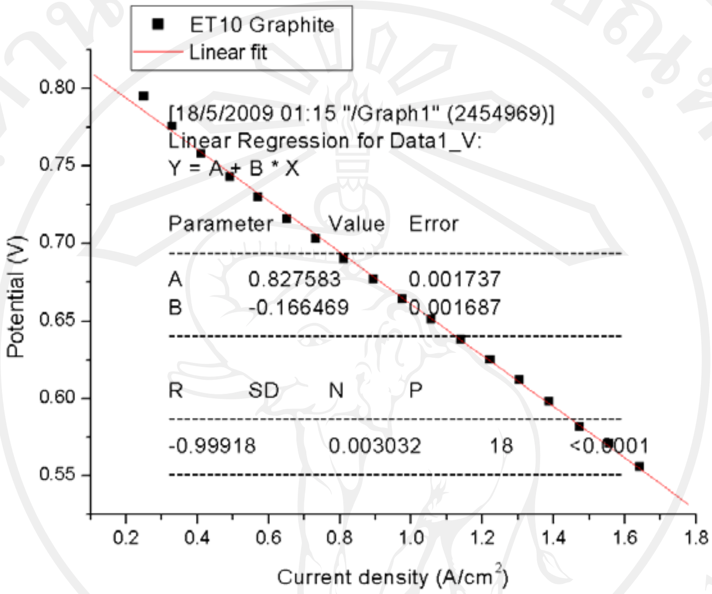
TABLE 1. DOE Technical Targets: Bipolar Plates (Table 3.4.14, Ref. 1)

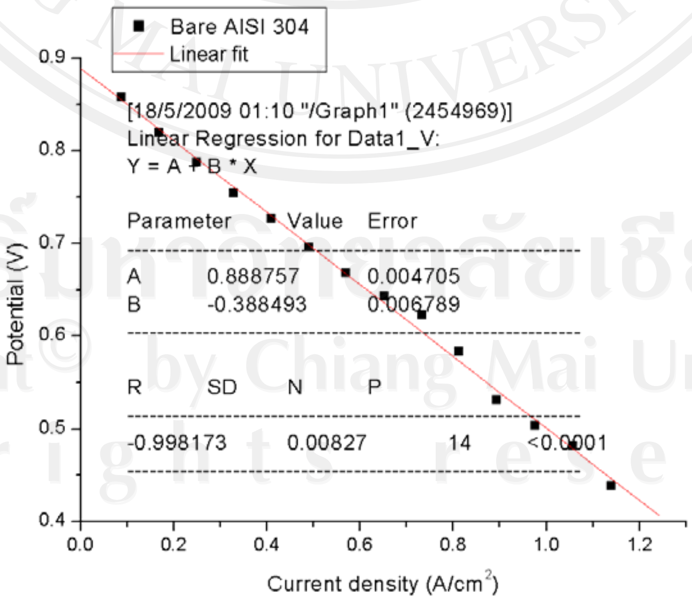
Characteristic	Units	2010/2015	Project 2008 Status
Cost[a]	\$/kW	5/3	TBD
Weight	kg/kW	<0.4	TBD
H_2 permeation flux	$cm^3\ sec^{-1}\ cm^{-2}$ at 80°C, 3 atm (equivalent to <0.1 mA/cm^2)	$<2 \times 10^{-6}$	TBD
Corrosion	$\mu A/cm^2$	<1[b]	<1[b]
Electrical conductivity	S/cm	>100	>1,000
Resistivity[c]	Ohm-cm	0.01	<0.010
Flexural Strength	MPa	>25	>55
Flexibility	% deflection at mid-span	3 to 5	TBD

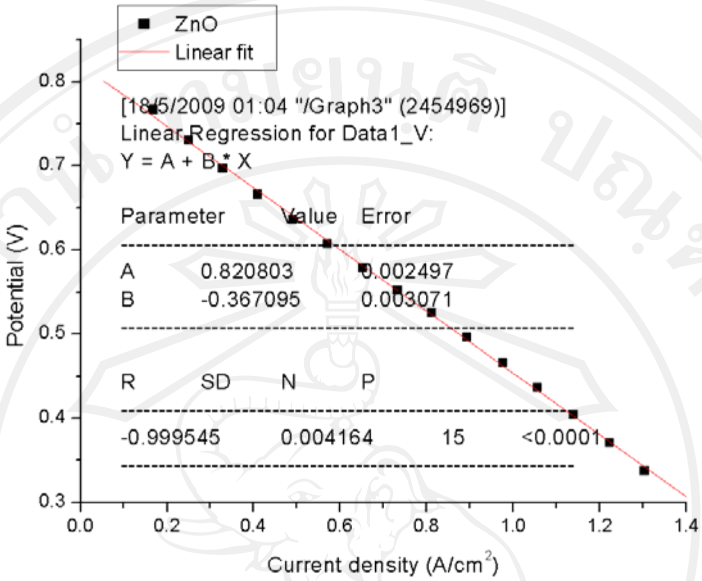
[a] Based on 2002 dollars and costs projected to high volume production (500,000 stacks per year).
[b] May have to be as low as 1 nA/cm if all corrosion product ions remain in ionomer for metal plates. Corrosion of flexible graphite plates is not an issue.
[c] Includes contact resistance.
[d] Developers have used ASTM C-651-91 using four point loading at room temperature.
TBD - to be determined

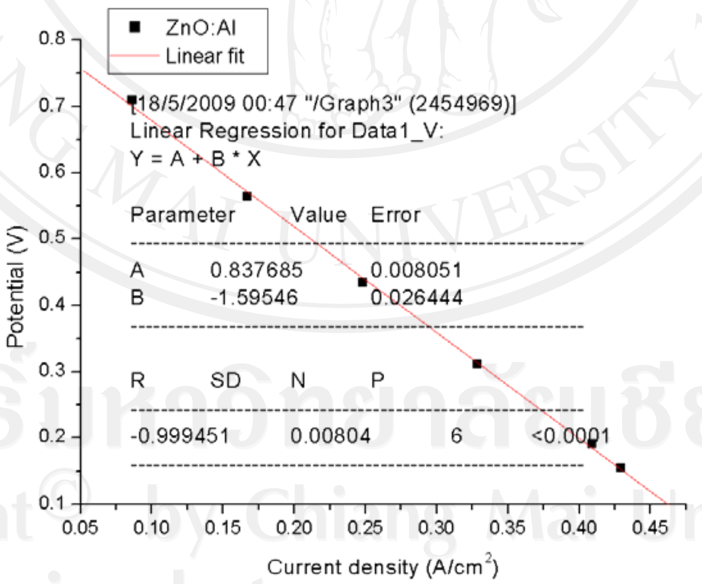
Appendix B-3 : Linear fit of polarization curve.

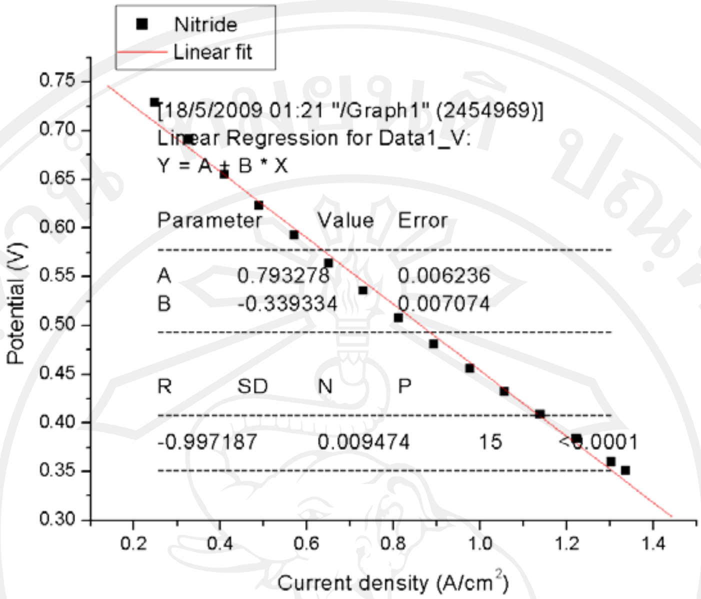
The linear fit of fuel cell polarization curve at center region (The cell potential drops linearly with current).

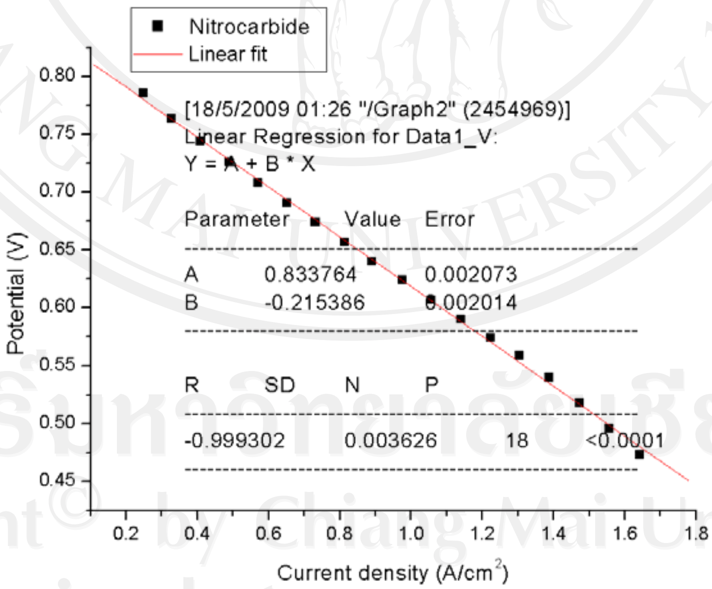





ZnO
Linear fit
[18/5/2009 01:04 "/Graph3" (2454969)]
Linear Regression for Data1_V:
Y = A + B * X
Parameter Value Error
A 0.820803 0.002497
B -0.367095 0.003071
R SD N P
-0.999545 0.004164 15 <0.0001
Potential (V)
Current density (A/cm2)


ZnO:Al
Linear fit
[18/5/2009 00:47 "/Graph3" (2454969)]
Linear Regression for Data1_V:
Y = A + B * X
Parameter Value Error
A 0.837685 0.008051
B -1.59546 0.026444
R SD N P
-0.999451 0.00804 6 <0.0001
Potential (V)
Current density (A/cm2)


Nitride
Linear fit
[18/5/2009 01:21 "/Graph1" (2454969)]
Linear Regression for Data1_V:
Y = A + B * X
Parameter Value Error
A 0.793278 0.006236
B -0.339334 0.007074
R SD N P
-0.997187 0.009474 15 <0.0001
Potential (V)
Current density (A/cm2)
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.2
0.4
0.6
0.8
1.0
1.2
1.4


Nitrocarbide
Linear fit
[18/5/2009 01:26 "/Graph2" (2454969)]
Linear Regression for Data1_V:
Y = A + B * X
Parameter Value Error
A 0.833764 0.002073
B -0.215386 0.002014
R SD N P
-0.999302 0.003626 18 <0.0001
Potential (V)
Current density (A/cm2)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

APPENDIX C

Publications and Presentation by Author

Publications:

[1] **S. Sansongsiri**, A. Andres and B. Yotsombat, *Electrical properties of a-C: Mo films produced by dual-cathode filtered cathodic arc plasma deposition*, Diamond & Related Materials, Vol. 17, pp. 2080-2083, 2008.

[2] N. Pasaja, **S. Sansongsiri**, S. Intarasiri, T. Vilaithong, A. Anders, *Mo-containing tetrahedral amorphous carbon deposited by dual filtered cathodic vacuum arc with selective pulsed bias voltage*, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Vol. 256, pp. 867-870, 2007.

[3] A. Anders, N. Pasaja and **S. Sansongsiri**, *Filtered cathodic arc deposition with ion-species-selective bias*, Review of scientific instruments, Vol. 78, 063901, 2007.

[4] **S. Sansongsiri**, B. Yotsombat, Ramon E. Galindo, M. Rhodes, T. Vilaithong and A. Anders, *Pulsed d.c. glow discharge nitridation and carburization of stainless steel for polymer electrolyte membrane fuel cell bipolar plates*, submitted for publication in J. Power Sources.

Presentations:

[1] **S. Sansongsiri**, B. Yotsombat and A. Anders, *Electrical properties of a-C:Mo films produced by dual-cathode filtered cathodic arc plasma deposition*, Poster presentation, CMU academic day 3, Chiang Mai University, Chiang Mai, Thailand, November 23-25, 2007.

[2] **S. Sansongsiri**, R. Escobar Galindo, B. Yotsombat, T. Vilaithong and A. Anders, *Development of conductive and non-corrosive coating for PEM fuel cell bipolar plates*, Poster presentation, SIAM PHYSICS CONGRESS 2008, Nakhon Ratchasima, Thailand, March 20-22, 2008.

[3] **S. Sansongsiri**, A. Andres and B. Yotsombat, *Electrical properties of a-C:Mo films produced by dual-cathode filtered cathodic arc plasma deposition*, Oral presentation, RGJ-Ph.D. Seminar LX, Chiang Mai, Thailand, March 28, 2008.

[4] **S. Sansongsiri**, B. Yotsombat, R. Escobar Galindo, M. Rhodes, T. Vilaithong, and A. Anders, *Pulsed d.c. glow discharge nitridation and carburization of stainless steel for polymer electrolyte membrane fuel cell bipolar plates,* Poster presentation, Fuel Cell Science & Technology 2008, Copenhagen, Denmark, October 8-9, 2008.

[5] **S. Sansongsiri**, B. Yotsombat, T. Vilaithong and A. Anders, *ZnO and ZnO:Al coated stainless steel bipolar plates for polymer electrolyte membrane fuel cell*, Poster presentation, CMU academic day 4, Chiang Mai University, Chiang Mai, Thailand, December 19-20, 2008.

CURRICULUM VITAE

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	1993-1997	B. Sc. (Physics)	Chiang Mai University
	2000-2002	M. Sc. (Physics)	Chulalongkorn University
Scholarship			
	2000-2006	The University Development Commission (UDC) scholarship in Physics, Commission on Higher Education.	
Training			
	2005-2006	Lawrence Berkeley National Laboratory (LBNL), Berkeley, USA.	