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APPENDICES

Appendix A Determination of ohmic's law regime.

Ohmic regime or linear regime is the regime in which applied voltage is limearly dependent on current according to ohmic's law in Equation A.1.

Due to the specific conductivity given by the Equation 3.1, the acceptable current which is used in the experiments should be in the ohmic's regime. Figures A.1 and A.2 are the plots of V_a and I using silicon wafer as a standard material and using polyaniline, respectively. These experiments were done under a pressure 1 atm, 46% relative humidity, and 26°C.

$$V_a=IR \tag{A.1}$$

where V_a = applied voltage (mV)

I = current (mA)

R = resistance (Ω).

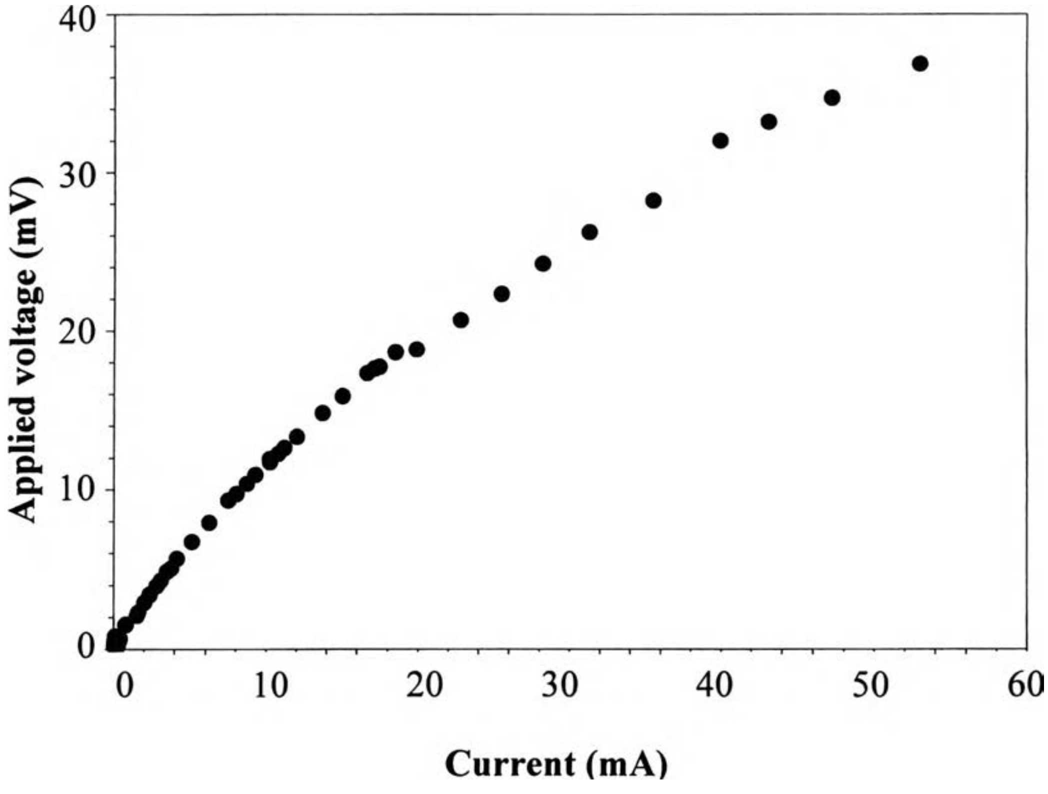


Figure A.1 The ohmic's law region of the current and the applied voltage by using the silicon wafer (Si10-28A) as a standard sheet.

From the Figure A.1, the current using for determination of geometric correction factor (K) of the probes should be in the range of 0-15 mA.

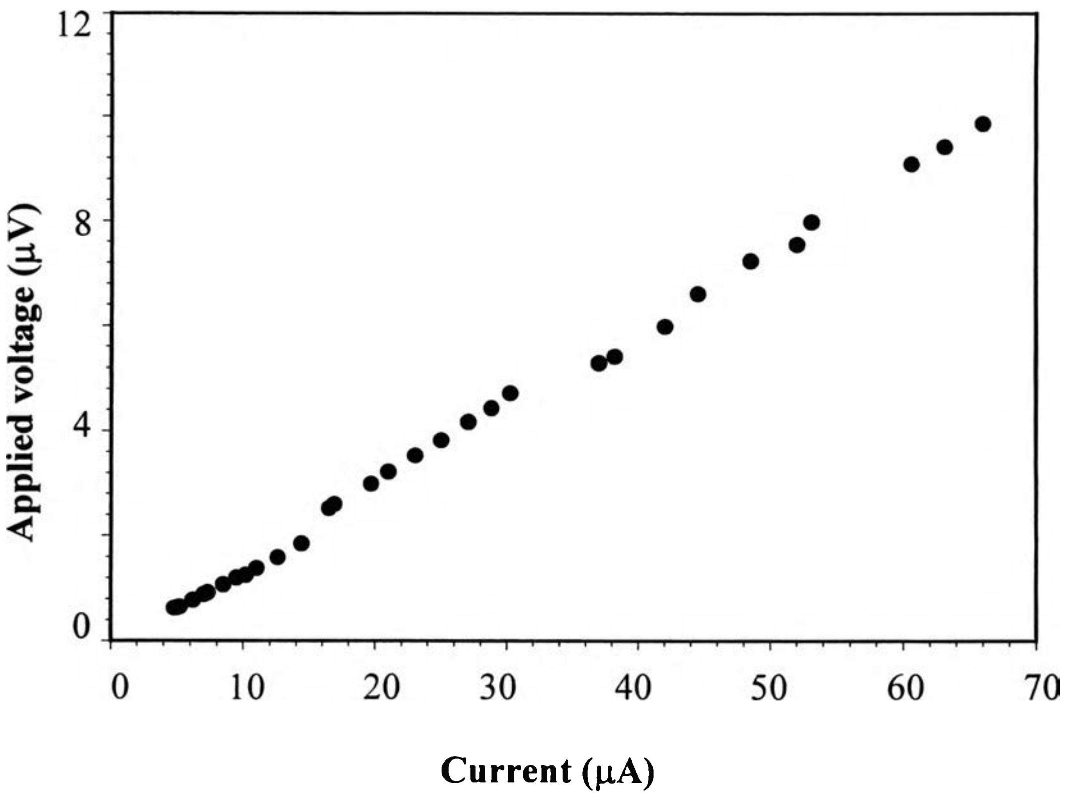
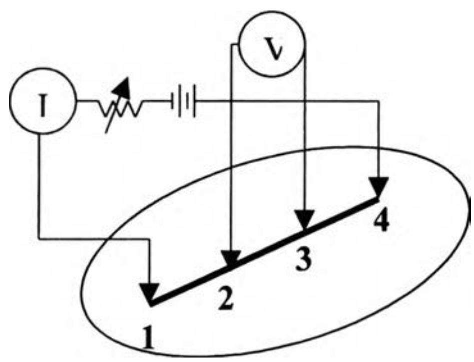


Figure A.2 The ohmic's law region of the current and the applied voltage by using the maleic acid doped polyaniline (PANI-HCl/MA) at doping ratio (N_A/N_{EB} =200) pellet.

From the Figure A.2, the current which could be used in the experiments should be in the range of 0-70 μA.

Appendix B Determination of the geometric correction factor (K).

The electrical conductivity of polyaniline thin film was commonly measured by a four point probe meter. Probe head assemblies are available in two different arrangements of the probe pins; the linear array and the square array. For the linear array, a constant current (I) was applied to the two outer electrodes and the sample voltage (V) was measured between the two inner electrodes as shown in Scheme B.



Scheme B A schematic of the linear array four point probe meter.

As in the case of microelectronic structures, four point probe sheet resistance measurements are susceptible to geometric error (K) which can be calculated by using Equation B.1.

$$K = \frac{w}{l} \tag{B.1}$$

where	K	=	correction factor
	w	=	probe width (cm)
	l	=	probe length (cm).

In this measurement, the constant K value was determined by using a standard sheet with a known resistivity value, we used silicon wafer chips (SiO). *K* was calculated by using Equation B.2.

$$K = \frac{\rho}{R \times t} = \frac{I \times \rho}{V \times t} \qquad \text{(B.2)}$$

where K = geometric correction factor

ρ = resistivity of stand materials which were calibrated from using a four point probe at King Mongkut's Institute Technology of Lad Krabang (Ω.cm)

t = film thickness (cm)

R = film resistance (Ω)

I = current (A)

V = Voltage drop (V).

The sheet resistivity (ρ) and thickness of silicon wafer chips are shown in Table B.1.

Table B.1 The sheet resistivity and thickness of standard sheet (SiO).

Standard No.	Material	Sheet Resistivity, ρ, (Ω.cm)	Thickness (cm)
11	Si 10-28A	3.50E+01	5.22E-02
22	SiO_B	9.23E-03	7.16E-02

Table B.2 Determination of K factor of the constructed four point probe meter (Probe A).

Condition : Temperature 26-28°C

Relative humidity 46-47%

Press 1 atm

Standard No.	I (mA)	V (mV)	K	Standard No.	I (mA)	V (mV)	K
11	.00077	1.03	4.97E-01	22	5.8	2.0	3.74E-01
	.00160	2.29	4.63E-01		6.5	2.0	4.19E-01
	.00158	2.99	3.52E-01		6.8	2.1	4.17E-01
	.00199	4.11	3.22E-01		7.9	2.4	4.24E-01
	.00213	3.65	3.88E-01		8.8	2.5	4.54E-01
	.00243	5.00	3.23E-01		9.1	2.6	4.51E-01
	.00281	5.30	3.53E-01		10.1	2.5	5.21E-01
	.00421	6.08	4.61E-01		10.8	3.2	4.51E-01
	.00502	6.35	5.26E-01		12.0	3.3	4.80E-01
	.00666	8.29	5.35E-01		12.5	3.4	4.74E-01
Average			4.22E-01	Average			4.74E-01
SD			0.084	SD			0.041
				K value			4.35E-01

Table B.3 Determination of K factor of the constructed four point probe meter (Probe B).

Condition : Temperature 26-27°C

Relative humidity 46-48%

Pressure 1 atm

Standard No.	I (mA)	V (mV)	K	Standard No.	I (mA)	V (mV)	K
11	.00165	2.75	3.99E-01	22	1.80	0.63	3.68E-01
	.00263	3.36	5.20E-01		2.80	1.01	3.57E-01
	.00268	3.50	5.08E-01		3.68	0.89	5.33E-01
	.00379	5.90	4.27E-01		3.72	1.10	4.36E-01
	.00385	6.40	4.00E-01		3.81	0.93	5.28E-01
	.00390	7.02	3.71E-01		4.29	1.02	5.42E-01
	.00455	6.82	4.45E-01		5.00	1.60	4.03E-01
	.00530	6.91	5.11E-01		6.74	1.63	5.11E-01
Average			4.48E-01	Average			4.60E-01
SD			0.058	SD			0.079
				K value			4.54E-01

Appendix C Conductivity measurement.

Specific conductivity values of polyaniline pellets were measured by using the four-point probe under the atmospheric pressure , 65-69 % relative humidity and 30.5-31.5°C. The K value of the probe is 0.454. The thickness of pellets were measured by a thickness gauge. The data of conductivity measurement are shown in Table C.1.

Table C.1 The raw data of conductivity measurement.

Acid	Doping ratio	Thickness (cm)	Applied voltage (mV)		Current (mA)		Voltage drop (mV)		σ (S/cm)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
EB1	0	0.0794	0.71	0.006	2.76E-05	8.17E-07	710.1	5.58	1.08E-06	2.84E-08
EB2	0	0.01055	0.76	0.057	3.65E-05	5.11E-06	772.5	56.83	9.85E-06	9.02E-07
EB3	0	0.01083	0.65	0.009	2.79E-05	8.55E-07	648.2	9.07	8.76E-06	2.29E-07
HBr	1	0.00819	0.79	0.006	0.065	0.008	320.5	35.55	0.055	0.009
HBr	1	0.01284	0.079	0.006	0.172	0.017	331	19.41	0.089	0.009
HBr	4	0.00748	0.665	0.717	0.064	0.033	42.85	17.73	0.428	0.078
HBr	4	0.0104	40.19	16.93	0.095	0.041	40.087	16.95	0.499	0.013
HBr	40	0.0097	0.003	4.22E-04	0.026	0.004	0.279	0.029	2.14E+01	0.802
HBr	40	0.00759	0.108	0.0068	0.019	0.005	0.11	0.007	4.93E+01	12.5
HBr	80	0.01275	0.072	0.016	0.1	0.015	0.4	0.132	4.25E+01	9.215
HBr	80	0.01293	0.084	0.013	0.088	0.018	0.4	0.125	4.05E+01	6.182
HBr	400	0.01289	11.43	3.78	0.085	0.025	2.98	0.922	4.87E+00	0.23
HBr	400	0.0125	9.52	2.681	0.069	0.016	2.32	0.199	5.23E+00	0.89
HBr	600	0.00998	7.85	1.29	0.0984	0.007	2.33	0.183	8.01E+00	0.97
HBr	600	0.01156	8.76	0.378	0.08	0.007	2.1	2.3	6.64E+00	0.58
HBr	800	0.01022	8.11	0.264	0.081	0.007	2.2	0.205	7.99E+00	1
HBr	800	0.0184	8.43	0.067	0.104	0.012	1.78	9.20E-02	6.99E+00	0.68
HBr	1295	0.00778	0.069	0.014	1.909	0.463	59.4	12.62	9.07E+00	0.73
HBr	1295	0.00759	0.104	0.009	2.904	0.77	109.1	7.71	7.19E+00	2.12

Acid	Doping ratio	Thickness (cm)	Applied voltage (mV)		Current (mA)		Voltage drop (mV)		σ (S/cm)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
CSA	1	0.01469	2.1	0.403	0.009	0.001	78.2	3.27	1.65E-02	0.002
CSA	1	0.0132	2.33	0.717	0.013	0.005	89.7	7.4	2.44E-02	0.009
CSA	4	0.01253	2.4	0.1	0.123	0.018	7.2	0.212	3.03E+00	0.45
CSA	4	0.01159	2.4	0.1	0.172	0.014	7.3	0.116	4.46E+00	0.41
CSA	40	0.01659	11.47	0.68	0.697	0.176	9.1	1.15	1.03E+01	2.69
CSA	40	0.00843	13.04	0.692	0.797	0.044	14.8	0.888	1.41E+01	0.614
CSA	80	0.01529	0.082	0.019	0.103	0.017	1.5	0.301	9.94E+00	0.44
CSA	80	0.01442	0.044	0.016	0.074	0.014	1.5	0.264	7.44E+00	0.8
CSA	120	0.01114	0.018	0.002	0.006	0.001	8.3	0.51	1.42E-01	0.015
CSA	120	0.0102	0.015	0.001	0.006	0.001	9.6	0.471	1.30E-01	0.011
CSA	160	0.00973	99.94	57.26	0.057	0.038	532.1	348.35	2.46E-02	0.001
CSA	160	0.01335	14.81	2.74	0.067	0.041	216.4	121.11	5.04E-02	0.007
CSA	200	0.0121	82.17	4.97	0.044	0.019	124.96	45.05	6.26E-02	0.004
CSA	200	0.0115	55.72	0	0.049	0.015	253.2	11.3	4.15E-02	0.01
CSA	250	0.0124	124.7	45	0.041	0.014	117.5	35.23	6.09E-02	0.001
CSA	250	0.0119	45.4	13	0.048	0.006	212.3	10.52	4.22E-02	0.001

Acid	Doping ratio	Thickness (cm)	Applied voltage (mV)		Current (mA)		Voltage drop (mV)		σ (S/cm)	
			Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
MA	1	0.00916	1.16	0.057	0.06	0.009	2130	48.31	7.31E-03	0.001
MA	1	0.00854	1.42	0.155	0.081	0.004	2225	113.65	9.44E-03	0.001
MA	4	0.0062	0.008	0	0.042	0.004	106.5	2.42	1.51E-01	0.02
MA	4	0.0085	0.011	0.004	0.078	0.004	101.5	2.42	6.59E-02	0.001
MA	40	0.0139	0.052	0.026	0.073	0.02	4.2	0.0786	2.71E+00	0.36
MA	40	0.0139	0.088	0.016	0.099	0.01	9.4	0.249	1.68E+00	0.19
MA	80	0.0151	0.054	0.026	0.073	0.02	2.0	0.682	5.47E+00	0.47
MA	80	0.013	0.081	0.014	0.095	0.009	2.4	0.053	6.87E+00	0.58
MA	200	0.013	0.049	0.017	0.075	0.015	0.6	0.228	2.11E+01	4.17
MA	200	0.0144	0.079	0.043	0.12	0.036	0.6	0.346	3.52E+01	10.04
MA	400	0.0097	0.108	0.007	0.019	0.005	0.5	0.063	7.62E+00	1.29
MA	400	0.0162	0.082	0.019	0.103	0.017	1.5	0.301	9.36E+00	0.41
MA	600	0.0147	0.084	0.019	0.071	0.016	2.1	0.603	5.13E+00	0.28
MA	600	0.0103	0.08	0.018	0.067	0.013	2	0.565	7.15E+00	0.64
MA	800	0.008	0.101	0.008	0.081	0.01	2.5	0.289	8.94E+00	0.35
MA	800	0.0075	0.093	0.008	4.304	0.608	127.2	8.657	9.93E+00	0.96
MA	1295	0.0095	0.0062	0.0021	0.062	0.005	1.4	0.112	1.04E+01	1.24
MA	1295	0.0148	236.5	58.2	6.147	0.414	89.5	5.469	1.03E+01	1.12
MA	1391	0.0144	236.5	58.2	7.06	0.463	236.5	58.2	4.78E+00	0.94
MA	1391	0.0136	31.1	12.8	4.495	1.251	149.7	48.5	4.93E+00	0.34

Appendix D % Bipolaron and % polaron determination by UV-Visible spectrometer.

According to Beer's law (Chambell and White, 1989),

$$A_i = a_i b_i c_i \qquad \text{(D.1)}$$

where A_i = area of each peak

a_i = absorptivity (cm^2/g)

b_i = path length (cm)

c_i = concentration of emeraldine base in solution (g/cm^3).

The calibration curves in which the areas are plotted as a function of the concentration of emeraldine base in the solution can give some important peaks. They are ~ 325 nm representing the benzenoid part, ~440 nm showing the bipolaron part, ~625 nm presenting the quinoid part, and ~700-900 nm giving the polaron part. The slopes of the calibration curves, thus, provide the products of absorptivity of particular species, a_i and the path length, b_i. Normally, the using path length, b_i is equal to 1 cm. In order to obtain the amount of the polaron and bipolaron in an unknown sample, they are often provided by the following Equation;

$$C_i = A_i/a_i b_i \qquad \text{(D.2)}$$

Hence, the % bipolaron and % polaron could be calculated by below Equations if total amounts of the benzenoid, quinoid, bipolaron, and polaron part are known.

$$A_{BZ} + A_{BP} + A_Q + A_P = A_{total} \quad (D.3)$$

$$\% \text{ bipolaron} = (A_{BP}/A_{total})100 \quad (D.4)$$

$$\% \text{ polaron} = (A_P/A_{total})100 \quad (D.5)$$

The area of each peaks which presented in UV-Visible spectrum could be calculated by using the Gaussian's Equation (Tripreuttonya, 1994).

$$(1/((S.D)(2\pi)^{0.5}))\exp(0.5((x - \bar{x})/S.D)^2) \quad .(D.6)$$

The calibration curves of HBr, CSA, and maleic acid are shown in Figures D.1-D3.

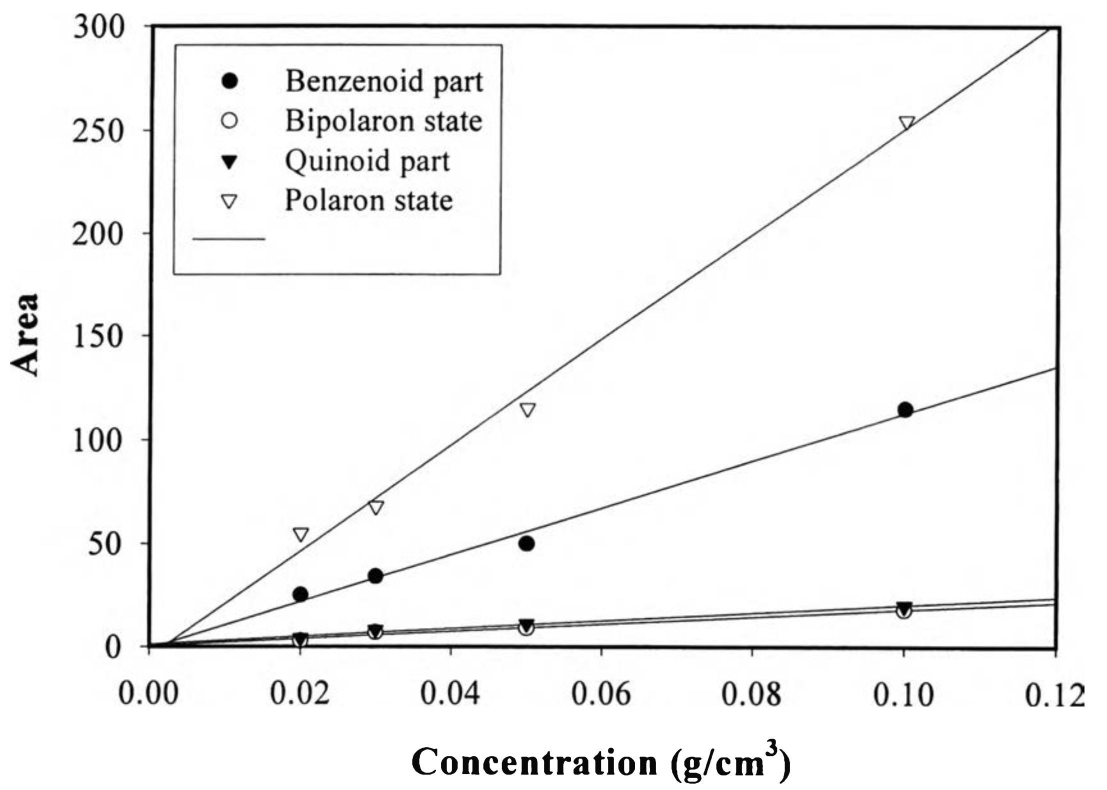


Figure D.1 The calibration curve of HBr doped polyaniline.

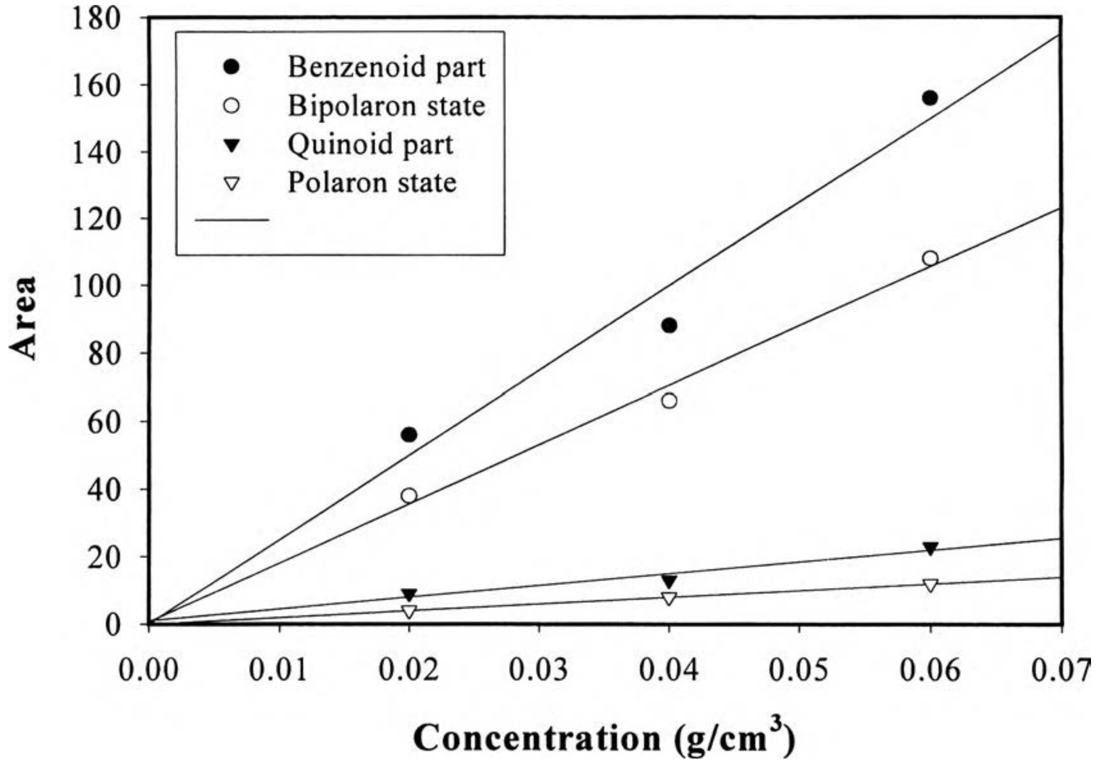


Figure D.2 The calibration curve of CSA doped polyaniline.

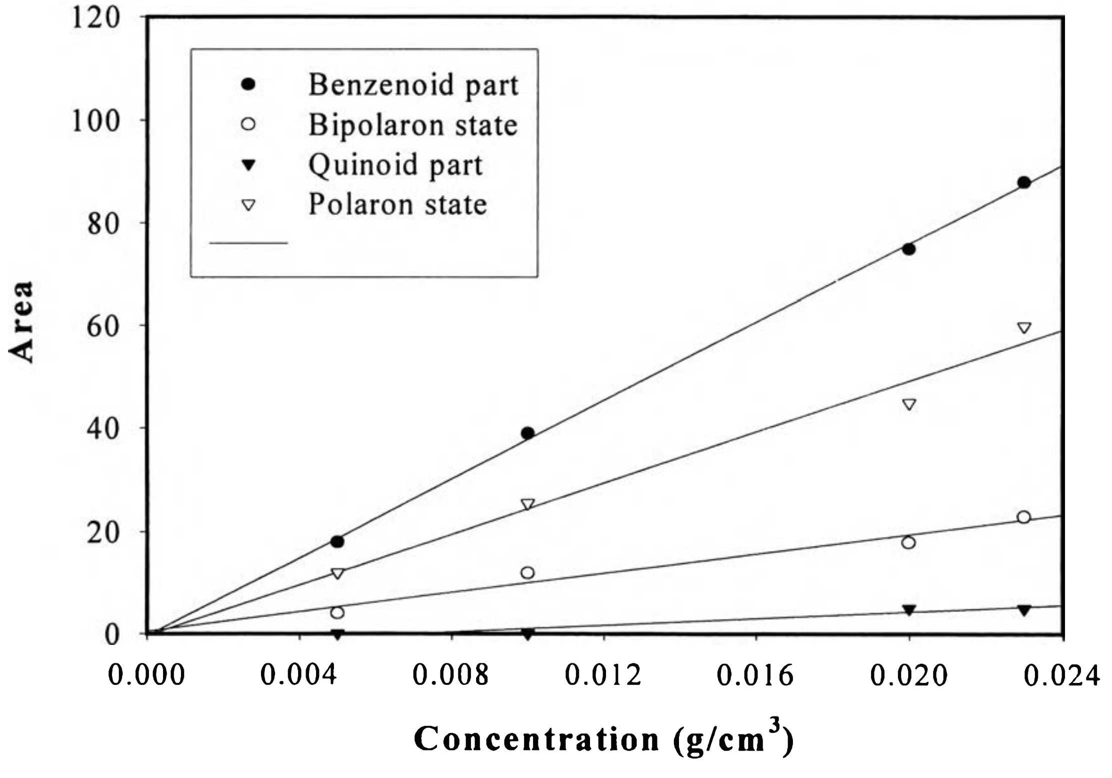


Figure D.3 The calibration curve of maleic acid doped polyaniline.

From Equation D.1, the slopes of the calibration curves, thus, provide products of absorptivity of particular species, a_i and the path length b_i. Table D.1 shows the products of the absorptivity, a_i, of particular species of doped polyaniline and the path lengths, b_i.

Table D.1 The products absorptivity (a_i) of particular species of doped polyaniline and the path lengths, b_i.

Doped PANI	$a_{Benzenoid} \times b_i$ (cm^3/g)	$a_{Bipolaron} \times b_i$ (cm^3/g)	$a_{Quinoid} \times b_i$ (cm3/g)	$a_{Polaron} \times b_i$ (cm^3/g)
PANI/HBr	1.14e+3	1.76e+2	1.89e+2	2.56e+3
PANI/CSA	2.50e+3	1.75e+3	3.50e+2	2.00e+2
PANI/MA	3.82e+3	9.50e+2	3.28e+2	2.48e+3

Table D.2 The raw data of the calibration curves of doped polyaniline.

Acid	Concentration (g/cm^3)	Area			
		Benzenoid	bipolaron	Quinoid	Polaron
HBr	0.02	25	3	4	55
	0.03	34	7	8	68
	0.05	50	9	11	115
	0.1	115	18	20	255
CSA	0.02	56	38	9	4
	0.04	88	66	13	8
	0.06	156	108	23	12
MA	0.005	18	4	0.01	12
	0.01	39	12	0.01	25.5
	0.02	75	18	5	45
	0.023	88	23	5	60

Table D.3 The raw data of % bipolaron and % polaron determination.

Acid	Doping ratio	Area				Concentration (g/cm^3)				%				%BP +%P
		BZ	BP	Q	P	BZ	BP	Q	P	BZ	BP	Q	P	
HBr	1	150	20	15	322	1.33E-01	1.14E-01	7.94E-02	1.26E-01	29.4	25.17	17.58	27.86	53.02
	4	144.0	22.00	15.00	300.0	1.27E-01	1.25E-01	7.94E-02	1.17E-01	28.38	27.84	17.68	26.1	53.94
	40	95.05	17.02	15.00	287.1	8.41E-02	9.67E-02	7.94E-02	1.12E-01	22.59	25.97	21.32	30.12	56.09
	80	91.79	15.59	15	285.5	8.12E-02	8.86E-02	7.94E-02	1.12E-01	22.52	24.56	22	30.92	55.47
	400	16	10	13	260	1.42E-02	5.68E-02	6.88E-02	1.02E-01	5.867	23.54	28.5	42.09	65.63
	600	16	8.3	10	250	1.42E-02	4.72E-02	5.29E-02	9.77E-02	6.683	22.26	24.97	46.09	68.34
	800	16	6.02	8	100	1.42E-02	3.42E-02	4.23E-02	3.91E-02	10.91	26.36	32.62	30.1	56.46
	1295	15	7.02	4	70	1.33E-02	3.99E-02	2.12E-02	2.73E-02	13.06	39.23	20.82	26.9	66.12
CSA	1	185	35	80	371	7.40E-02	2.00E-02	2.29E-01	1.86E+00	3.3983	0.918	10.5	85.19	86.10
	4	172	38	70	410	6.88E-02	2.17E-02	2.00E-01	2.05E+00	2.94	0.928	8.545	87.59	88.51
	40	205	36.1	33.5	330	8.20E-02	2.06E-02	9.57E-02	1.65E+00	4.436	1.116	5.178	89.27	90.38
	80	198	34.3	10	230	7.92E-02	1.96E-02	2.86E-02	1.15E+00	6.2	1.534	2.237	90.03	91.56
	120	198	32.8	3.5	200	7.92E-02	1.87E-02	1.00E-02	1.00E+00	7.148	1.692	0.903	90.26	91.94
	160	198	30.5	3.4	195	7.92E-02	1.74E-02	9.71E-03	9.75E-01	7.324	1.612	0.898	90.17	91.77
	200	63	22.9	3.5	180	2.52E-02	1.31E-02	1.00E-02	9.00E-01	2.657	1.38	1.055	94.91	96.28
	250	48	12	3	143	1.92E-02	6.86E-03	8.57E-03	7.15E-01	2.561	0.915	1.143	95.38	96.29
MA	1	190	1.8	435	0.454	4.97E-02	1.89E-03	1.3E+00	1.83E-04	3.609	0.137	96.24	0.013	0.150
	4	18.7	2	426	0.498	4.90E-03	2.10E-03	1.3E+00	2.01E-04	0.375	0.161	99.45	0.015	0.176
	40	150	250	95.1	180	3.93E-02	2.63E-01	2.9E-01	7.26E-02	5.908	39.55	43.62	10.92	50.47
	80	130	130	3	215	3.40E-02	1.37E-01	9.1E-03	8.67E-02	12.77	51.28	3.431	32.52	83.80
	200	68	140	206	20	1.78E-02	1.47E-01	6.3E-01	8.06E-03	2.222	18.38	78.4	1.007	19.38
	400	299	5	125	0.2	7.83E-02	5.26E-03	3.8E-01	8.06E-05	16.84	1.131	82.01	0.017	1.148
	600	175	7.97	200	0	4.58E-02	8.38E-03	6.1E-01	0.00E+00	6.9	1.262	91.84	0	1.262
	800	36	7.97	0	36	9.42E-03	8.38E-03	0.0E+00	1.45E-02	29.16	25.93	0	44.91	70.84
	1295	35	9.97	0	743	9.16E-03	1.05E-02	0.0E+00	3.00E-01	2.87	3.284	0	93.85	97.13
	1320	299	5	131	0.125	7.83E-02	5.26E-03	4.0E-01	5.04E-05	24.52	1.647	125.1	0.016	1.662

Table D.4 The amount of % bipolaron and % polaron of doped polyaniline at various doping ratios versus the conductivity in air.

Acid	Doping ratio	%BP	%P	%BP+%P	σ1 (S/cm)	σ2 (S/cm)
HBr	1	25.17	27.86	53.02	0.055	0.089
	4	27.84	26.10	53.94	0.428	0.499
	40	25.97	30.12	56.09	2.14E+01	4.93E+01
	80	24.56	30.92	55.48	4.25E+01	4.05E+01
	400	23.54	42.09	65.63	4.87	5.23
	600	22.26	46.09	68.35	8.01	6.64
	800	26.36	30.10	56.47	7.99	6.99
	1295	39.23	26.90	66.13	9.07	7.19
CSA	1	0.92	85.19	86.11	1.65E-02	2.44E-02
	4	0.93	87.59	88.52	3.03	4.46
	40	1.12	89.27	90.39	1.03E+01	1.41E+01
	80	1.53	90.03	91.56	9.94	7.44
	120	1.69	90.26	91.95	1.42E-01	1.30E-01
	160	1.61	90.17	91.78	2.46E-02	5.04E-02
	200	1.38	94.91	96.29	6.26E-02	4.15E-02
	250	0.91	95.38	96.30	6.09E-02	4.22E-02
MA	1	0.14	0.01	0.15	7.31E-03	9.44E-03
	4	0.16	0.02	0.18	1.51E-01	6.59E-02
	40	39.55	10.92	50.47	2.71	1.68
	80	51.28	32.52	83.80	5.47	6.87
	200	18.38	1.01	19.38	2.11E+01	3.52E+01
	400	1.13	0.02	1.15	7.62	9.36
	600	1.26	0.00	1.26	5.13	7.15
	800	25.93	44.91	70.84	8.94	9.93
	1295	3.28	93.85	97.13	1.04E+01	1.03E+01
	1320	1.09	0.01	1.10	4.78	4.93

Appendix E Calculation of number of charge carrier (n).

The conductivity, σ, is proportional to the product of the free-carrier concentration, n, and the carrier mobility, μ, according to the following Equation:

$$\sigma = ne\mu \quad (1)$$

where e is the unit electronic charge, 1.6×10^{-9}C (Smith, 1974).

The charge carriers of polyaniline are present in terms of bipolaron and polaron species which have two and one unit charges, respectively, in each repeating unit of polyaniline. The number of repeat unit (N) in polyaniline can be calculated from the molecular weight of polyaniline (M_w) divided by the molecular weight of repeating unit of polyaniline (MW). Because the molecular weight of polyaniline was 22,000 (Matt, 1999), so the number of repeat unit (N) was 61. The numbers of charge carrier of bipolaron and polaron species could be calculated by the following Equations:

$$n_{BP} = (2\times\%BP\times N)100 \quad (E.1)$$

$$n_{P} = (\%P\times N)100 \quad (E.2)$$

So that, the total number charge carrier of polyaniline (n) is the sum of the numbers of bipolaron and polaron species as shown in Equation (E.3).

$$n = n_{BP} + n_{P} \quad (E.3)$$

The relationship between the total number of charge carrier of polyaniline (n) versus the measured conductivity in air is shown in Table E.1.

Table E.1 The total number of charge carrier of polyaniline (n) versus the measured conductivity in air.

Acid	Doping ratio	%BP	%P	%BP+ %P	n_{BP}	n_P	n	σ (S/cm)	
								1	2
HBr	1	25.17	27.86	53.03	30.59	16.93	47.52	5.50E-02	8.90E-02
	4	27.84	26.10	53.94	33.84	15.86	49.70	4.28E-01	4.99E-01
	40	25.97	30.12	56.09	31.57	18.30	49.87	2.14E+01	4.93E+01
	80	24.56	30.92	55.48	29.85	18.79	48.64	4.25E+01	4.05E+01
	400	23.54	42.09	65.63	28.62	25.58	54.19	4.87E+00	5.23E+00
	600	22.26	46.09	68.35	27.05	28.01	55.06	8.01E+00	6.64E+00
	800	26.36	30.10	56.47	32.04	18.29	50.33	7.99E+00	6.99E+00
	1295	39.23	26.90	66.13	47.68	16.34	64.03	9.07E+00	7.19E+00
CSA	1	0.918	85.19	86.11	1.12	51.77	52.88	1.65E-02	2.44E-02
	4	0.928	87.59	88.52	1.13	53.23	54.35	3.03E+00	4.46E+00
	40	1.12	89.27	90.39	1.36	54.25	55.61	1.03E+01	1.41E+01
	80	1.53	90.03	91.56	1.86	54.71	56.58	9.94E+00	7.44E+00
	120	1.69	90.26	91.95	2.06	54.85	56.91	1.42E-01	1.30E-01
	160	1.61	90.17	91.78	1.96	54.79	56.75	2.46E-02	5.04E-02
	200	1.38	94.91	96.29	1.68	57.68	59.35	6.26E-02	4.15E-02
	250	0.915	95.38	96.30	1.11	57.96	59.07	6.09E-02	4.22E-02

Acid	Doping ratio	%BP	%P	%BP+ %P	n_{BP}	n_P	n	σ (S/cm)	
								1	2
MA	1	0.137	0.01	0.15	0.17	0.01	0.18	7.31E-03	9.44E-03
	4	0.161	0.02	0.18	0.20	0.01	0.21	1.51E-01	6.59E-02
	40	39.55	10.92	50.47	48.07	6.64	54.71	2.71E+00	1.68E+00
	80	51.28	32.52	83.80	62.33	19.76	82.09	5.47E+00	6.87E+00
	200	18.37	1.01	19.38	22.33	0.61	22.95	2.11E+01	3.52E+01
	400	1.13	0.02	1.15	1.38	0.01	1.39	7.62E+00	9.36E+00
	600	1.26	0.00	1.26	1.53	0.00	1.53	5.13E+00	7.15E+00
	800	25.93	44.91	70.84	31.51	27.29	58.81	8.94E+00	9.93E+00
	1295	3.28	93.85	97.13	3.99	57.03	61.02	1.04E+01	1.03E+01
	1320	1.08	0.01	1.10	1.32	0.01	1.33	4.78E+00	4.93E+00

Appendix F Sensitivity measurement ($\Delta\sigma$).

Specific conductivity of polyaniline pellets were measured by using the four point probe at various CO/N_2 concentrations under the pressure guage of 1 atm, 65-69% relative humidity and 30.5-31.5°C. The thickness of pellets was measured by a thickness gauge. Sensitivity ($\Delta\sigma$) was calculated by the following Equation;

$$\Delta\sigma = \sigma_{CO} - \sigma_{air} \qquad \text{(F.1)}$$

where; $\Delta\sigma$ = Sensitivity (S/cm)

σ_{CO} = Specific conductivity in CO (S/cm)

σ_{air} = Specific conductivity in air (S/cm).

The data of sensitivity measurement are shown in the Table F.1 and Table F.2.

Table F.1 The data of sensitivity measurement of doped polyaniline in CO/N_2 at various concentrations by using four point probe (K=0.454).

Acid	Doping ratio	Thickness (cm)	CO/N2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
CSA	40	0.0172	0	0.125	2.36E-03	27.83	0.365	0.7	8.20E-02	5.15	0.573	0
			1000	0.144	6.39E-03	24.69	0.35	5.69	0.779	0.569	0.1	-4.58
			500	0.158	3.11E-03	23.89	0.235	6.65	0.478	0.462	0.036	-4.69
			250	0.156	6.39E-03	21.28	0.369	4.92	0.469	0.559	0.061	-4.59
			125	0.153	6.30E-03	21.17	0.328	5.1	0.385	0.535	0.045	-4.62
			62.5	0.156	5.07E-03	20.87	0.375	4.66	0.399	0.578	0.056	-4.57
			31.25	0.154	6.33E-03	20.23	0.276	4.44	1.392	0.689	0.384	-4.46
			15.63	0.156	4.97E-03	21.06	0.393	3.78	0.713	0.738	0.14	-4.41
			7.82	0.149	3.16E-03	20.67	0.432	3.46	0.401	0.774	0.084	-4.38
			3.91	0.155	9.66E-02	20.58	0.391	2.86	0.639	0.966	0.214	-4.19
			1.96	0.153	5.71E-03	20.51	0.275	2.56	0.787	1.1	0.277	-4.05
			0.975	0.153	4.80E-03	20.12	0.242	1.76	0.206	1.48	0.175	-3.67
CSA	80	0.01299	0	0.054	5.48E-03	44.6	0	1.24	0.182	6.48	0.957	0
			1000	0.106	0.054	44.6	0	1.5	0.229	5.42	4.09	-1.06
			500	0.163	0.01	44.6	0	1.96	0.336	4.17	0.943	-2.31
			250	0.171	0.007	44.6	0	1.96	0.32	4.13	0.649	-2.34
			125	0.17	0	44.7	0	2.09	0.078	3.79	0.141	-2.68
			62.5	0.17	0	44.7	0	1.93	0.253	4.18	0.578	-2.29
			31.25	0.17	0	44.6	0	1.744	0.467	4.91	1.45	-1.57
			15.63	0.17	0	44.6	0	1.64	0.202	4.58	1.01	-1.89
			7.82	0.17	0	44.6	0	1.56	0.68	5.9	2.19	-0.57
			3.91	0.17	0	44.6	0	1.37	0.326	5.99	1.05	-0.47
			1.96	0.17	0	44.6	0	1.27	0.064	6.22	0.313	-0.26
			0.975	0.17	0	44.6	0	1.19	0.127	6.71	0.711	0.23

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
CSA	200	0.00981	0	0.179	5.39E-03	85.27	9.52	2.54	2.04	11.04	4.61	0
			1000	0.175	6.50E-03	84.56	1.57	6.94	0.819	2.79	0.582	-8.24
			500	0.18	0	84.13	1.68	8.8	1.49	2.01	0.46	-9.03
			250	0.17	0	83.14	1.34	10.48	2.48	1.73	0.5	-9.3
			125	0.19	0	102.09	10.5	9.09	2.6	2.93	1.92	-8.11
			62.5	0.18	0	108.98	2.58	7.32	0.8	3.38	0.33	-7.66
			31.25	0.18	0	103.03	2.94	5.83	1.6	4.5	2.2	-6.53
			15.63	0.18	0	103.56	1.14	5.18	0.88	4.65	0.94	-6.39
			7.82	0.19	0	79.54	1.13	3.95	0.88	4.71	0.91	-6.33
			3.91	0.18	0	81.61	1.09	3.7	0.67	4.78	1.2	-6.26
			1.96	0.18	0.01	80.28	1.36	3.48	0.59	5.32	0.97	-5.71
			0.975	0.18	0	78.16	1.47	3.25	0.22	5.43	0.33	-5.61
MA	40	0.01245	0	0.05	0	51.25	0.05	1.46	0.08	6.24	0.34	0
			1000	0.05	0	51.2	0	1.84	0.1	4.92	0.26	-1.32
			500	0.05	0	51.28	0.04	1.87	0.05	4.86	0.13	-1.38
			250	0.05	0	51.2	0.03	1.97	0.07	4.61	0.15	-1.63
			125	0.05	0	51.2	0.03	1.83	0.07	4.95	0.18	-1.3
			62.5	0.05	0	51.88	0.13	1.73	0.11	5.34	0.35	-0.9
			31.25	0.05	0	51.69	0.25	1.6	0.13	5.75	0.46	-0.5
			15.63	0.05	0	52	0	1.49	0.03	5.78	1.3	-0.46
			7.82	0.05	0	51.75	0.26	1.5	0.09	6.1	0.37	-0.14
			3.91	0.05	0	51.21	0.12	1.48	0.05	6.15	0.18	-0.09
			1.96	0.05	0	51.39	0.11	1.48	0.07	6.18	0.31	-0.06
			0.975	0.05	0	51.41	0.12	1.48	0.13	6.21	0.56	-0.04

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
CSA	200	0.01175	0	0.194	1.20E-02	146.34	9.43	2.63	0.411	10.25	3.13	0
			1000	0.163	5.00E-03	143.83	8.82	7.1	0.364	4.07	0.774	-6.18
			500	0.182	0.011	147.03	10.81	7.44	0.189	3.76	0.689	-6.49
			250	0.197	0.008	161.42	10.94	8.16	0.356	3.99	0.478	-6.26
			125	0.217	0.029	186.14	6.09	7.4	0.397	4.67	1.06	-5.59
			62.5	0.229	0.008	186.26	7.03	7.09	0.493	4.91	0.696	-5.35
			31.25	0.228	0.008	157.62	56.4	6.27	1.4	5.13	2.26	-5.12
			15.63	0.218	0.001	73.31	0.867	2.92	0.792	5.23	1.26	-5.02
			7.82	0.241	0.027	71.93	0.699	5.68	0.283	5.31	0.511	-4.94
			3.91	0.234	0.002	72.81	0.637	5.68	0.452	5.47	0.879	-4.78
			1.96	0.239	0.005	74.94	0.978	2.37	0.172	6.22	0.407	-4.03
			0.975	0.247	0.001	76.03	0.344	2.35	0.258	6.41	0.726	-3.84
MA	40	0.0138	0	0.054	0.001	57.24	0.101	2.3	0.1	4.15	0.17	0
			1000	0.053	0.001	57.32	0.132	3.53	0.349	2.73	0.257	-1.42
			500	0.052	0	57.43	0.067	3.58	0.379	2.69	0.279	-1.45
			250	0.053	0	57.3	0.094	3.77	0.353	2.55	0.259	-1.59
			125	0.052	0.001	57.27	0.05	3.23	0.206	2.96	0.186	-1.19
			62.5	0.052	0	57.23	0.07	2.91	0.166	3.29	0.207	-0.87
			31.25	0.053	0	57.22	0.114	2.67	0.258	3.59	0.338	-0.55
			15.63	0.052	0	57.15	0.069	2.55	0.19	3.75	0.274	-0.4
			7.82	0.053	0	57.18	0.048	2.37	0.082	4.02	0.135	-0.13
			3.91	0.053	0	54.12	2.95	2.24	0.186	4.05	0.33	-0.11
			1.96	0.052	0	57.21	0.11	2.35	0.108	4.06	0.183	-0.09
			0.975	0.052	0.001	57.25	0.097	2.35	0.165	4.08	0.294	-0.08

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
MA	80	0.00965	0	0.055	4.22E-04	56.36	0.052	1.7	0.078	7.91	0.361	0
			1000	0.056	9.49E-04	56.42	0.063	4.9	0.516	2.77	0.304	-5.14
			500	0.056	7.38E-04	56.49	0.032	5.01	0.331	2.69	0.177	-5.22
			250	0.056	6.32E-04	56.51	0.032	4.86	0.455	2.79	0.258	-5.12
			125	0.056	6.67E-04	56.47	0.067	4.28	0.355	3.16	0.254	-4.75
			62.5	0.054	6.32E-04	56.54	0.084	4.14	0.284	3.27	0.221	-4.65
			31.25	0.055	3.16E-04	56.51	0.032	3.72	0.41	3.66	0.429	-4.25
			15.63	0.053	6.32E-04	56.52	0.079	3.48	0.365	3.91	0.417	-4.01
			7.82	0.053	6.32E-05	56.61	0.099	3.32	0.253	4.08	0.309	-3.83
			3.91	0.053	0	56.62	0.079	3.18	0.193	4.26	0.249	-3.66
			1.96	0.053	3.16E-04	56.38	0.487	3.05	0.227	4.42	0.305	-3.49
			0.975	0.056	5.16E-04	56.62	0.079	2.95	0.314	4.62	0.501	-3.29
MA	200	0.0156	0	0.426	1.51E-03	1.34	0.012	0.17	0.013	1.17	0.085	0
			1000	0.42	9.94E-04	1.31	0.004	0.652	0.01	0.297	0.005	-0.87
			500	0.416	0.001	1.28	0.006	0.705	0.008	0.268	0.003	-0.89
			250	0.423	0.002	1.31	0.006	0.708	0.004	0.273	0.002	-0.89
			125	0.435	0.001	1.35	0.001	0.742	0.012	0.269	0.005	-0.9
			62.5	0.441	0.002	1.36	0.005	0.865	0.052	0.25	0.011	-0.02
			31.25	0.441	1.52	1.36	0.009	0.888	0.081	0.25	0.08	-0.92
			15.63	0.442	0.002	1.38	0.006	0.744	0.01	0.277	0.002	-0.89
			7.82	0.443	9.49E-04	1.38	0.006	0.856	0.025	0.241	0.007	-0.93
			3.91	0.444	1.23E-03	1.38	0.006	0.885	0.013	0.229	0.003	-0.94
			1.96	0.442	8.16E-04	1.37	0.001	3871	0.016	0.235	0.003	-0.93
			0.975	0.445	8.49E-04	1.36	0.004	0.967	0.013	0.208	0.003	-0.96

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
MA	1000	0.00942	0	0.1	0.002	41.29	0.145	0.22	0.026	46.36	5.31	0
			1000	0.099	1.96E-03	41.27	0.14	0.566	0.044	17.91	1.45	-22.31
			500	0.093	0.003	42.56	0.159	0.518	0.085	20.61	3.68	-19.61
			250	0.092	0.001	43.25	0.07	0.42	0.03	25.33	2.24	-14.89
			125	0.091	1.84E-04	43.24	0.382	0.038	27.91	3.22	-12.3	-12.3
			62.5	0.092	8.43E-04	43.11	0.218	0.38	0.059	28.34	4.71	-11.88
			31.25	0.092	9.66E-04	43.43	0.092	0.3	0.375	28.9	4.54	-11.32
			15.63	0.092	9.66E-04	43.43	0.148	0.37	0.063	29.39	4.97	-10.82
			7.82	0.092	6.99E-04	43.58	0.148	0.34	0.061	32.31	0.06	-7.91
			3.91	0.093	3.16E-03	43.66	0.069	0.315	0.024	33.99	2.45	-6.22
			1.96	0.094	8.23E-04	43.66	0.0967	0.295	0.037	36.63	4.62	-3.58
			0.975	0.093	0.002	43.6	0.094	0.285	0.041	38.15	6.36	-2.07

Table F.2 The data of sensitivity measurement of doped polyaniline in CO/N_2 at various concentrations by using four point probe (K=0.435).

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
CSA	40	0.0165	0	0.053	7.56E-04	44.48	0.046	1.1	5.90E-02	5.65	0.313	0
			1000	0.052	0.00E+00	44.5	0	5.63	0.675	1.12	0.14	-4.53
			500	0.053	9.16E-04	44.54	0.052	6.1	0.441	1.02	0.079	-4.63
			250	0.053	5.16E-04	44.6	0	5.25	0.288	1.19	0.073	-4.46
			125	0.054	5.27E-04	44.61	0.032	5.05	0.443	1.24	0.111	-4.41
			62.5	0.052	4.22E-04	44.51	0.032	4.43	0.51	1.42	0.164	-4.23
			31.25	0.053	3.16E-04	44.5	0	4.78	0.244	1.3	0.067	-4.35
			15.63	0.054	6.99E-04	44.5	0	4.25	0.196	1.46	0.067	-4.19
			7.82	0.053	3.16E-04	44.5	0	3.88	0.549	1.63	0.225	-4.02
			3.91	0.052	1.37E-03	44.5	0	3.73	0.495	1.69	0.199	-3.96
			1.96	0.053	5.68E-04	44.5	0	3.16	0.359	1.99	0.244	-3.66
			0.975	0.054	3.16E-04	44.5	0	2.59	0.314	2.43	0.314	-3.22
CSA	80	0.01247	0	0.053	4.33E-03	43.1	0.487	1.44	0.306	5.74	1.13	0
			1000	0.055	0	43.62	0.204	1.71	0.109	4.72	0.326	-1.02
			500	0.055	2.69E-03	32.62	1.81	1.49	0.187	4.17	2.48	-1.57
			250	0.059	3.63E-03	44.27	0.292	2.01	0.045	4.06	0.087	-1.68
			125	0.058	2.58E-03	44	0.331	2.18	0.142	3.73	0.242	-2.01
			62.5	0.052	1.29E-02	41.43	1.03	1.33	0.314	5.59	1.39	-0.15
			31.25	0.055	0	43.74	0.162	1.48	0.101	5.48	0.396	-0.26
			15.63	0.05	0.013	40.93	1.53	1.39	0.36	5.17	1.37	-0.57
			7.82	0.057	4.92E-03	43.52	0.111	1.53	0.229	5.34	0.83	-0.39
			3.91	0.055	5.22E-03	43.4	1.15E-06	1.43	0.148	5.66	0.703	-0.08
			1.96	0.051	3.16E-03	43.4	8.99E-07	1.43	0.159	5.69	0.805	-0.05
			0.975	0.059	3.16E-03	43.4	8.99E-07	1.42	0.162	5.7	0.668	-0.04

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
CSA	200	0.01175	0	0.194	1.20E-02	146.34	9.43	2.63	0.411	10.25	3.13	0
			1000	0.163	5.00E-03	143.83	8.82	7.1	0.364	4.07	0.774	-6.18
			500	0.182	0.011	147.03	10.81	7.44	0.189	3.76	0.689	-6.49
			250	0.197	0.008	161.42	10.94	8.16	0.356	3.99	0.478	-6.26
			125	0.217	0.029	186.14	6.09	7.4	0.397	4.67	1.06	-5.59
			62.5	0.229	0.008	186.26	7.03	7.09	0.493	4.91	0.696	-5.35
			31.25	0.228	0.008	157.62	56.4	6.27	1.4	5.13	2.26	-5.12
			15.63	0.218	0.001	73.31	0.867	2.92	0.792	5.23	1.26	-5.02
			7.82	0.241	0.027	71.93	0.699	5.68	0.283	5.31	0.511	-4.94
			3.91	0.234	0.002	72.81	0.637	5.68	0.452	5.47	0.879	-4.78
			1.96	0.239	0.005	74.94	0.978	2.37	0.172	6.22	0.407	-4.03
			0.975	0.247	0.001	76.03	0.344	2.35	0.258	6.41	0.726	-3.84
MA	40	0.0138	0	0.054	0.001	57.24	0.101	2.3	0.1	4.15	0.17	0
			1000	0.053	0.001	57.32	0.132	3.53	0.349	2.73	0.257	-1.42
			500	0.052	0	57.43	0.067	3.58	0.379	2.69	0.279	-1.45
			250	0.053	0	57.3	0.094	3.77	0.353	2.55	0.259	-1.59
			125	0.052	0.001	57.27	0.05	3.23	0.206	2.96	0.186	-1.19
			62.5	0.052	0	57.23	0.07	2.91	0.166	3.29	0.207	-0.87
			31.25	0.053	0	57.22	0.114	2.67	0.258	3.59	0.338	-0.55
			15.63	0.052	0	57.15	0.069	2.55	0.19	3.75	0.274	-0.4
			7.82	0.053	0	57.18	0.048	2.37	0.082	4.02	0.135	-0.13
			3.91	0.053	0	54.12	2.95	2.24	0.186	4.05	0.33	-0.11
			1.96	0.052	0	57.21	0.11	2.35	0.108	4.06	0.183	-0.09
			0.975	0.052	0.001	57.25	0.097	2.35	0.165	4.08	0.294	-0.08

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
MA	80	0.00965	0	0.055	4.22E-04	56.36	0.052	1.7	0.078	7.91	0.361	0
			1000	0.056	9.49E-04	56.42	0.063	4.9	0.516	2.77	0.304	-5.14
			500	0.056	7.38E-04	56.49	0.032	5.01	0.331	2.69	0.177	-5.22
			250	0.056	6.32E-04	56.51	0.032	4.86	0.455	2.79	0.258	-5.12
			125	0.056	6.67E-04	56.47	0.067	4.28	0.355	3.16	0.254	-4.75
			62.5	0.054	6.32E-04	56.54	0.084	4.14	0.284	3.27	0.221	-4.65
			31.25	0.055	3.16E-04	56.51	0.032	3.72	0.41	3.66	0.429	-4.25
			15.63	0.053	6.32E-04	56.52	0.079	3.48	0.365	3.91	0.417	-4.01
			7.82	0.053	6.32E-05	56.61	0.099	3.32	0.253	4.08	0.309	-3.83
			3.91	0.053	0	56.62	0.079	3.18	0.193	4.26	0.249	-3.66
			1.96	0.053	3.16E-04	56.38	0.487	3.05	0.227	4.42	0.305	-3.49
			0.975	0.056	5.16E-04	56.62	0.079	2.95	0.314	4.62	0.501	-3.29
MA	200	0.0156	0	0.426	1.51E-03	1.34	0.012	0.17	0.013	1.17	0.085	0
			1000	0.42	9.94E-04	1.31	0.004	0.652	0.01	0.297	0.005	-0.87
			500	0.416	0.001	1.28	0.006	0.705	0.008	0.268	0.003	-0.89
			250	0.423	0.002	1.31	0.006	0.708	0.004	0.273	0.002	-0.89
			125	0.435	0.001	1.35	0.001	0.742	0.012	0.269	0.005	-0.9
			62.5	0.441	0.002	1.36	0.005	0.865	0.052	0.25	0.011	-0.02
			31.25	0.441	1.52	1.36	0.009	0.888	0.081	0.25	0.08	-0.92
			15.63	0.442	0.002	1.38	0.006	0.744	0.01	0.277	0.002	-0.89
			7.82	0.443	9.49E-04	1.38	0.006	0.856	0.025	0.241	0.007	-0.93
			3.91	0.444	1.23E-03	1.38	0.006	0.885	0.013	0.229	0.003	-0.94
			1.96	0.442	8.16E-04	1.37	0.001	3871	0.016	0.235	0.003	-0.93
			0.975	0.445	8.49E-04	1.36	0.004	0.967	0.013	0.208	0.003	-0.96

Acid	Doping ratio	Thickness (cm)	CO/N_2 conc. ppm	Applied voltage (V)		Current (μA)		Voltage drop (mV)		σ (S/cm)		Δσ (S/cm)
				Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	
MA	1000	0.00942	0	0.1	0.002	41.29	0.145	0.22	0.026	46.36	5.31	0
			1000	0.099	1.96E-03	41.27	0.14	0.566	0.044	17.91	1.45	-22.31
			500	0.093	0.003	42.56	0.159	0.518	0.085	20.61	3.68	-19.61
			250	0.092	0.001	43.25	0.07	0.42	0.03	25.33	2.24	-14.89
			125	0.091	1.84E-04	43.24	0.382	0.038	27.91	3.22	-12.3	-12.3
			62.5	0.092	8.43E-04	43.11	0.218	0.38	0.059	28.34	4.71	-11.88
			31.25	0.092	9.66E-04	43.43	0.092	0.3	0.375	28.9	4.54	-11.32
			15.63	0.092	9.66E-04	43.43	0.148	0.37	0.063	29.39	4.97	-10.82
			7.82	0.092	6.99E-04	43.58	0.148	0.34	0.061	32.31	0.06	-7.91
			3.91	0.093	3.16E-03	43.66	0.069	0.315	0.024	33.99	2.45	-6.22
			1.96	0.094	8.23E-04	43.66	0.0967	0.295	0.037	36.63	4.62	-3.58
			0.975	0.093	0.002	43.6	0.094	0.285	0.041	38.15	6.36	-2.07

Appendix G Flowmeter calibration data.

Flowmeters, with tube number N032-41 (Cole-Parmer Instrument Company) were used in order to measure gas volume flow rate in the range between 25 to 375 ml/min. Flow ranges in the charts are based on air at standard conditions of one atmosphere (14.7 psi) and 70°F (21°C). Normally, the flowmeter calibration data sheets for other common gases such as argon (Ar), carbon dioxide (CO_2), helium (He), hydrogen (H_2), nitrogen (N_2), and oxygen (O_2) are provided with the instrument charts. For other gases, volume flow rates can be converted using the following formula:

$$Q_{N_2} = K_{gas} \times Q_{gas} \tag{G.1}$$

$$K_{gas} = \sqrt{\frac{G_{gas} \times T_{act} \times P_O}{G_{N_2} \times T_O \times P_{act}}} \tag{G.2}$$

where; Q_{N_2} = equivalent nitrogen gas flow capacity at standard conditions

Q_{gas} = maximum flow of metered gas

G_{gas} = specific gravity of metered gas (From Table G.1)

G_{N_2} = specific gravity of nitrogen gas

T_{act} = absolute temperature at flow conditions (K)

T_O = absolute temperature at standards conditions (K)

P_{act} = pressure at flow conditions (psi)

P_O = pressure at standard conditions (psi).

Table G.1 Density, viscosity, and specific gravity of gases.

Gas	Density (g/ml)	Viscosity (centipoise)	Specific gravity,G (Air = 1.0)
Air	0.001200	0.0181	1.0000
Ammonia	0.000716	0.00994	0.5963
Argon	0.001660	0.0222	1.3796
Butane	0.002484	0.00848	2.0854
Carbon Dioxide	0.001835	0.01470	1.5290
Carbon Monoxide	0.001163	0.01750	0.9671
Chlorine	0.002983	0.01330	2.4860
Ethane	0.001260	0.00901	1.0493
Helium	0.0001656	0.01980	0.13804
Hydrogen	0.0000834	0.00885	0.06952
Methane	0.0006653	0.01099	0.5544
Nitrogen	0.001160	0.01756	0.96724
Oxygen	0.001376	0.0230	1.10527
Propane	0.001874	0.00805	1.5620
Sulfur Dioxide	0.002717	0.01270	2.2638

The calculated flow rate data of sulfur dioxide (SO_2) and carbon monoxide (CO) are shown in Table G.2.

Table G.2 Flowmeter calibration data of nitrogen gas (N_2), sulfur dioxide (SO_2), and carbon monoxide (CO).

Scale Reading	Float Material			
	Stainless Steel	Carboloy		
	N_2 Flow (ml/min)	N_2 Flow (ml/min)	SO_2 Flow (ml/min)	CO Flow (ml/min)
150	481	748	488.93	748.05
140	456	715	467.36	715.05
130	426	683	446.45	683.05
120	400	644	420.95	644.05
110	356	602	393.50	602.04
100	326	544	355.59	544.04
90	288	490	320.29	490.03
80	247	431	281.72	431.03
70	208	372	243.16	372.03
60	168	316	206.55	316.02
50	132	253	165.37	253.02
40	101	200	130.73	200.01
30	78	148	96.74	148.01
20	54	108	70.59	108.01
10	34	68	44.45	68.00

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