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APPENDICES

Appendix A Identification of FT-IR Spectrum

Poly(2,5-dimethoxyaniline) (PDMA) was synthesized via the electrochemical polymerization of 2,5-dimethoxyaniline and oxalic acid to obtain doped-PDMA. FT-IR spectrometer (Bruker, Equinox 55/FRA 106/S) was used to identify the functional groups in the absorption mode with 32 scans and a resolution of $\pm 2 \text{ cm}^{-1}$, covering a wavenumbers range of $4000\text{-}400 \text{ cm}^{-1}$, using a deuterated triglycine sulfate as a detector. Optical grade KBr (Carlo Erba Reagent) was used as the background material and the polymer was mixed with dried KBr at a ratio 1:20. The FT-IR spectra of D-PDMA show absorption bands as shown in Figure A1 and tabulated in Table A1.

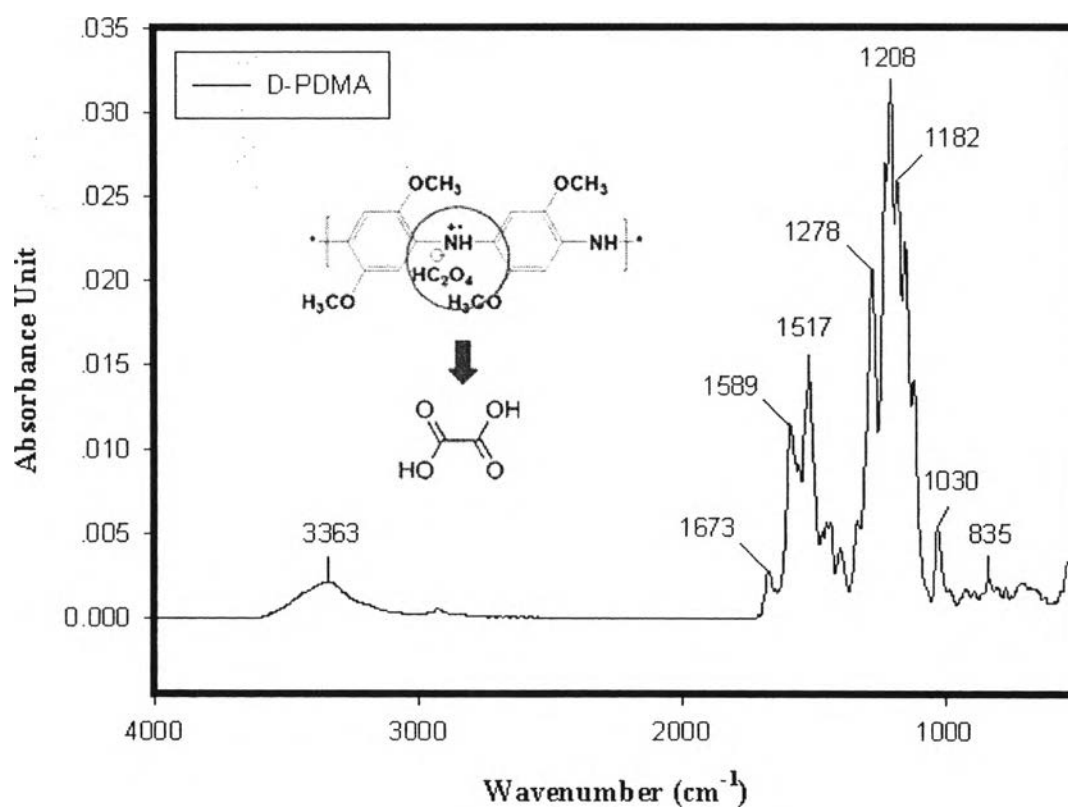


Figure A1 The FT-IR spectra of dope- Poly(2,5-dimethoxyaniline) (D-PDMA).

Figure A1 shows the FT-IR spectra of dope- Poly(2,5-dimethoxyaniline) displaying characteristics of the oxalic acid group. The band at 835 cm^{-1} can be assigned to the O–C=O in-plane deformation. The absorption bands at 1208 and 1182 cm^{-1} are assigned to the C–O stretching. The bands at 1673 and 3363 cm^{-1} represent the C=O oxalate ion and the O–H stretching, respectively. These results confirm the success of the doped-PDMA.

Table A1 The FT-IR absorption spectra of D-PDMA

Wavenumbers (cm^{-1})	Assignments	References
817	O–C=O (in-plane deformation)	Patil <i>et al.</i> , 2002
1260-1000	C–O (stretching)	Patil <i>et al.</i> , 2002
1647	C=O (oxalate ion)	Patil <i>et al.</i> , 2002
3350	O–H (stretching)	Patil <i>et al.</i> , 2002

Appendix B The Thermogravimetry Analysis or TGA

The thermogravimetric analyzer (Perkin Elmer, TGA7) was used to study the thermal stability and to determine the decomposition temperature of poly(2,5dimethoxyaniline). The experiment was carried out by weighting a powder sample of 5-10 mg and placed it in a platinum pan, and then heated it with a nitrogen flow at the heating rate of 10 °C/min from 50 - 800 °C.

From Figure B1, the TGA thermogram of D-PDMA shows a two-stage weight change:

- 1) The decomposition of D-PDMA chain around 118.7 °C
- 2) The complete degradation of D-PDMA around 283.0 °C.

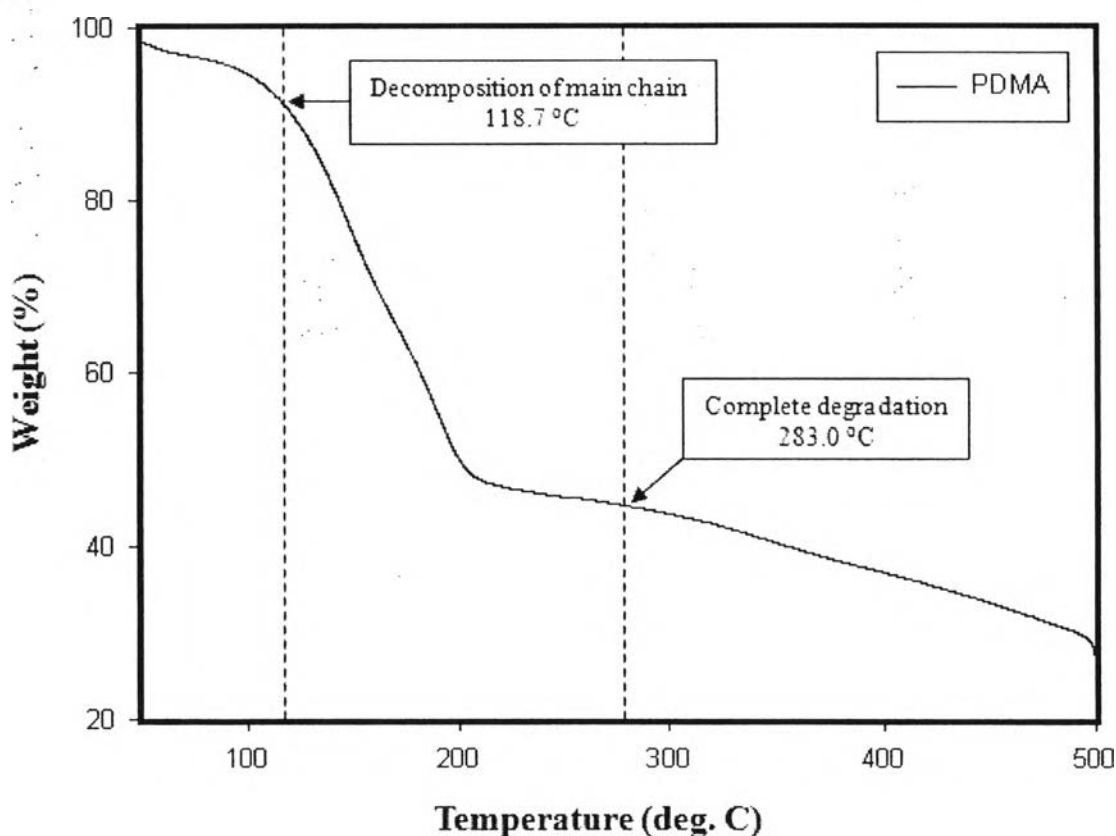


Figure B1 TGA thermogram of D-PDMA.

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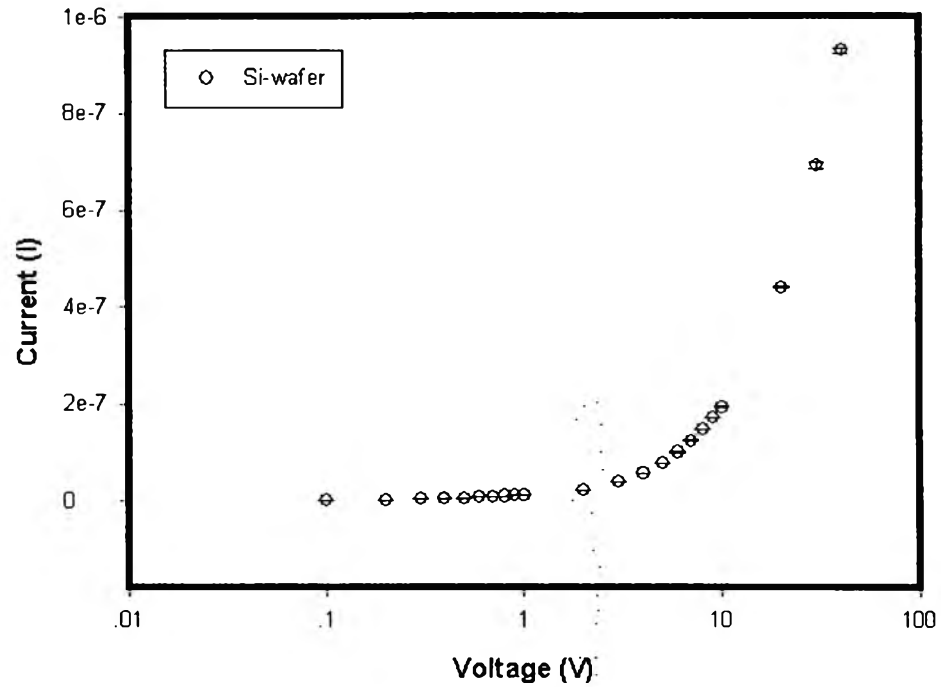


Figure C1 Voltage vs. current data of the probe number 1 calibration with Si-wafer whose sheet resistivity of $107.373 \Omega/\text{sq}$, 25°C , 60-65 %RH on a log scale.

Table C1 Voltage-current data of the probe number 1 calibration with Si-wafer whose sheet resistivity of $107.373 \Omega/\text{sq}$, 25°C , 60-65 %RH

V			I			K=I/V* ρ/t		
1	2	3	1	2	3	1	2	3
0.9	0.9	0.9	1.82E-06	1.83E-06	1.88E-06	0.000217026	0.000217965	0.000224296
0.8	0.8	0.8	1.56E-06	1.55E-06	1.56E-06	0.000209111	0.000207938	0.000208828
0.7	0.7	0.7	1.28E-06	1.26E-06	1.26E-06	0.000196204	0.000194032	0.000192967
0.6	0.6	0.6	1.22E-06	1.25E-06	1.22E-06	0.000217884	0.000224239	0.000218999
0.5	0.5	0.5	1.08E-06	1.09E-06	1.10E-06	0.000232057	0.000233194	0.000235675
0.4	0.4	0.4	7.47E-07	7.58E-07	7.34E-07	0.000200519	0.000203495	0.000197146
0.3	0.3	0.3	4.19E-07	3.83E-07	3.73E-07	0.000149869	0.000136913	0.000133588
0.2	0.2	0.2	2.58E-07	2.57E-07	2.08E-07	0.000138291	0.000138013	0.000111561
0.1	0.1	0.1	9.30E-08	9.35E-08	9.55E-08	9.98287E-05	0.000100367	0.00010253
0.05	0.05	0.05	4.30E-08	4.26E-08	4.19E-08	9.23326E-05	9.14044E-05	8.99446E-05
0.01	0.01	0.01	1.14E-08	1.13E-08	1.17E-08	0.000122844	0.000120863	0.000125595

Correction factor (K)				
1	2	3	Avg.	SD
0.000170542	0.000169857	0.000167375	1.69E-04	1.66623E-06

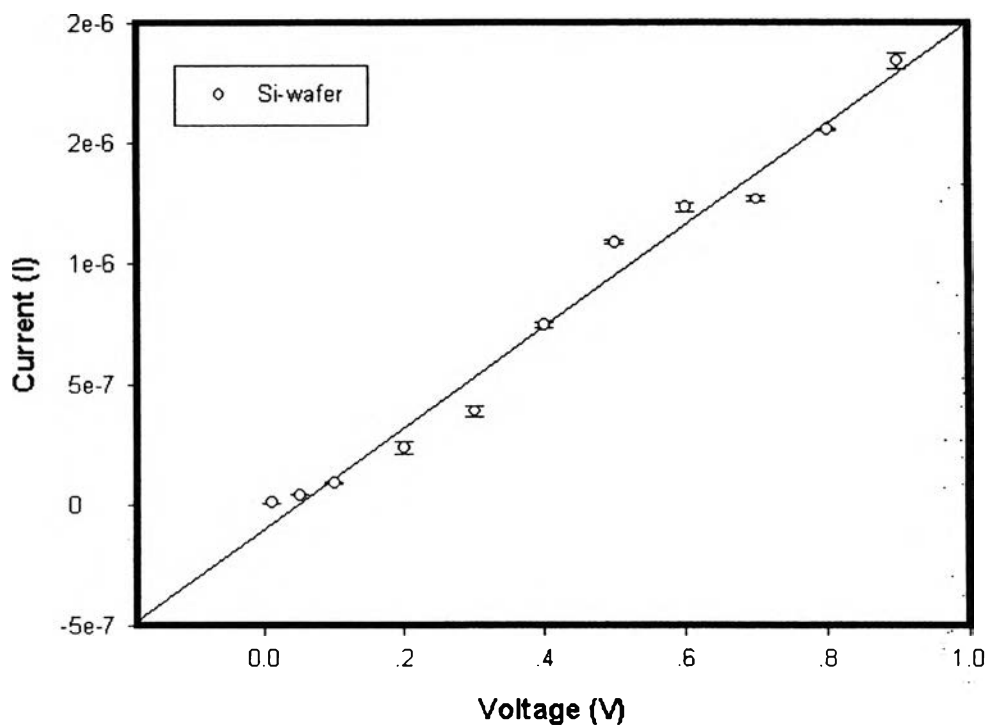


Figure C2 Voltage vs. current data of the probe number 1 calibration with Si-wafer whose sheet resistivity of $107.373 \Omega/\text{sq}$, 25°C , 60-65 %RH.

The electrical conductivity (σ) was measured by using the two-point probe mater connected with a voltage supplier in which constant voltage can be varied and the current is measured. The regime that the responsive current is linearly proportional to the applied voltage is called the linear Ohmic regime which can be identified by plotting the applied voltage against the resultant current. The voltage and the current in the regime were converted to the electrical conductivity by following equation:

$$\sigma = 1/\rho = 1/(R \times t) = I/(R_s \times V \times t) \quad (\text{C4})$$

- where σ is the specific conductivity (S/cm),
 ρ is the specific resistivity (Ω .cm),
 R_s is the sheet resistance (Ω /sq),
 t is the thickness of sample pellet (cm),
 V is the applied voltage (Voltage drop)(V),
 I is the measured current (A),
 K is the geometric correction factor of the two-point probe meter.

All sample thicknesses were measured by using a thickness gauge.

Table C2 Thicknesses of PDMA sample

Thickness (cm)			Avg
0.192	0.197	0.195	0.1947

Table C3 Voltage-current data of PDMA

V	I			$\sigma = I/(R_s \times V \times t)$		
0.1	1.03E-09	1.02E-09	1.02E-09	0.0003120	0.0003091	0.0003090
0.2	2.23E-09	2.27E-09	2.23E-09	0.0003385	0.0003452	0.0003393
0.3	3.23E-09	3.57E-09	3.43E-09	0.0003274	0.0003615	0.0003480
0.4	4.66E-09	4.62E-09	4.52E-09	0.0003539	0.0003512	0.0003432
0.5	5.80E-09	6.09E-09	6.12E-09	0.0003529	0.0003703	0.0003718
0.6	7.64E-09	7.53E-09	7.73E-09	0.0003871	0.0003813	0.0003916
0.7	8.84E-09	8.94E-09	8.93E-09	0.0003839	0.0003882	0.0003876
0.8	9.51E-09	9.64E-09	9.68E-09	0.0003614	0.0003663	0.0003677
0.9	1.07E-08	1.02E-08	1.03E-08	0.0003605	0.0003438	0.0003475

Specific conductivity(S/cm)				
1	2	3	Avg.	SD
0.0003531	0.0003574	0.0003562	0.0003556	0.0000022

Table C4 The specific conductivity (S/cm) of PDMA

Samples	Specific conductivity(S/cm)
PDMA	$(3.556 \pm 0.022) \times 10^{-4}$

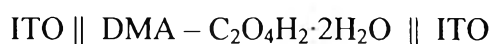
Appendix D Cyclic voltammetry (CV) of PDMA

Multi-Channel Potentiostat (VMP, Bio Logic Science Instrument) was used to determine the electrochemical properties of PDMA through the cyclic voltammetry (Huang, *et al.* 2002). Cyclic voltammetry (CV) is a simple and valuable technique to study the polymerization and properties of electroactive polymers. The current flowing through the working electrode/solution interface is monitored as a function of the applied potential. Both qualitative and quantitative data may be obtained and the technique finds a particular use in preliminary studies of new systems. CV shows the potentials at which oxidation and reduction processes occur, the potential range over which the solvent is stable, and the degree of reversibility of the electrode reaction (Argun, 2004).

The experiment was separated in two parts:

First Part

Cyclic voltammetry was used to study the synthesis performance of PDMA between -0.5 to +0.5 V for 50 cycles with a sweep rate 20 mV/s in a solution of 0.1 M of oxalic acid and 0.125 mol of DMA. Measurements were carried in a cuvette cell of a 1 cm path length, assembled with a three electrodes cell consisting of a Ag/AgCl electrode and two pieces of the ITO glass, used as the reference electrode, the working electrode, and the counter electrode, respectively, as shown in Figure D1. The electrochromic device was compiled with the following configuration:



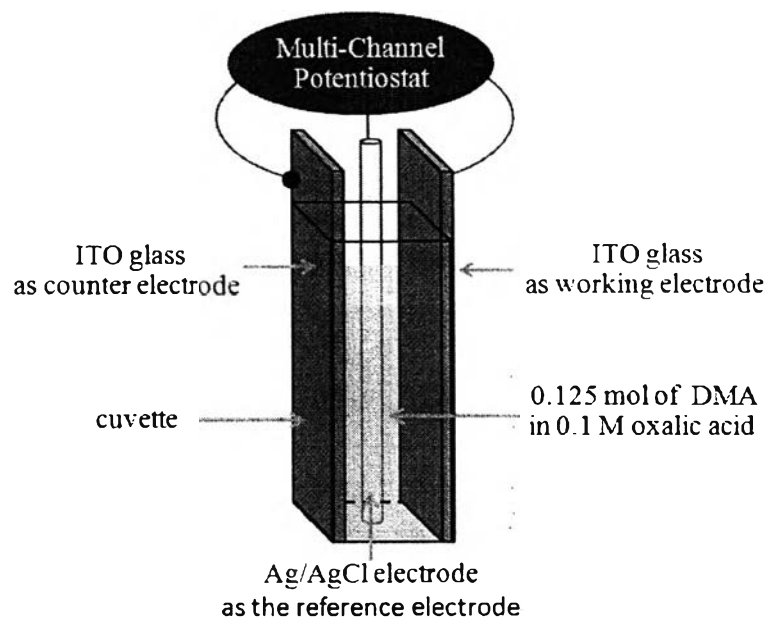


Figure D1 Schematic of a Multi-Channel Potentiostat cell to study the synthesis PDMA.

The CV curve was recorded during the electropolymerization of PDMA. It can be seen that the DMA monomer was electroactive. Figure D2 shows cycles of the CV curve revealing two redox peaks corresponding to the transition. The first redox is the transition between leucoemeraldine and emeraldine (A/A', +0.15 / -0.02 V) and the second redox is the transition between emeraldine and pernigraniline (B/B', + 0.28 / +0.18 V) during to the growth of the film in the oxalic acid (Huang, *et al.* 2003). Upon subsequent cycles, there were gradual increases in the current intensity representing the broad anodic and cathodic peaks corresponding to the oxidation and the reduction of PDMA, indicating that the films were formed on the surface of ITO more easily (Longjian, *et al.* 2009).

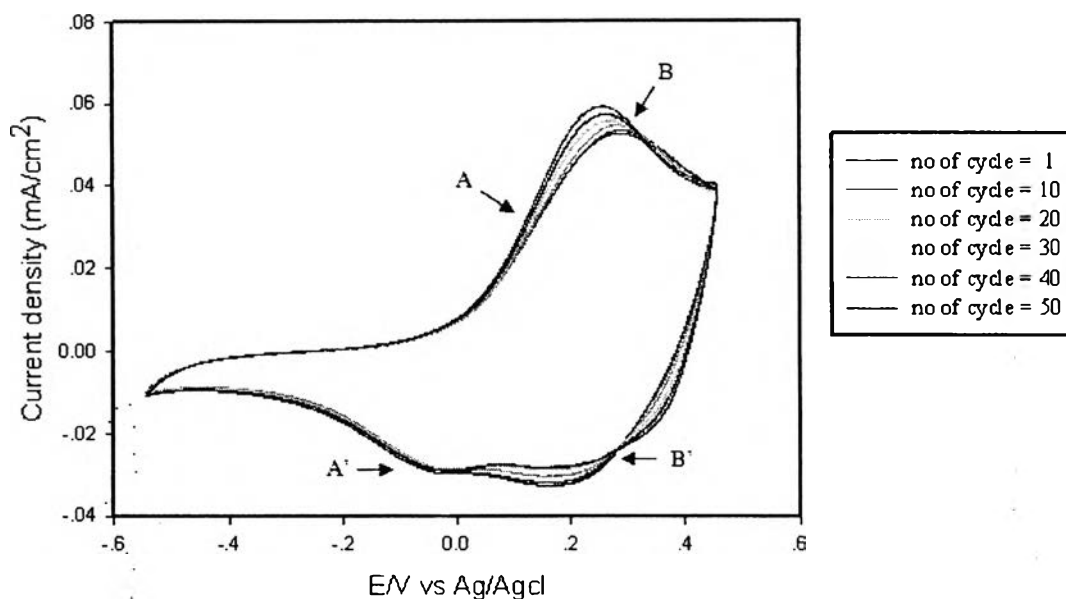


Figure D2 Cyclic voltammogram of the PDMA film grown on the ITO electrode in the 0.1 M of oxalic acid aqueous electrolyte, [DMA] = 0.125 mol at the potential range of -0.5 to +0.5 V, and a scan rate of 20 mV/s for 1-50 cycles.

Second Part

The potentials were used to study the life time of PDMA film, between -0.5 to +0.5 V for 100 cycles with a sweep rate 20 mV/s in 0.001 M HCl electrolyte solution and 0.001 M H₂SO₄ electrolyte solution, respectively. Measurements were carried in a cuvette of a 1 cm path length, assembled with a three electrodes cell consisting of a Ag/AgCl electrode, ITO glass and PDMA on ITO glass used as the reference electrode, the working electrode, and the counter electrode, respectively, as shown in Figure D3. The electrochromic device was compiled with the following configuration:



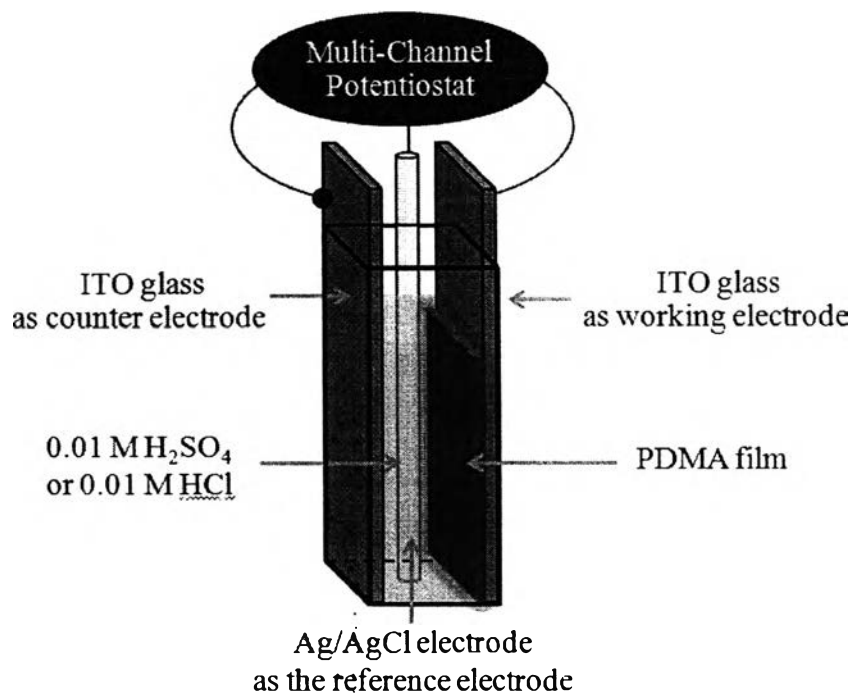


Figure D3 Schematic of a Multi-Channel Potentiostat cell to study the life time of PDMA film.

Figures D4 and D5 show the cycles of the CV curve switching between the fully oxidized and the fully reduced state for 100 cycles. PDMA films on ITO glass in 0.001 M HCl and 0.001 M H₂SO₄ show only 1.43% and 2.43% change in the transmittance, as represented in Figures D6 and D7, respectively. The results indicate that after 100 cycles, this PDMA film in both electrolyte still have good efficiency.

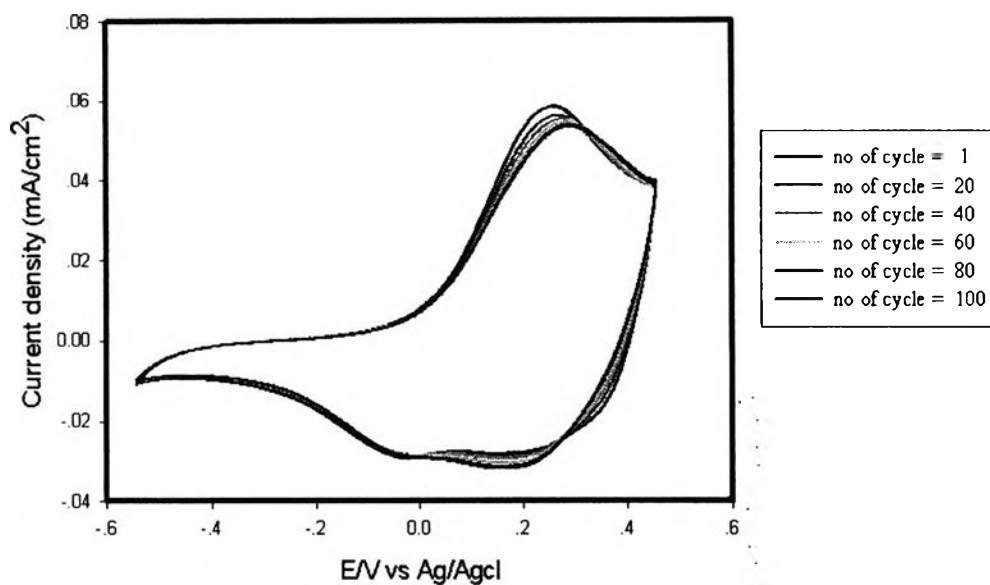


Figure D4 Cyclic voltammogram of the PDMA film on the ITO electrode switching between redox reactions in the 0.001 M of HCl aqueous electrolyte at the potential range of -0.5 to +0.5 V and with a sweep rate 20 mV/s for 1-100 cycles.

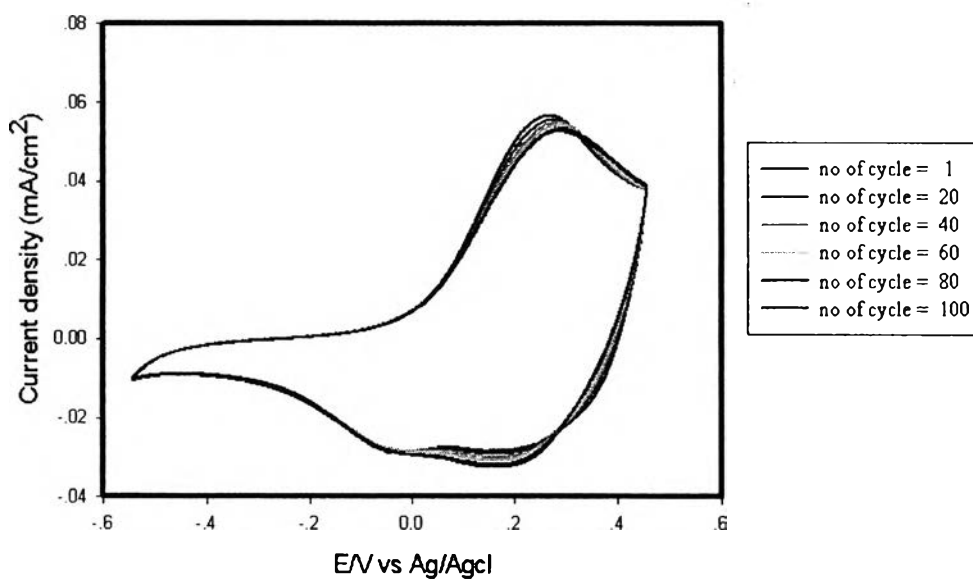


Figure D5 Cyclic voltammogram of the PDMA film on the ITO electrode switching between redox reactions in the 0.001 M of H₂SO₄ aqueous electrolyte at the potential range of -0.5 to +0.5 V and with a sweep rate 20 mV/s for 1-100 cycles.

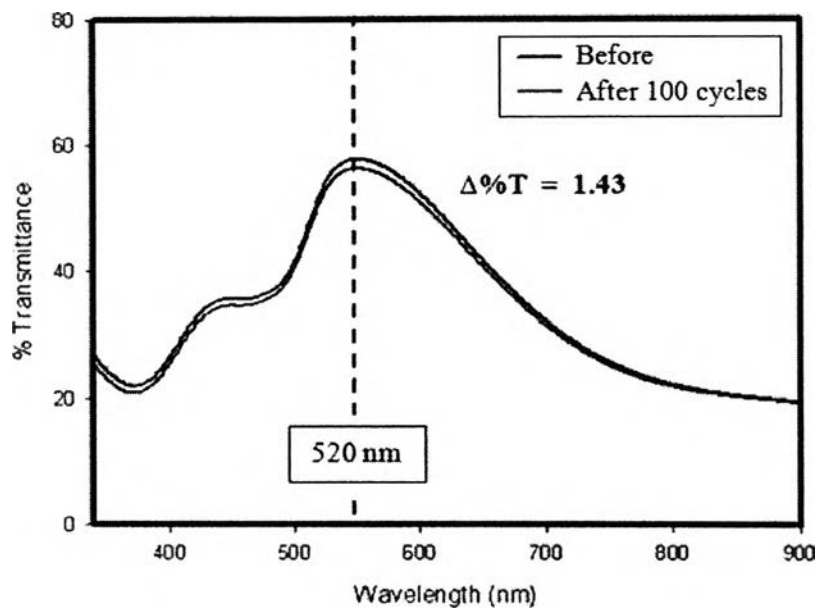


Figure D6 The % transmittance of PDMA film coated on the ITO electrode before and after 100 cycles in 0.001 M HCl electrolyte.

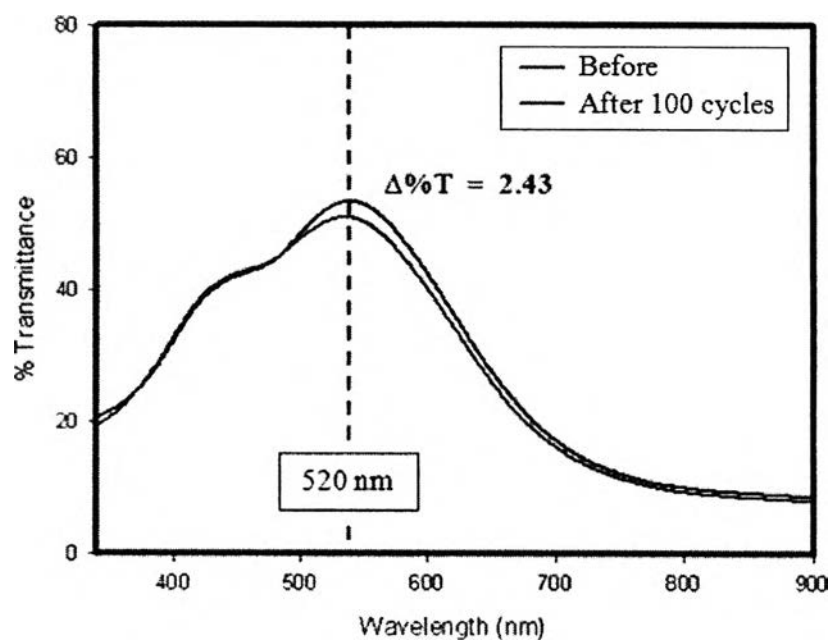


Figure D7 The % transmittance of PDMA film coated on the ITO electrode before and after 100 cycles in 0.001 M H₂SO₄ electrolyte.

Appendix E UV-VIS absorption spectrophotometer of PDMA

UV-VIS absorption spectrophotometer (Shimadzu, UV-1800) was used to investigate the electrochromic properties, and to identify properties of the conducting polymer related to the electronic structure and the optical behavior of the redox processes. Measurements were carried out in a cuvette cell of 1 cm path length, assembled as an electrochemical cell with the PDMA film coated ITO glass as the working electrode, another ITO glass as the counter electrode, and with HCl and H₂SO₄ as supporting electrolyte, respectively, as shown in figure E1. The wavelength range was 300-900 nm, the scan speed was 240 nm/min, a slit width of 1.0 nm, using a deuterium, and a tungsten lamp as the light source.

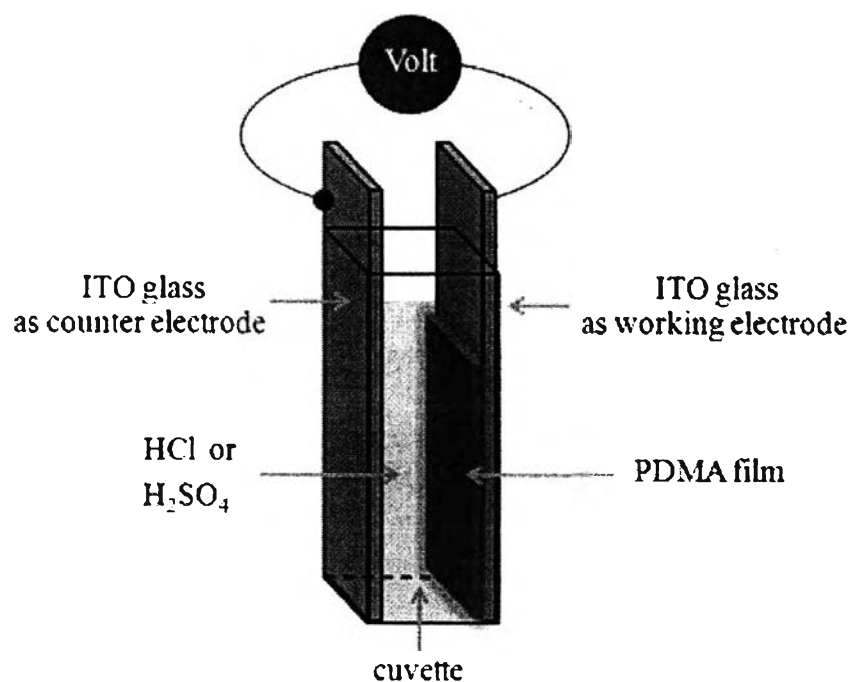


Figure E1 Schematic of a typical electropolymerization cell for used with UV-VIS absorption spectrophotometer.

This spectrophotometer was used to investigate the reversible color change of PDMA as shown in Figure E2 and to observe the transient color change and the response times in the HCl and H₂SO₄ electrolytes.

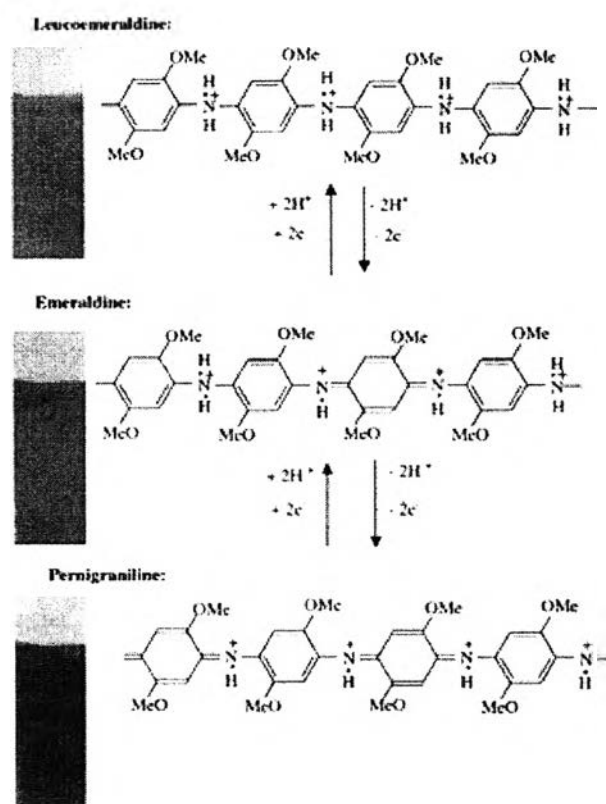


Figure E2 Scheme for the PDMA redox process and the samples.

The absorption spectra of PDMA film on the ITO electrode recorded at different potential times in both electrolytes show three peaks at 370 nm, 470 nm and 720 nm, which correspond to yellow, green, and blue color, respectively. The first band at 370 nm corresponds to the fully reduced state of PDMA, called “Leucoemeraldine” (yellow color). This band disappears upon the oxidation reaction. A decreasing intensity of this band is observed when the potential is shifted to a higher value or an extended time. The second band at 470 nm represents to the intermediate state, called “Emeraldine” (green color). After a long time, it transforms into a fully oxidized state at 720 nm corresponding to “Pernigraniline” (blue color), as shown in Figure E3.

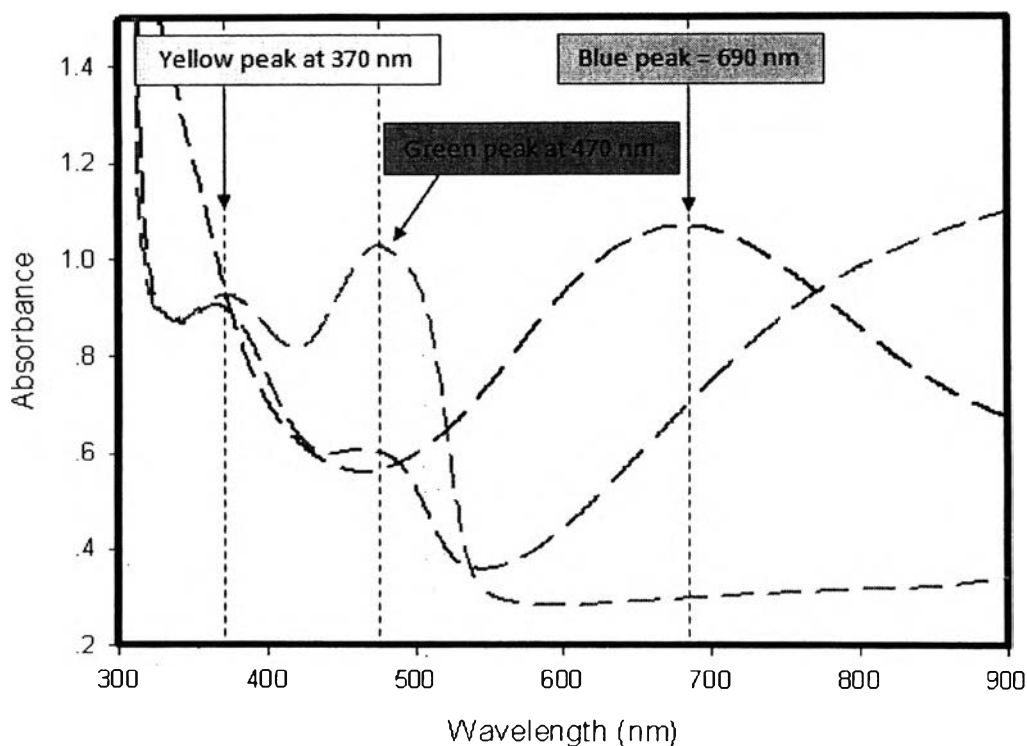


Figure E3 UV-VIS spectra of the PDMA film coated on the ITO electrode obtained at different times and potentials.

The ability of PDMA switching in redox reaction was detected by color change which can be measured by a spectrophotometer. The experiment was separated into two parts:

1. Compare the response time between 0.001 M HCl electrolyte and 0.001M H₂SO₄ electrolyte for each potential.
2. Compare the response time at 1.2 V with different concentrations: 0.001 M, 0.01 M and 0.1 M for each electrolyte.

First Part

Compare the response time between 0.001 M HCl electrolyte and 0.001 M H₂SO₄ electrolyte at each applied voltage

The oxidation reaction

Table 1 shows the response time of the PDMA film in the oxidation reaction with a fixed voltage and the response time are varied in the 0.001 M HCl electrolyte and the 0.001 M H₂SO₄ electrolyte. For both electrolytes at 0.2 V to 0.6 V, the colors of the PDMA films do not change while at 0.8 V to 1.6 V, the colors of the PDMA films change from yellow to blue color.

Table E1 The response time of PDMA in oxidation reaction at various potentials in the 0.001 M HCl and the 0.001 M H₂SO₄ electrolytes

Electrolyte Volt	Oxidation (Positive Potential)	
	0.001 M HCl	H ₂ SO ₄
0.2 V	No change in color (Yellow color)	No change in color
0.4 V	No change in color (Yellow color)	No change in color
0.6 V	No change in color (Yellow color)	No change in color
0.8 V	34 minute (Yellow to Blue color)	40 minute
1.0 V	22 minute (Yellow to Blue color)	18 minute
1.2 V	14 minute (Yellow to Blue color)	8 minute
1.4 V	6 minute (Yellow to Blue color)	4 minute
1.6 V	2 minute (Yellow to Blue color)	1 minute

The UV spectra of PDMA film were investigated at 0.2 to 1.6 V every 6 minute time intervals in the 0.001 M HCl electrolyte and the 0.001 M H₂SO₄ electrolyte.

The spectra at 0.2 V to 0.6 V in the 0.001 M HCl electrolyte are shown in figures E4 – E6 and in the 0.001 M H₂SO₄ electrolyte are shown in figures E2 – E14. The initial peak is around 480 nm (yellow color). With increasing the potential time, their colors do not change.

The spectra at 0.8 V to 1.6 V in the 0.001 M HCl electrolyte are shown in figures E7 – E11 and in the 0.001 M H₂SO₄ electrolyte are shown in figures E15 – E19. The highest intensity occurs at around 480 nm which can be referred to a yellow color as can be clearly seen in the first spectra. The intensity of this peak gradually decreases with increasing potential time. At the same time, the presence of another peak at around 680 nm which can be referred to blue color occurs.

Oxidation reaction of PDMA film coated on the ITO electrode in 0.01 M HCl electrolyte at 0.2 – 1.6 Volt.

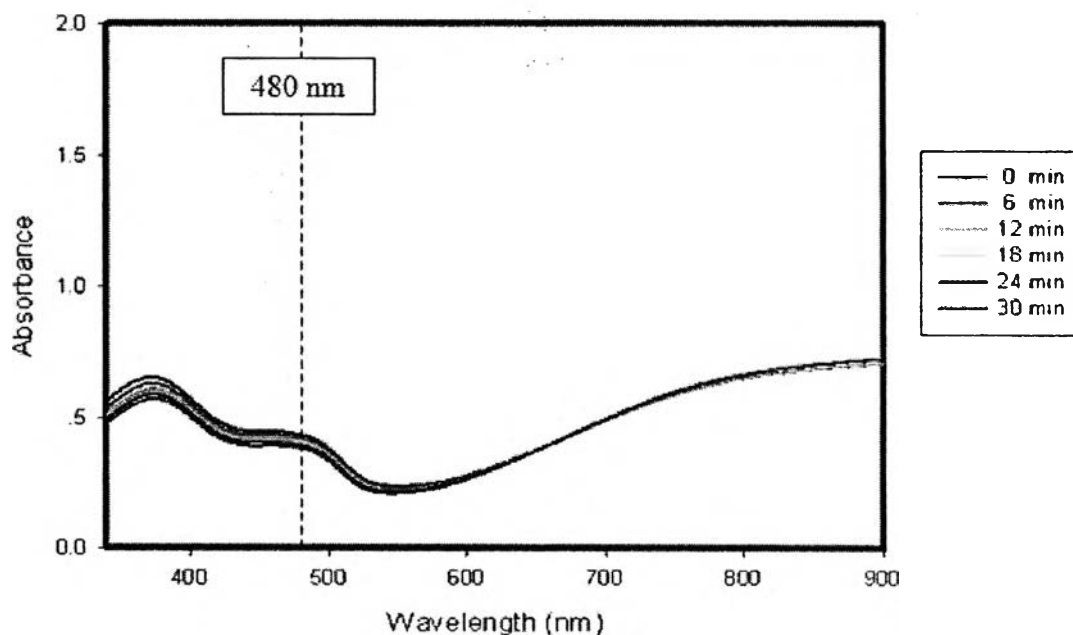


Figure E4 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 0.2 V at 6 minute intervals.

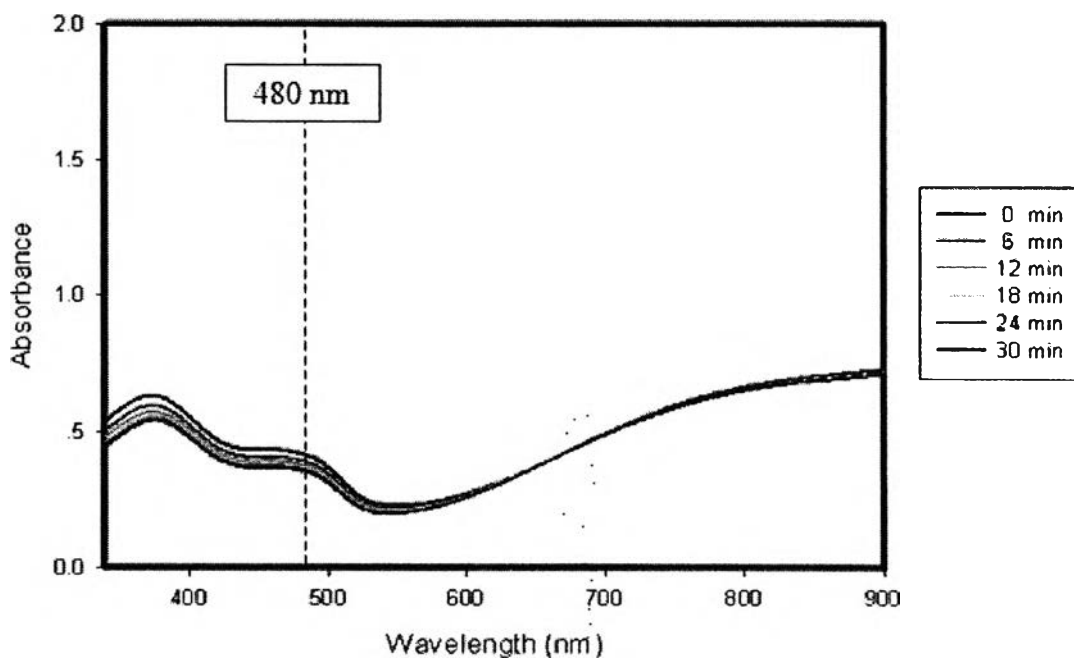


Figure E5 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 0.4 V at 6 minute intervals.

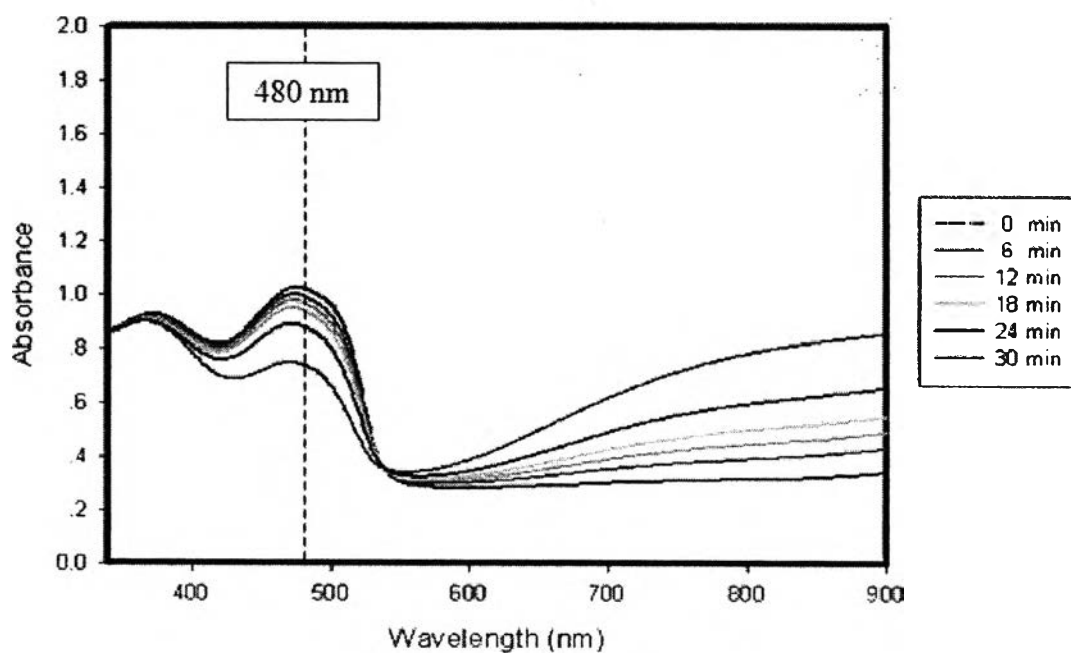


Figure E6 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 0.6 V at 6 minute intervals.

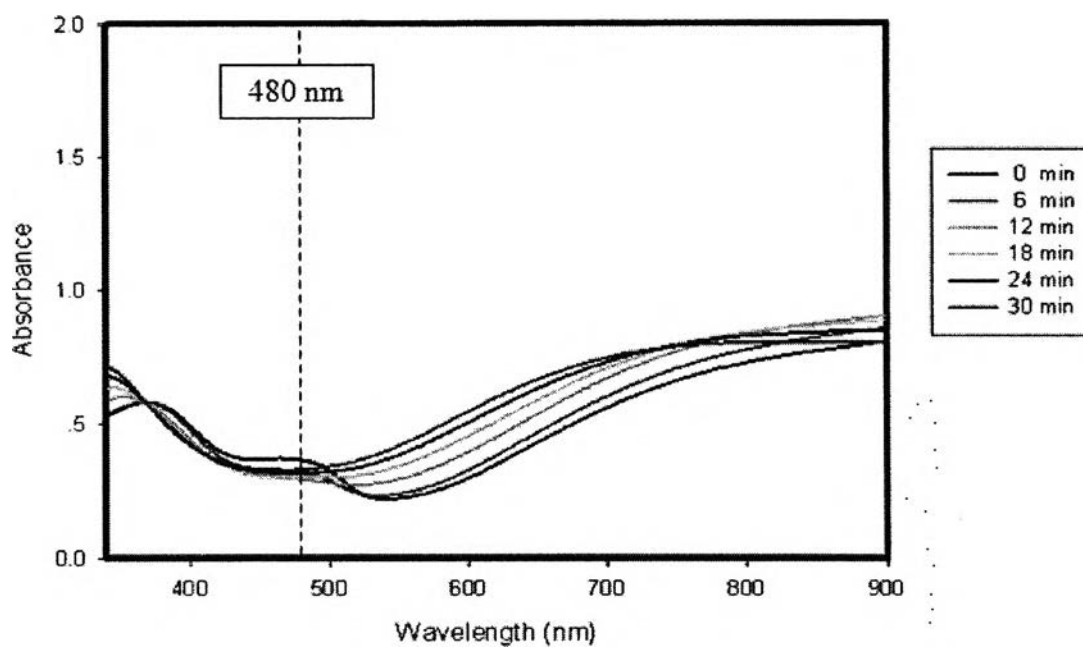


Figure E7 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 0.8 V at 6 minute intervals.

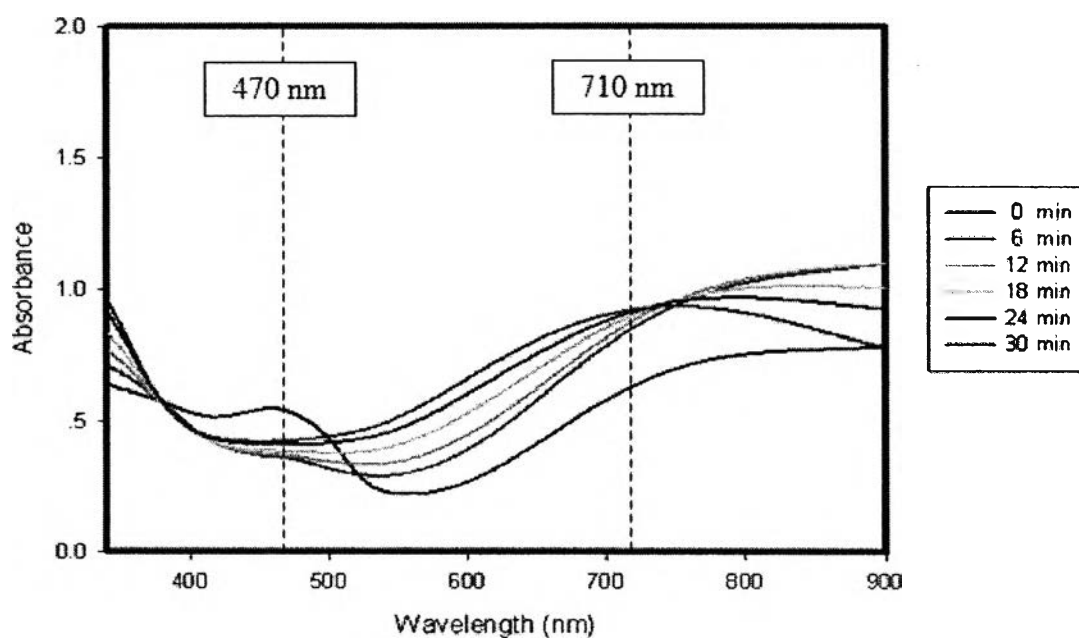


Figure E8 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 1.0 V at 6 minute intervals.

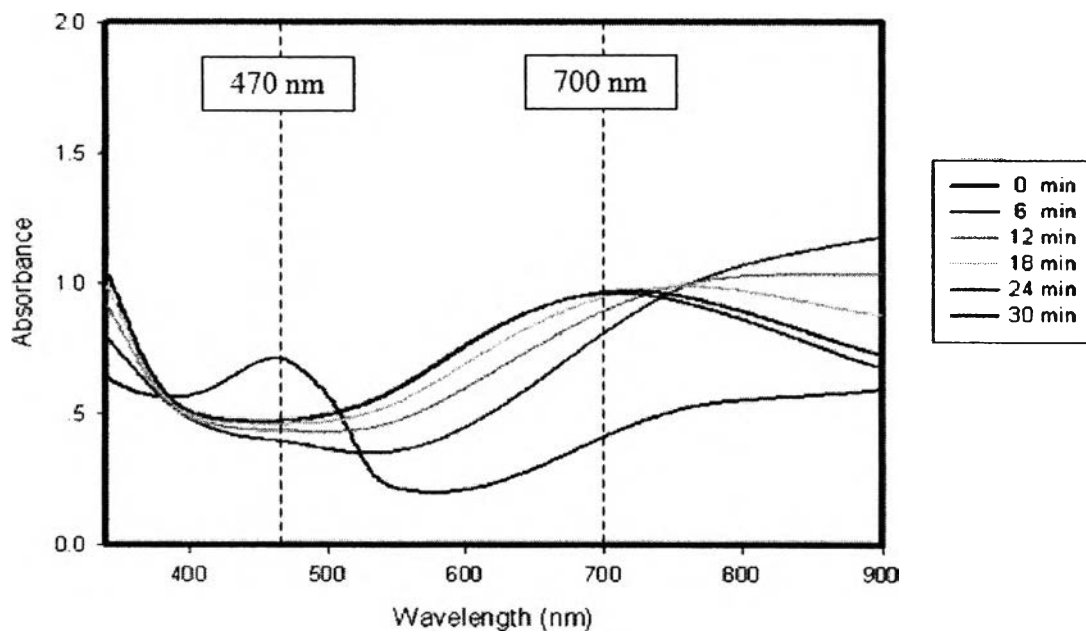


Figure E9 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 1.2 V at 6 minute intervals.

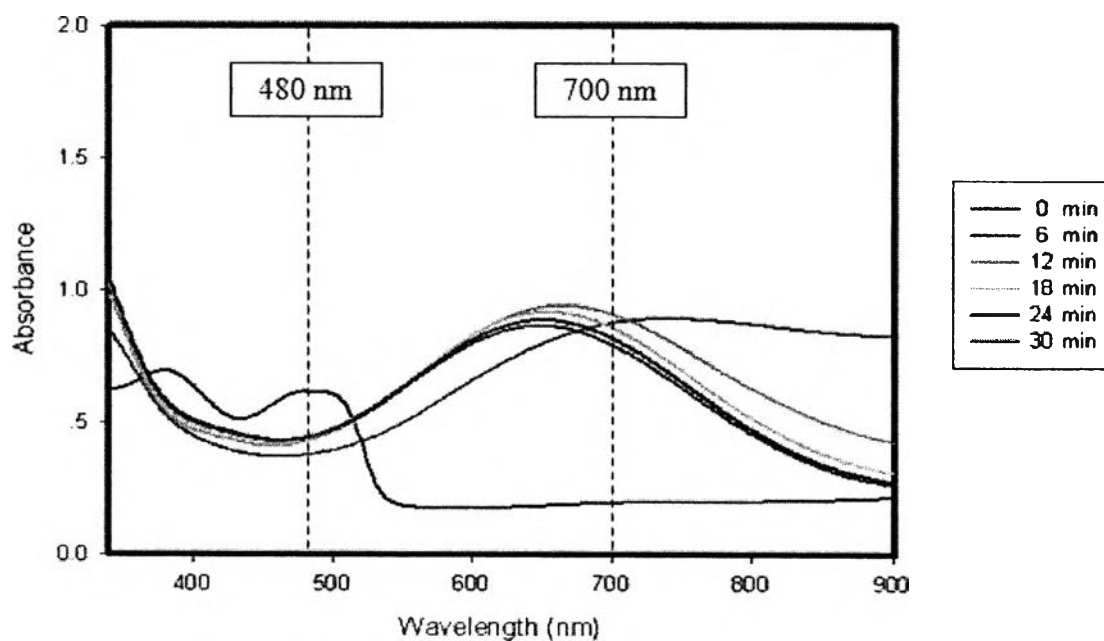


Figure E10 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 1.4 V at 6 minute intervals.

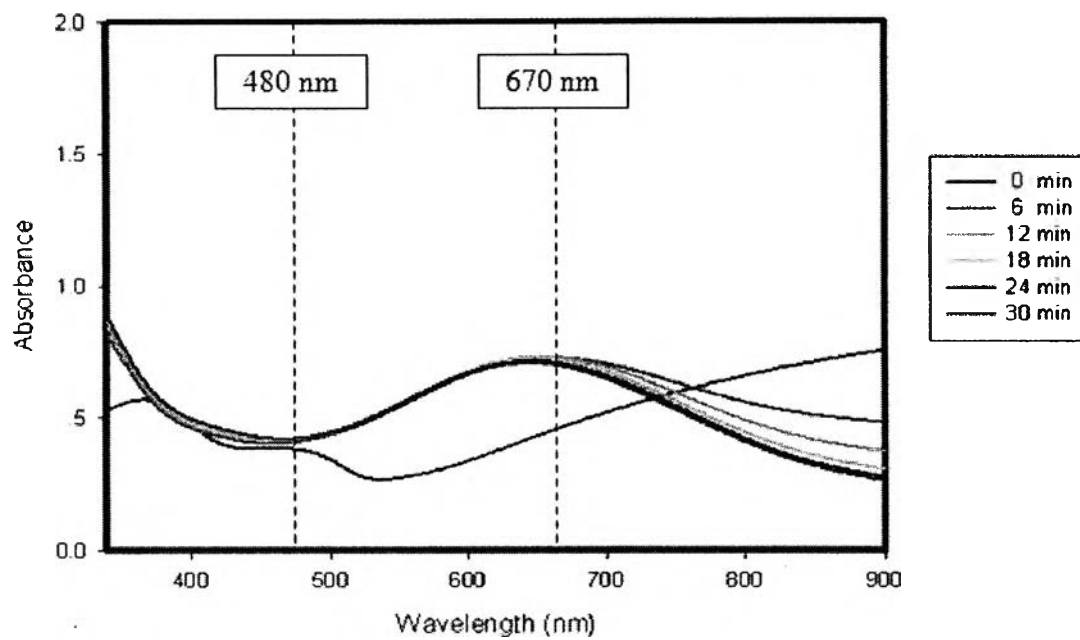


Figure E11 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M HCl electrolyte at 1.6 V at 6 minute intervals.

Oxidation reaction of PDMA film coated on the ITO electrode in 0.01 M H₂SO₄ electrolyte at 0.2 – 1.6 Volt.

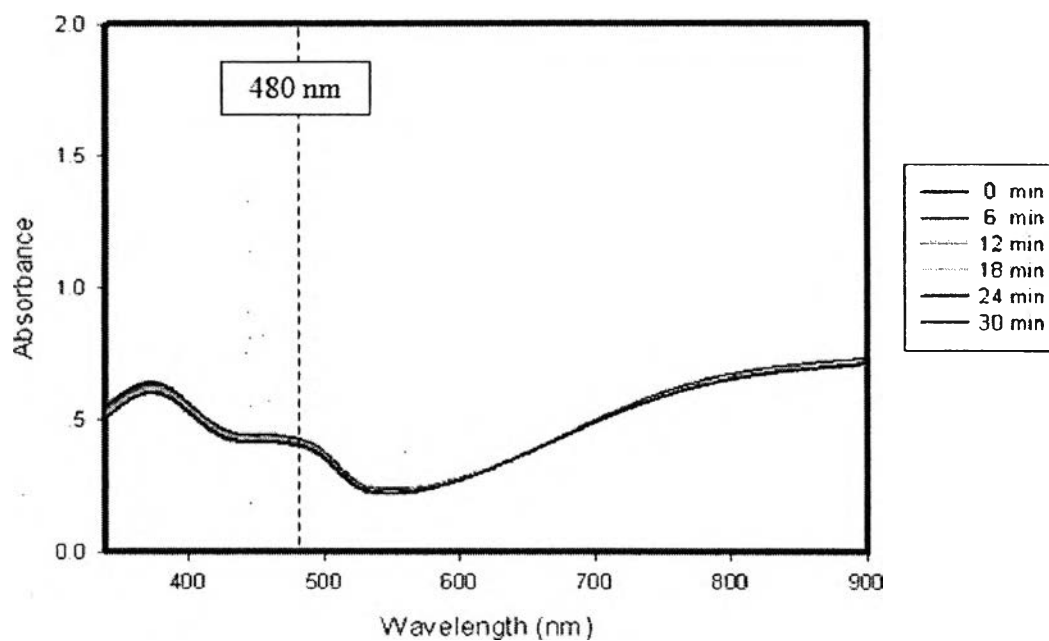


Figure E12 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H₂SO₄ electrolyte at 0.2 V at 6 minute intervals.

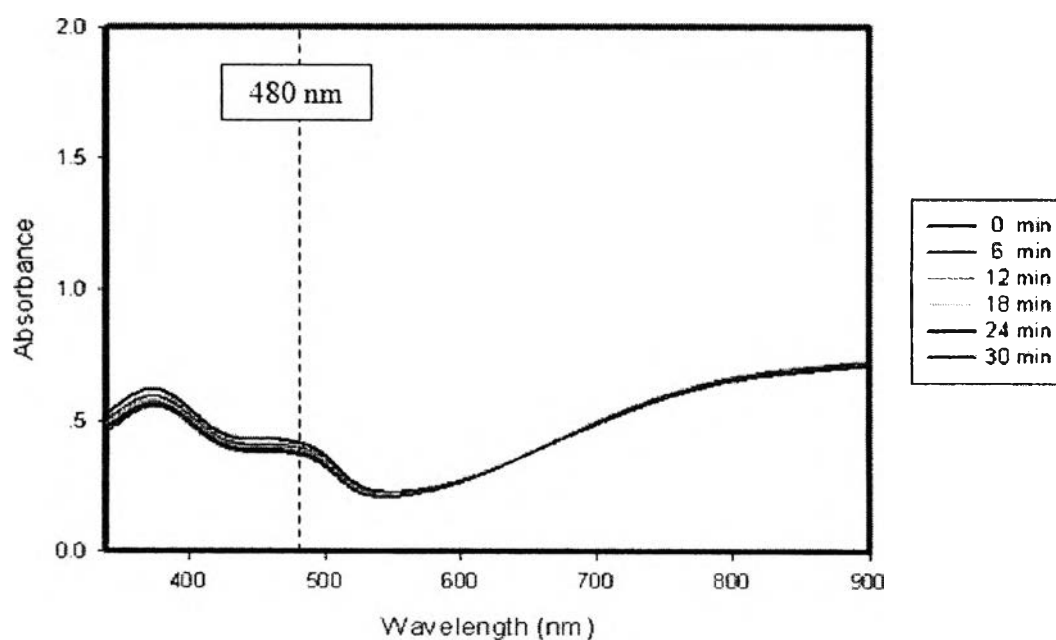


Figure E13 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H₂SO₄ electrolyte at 0.4 V at 6 minute intervals.

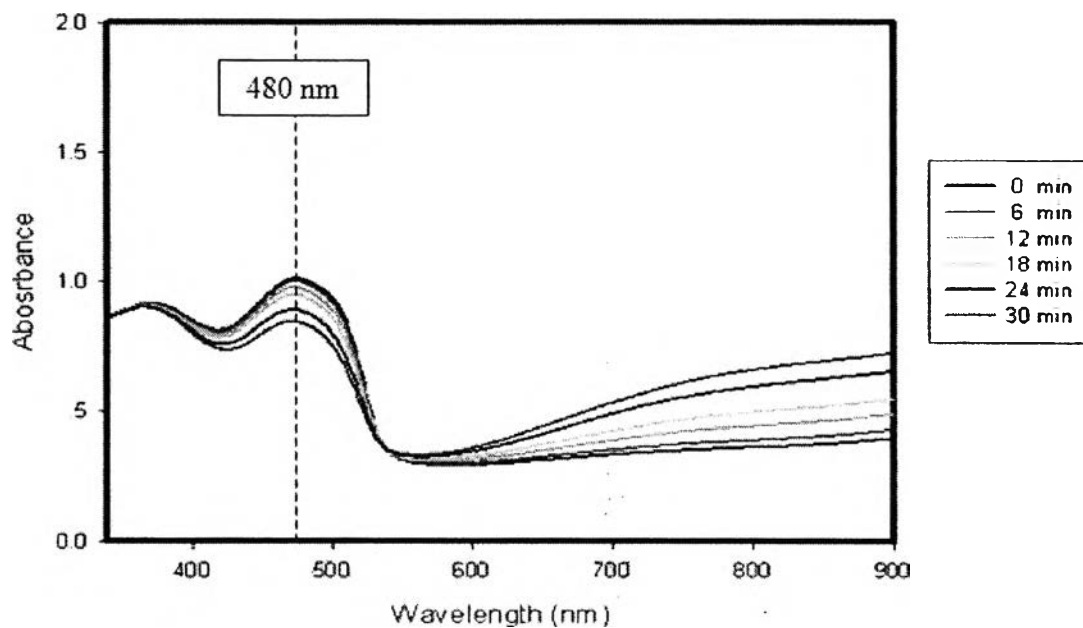


Figure E14 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 0.6 V at 6 minute intervals.

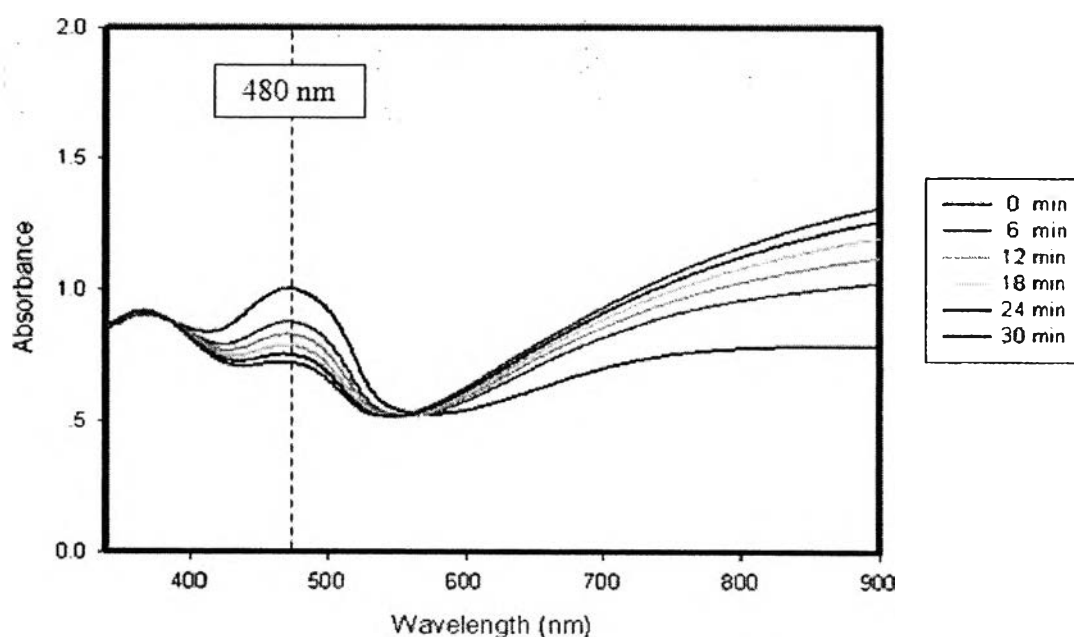


Figure E15 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 0.8 V at 6 minute intervals.

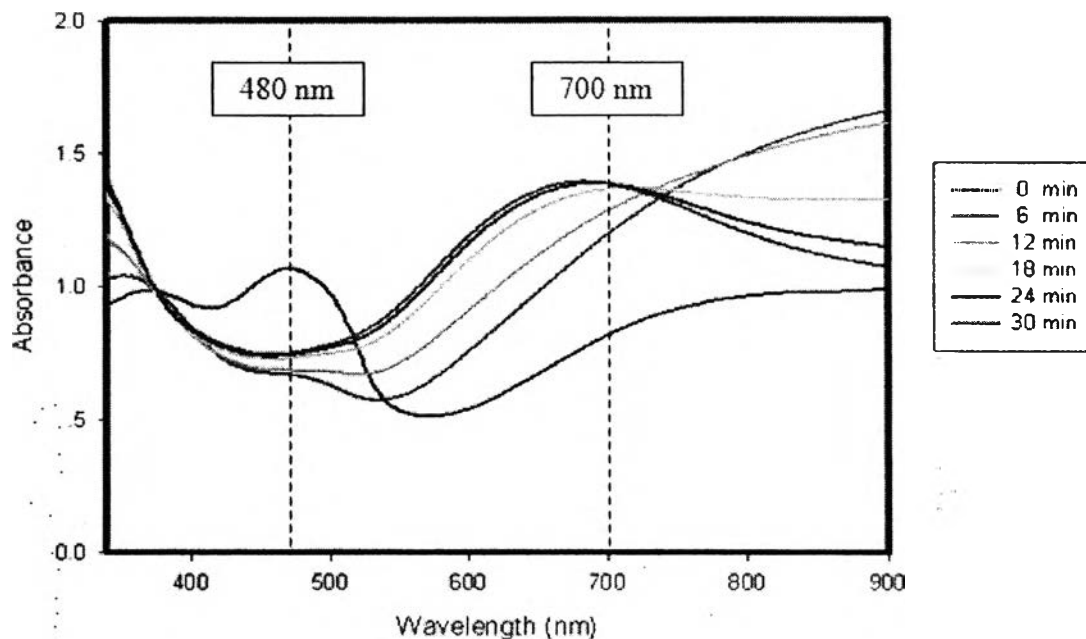


Figure E16 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 1.0 V at 6 minute intervals.

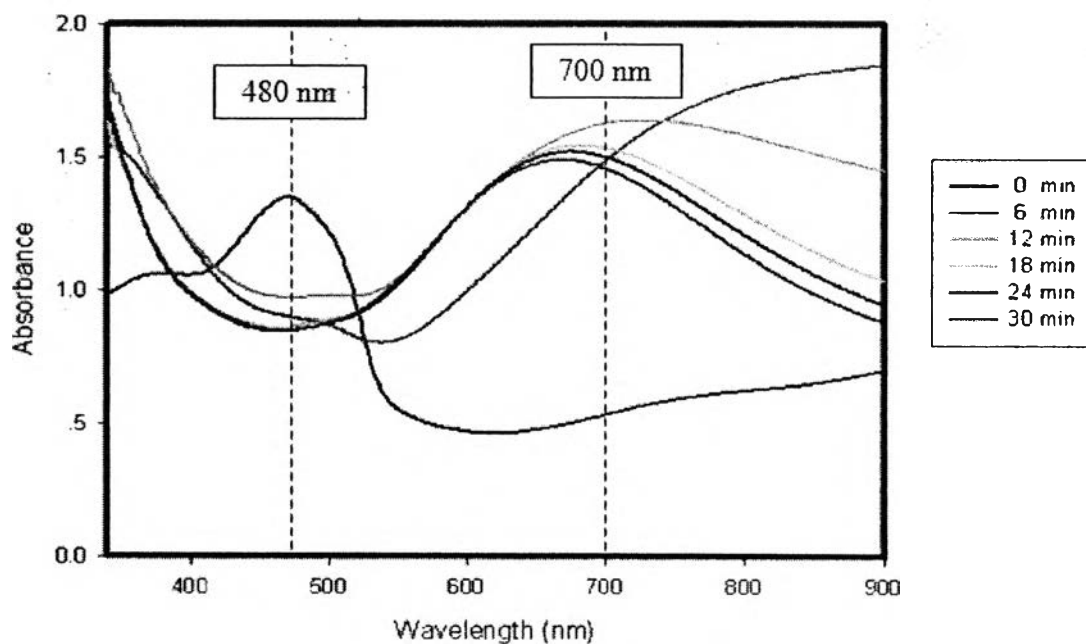


Figure E17 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 1.2 V at 6 minute intervals.

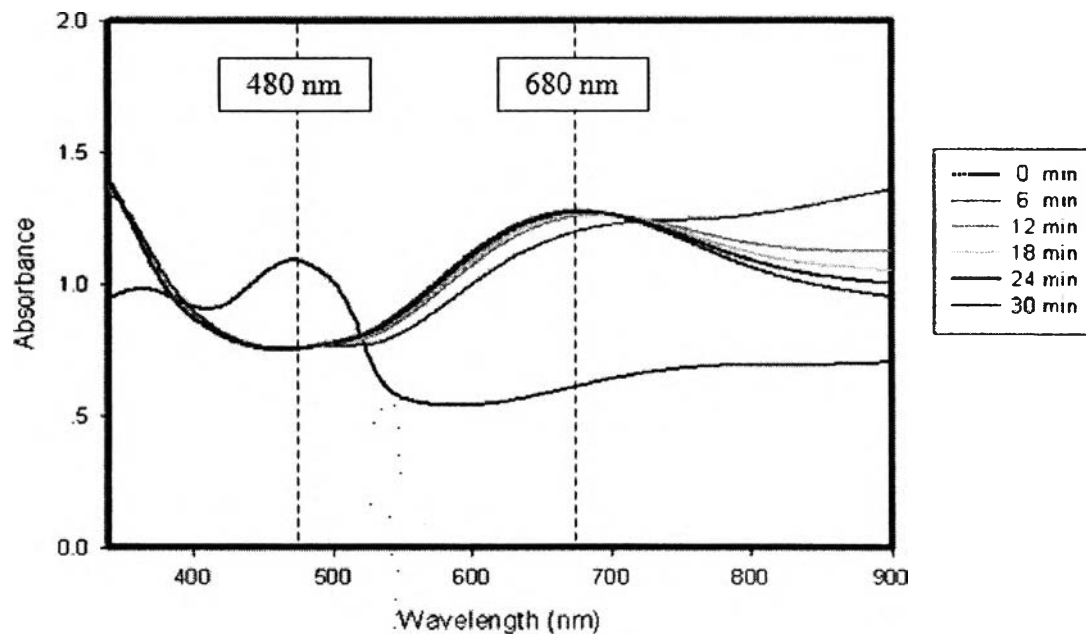


Figure E18 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 1.4 V at 6 minute intervals.

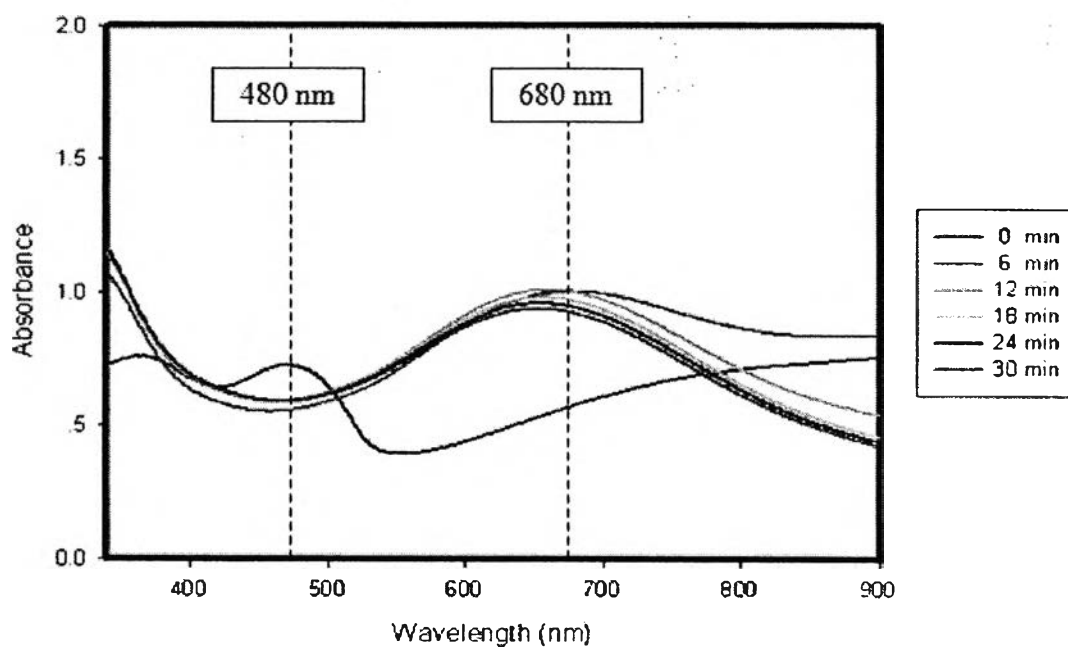


Figure E19 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.001 M H_2SO_4 electrolyte at 1.6 V at 6 minute intervals.

The reduction reaction

Table 2 shows the response time of the PDMA film in the reduction reaction when the voltage is fixed and the response time is varied in the 0.001 M HCl electrolyte and in the 0.001 M H₂SO₄ electrolyte. For both electrolytes at 0.2 V to 0.6 V, the colors of PDMA films do not change while at 0.8 V to 1.6 V, the colors of the PDMA films change from blue to yellow color.

Table E2 The response time of PDMA in the reduction reaction at various potentials in the 0.001 M HCl and the 0.001 M H₂SO₄ electrolytes

Electrolyte Volt	Reduction (Negative Potential)	
	0.001 M HCl	0.001 M H ₂ SO ₄
0.2 V	No change in color (Blue color)	No change in color (Blue color)
0.4 V	No change in color (Blue color)	No change in color (Blue color)
0.6 V	No change in color (Blue color)	No change in color (Blue color)
0.8 V	12 minute (Blue to Yellow color)	No change in color (Blue color)
1.0 V	10 minute (Blue to Yellow color)	6 minute (Blue to Yellow color)
1.2 V	6 minute (Blue to Yellow color)	6 minute (Blue to Yellow color)
1.4 V	4 minute (Blue to Yellow color)	4 minute (Blue to Yellow color)
1.6 V	2 minute (Blue to Yellow color)	1 minute (Blue to Yellow color)

The UV spectra of PDMA film were investigated at 0.2 to 1.6 V every 6 minute time intervals in the 0.001 M HCl electrolyte and in the 0.001 M H₂SO₄ electrolyte.

The spectra at 0.2 V to 0.6 V in 0.001 M HCl electrolyte are shown in figures E20 – E22 and in the 0.001 M H₂SO₄ electrolyte are shown in figures E28 – E30. The initial peak occurs at around 700 nm (blue color). With increasing negative potential time, their colors do not change.

The spectra at 0.8 V to 1.6 V in the 0.001 M HCl electrolyte are shown in figures E23 – E27 and in the 0.001 M H₂SO₄ electrolyte are shown in figures E31 – E35. The highest intensity occurs at around 700 nm which can be referred to blue color as can be clearly seen in the first spectra. The intensity of this peak gradually decreases with increasing negative potential time. At the same time, the presence of other peak at around 480 nm which can be referred to yellow color occurs.

Reduction reaction of PDMA film coated on the ITO electrode in the 0.01 M HCl electrolyte at 0.2 – 1.6 Volt.

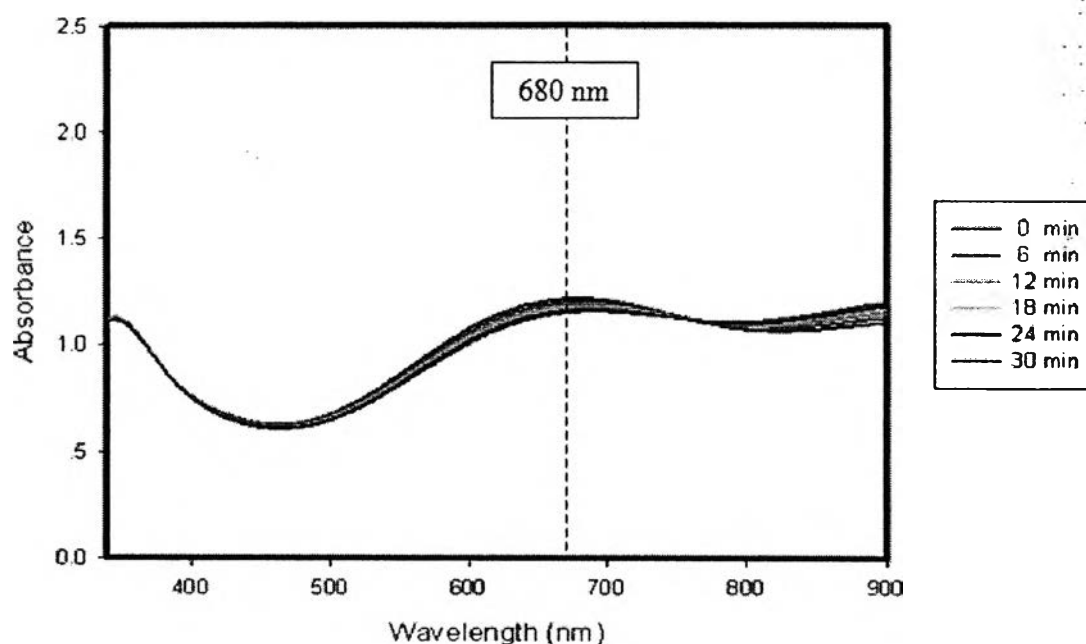


Figure E20 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 0.2 V at 6 minute intervals.

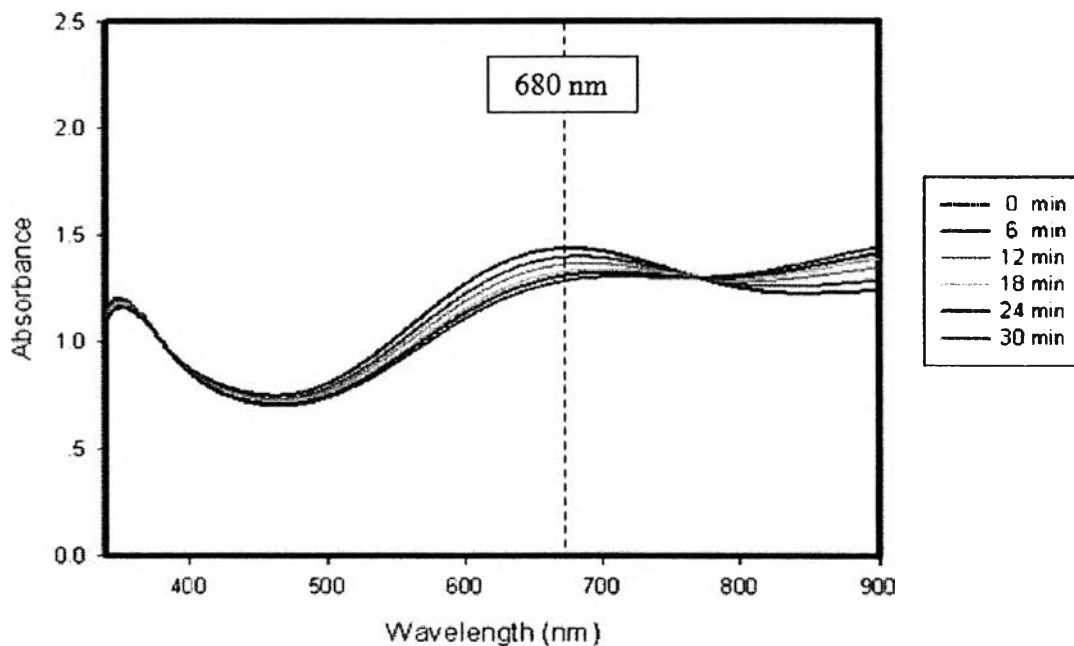


Figure E21 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 0.4 V at 6 minute intervals.

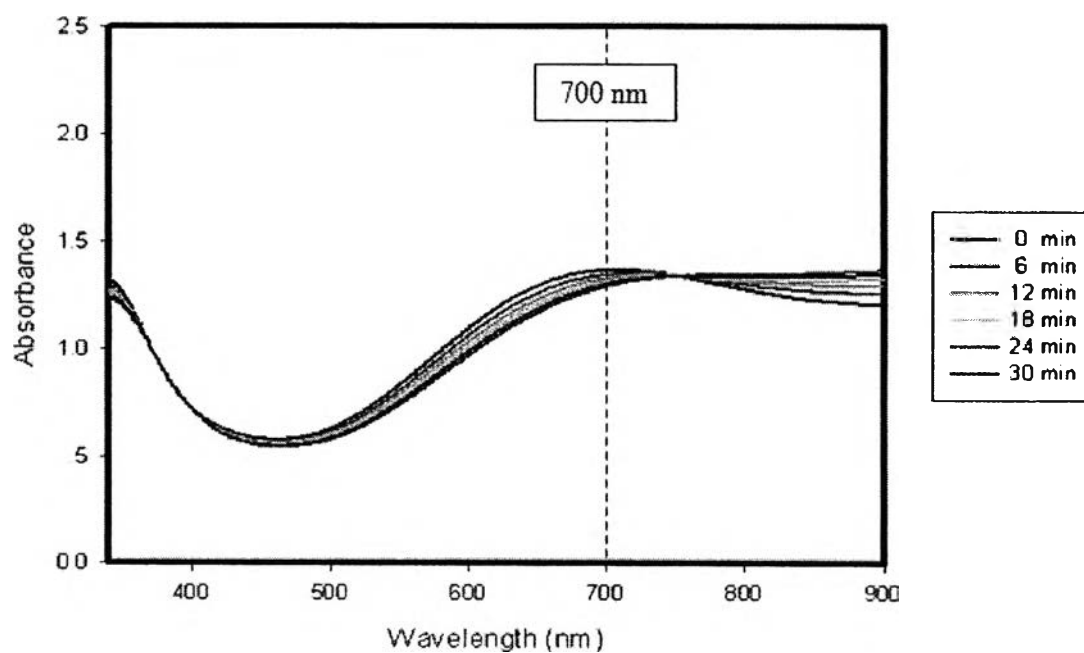


Figure E22 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 0.6 V at 6 minute intervals.

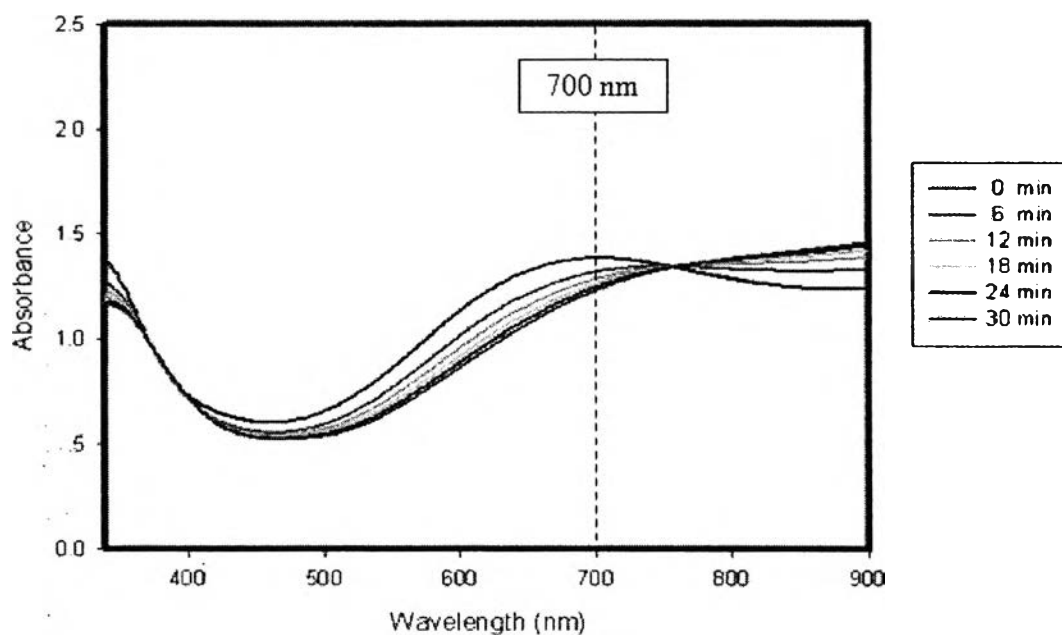


Figure E23 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 0.8 V at 6 minute intervals.

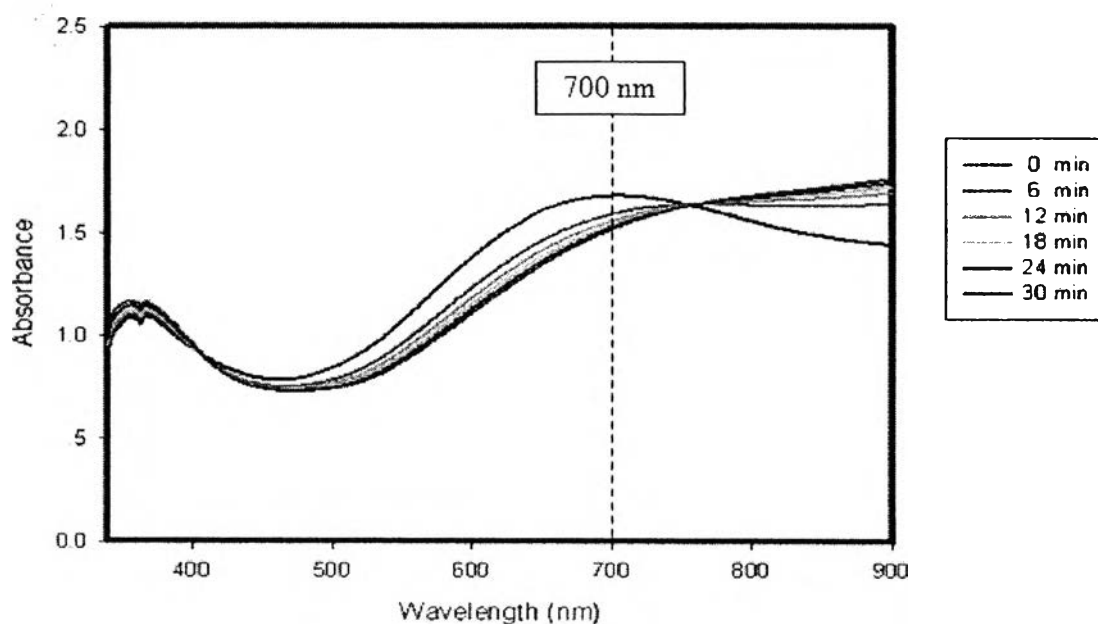


Figure E24 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 1.0 V at 6 minute intervals.

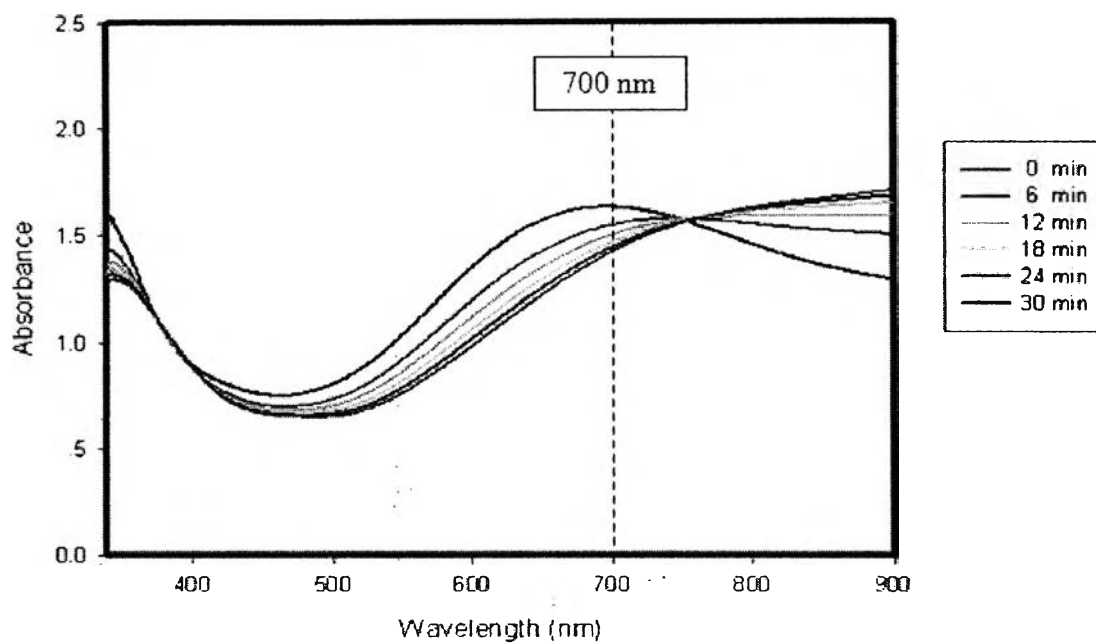


Figure E25 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 1.2 V at 6 minute intervals.

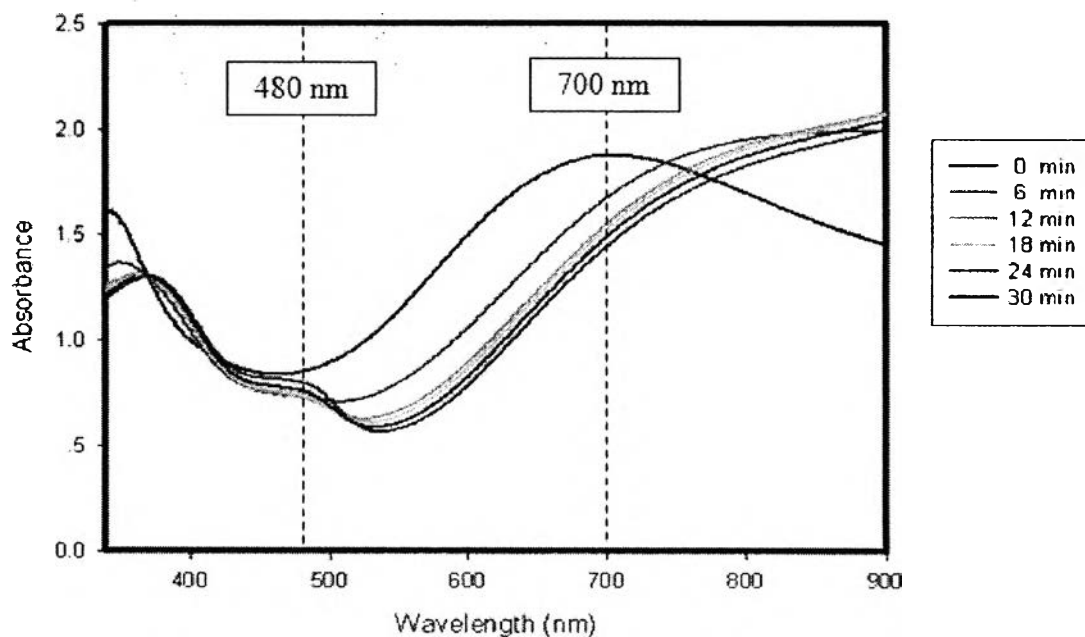


Figure E26 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 1.4 V at 6 minute intervals.

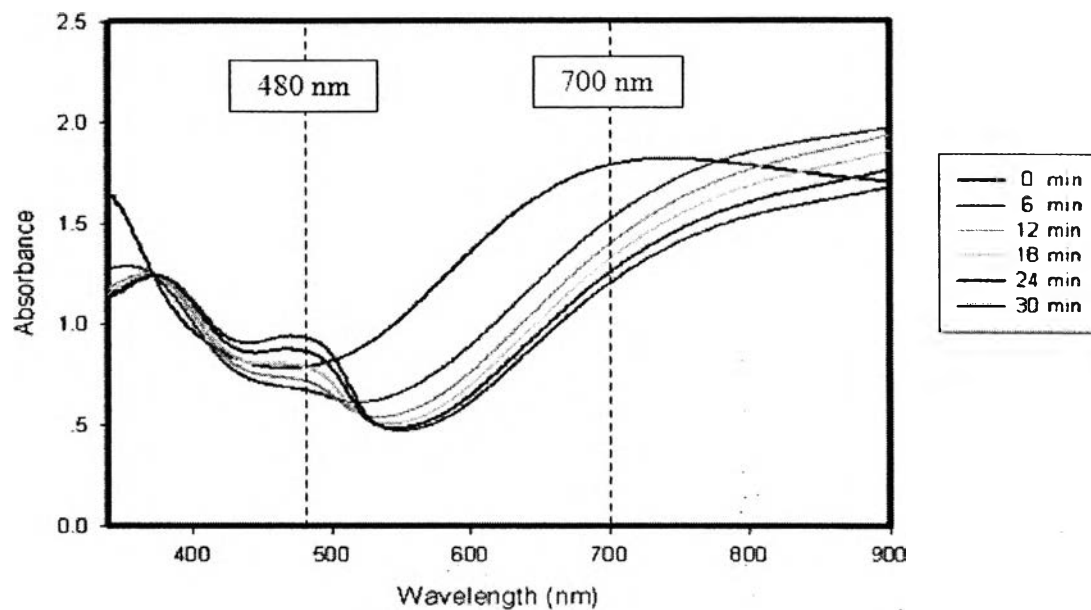


Figure E27 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M HCl electrolyte at 1.6 V at 6 minute intervals.

Reduction reaction of PDMA film coated on the ITO electrode in 0.01 M H₂SO₄ electrolyte at 0.2 – 1.6 Volt.

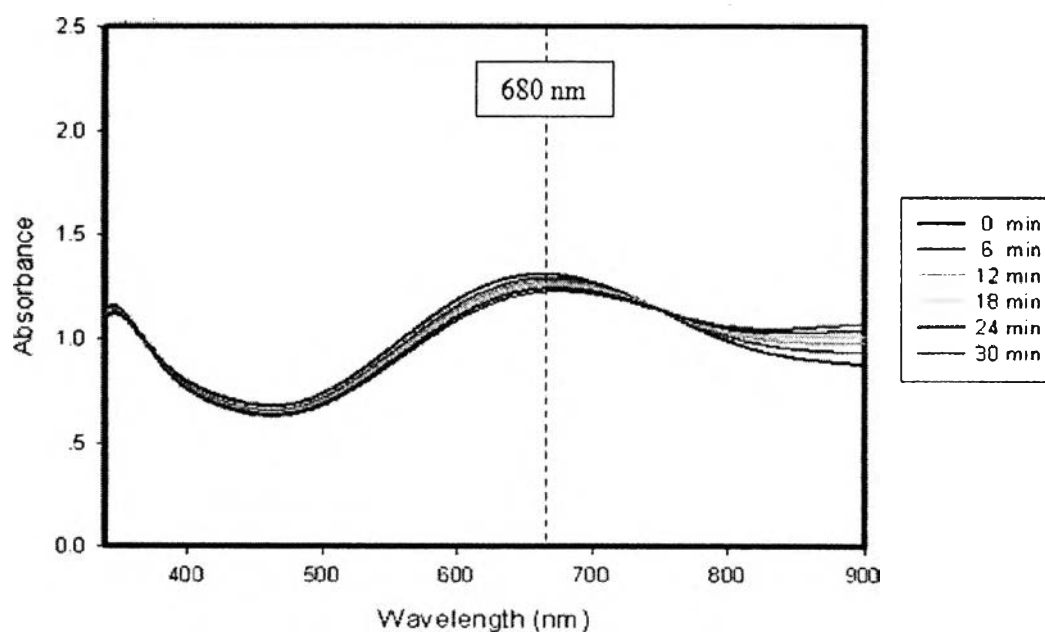


Figure E28 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H₂SO₄ electrolyte at 0.2 V at 6 minute intervals.

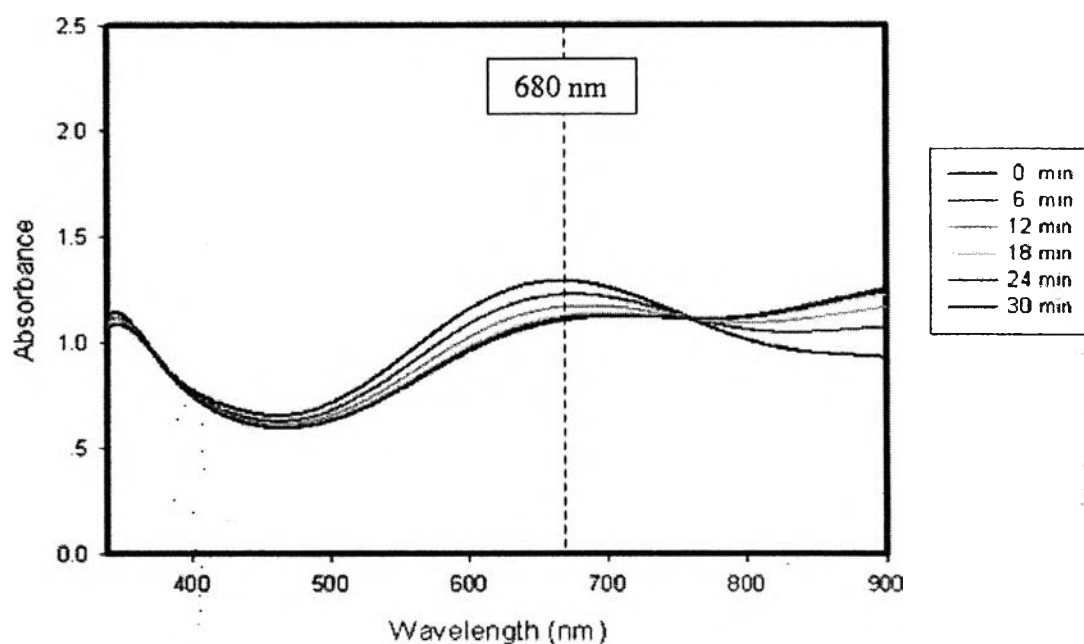


Figure E29 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 0.4 V at 6 minute intervals.

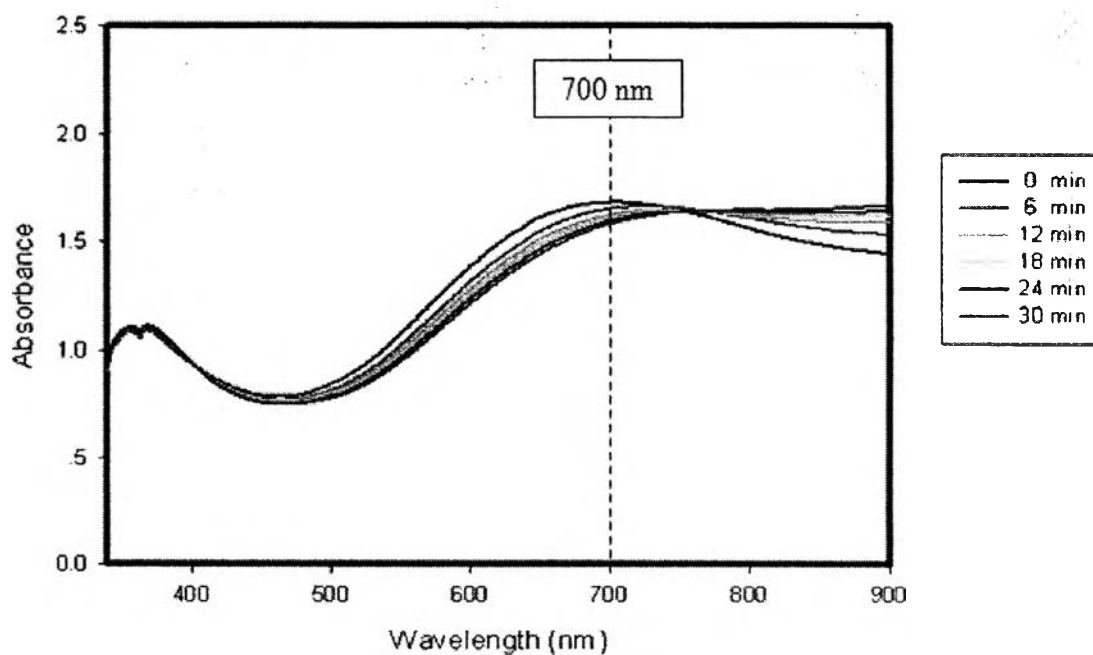


Figure E30 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 0.6 V at 6 minute intervals.

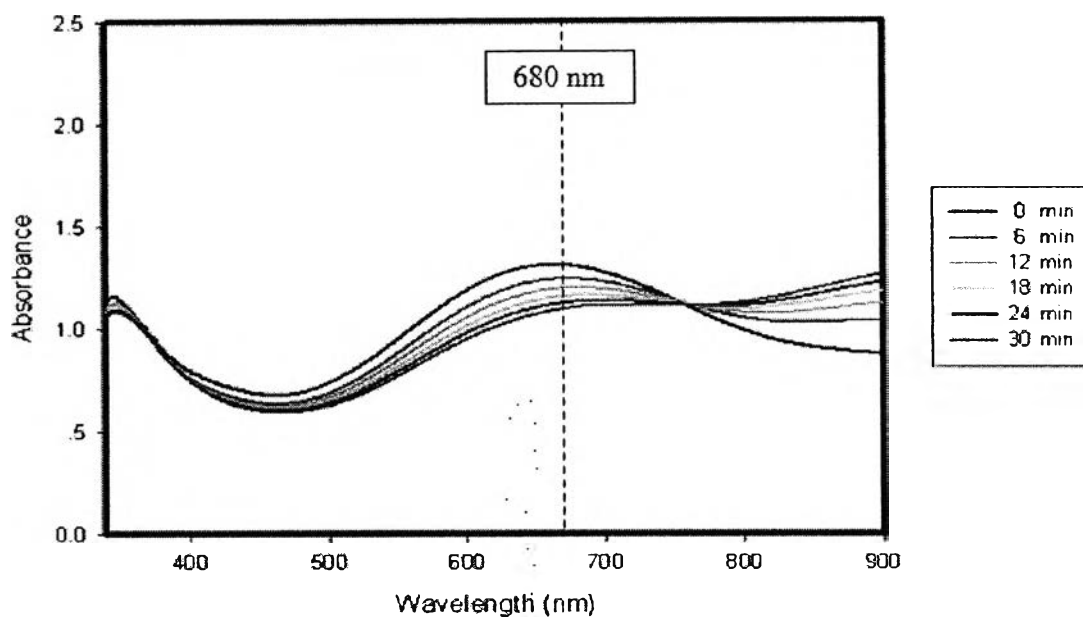


Figure E31 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 0.8 V at 6 minute intervals.

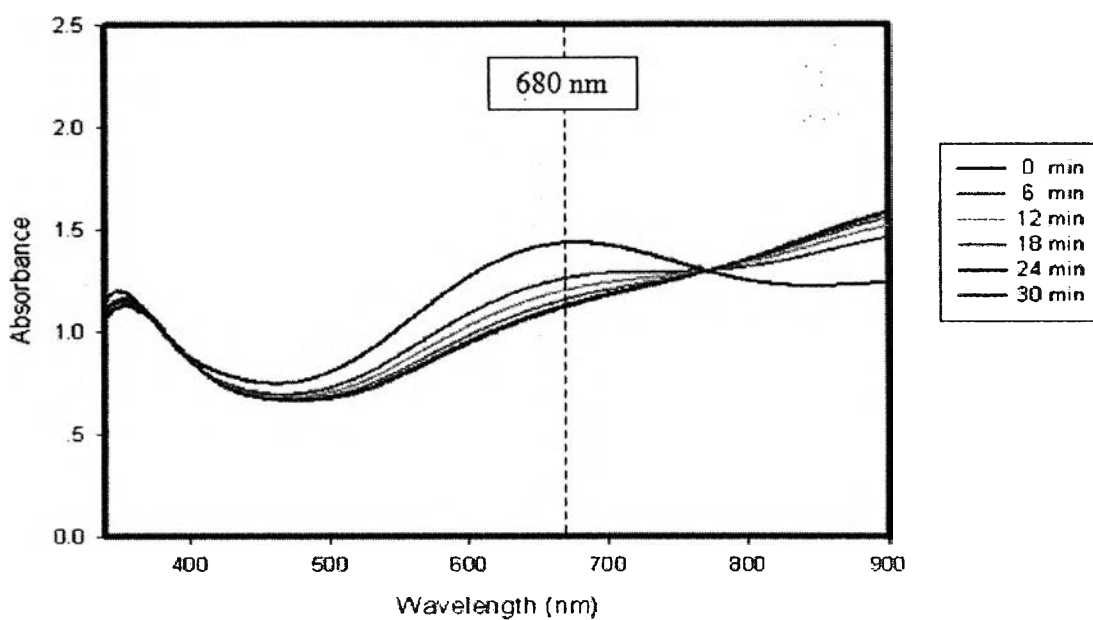


Figure E32 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 1.0 V at 6 minute intervals.

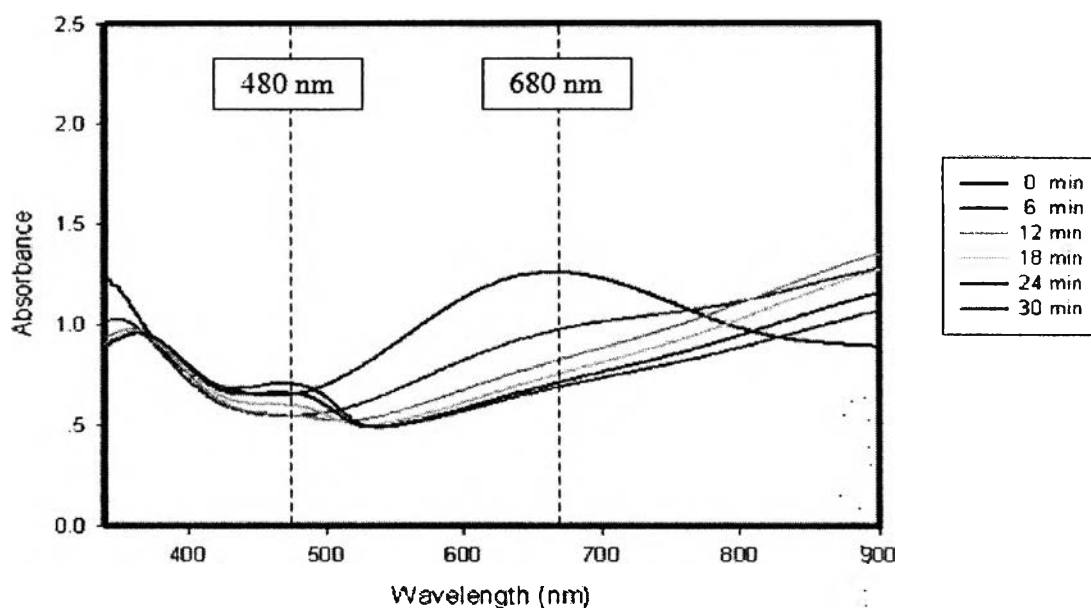


Figure E33 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 1.2 V at 6 minute intervals.

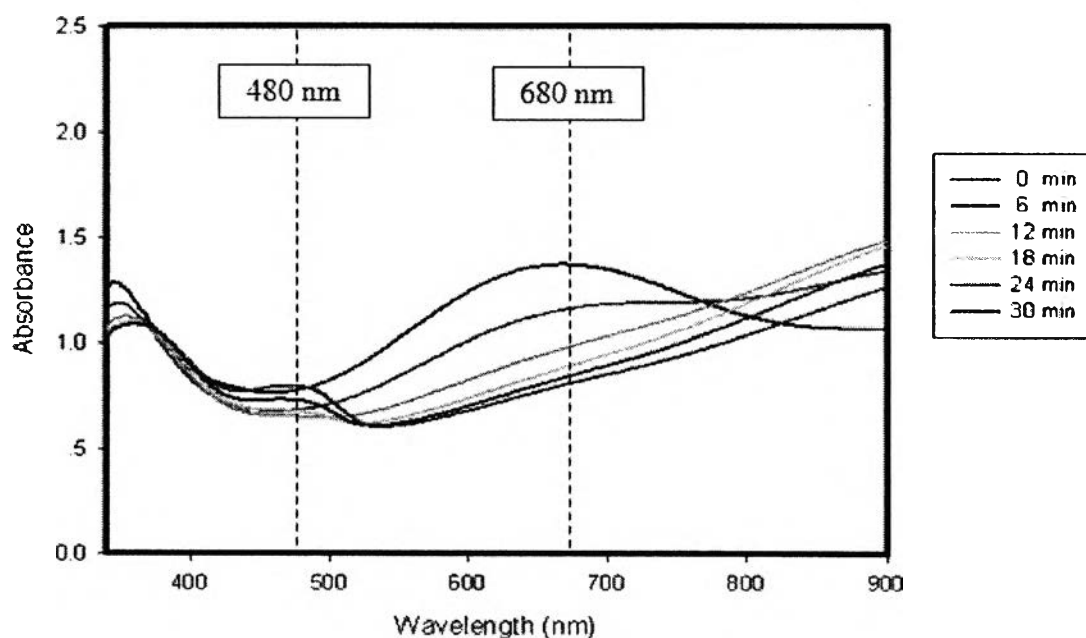


Figure E34 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 1.4 V at 6 minute intervals.

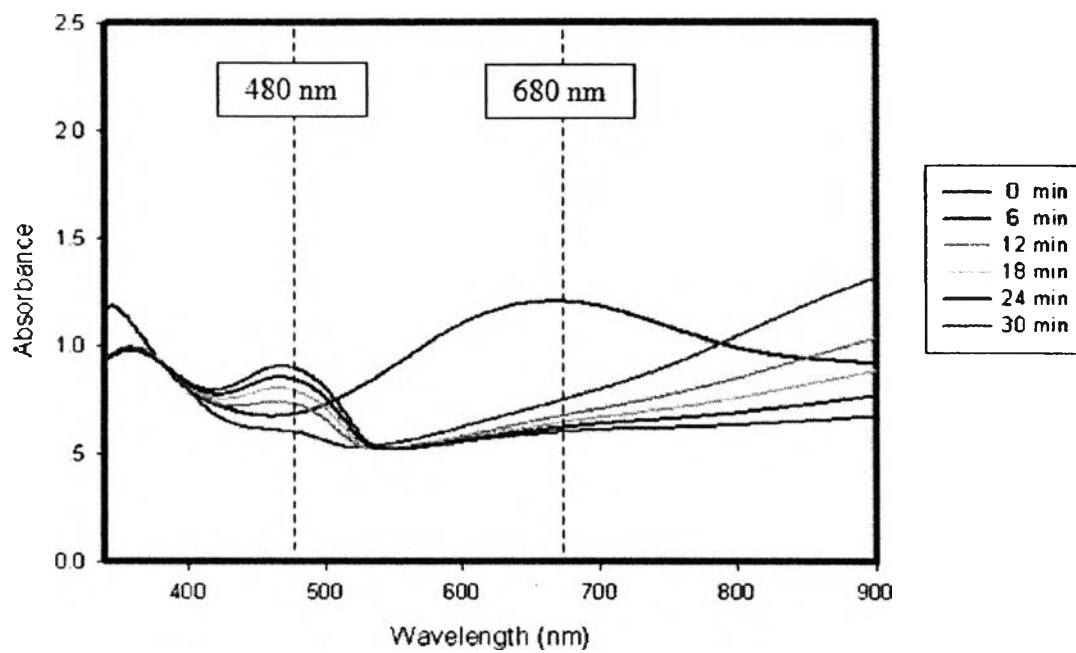


Figure E35 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.001 M H_2SO_4 electrolyte at 1.6 V at 6 minute intervals.

Second Part

Compare the respond time in the different concentration 0.001 M, 0.01 M and 0.1 M of each electrolyte.

The oxidation reaction

Table 3 shows the response time of the PDMA film in the oxidation reaction when the voltage is fixed at 1.2 V and the response time is varied in the various concentrations of 0.001 M, 0.01 M and 0.1 M of the HCl electrolyte and the H₂SO₄ electrolyte, respectively. For both electrolytes at 0.01 M and 0.1 M, the colors of PDMA films do not change while at 0.001 M, the colors of the PDMA films change from yellow to blue color.

Table E3 The response time of PDMA in the oxidation reaction at 1.2 V at various concentrations in the HCl and H₂SO₄ as electrolytes

Electrolyte Concentration	Oxidation (Positive Potential)	
	HCl	H ₂ SO ₄
0.001 M	14 minute (Yellow to Blue color)	8 minute (Yellow to Blue color)
0.01 M	No change in color (Yellow color)	No change in color (Yellow color)
0.1 M	No change in color (Yellow color)	No change in color (Yellow color)

The UV spectra of PDMA film were measured at 1.2 V in the concentrations of 0.001 M, 0.01 M and 0.1 M for the HCl electrolyte and the H₂SO₄ electrolyte.

The spectra in the concentrations of 0.01 M and 0.1 M HCl electrolyte are shown in figures E36 and E37 and the H₂SO₄ electrolyte are shown in figures E38 and E39. The initial peak occurs at around 480 nm (yellow color). With increasing positive potential time, their colors do not change.

The spectra in the concentrations of 0.01 M HCl electrolyte are shown in figures E9 and of the 0.001 M H₂SO₄ electrolyte are shown in figure E17. The first spectra occurs at around 380 and 480 nm which can be referred to yellow which gradually decreases with increasing positive potential time. At the same time, the presence of other peak at around 680 nm which can be referred to blue color occurs.

Oxidation reaction of the PDMA film coated on the ITO electrode at 1.2 Volt in the concentrations of 0.01 M and 0.1 M HCl and H₂SO₄ electrolytes.

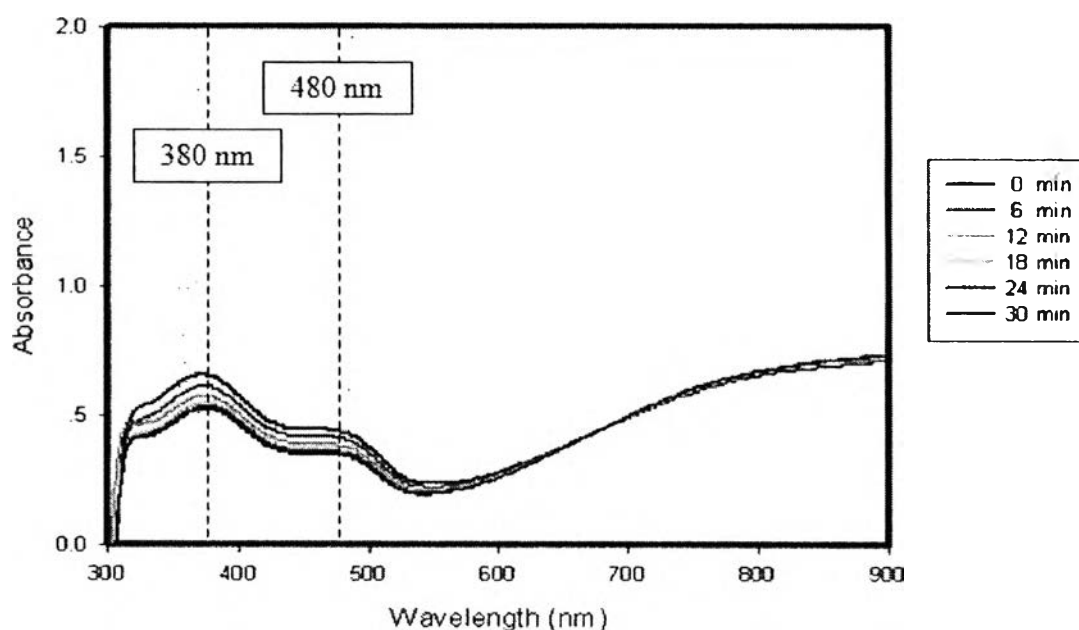


Figure E36 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.01 M HCl electrolyte at 1.2 V at 6 minute intervals.

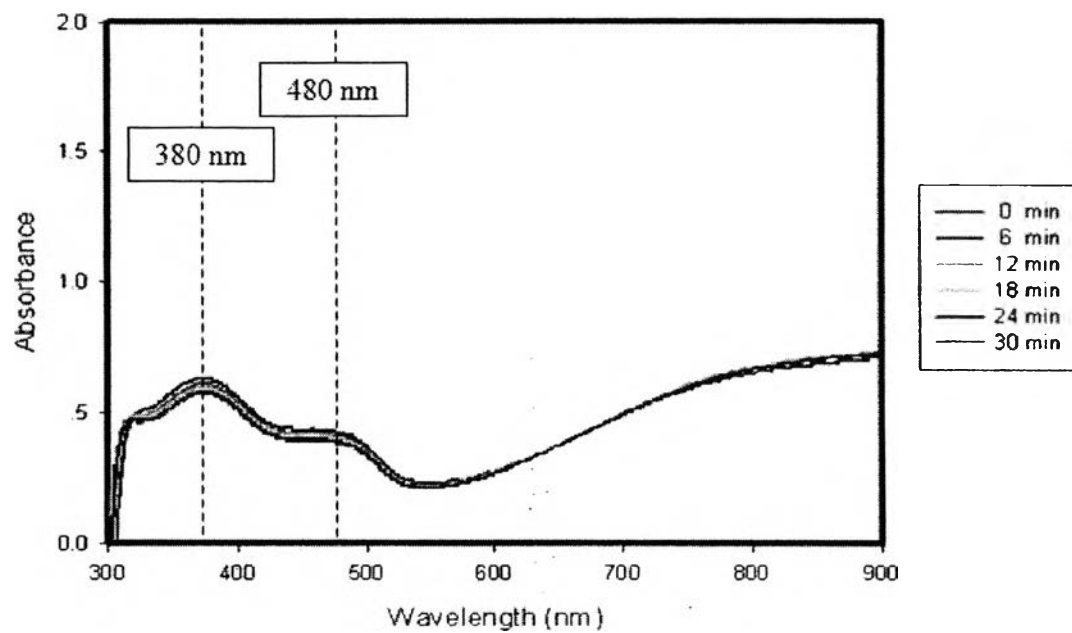


Figure E37 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.1 M HCl electrolyte at 1.2 V at 6 minute intervals.

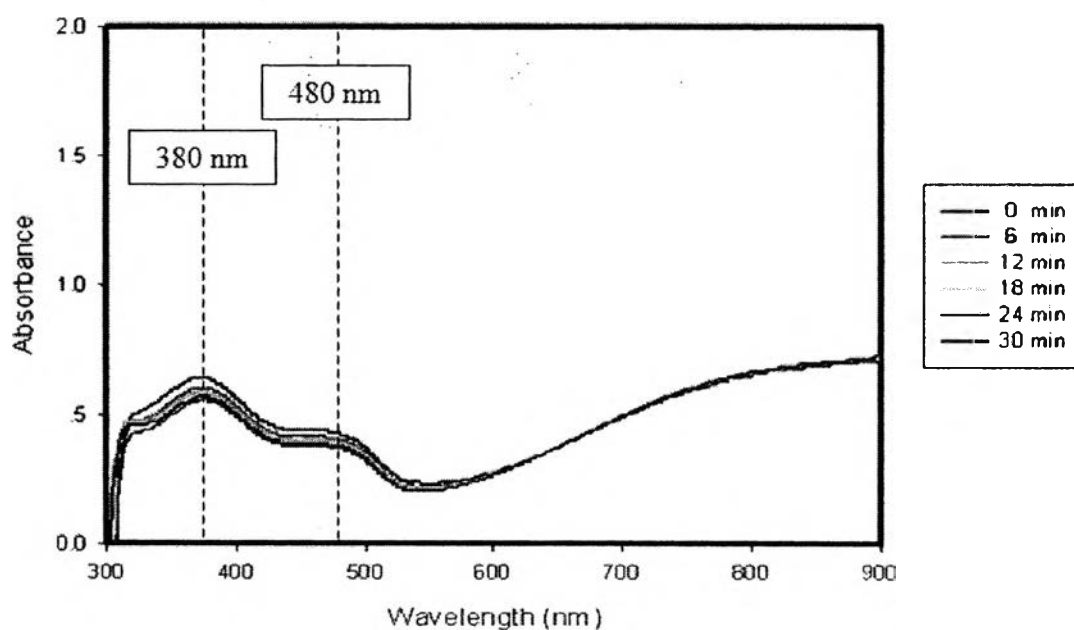


Figure E38 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.01 M H₂SO₄ electrolyte at 1.2 V at 6 minute intervals.

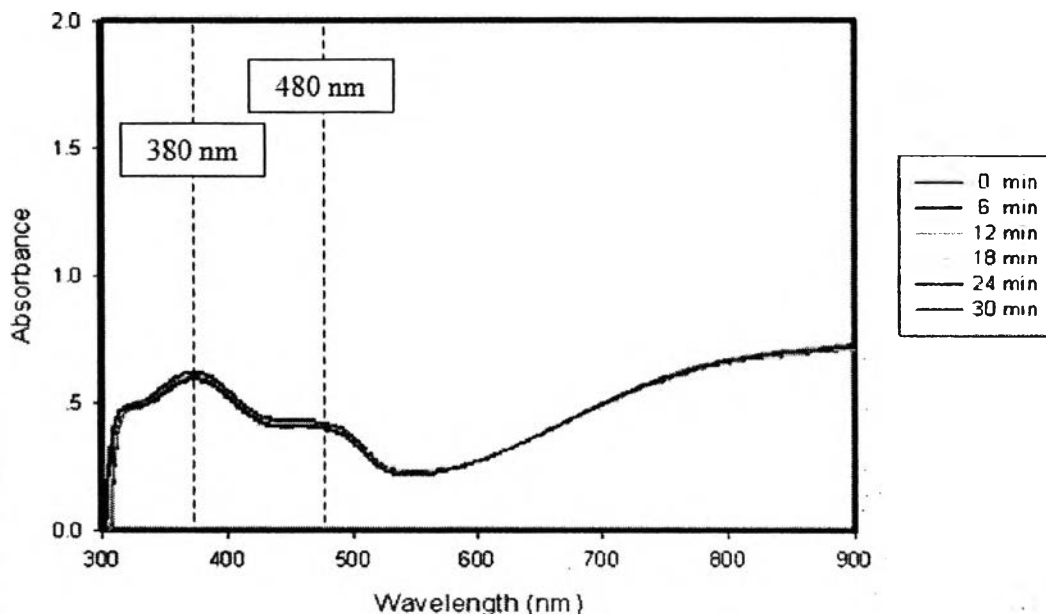


Figure E39 In situ spectra of PDMA film coated on the ITO electrode during the oxidation reaction in the 0.1 M H_2SO_4 electrolyte at 1.2 V at 6 minute intervals.

The reduction reaction

Table 4 shows the response time of the PDMA film in the reduction reaction when the voltage is fixed at 1.2 V and the response time is varied in the different concentrations of 0.001 M, 0.01 M and 0.1 M of the HCl electrolyte and H_2SO_4 electrolyte, respectively. For both electrolytes the colors of the PDMA films change from blue to yellow color.

Table E4 The response time of PDMA in the reduction reaction at 1.2 V in various concentrations in HCl and H_2SO_4 as electrolytes

Electrolyte Concentration	Reduction (Negative Potential)	
	HCl	H_2SO_4
0.001 M	6 minute (Blue to Yellow color)	6 minute (Blue to Yellow color)
0.01 M	1 minute (Blue to Yellow color)	1 minute (Blue to Yellow color)
0.1 M	0.2 minute (Blue to Yellow color)	0.2 minute (Blue to Yellow color)

The UV spectra of PDMA film were measured at 1.2 V in the concentrations of 0.001 M, 0.01 M and 0.1 M for HCl electrolyte are shown in figures E25, E40 and E41, and the H₂SO₄ electrolyte are shown in figures E33, E42 and E43, respectively. With increasing the negative potential time, their colors change from the highest intensity peak at around 700 nm which can be referred to blue color to the another peak at around 480 nm which can be referred to yellow color.

Reduction reaction of the PDMA film coated on the ITO electrode at 1.2 Volt in the concentration of the 0.01 M and 0.1 M of the HCl and H₂SO₄ electrolytes.

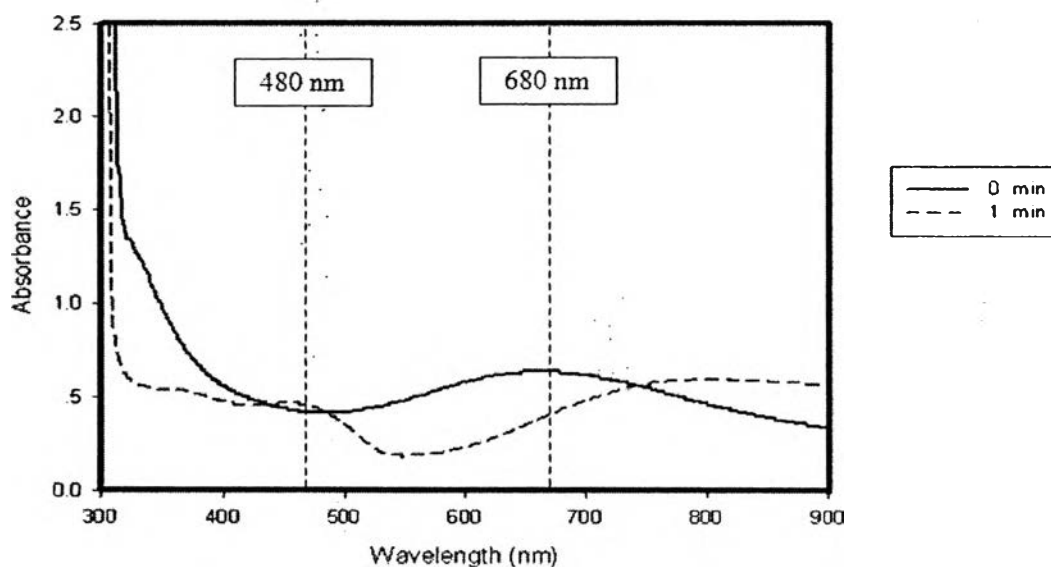


Figure E40 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.01 M HCl electrolyte at 1.2 V at 6 minute intervals.

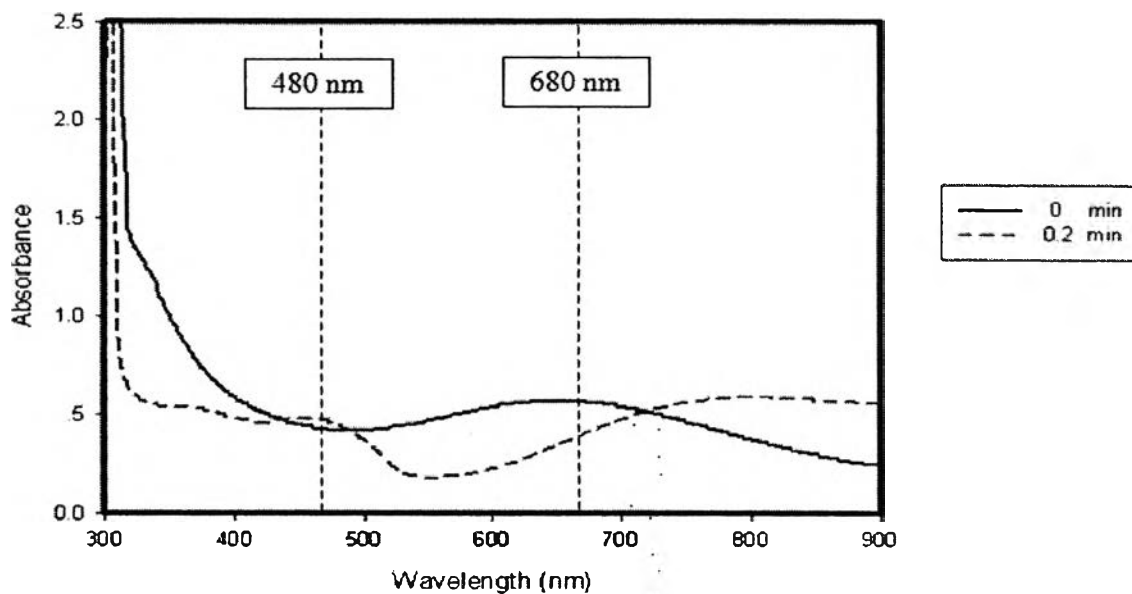


Figure E41 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.1 M HCl electrolyte at 1.2 V at 6 minute intervals.

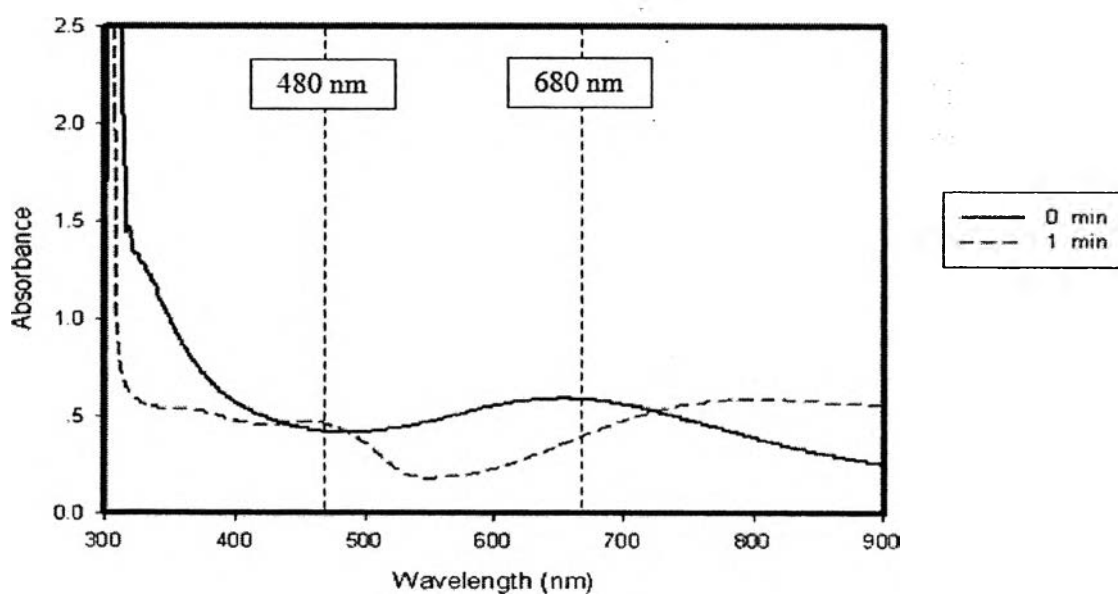


Figure E42 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.01 M H₂SO₄ electrolyte at 1.2 V at 6 minute intervals.

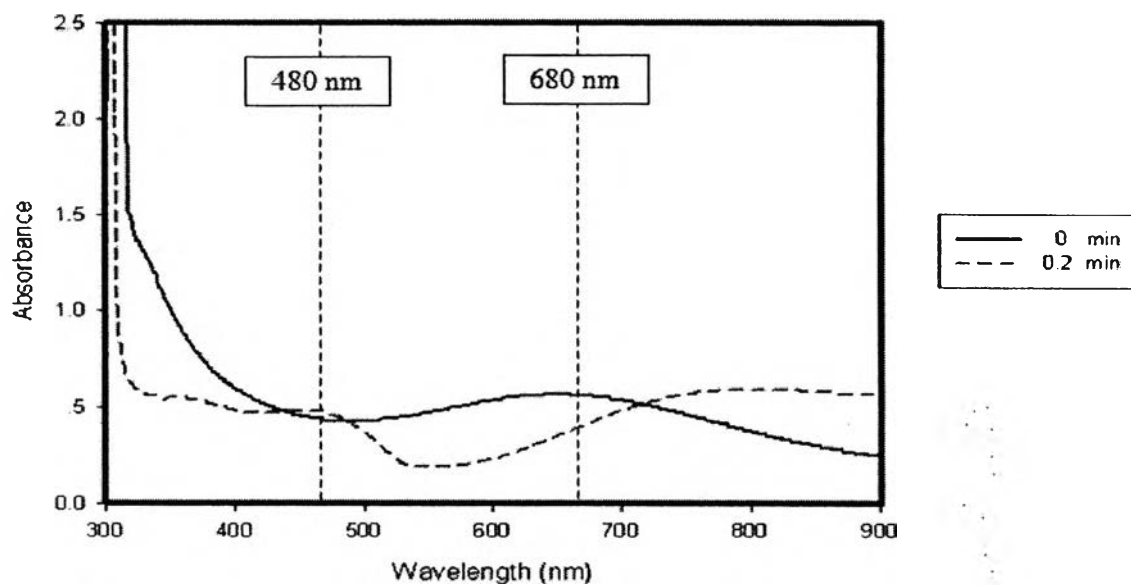


Figure E43 In situ spectra of PDMA film coated on the ITO electrode during the reduction reaction in the 0.1 M H_2SO_4 electrolyte at 1.2 V at 6 minute intervals.

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Proceedings:

1. Mungkalodom, P.; and Sirivat, A. (2011, April 26) Synthesis and Characterization of Poly (2,5 – dimethoxyaniline) for Use as Electrochromic Smart Materials. Proceedings of the 2nd National Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and The 17th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

Presentations:

1. Mungkalodom, P.; and Sirivat, A. (2011, April 26) Synthesis and Characterization of Poly (2,5 – dimethoxyaniline) for Use as Electrochromic Smart Materials. Paper presented at the 2nd National Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and The 17th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.