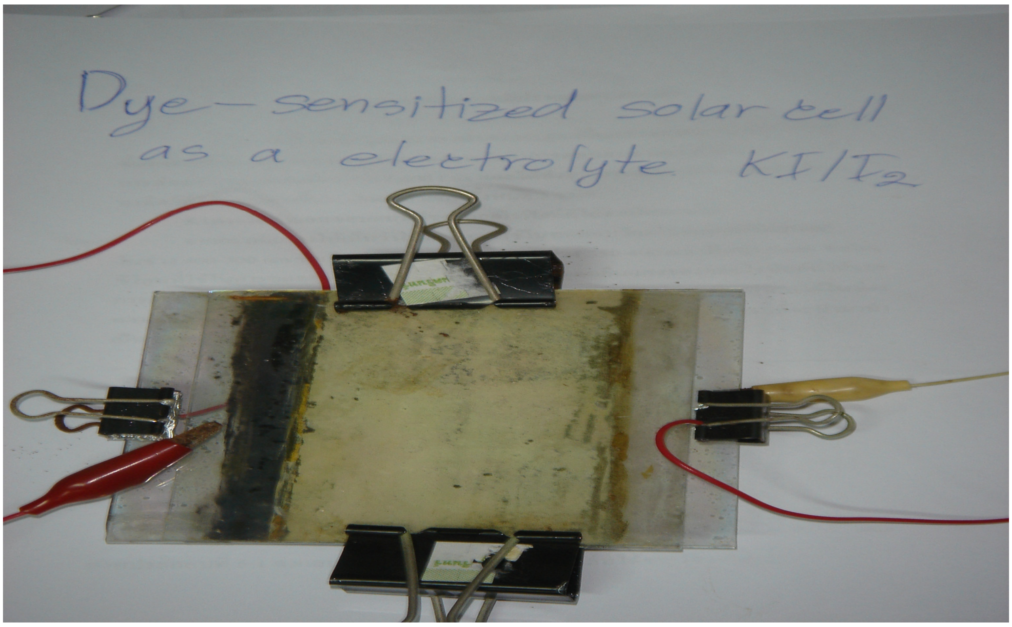
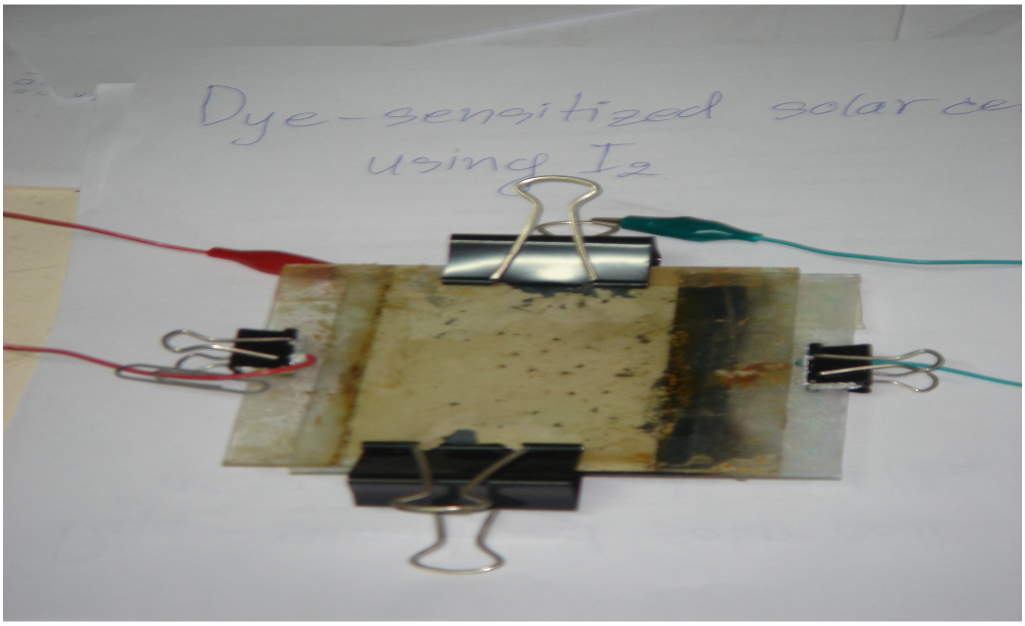
ภาคผนวก ก

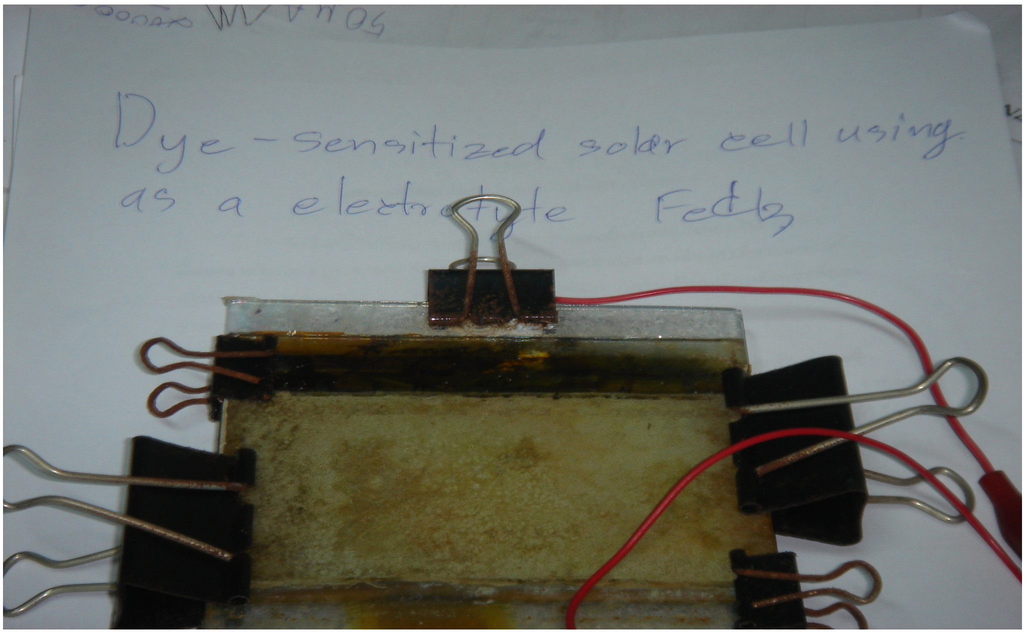
ภาพของเซลล์แสงอาทิตย์ทั้ง 3 ชนิด



ภาพประกอบที่ ก-1 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้อิเล็กโตรไลท์KI/I_2



ภาพประกอบที่ ก-2 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้ไอ I_2บริสุทธิ์



ภาพประกอบที่ ก-3 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้อิเล็กโตรไลท์ $FeCl_3$

ภาคผนวก ข

ตารางข้อมูลการวัดค่าแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์

ตารางที่ ข-1 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้อิเล็กโตรไลท์ KI/I_2 ครั้งที่ 1

Time (min)	Potential (mV)	Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	0.4	47	73.8	94	1.1
1	54.2	48	74.1	95	0.4
2	63.6	49	74.3	96	-0.1
3	68.4	50	74.4	97	-0.7
4	70.7	51	74.3	98	-1.3
5	71.6	52	74.4	99	-1.7
6	72.6	53	74.5	100	-2.2
7	72.4	54	74.3	101	-2.5
8	72.3	55	74.3	102	-2.9
9	72.5	56	74.3	103	-3.2
10	72.6	57	74.6	104	-3.5
11	72.6	58	75	105	-3.7
12	72.6	59	75.4	106	-4
13	72.8	60	75.6	107	-4.2
14	72.8	61	75.5	108	-4.4
15	73.5	62	75.6	109	-4.5
16	73.7	63	75.7	110	-4.7
17	73.6	64	74.9	111	-4.9
18	73.3	65	73.8	112	-5
19	73.1	66	73.5	113	-5.1
20	72.7	67	73.6	114	-5.2
21	72	68	73.7	115	-5.3
22	71.6	69	73.8	116	-5.4
23	71.8	70	73.9	117	-5.5
24	72.1	71	73.9	118	-5.6
25	71.8	72	73.1	119	-5.7
26	71.3	73	72.8	120	-5.8
27	70.9	74	72.7	121	-5.9
28	70.8	75	72.8	122	-5.9
29	70.9	76	73.1	123	-6
30	71	77	73.3	124	-6
31	71.1	78	51.3	125	-6.1
32	71.2	79	42	126	-6.2
33	71.3	80	34.7	127	-6.3
34	71.2	81	28.5	128	-6.3
35	71.3	82	24.3	129	-6.4
36	71.5	83	20.1	130	-6.4
37	71.7	84	17.1	131	-6.4
38	72	85	14.3	132	-6.5
39	72.4	86	11.9	133	-6.5
40	72.7	87	9.9	134	-6.5
41	73	88	8	135	-6.6
42	73	89	6.5	136	-6.6
43	73.1	90	5.2	137	-6.6
44	73.2	91	3.9	138	-6.6
45	73.3	92	2.9	139	-6.6
46	73.4	93	2		

จากตารางที่ ข-1 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 1 (เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้อิเล็กโตรไลท์ KI/I_2) ของการทดลองครั้งที่ 1 ช่วงที่เวลา 0-77 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 78-139 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-2 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้อิเล็กโตรไลท์ KI/I_2 ครั้งที่ 2

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	0.4	32	77.1
1	61.5	33	77.1
2	83.2	34	76.7
3	90.2	35	76.7
4	91.5	36	76.7
5	91.6	37	76.7
6	90.8	38	76.7
7	89.9	39	59.6
8	89.4	40	48.1
9	89	41	42.5
10	88.3	42	36.5
11	87.1	43	31.6
12	86.6	44	26.2
13	85.6	45	23.2
14	85.1	46	20.7
15	86.6	47	18.9
16	83.6	48	15.9
17	80.6	49	13.8
18	79.6	50	12.1
19	78.2	51	10.6
20	78.2	52	9.2
21	78.2	53	8
22	78.2	54	6.8
23	78.2	55	5.8
24	77.8	56	4.8
25	77.8	57	4
26	77.8	58	3.3
27	77.8	59	2.6
28	77.8	60	1.9
29	77.1	61	1.3
30	77.1	62	0.7
31	77.1	63	0.2

จากตารางที่ ข-2 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลลแสงอาทิตย์ชนิดที่ 1 ของการทดลองครั้งที่ 2 ช่วงที่เวลา 0-38 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 39-63 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-3 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้อิเล็กโตรไลท์ KI/I_2 ครั้งที่ 3

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	2.9	35	11.2
1	37.6	36	10.8
2	47.8	37	10.3
3	52.2	38	9.9
4	54.6	39	9.5
5	56.6	40	9.2
6	58.3	41	8.8
7	59.3	42	8.5
8	60.6	43	8.3
9	61.4	44	7.9
10	62	45	7.6
11	62.5	46	7.4
12	62.8	47	7.1
13	63.4	48	6.9
14	63.7	49	6.7
15	63.3	50	6.4
16	62.9	51	6.2
17	63.1	52	6
18	63.3	53	5.8
19	63.8	54	5.6
20	64.3	55	5.4
21	39.8	56	5.2
22	28.2	57	5.1
23	23.6	58	4.9
24	21.5	59	4.7
25	19.8	60	4.6
26	18.3	61	4.4
27	17.2	62	4.3
28	16.1	63	4.2
29	15.2	64	4
30	14.4	65	3.9
31	13.6	66	3.8
32	12.9	67	3.7
33	12.3	68	3.5
34	11.8		

จากตารางที่ ข-3 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 1 ของการทดลองครั้งที่ 3 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-68 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-4 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้ไอ I_2บริสุทธิ์ ครั้งที่ 1

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	0	38	11.9
1	34.2	39	11.2
2	53.5	40	10.6
3	66.4	41	10.1
4	75.3	42	9.6
5	80.6	43	9.1
6	85	44	8.8
7	88.3	45	8.4
8	90.1	46	8.1
9	90.8	47	7.8
10	91.5	48	7.5
11	92.4	49	7.3
12	92.9	50	7.1
13	93.5	51	6.8
14	92.3	52	6.7
15	90.8	53	6.5
16	90.2	54	6.3
17	90	55	6.2
18	90.1	56	6.1
19	90.8	57	5.9
20	93	58	5.8
21	72.1	59	5.7
22	60.6	60	5.6
23	51.9	61	5.5
24	44.8	62	5.4
25	39.2	63	5.3
26	34.5	64	5.2
27	30.5	65	5.1
28	27.4	66	5.1
29	24.6	67	5
30	22.4	68	4.9
31	20.3	69	4.9
32	18.6	70	4.8
33	17.1	71	4.8
34	15.8	72	4.7
35	14.6	73	4.6
36	13.5	74	4.6
37	12.7	75	4.5

จากตารางที่ ข-4 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 2 (เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้ไอ I_2บริสุทธิ์) ของการทดลองครั้งที่ 1 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-75 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-5 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้ไอ I_2บริสุทธิ์ ครั้งที่ 2

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	3.9	38	8.4
1	31.7	39	8
2	47.9	40	7.6
3	58.2	41	7.3
4	64.4	42	7
5	68.4	43	6.8
6	71.7	44	6.6
7	72.8	45	6.4
8	73.5	46	6.2
9	74.2	47	6
10	74.4	48	5.9
11	74.2	49	5.8
12	74.4	50	5.6
13	74.9	51	5.5
14	73.6	52	5.4
15	74.1	53	5.3
16	74.4	54	5.2
17	74.7	55	5.1
18	75.3	56	5.1
19	76.1	57	5
20	76.4	58	4.9
21	58.2	59	4.9
22	46.2	60	4.8
23	37.8	61	4.7
24	32	62	4.6
25	21.1	63	4.6
26	23.5	64	4.5
27	20.6	65	4.5
28	18.1	66	4.4
29	16.4	67	4.4
30	14.8	68	4.4
31	13.5	69	4.3
32	12.1	70	4.3
33	11.4	71	4.3
34	10.6	72	4.2
35	9.9	73	4.2
36	9.3	74	4.2
37	8.8	75	4.1

จากตารางที่ ข-5 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 2 ของการทดลองครั้งที่ 2 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-75 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-6 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้ไอ I_2 บริสุทธิ์ ครั้งที่ 3

3

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	1.1	38	1.8
1	26.3	39	1.6
2	40.3	40	1.5
3	48.2	41	1.3
4	52.1	42	1.2
5	54.4	43	1.1
6	57.3	44	1
7	58.2	45	1
8	59	46	0.9
9	58.8	47	0.9
10	57.5	48	0.8
11	57.1	49	0.8
12	57	50	0.7
13	57.2	51	0.7
14	57.4	52	0.7
15	57.6	53	0.7
16	58	54	0.6
17	58.3	55	0.6
18	58.6	56	0.6
19	58.9	57	0.5
20	59	58	0.5
21	40.3	59	0.5
22	29.3	60	0.5
23	22.2	61	0.4
24	17.3	62	0.4
25	13.6	63	0.4
26	11	64	0.4
27	9	65	0.4
28	7.4	66	0.4
29	6.2	67	0.4
30	5.2	68	0.4
31	4.4	69	0.4
32	3.8	70	0.4
33	3.2	71	0.4
34	2.9	72	0.4
35	2.5	73	0.4
36	2.2	74	0.4
37	2	75	0.4

จากตารางที่ ข-6 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 2 ของการทดลองครั้งที่ 3 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-75 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-7 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้อิเล็กโตรไลท์ $FeCl_3$ ครั้งที่ 1

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	5.590	38	5.523
1	5.723	39	5.509
2	5.751	40	5.497
3	5.796	41	5.487
4	5.853	42	5.48
5	5.901	43	5.472
6	5.944	44	5.466
7	5.952	45	5.461
8	6.027	46	5.454
9	6.070	47	5.447
10	6.071	48	5.443
11	6.067	49	5.436
12	6.069	50	5.433
13	6.141	51	5.422
14	6.131	52	5.412
15	6.127	53	5.410
16	6.105	54	5.408
17	6.099	55	5.402
18	6.131	56	5.398
19	6.127	57	5.394
20	6.131	58	5.388
21	6.079	59	5.382
22	6.012	60	5.380
23	5.928	61	5.379
24	5.853	62	5.372
25	5.779	63	5.368
26	5.749	64	5.365
27	5.715	65	5.362
28	5.691	66	5.357
29	5.667	67	5.352
30	5.647	68	5.349
31	5.624	69	5.344
32	5.607	70	5.338
33	5.592	71	5.334
34	5.582	72	5.328
35	5.564	73	5.326
36	5.556	74	5.324
37	5.545	75	5.324

จากตารางที่ ข-7 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 3 (เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้อิเล็กโตรไลท์ $FeCl_3$) ของการทดลองครั้งที่ 1 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-75 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-8 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์โดยใช้อิเล็กโตรไลท์ $FeCl_3$ ครั้งที่ 2

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	3.360	38	3.670
1	3.440	39	3.660
2	3.520	40	3.650
3	3.610	41	3.630
4	3.690	42	3.620
5	3.730	43	3.610
6	3.780	44	3.600
7	3.840	45	3.590
8	3.890	46	3.580
9	3.930	47	3.570
10	3.970	48	3.560
11	4.000	49	3.550
12	4.050	50	3.540
13	4.080	51	3.530
14	4.130	52	3.520
15	4.150	53	3.510
16	4.180	54	3.510
17	4.210	55	3.500
18	4.230	56	3.500
19	4.260	57	3.490
20	4.300	58	3.490
21	4.170	59	3.480
22	4.130	60	3.480
23	4.080	61	3.470
24	4.040	62	3.470
25	4.000	63	3.460
26	3.960	64	3.460
27	3.920	65	3.450
28	3.890	66	3.450
29	3.860	67	3.450
30	3.830	68	3.440
31	3.800	69	3.440
32	3.780	70	3.430
33	3.760	71	3.430
34	3.740	72	3.420
35	3.720	73	3.420
36	3.700	74	3.420
37	3.680	75	3.410

จากตารางที่ ข-8 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 3 ของการทดลองครั้งที่ 2 ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-75 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

ตารางที่ ข-9 เซลล์แสงอาทิตย์ชนิดดายเซนซิไทเซอร์ที่ใช้ไอ I_2บริสุทธิ์ ที่ทดสอบกับแสงอาทิตย์

Time (min)	Potential (mV)	Time (min)	Potential (mV)
0	29.3	41	57.0
1	271.0	42	55.8
2	231.0	43	53.6
3	258.0	44	52.7
4	235.0	45	51.7
5	260.0	46	50.8
6	252.0	47	49.8
7	261.0	48	49.1
8	257.0	49	48.4
9	253.0	50	47.7
10	251.0	51	46.9
11	253.0	52	44.1
12	255.0	53	45.5
13	250.0	54	45.0
14	257.0	55	44.0
15	263.0	56	43.9
16	267.0	57	43.3
17	267.0	58	42.7
18	267.0	59	42.2
19	268.0	60	41.8
20	273.0	61	41.4
21	125.0	62	40.9
22	110.0	63	40.5
23	102.1	64	40.0
24	97.8	65	39.6
25	93.1	66	39.2
26	89.0	67	38.8
27	85.5	68	38.4
28	82.2	69	38.0
29	78.8	70	37.7
30	76.3	71	37.3
31	74.2	72	36.9
32	71.9	73	36.6
33	69.7	74	36.3
34	67.5	75	36.0
35	65.8	76	35.7
36	64.2	77	35.3
37	62.6	78	35.0
38	61.0	79	34.8
39	59.6	80	34.5
40	58.2		

จากตารางที่ ข-9 แสดงเวลาและแรงดันไฟฟ้าวงจรเปิดของเซลล์แสงอาทิตย์ชนิดที่ 2 ของการทดลองกับแสงอาทิตย์ ช่วงที่เวลา 0-20 นาทีแรกได้รับแสงค่าการส่องสว่าง 1,000 Lux และช่วงที่เวลา 21-80 นาทีหลังได้รับแสงค่าการส่องสว่าง 0 Lux

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Manuscripts

A Development of Dye-sensitized Solar Cells using Chlorophyll

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Abstract

A dye-sensitised solar cell using the visible light sensitization of extracted chlorophyll from lemon leaves adsorbed on a TiO_2 film was developed. The visible spectrum of chlorophyll adsorbed on a TiO_2 film and its photovoltage characteristics voltage response were studied. The dye sensitized solar cells were prepared using different type of the electrolyte which are KI/I_2 and the evaporated I_2. The dye sensitized solar cells using KI/I_2 as an electrolyte , the evaporated I_2 under light illumination of 1000 lux gave the maximum of open circuit voltage are 91.6 and 93.5 mV , respectively The evaporated I_2 dye-sensitized solar cells was then tested with the sunlight. The result showed that the open circuit voltage is 273 mV. The obtained response of I_2 dye-sensitized solar cells gave long term stability obtained with this new type of solar cell. The advantages of the fabricated dye-sensitized solar cells could be useful to apply with the sunlight, low cost and easier to prepare when compared with silicon solar cell.

Keyword: Dye-sensitized solar cells; Chlorophyll; TiO_{2} ; Visible light sensitisat

1. Introduction

Dye sensitized solar cells (DSCs) have been interesting considerable attention for the conventional solid-state photovoltaic cells because of simple fabrication process and low fabrication cost (O'Regan and Grätzel, 1991). Various studies on the dye-sensitized solar cell have been reported in recent years (Grätzel, 2001), (Hagfeldt and Grätzel, 2000), (Wang, *et al*., 2003), (Grätzel, 2004). The most successful photo-induced electron transfer sensitisers employed so far in these cells are ruthenium(II) polypyridyl complexes. The overall photovoltaic conversion efficiencies was 10% in the dye-sensitized solar cells using organometallic compounds based on the ruthenium(II) polypyridyl complexes (O'Regan and Grätzel, 1991), (Nazeeruddin, *et al.* 1993). To further improvement of the dye-sensitized solar cells, there have been the used of the chlorophylls instead of using the organimetallic dye because it is more cheaper and easier to prepare. Chlorophylls, which act as an effective photosensitizer in photosynthesis of green plant, has absorption maximum at 670 nm (Scheer, 1991). Thus, chlorophylls are attractive compound as a photosensitizer for the dye-sensitized solar cell in visible region. A new kind of solar cell, based on dye sensitized nanocrystalline titanium dioxide has been developed by Gratzel et al. (O'Regan and Grätzel, 1991). In the simplest method the dye sensitized solar cell consists of two glass plates with a transparent conducting coating such as SnO_2. One side, the photoelectrode, is coated with a porous layer of a wide band gap semiconductor, usually TiO_2, which is sensitized for visiblelight by an adsorbed dye light by an adsorbed dye. The other conducting glass is coated with a catalytic amount of platinum and serves as counter electrode. The space between the two electrodes is filled with an electrolyte containing a redox couple, such as iodide (I-)/triiodide (Kay and Grätzel, 1996). Here we develop the conducting glass by coating the SnO_2. For the counting electrode the conducting glass was coated using the

Also we develop the use of the evaporated I_2 as the electrolyte. However, the use of evaporated I_2 has not been yet reported. In this work, chlorophyll solution, extracted from lemon leave, immobilized TiO_2 film electrode was prepared and the photoelectrochemical properties of the dye-sensitized solar cell using visible light sensitization of TiO_2 film by chlorophyll from lemon leave were investigated.

2. Experimental

2.1. Materials

Titanium dioxide powder was purchased in commercial grade. The I_2 (purity 100%) was obtained from BDH Laboratory Supplies, England. Tin(IV) chloride pentahydrate ($SnCl_4 \cdot 5H_2O$, purity 99%) and KI were purchased from Aldrich. The other chemicals were analytical grade or the highest grade available.

2.2. Preparation of dye sensitizer

As a simplified procedure, fresh lemon green leaves were minced to pieces and put in the 50 ml (99.5%) of acetone. The solution was shaken for 200 times and then left it overnight. The dark green acetone solution was obtained from this procedure (Smestad, 1998). The obtained solution was studied using spectroscopic measurements UV-Vis absorption with Lamda 35 spectrophotometer (Perkin Elmer). The UV spectra shown in Fig. 2.

2.3. The preparation of dye-sensitized solar cell.

Firstly, the conductive glass plate was coated with a layer of SnO_2 by procedure modified by (Tanaka and Suib, 1984). The oven was cleaned by heating 1200 °C 12 hours. Put a ceramic tile glazed side up in an oven to serve as a support. Preheat the oven to 650 ° C. Place a glass microscope slide on the unglazed side of a ceramic tile and place both in the oven. After heating the glass and tile for 2 minutes, remove both from the oven, immediately spray with a fine mist of tin(IV) chloride solution , 30 g of $SnCl_45H_2O$ dissolved in 300 ml of methanol and return the glass and tile to the oven. The treatment was then repeated 15 cycles.

Secondly TiO_2 electrode was prepared on the conductive glass. The preparation was followed. Ten grams of titanium dioxide (TiO_2) were grinded in a mortar and pestle with a few drops of very dilute acetic acid. It was alternated grinding and addition of a few drops of acetic acid, 0.1 ml concentrated acetic acid to 50 ml of water until obtained a colloidal suspension with a smooth consistency. Few drops of clear dishwashing detergent (triton X-100 surfactant) was added.

With the conducting side up, the glass was tape on three sides using the thickness 250-270 micrometer of tape to control the thickness of the paste layer. The cleaning using a tissue wet with acetone was removed any fingerprints or oils. The titanium dioxide was pasted and spreaded using a glass rod on the space on the taped glass slide. The taped was removed without scratching the TiO_2 coating. The glass was heated on a hotplate in a hood for 60 minutes. The glass was cooled at room temperature and the slide was immersed in the chlorophyll solution to coating. The white TiO_2 will change color as the dye is absorbed and complexed to the Ti(IV). Another piece of tin oxide glass, conducting side down, was prepared through a candle flame to coat the conducting side with carbon (soot). For best results, pass the glass piece quickly and repeatedly through the middle part of the flame. The two glass plates with coated sides were assembled together and clamp the plates together. The two types of dye-sensitized solar cell were prepared with different electrolytes which are KI/I_2 (triiodide) and evaporated I_2 crystal

The dye-sensitized solar cell with the KI/I_2 (triiodide) was prepared by adding a few drops of a KI solution were to the edge of the plate. The dye-sensitized solar cell with evaporated I_2 crystal was prepared by placing the TiO_2 electrode on the I_2 crystal. Then the I_2 crystal was evaporated and doped on the TiO_2 electrode surface. The solar cell was connected (the negative electrode is the TiO_2 coated glass and the positive electrode is the carbon coated glass) to test the voltage produced by dye-sensitized solar cell.

2.4. Photovoltage response of chlorophyll adsorbed on a TiO_2 electrode

Photovoltage response of the chlorophyll adsorbed on a TiO_2 electrode was measured with a sandwich type cell. The working electrode with the chlorophyll adsorbed on a TiO_2 electrode was gently squeezed together with a carbon-coated glass electrode. The KI/I_2 (triiodide) solution and evaporated I_2 crystal was used as the redox electrolyte. A 500 W tungsten lamp was used as light source for the voltage response with the digital multimeter with model 197 (Fluke) (Curri, *et. al.,* 2003). A scheme of the experimental set-up is shown in Fig. 1. The distance between lamp and test cell was 60.00 ± 0.05 cm. The active electrode area was 8×5.5 cm^2. The light illumination on the surface of cell was 1000 lux measured with lux meter The light illumination of 1000 lux was applied to the solar cell. Then, the light was not applied to the solar cell and repeats the experiment 3 times.

Fig. 1. The experimental set-up for the measurement of photovoltage response of dye-sensitized solar cells on a TiO_2 electrode with light illumination 1000 lux.

3. Result and Discussion

3.1. Spectroscopic characterization of chlorophyll adsorbed on a TiO_2 electrode.

The absorption spectrum of extracted chlorophyll solution from fresh lemon green leaves is shown in Fig. 2. The intense absorption band of chlorophyll in the visible region has a maximum at 431.97 and 662.46 nm which is the working range of the sensitizer. This result shows that this chlorophyll is useful for a solar cell using visible light sensitization.

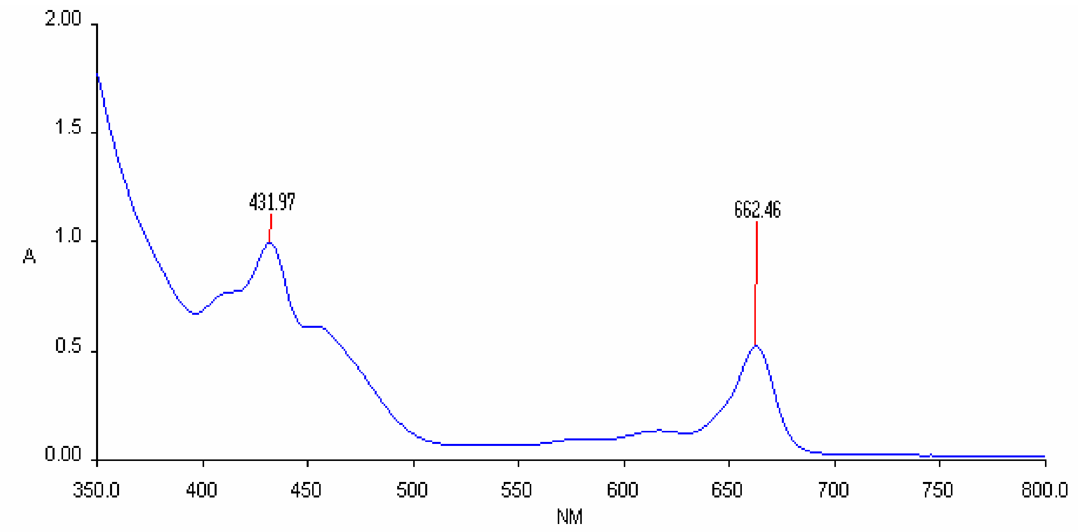

Fig. 2. UV-Vis absorption spectra of extracted chlorophyll from the lemon leaves in acetone solution.

3.2. Voltage response of dye-sensitized solar cell with KI/I_2 (triiodide) solution as an electrolyte.

Fig. 3 shows the voltage response of a sandwich solar cell based on chlorophyll adsorbed on TiO_2 film electrode irradiated with 500 W tungsten lamp with a light illumination of 1000 lux as a light source. The voltage versus time was investigated. The result show that the voltage was increase after applied the light. Electrons in the sensitizer are excited by the photons and gain energy from ground state to excited state. Therefore, the electrons are drifted to the external circuit. When the sensitizer loses its electrons, the molecules have the ground-state energy and will receive the electrons from the electrolyte. The V_{max} of each measurement are 72.6, 91.6 and 64.3 mV respectively which are indicated in Fig. 3.

Then not applied light, the voltage was continuously decreased because the electron was not generated from the dye. The voltage changes were observed, indicating that dye sensitizer solar cell using chlorophyll adsorbed on a TiO_2 electrode is relatively response with irradiation.

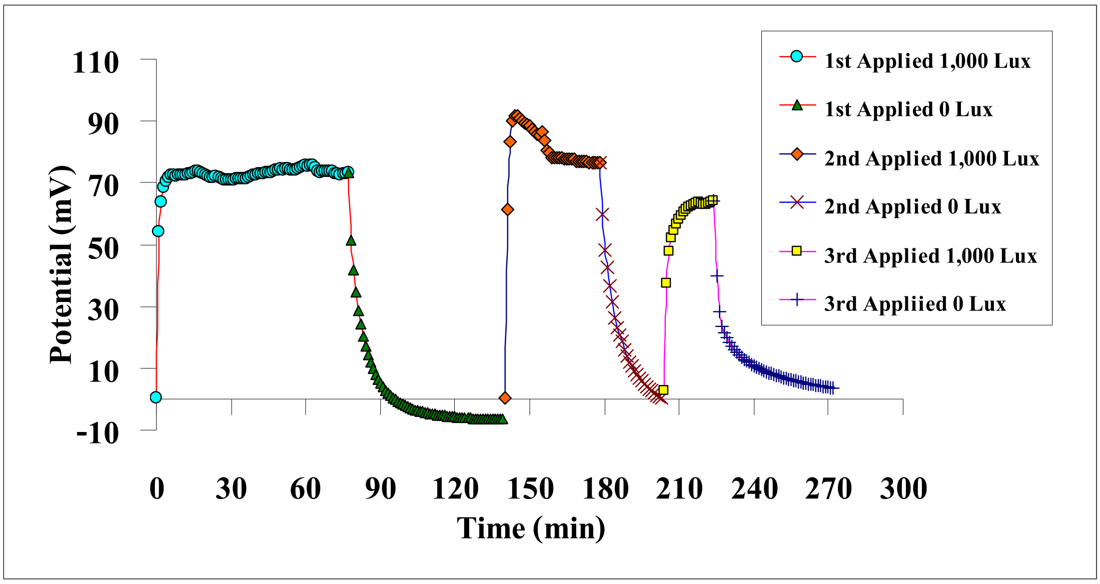

Fig. 3. Voltage response of dye-sensitized solar cell with KI/I_2 (triiodide) solution as an electrolyte.

3.3. Voltage response of dye-sensitized solar cell with evaporated I_2 crystal as an electrolyte.

Fig. 4 shows the voltage response of a sandwich solar cell based on chlorophyll adsorbed on TiO_2 film electrode irradiated with 500 W tungsten lamp with a light illumination of 1000 lux as a light source. The voltage versus time was investigated. The result shows that the voltage was increase after applied the light. Electrons in the sensitizer are excited by the photons and gain energy from ground state to excited state. Therefore, the electrons are drifted to the external circuit. When the sensitizer loses its electrons, the molecules have the ground-state energy and will receive the electrons from the electrolyte. The V_{max} of each measurement are 93.5, 76.4 and 59.0 mV respectively which are indicated in Fig. 4. Three measurements was investigated within 1 months by testing 2 weeks of each measurements without any filling the electrolyte solution.

Then not applied light, the voltage was continuously decreased because the electron was not generated from the dye. The voltage changes were observed, indicating that dye sensitizer solar cell using chlorophyll adsorbed on a TiO_2 electrode is relatively response with irradiation.

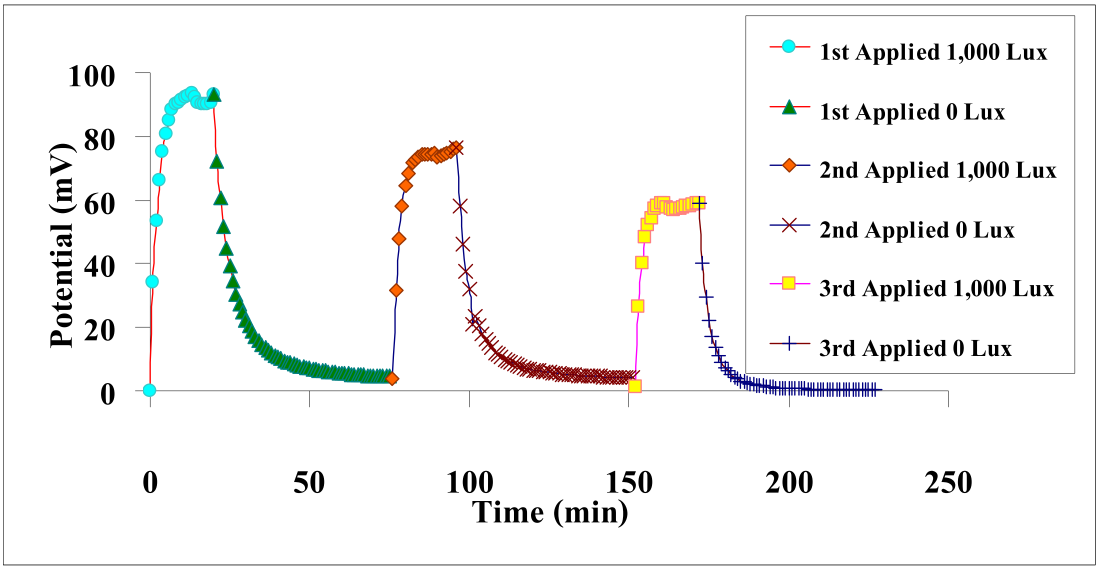

Fig. 4. Voltage response of dye-sensitized solar cell with evaporated I_2

3.4. Voltage response of dye-sensitized solar cell with evaporated I_2 crystal as an electrolyte with the sunlight.

Fig. 5 shows the voltage response of a sandwich solar cell based on chlorophyll adsorbed on TiO_2 film electrode irradiated with sunlight for 20 min. The voltage versus time was investigated. The result shows that the voltage was increase from 29.3 mV after applied the light. Electrons in the sensitizer are excited by the photons and gain energy from ground state to excited state. Therefore, the electrons are drifted to the external circuit. When the sensitizer loses its electrons, the molecules have the ground-state energy and will receive the electrons from the electrolyte. The V_{max} is 273.0 mV which are indicated in Fig. 5. Then the dark box was covered, the voltage was continuously decreased until 34.5 mV because the electron was not generated from the dye. The voltage changes were observed, indicating that dye sensitizer solar cell using chlorophyll adsorbed on a TiO_2 electrode is relatively response with irradiation.

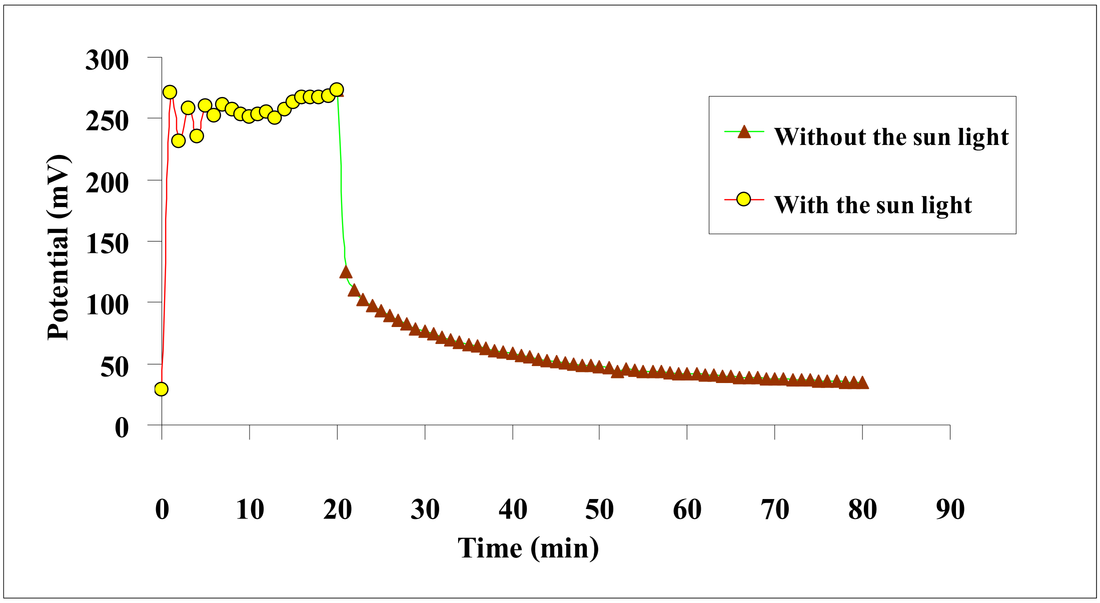

Fig. 5. Voltage response of dye-sensitized solar cell with evaporated I_2 crystal as an electrolyte with the sunlight.

4. Conclusions

In this work the chlorophyll extracted from the lemon leaves was investigated the spectroscopic characterization. The dye-sensitized solar cell using the extracted chlorophyll adsorbed TiO_2 film electrode was prepared and its photovoltage characteristics voltage response was studied. The dye sensitized solar cells were prepared using different type of the electrolyte which are KI/I_2, the evaporated I_2. The dye sensitized solar cells using KI/I_2 as an electrolyte , the evaporated I_2 under light illumination of 1000 lux gave the maximum of open circuit voltage are 91.6 and 93.5 mV , respectively. The dye sensitized solar cell using the evaporated I_2 as an electrolyte was also tested with the sunlight. The result showed that the open circuit voltage is 273 mV The advantages of The fabricated dye-sensitized solar cell could be useful to apply with the sunlight, low cost and easier to prepare when compared with silicon solar cell.

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