**Influence of environmental parametrs; THERMAL, IRRADIANCE, AND dust on SOME INORGANIC SOLAR CELL**

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**Abstract**

This study conducted a series of systematic experimental measurements to investigate the irradiance and temperature performance of CdS/Cu2S solar cell and to determine the influence of dust on the efficiency of crystalline silicon solar cell. The decrease in short circuit current and open circuit voltage with variation in irradiance (9953-117100 Lux) of a clear summer day and temperature (31-36°C) was 90% and 19%, respectively. The decrease of output power with variation of irradiance and temperature is 92%. The accumulation of dust on the surface of crystal Si solar cell at a heavy commercial activities street is investigated. Results show that the presence of dust has a considerable effect on the performance of crystalline silicon solar cell.

**Keywords:** Photovoltaic, irradiance, temperature, dust

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**Introduction**

In recent decades, air quality at the local, regional, and even worldwide level has received great attention from scientists, policy makers, and the general public alike **(Panis et al., 2006)**. The increased industrialization and economic activity as well as the high population density constitute the prime causes for the increased levels of air pollution. The two most commonly observed types of air pollutants; high concentrations of particulate matter and gaseous pollutants are mainly deriving from the combustion of fossil fuels and industrial processes **(Nastos et al., 2006)**.

In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions. Among the many types of renewable energy solar energy is considered promising, since it is comparatively more evenly distributed geographically **(George et al., 1999)**. A branch of solar energy research that has received worldwide attention is photovoltaic (PV). Solar photovoltaic (PV) modules convert solar energy directly into electricity and bring about environmental benefits such as greenhouse gas and air pollution reduction, all with minimal maintenance requirements **(Tsoutsos et al., 2005)**. Residential, vehicular, space and aircraft are the main fields of solar energy applications **(Khaligh and Onar, 2010)**. In order to establish PVs as a commercially competitive technology, high attention should be paid to the factors which affect their energy performance **(Gan, 2009)**. In this context, a part from the variation of the solar radiation intensity, which is the main factor affecting the PV-modules’ output, reductions up to 15% on PVs’ energy production may also be the result of several other parameters such as; temperature, angle of incidence, ageing, soil, snow, and partial shading **(Thevenard, 2005)**.

In addition, the dust accumulate on the surface of the solar cell can cause a significant degradation in the efficiency of the solar cell and may considerably reduce the amount of solar energy absorbed by the panels mainly due to the increased reflection which leads to the reduction of the incident solar irradiance on the PV-cell **(Biryukov, 1998)**. Furthermore, the dust accumulation may indirectly influence the rate of heat transfer between the PV and the environment through convection in a negative way (**Kappos et al., 1996)**. Although dust effects depend on local conditions such as the presence of air pollution, frequency of rain, wind speed, humidity, as well as the panels’ orientation and inclination, certain attempts have been made to determine the influence of dust on the performance of PV-panels **(Al-Hasan and Ghoneim, 2005)**.

In this context, investigation of the dust effects on the performance of PV modules becomes of special interest, especially in the case of an urban environment heavily aggravated from air pollution. The temperature is another significant factor that strongly affects the PV cell efficiency and performance **(Mattei et al., 2006)**. The physical properties that change with temperature are the band gap, the minority-carrier life time, built-in voltage drop, the potential barrier of the p-n junction of the solar cell, and the separation ability of the junction **(Radziemska and Klugmann, 2002)**. Therefore, the present study focuses on the influence of some environmental parameters such as; irradiance, temperature, and dust on the characteristics and performance of some inorganic solar cells.

**Experimental Methodology**

In this study, the influence of some air pollutants, namely; dust, temperature, and humidity on the characteristics of CdS/Cu2S and crystalline Si solar cell was investigated.

***Irradiance and Temperature Performance of CdS/Cu2S Solar Cell***

In this study, the current-voltage (I-V) characteristics of cadmium sulfide/copper sulfide (CdS/Cu2S) solar cell with area of 5cm2 were investigated in dark and under different light intensities from 462 to 5600 Lux in a clean laboratory environment. Stabilized power supply and high impedance electrometers (Keithley 617) were used, while the illumination source was an ordinary tungsten filament lamp. The intensity of the light was recorded using a calibrated digital light meter (Lutron-Model LX-107). In addition, the variation of CdS/Cu2S characteristics with change in irradiance and temperature during the time period of a day of 25/7/2010 and of three months (June, July, and August) was investigated under field conditions on the roof of the Faculty of Science, New Damietta, Egypt (Map 1). The cell was mounted horizontally on a designed stand and placed on the roof. The current-voltage (I-V) characteristics of CdS/Cu2S solar cell were measured every two hours throughout the day to establish a base line for daily irradiance, later measurements were limited to the time of peak irradiance (1PM) through one day of the three months. The temperature was measured using Chromel-Alumel thermocouple connected to a thermometer.

***Investigate the Influence of Dust on Crystalline Si Solar Cell at Al-Harby Street***

The influence of dust on characteristics of crystalline silicon solar cell was investigated at Al-Harby Street in Damietta city, Egypt (Map 1), from January to March 2011. It is characterized by heavy commercial activities, furniture workshops, and heavy traffic flow. The crystalline Si solar cell with an area of 2.83cm2 was mounted in a cubic glass test box with dimensions of 15 ×15 ×15 cm3, and was placed at 6 ±2 m height at rooftop level subjected to the atmosphere of Al-Harby street. The cubic box was designed with a configuration which allowed the entry of dust into the box using a suction pump. The concentration of dust accumulate on the surface of the solar cell was measured in microgram per cubic meter (µg/m3). The dust samples were collected on a membrane filter (0.45µm), using an open face holder connected to the sampling pump operating for 24hr. The flow rate of the pumps was calibrated to 4 L/min **(Katz, 1986).** The humidity and the temperature of the atmosphere were recorded during all tests.

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| **Map 1** Location map of the study area |

**Experimental Results Analysis and Discussion**

***Effect of Irradiance on CdS/Cu2S Solar Cell at the laboratory***

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| **Fig.1** I–Vcharacteristics of CdS/Cu2S solar cell at different illumination intensities. |

The current–voltage characteristics of CdS/Cu2S solar cell in the dark and under different light intensity conditions are shown in fig.(1). The current value at a given voltage for CdS/Cu2S solar cell under illumination is higher than that in the dark. This indicates that the light generates carrier-contributing photocurrent due to the production of electron-hole pairs as a result of the light absorption **(El-Nahass et al., 2005)**. In spite that the forward current was greater than the reverse current, the effect of solar irradiation on the reverse current was much more pronounced than that on the forward current. The Isc is proportional to the illumination intensity and the applied voltage. In reverse, bias region, Isc is independent of applied voltage. Increasing light intensity from 462 to 5600 Lux, the open circuit voltage and short circuit current in CdS/Cu2S solar cell increased from 0.39 to 0.48V and from 7 to 73.97mA, respectively, as shown in fig.(2). However, **Gupta et al. (2002)** investigated the effect of illumination intensity on the I-V characteristics of n-C/p-Si heterojunction solar cell. The Isc was found to be proportional to the illumination intensity and was independent of the applied voltage. Figure (3) illustrates a linear increase in short circuit current density (Jsc) of the CdS/Cu2S solar cell with the increase in light intensity. This is due to the increase in the number of photo-generated carriers occurring in a semiconductor with the increase of light intensity. The relationship between light intensity (Pin) and short circuit current density for CdS/Cu2S may be expressed by the following equation:

Jsc (CdS/Cu2S solar cell) = 0.34+0.003 Pin (1)

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| **Fig.2** Current-voltage curves of maximum power region for CdS/Cu2S solar cell under different illumination intensities |  **Fig.3** Variation of Jsc with light intensity for CdS/Cu2S solar cell under different illumination intensities |

This is in agreement with **Anuforom et al. (1987)** who reported that the short-circuit current of silicon solar cells exposed to changes in intensity of solar radiation under tropical atmospheric conditions in Nigeria increases non-linearly with intensity of solar radiation. Figure (4) shows that Voc of the CdS/Cu2S solar cell increases non-linearity with increasing light intensity. The maximum power Pm of CdS/Cu2S solar cell increases from 1.36 to 17.77mW with the increase of light intensity (Fig.5). Whereas, fig.(6) illustrates a linear increase in maximum power (Pm) of the CdS/Cu2S solar cell with increase light intensity (Pin), the relationship may be expressed by the following equation:

Pm(CdS/Cu2S solar cell) = 0.05 +6.46×10-4 Pin (2)

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| **Fig.4** Voc versus light intensity for CdS/Cu2S solar cell under different illumination intensities | **Fig.5** Output power versus voltage of CdS/Cu2S solar cell under different illumination intensities |

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| **Fig.6** Pm versus light intensity for CdS/Cu2S solar cell under different illumination intensities |

This finding is in agreement with **Tian et al. (2007)** who observed that the dimming of solar radiation in the urban environment was the main reason for the decrease of PV module output using the climatic data of urban and rural sites in Mexico City for year 2003. Moreover, **Amin et al. (2009)** investigated the effects of irradiance level change on the output power of monocrystalline silicon solar cells and observed that the output power of these cells increased with solar irradiance.

***Effect of Irradiance and Temperature on CdS/Cu2S Cell*** ***on Roof of the Faculty***

Figure (7) shows the variation of I-V characteristics curves of CdS/Cu2S solar cell under the influence of irradiance (9953-117100 Lux) on a clear summer day and solar cell temperature in the range (31-36°C). The influence of irradiance and temperature on short circuit current was much more remarkable than an open circuit voltage. The decrease in short circuit current and open circuit voltage with variation in irradiance and temperature was 90% and 19%, respectively. The variation of short circuit current and open circuit voltage with irradiance and temperature influenced the output power of a solar cell. The output power of a solar cell varied along the hours of a day depending on irradiance and temperature as shown in fig.(8). The highest output power was attained at 1PM. The decrease of output power with variation of irradiance and temperature was 92%.

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| **Fig.7** I-V characteristics of CdS/Cu2S solar cell under different irradiance and temperature of a clear summer day (25/7/2010) | **Fig.8** Output power versus voltage of CdS/Cu2S solar cell under different irradiance and temperature of a clear summer day (25/7/2010) |

Figure (9) shows the influence of irradiance and temperature on (I-V) characteristics of CdS/Cu2S solar cell through the study period (Table 1). The temperature was constant at 32°C and the irradiance showed a little variation during the test at the 15th of June (1PM) and July. Table (1) and fig.(9) show stability of the characteristics under these conditions. At 1PM of the 4th of August; the temperature increased to 35°C and irradiance decreased to 113300Lux, the short circuit current and maximum power were observed to decrease while open circuit voltage had no variation. The decrease in maximum output power was ~40% (Fig.10).

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| **Table 1** Effect of variation of irradiance and temperature on CdS/Cu2S solar cell parameters at different months. |
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| **Pm(mW/cm2)** | **Im (mA)** | **Vm (V)** | **Voc (V)** | **Jsc (mA/cm2)** | **T (°C)** | **Irradiance****(Lux)** | **Date** |
| 14.59 | 194.52 | 0.37 | 0.52 | 46.65 | 32 | 115120 | 15/6/2010 |
| 14.64 | 185.38 | 0.39 | 0.53 | 47.76 | 32 | 116800 | 15/7/2010 |
| 8.83 | 147.76 | 0.3 | 0.52 | 35.4 | 35 | 113300 | 4/8/2010 |

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| **Fig.9** Variation of irradiance and temperature on the (I-V) characteristics of CdS/Cu2S solar cell through the study period | **Fig.10** Output power versus voltage of CdS/Cu2S solar cell through the study period |

***Influence of Dust on Crystalline Si Solar Cell at Al-Harby Street***

The average concentrations of dust accumulate on the surface of the solar cell at Al-Harby Street was 322.72µg/m3 (Fig.11). This concentration is about 4.6 times the maximum allowable concentration given by the Egyptian Environmental Law No. 4, 1994 (70 µg/m3 24 hr). The high concentrations of PM at this site may be attributed to the heavy commercial activity, furniture work-shops, coupled with the high concentration of particulate matter emitted from traffic **(El-Henawy, 2011)**. Figure (12) presents the current-voltage characteristics curve of maximum power region for crystalline Si solar cell. The short circuit current and open circuit voltage decreased with the increase of exposure time. The decrease of short circuit current was much more remarkable than that of open circuit voltage.

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| **Fig.11** The daily concentrations of dust (µg/m3) through the study period | **Fig.12** Current-voltage curves of maximum power region for crystalline Si solar cell under various concentrations of air pollutants. |

Figure (12) implies that with further dust accumulation beyond (1701µg/m3) the short circuit current decreased less steeply, i.e., it becomes less sensitive to dust accumulation. A quantitative estimation of the dependence of short circuit current density and open circuit voltage on accumulated dust concentration is depicted in fig.(13). Jsc and Voc decreased non-linearly with the increase in accumulated dust concentration and they arrived to least constant values in the seventh week where accumulated dust concentration was (2200 µg/m3). The reduction in the short circuit current and the open circuit voltage after exposure for seven weeks was 43% and 7%, respectively. **El-Shobokshy et al. (1985)** concluded that the change in I-V characteristics due to dust accumulation per unit area was more dominant than the exposure time. For dust accumulation higher than (2200 µg/m3), the short circuit current density and the open circuit voltage arrived to approximately constant values. The particles tend to accumulate on the surface of a solar cell forming a homogenous dust thickness. The reduction in short circuit current density and open circuit voltage was attributed to the decrease in the light transmittance. This opinion is supported by **Al-Hasan and Ghonein (2005)** whom found that the short circuit current increased as the incident power increases for both clean and dusty modules.

The reduction in Jsc and Voc with accumulated dust reflected on the output power versus voltage curve of crystalline Si solar cell under various concentrations of air pollutants (Fig.14).

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| **Fig.13** Variation of Voc and Jsc with different concentrations of dust | **Fig.14** Output power versus voltage of crystalline Si solar cell under various concentrations of air pollutants |

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| **Fig.15** Maximum power versus accumulated dust concentration |

 The output power decreased with the increase of exposure time. The output power decreased less steeply after the sixth week of exposure. The maximum output power decreased non-linearly with the increase the concentration of accumulated dust and it had a constant value at dust concentration of (2200 µg/m3) (Fig.15). These results indicate that the short circuit current is the dominant factor influencing the output power of a solar cell. The observed degradation of output power can also be attributed to the fact that the dust particles scatter and absorb some of the sunlight resulting in a decrease of sunlight reaching the solar cell. The changes of Jsc and Voc with time reflected on the solar cell parameters with small changes in temperature and humidity were not regular (Table 2). Therefore, the changes in solar cell parameters may be attributed to accumulation of particulates.

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| **Table 2** Effects of temperature and humidity on crystalline Si solar cell parameters. |
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| **fter 8weeks** | **after 7weeks** | **after 6weeks** | **after 5weeks** | **after 4weeks** | **after 2weeks** | **after 1 week** | **Before exposure** | **Time** |
| 14.87 | 16.87 | 17.11 | 16.5 | 16.75 | 15.75 | 16 | 15 | **Mean of Temp.,ºC** |
| 70 | 74 | 72 | 72 | 78 | 84 | 75 | 75 | **Mean of Humidity** |

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**Conclusion** **and Recommendations**

The obtained results demonstrate that the short circuit current, open circuit voltage and maximum power of CdS/Cu2S solar cell increase with increasing irradiance level. However, under field conditions the output power of the solar cell varies along the hours of the day depending on irradiance and temperature. Moreover, dust has a significant effect on the performance of crystalline Si solar cell. A decrease in short circuit current, open circuit voltage and maximum power were observed. Actually, the most of cities in Egypt are dusty because of the nature of surface beside the development of industrial activities as well as traffic emissions. Therefore, it is important to accelerate efforts to minimize air pollutants aiming to improve air quality of the cities.

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