Proceedings of the Technical Sessions, 28 (2012) 1-8
Institute of Physics – Sri Lanka

Construction of Cu_2O Thin Film Based Light Detector

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ABSTRACT

The purpose of this study was a construction of a practically useful low cost device to measure and display the light intensity by using photo sensitive Cu_2O thin films and to study the effects of light on these films. In this study, a Cu_2O thin film is used as the light sensor of the device. These photosensitive films could be used in different forms for this task. Light can be monitored either using a single n-type / p-type thin film or in the form of a hetero-junction. It was found that a Cu_2O/Cu_2S hetero-junction produced better photo-voltaic properties. This study reports the performance of a Cu_2O/Cu_2S hetero-junction as a light detector. The detected signal was converted into an output voltage that could be amplified to detect light of very low intensities. For A-D conversion and the display of intensity measurements, a PIC Microcontroller was used. The device demonstrated its ability to measure the light intensity of the environment with intensities as low as 1 lux. It is highly cost effective compared to the commercially available light detectors.

1. INTRODUCTION

Cuprous Oxide (Cu_2O) was the first substance known to behave as a semiconductor. Rectifier diodes based on this material were used industrially as early as 1924 and most of the theory of semiconductors was developed using the data on Cu_2O based devices [1]. Cu_2O forms a cubic structure with a lattice parameter of 4.27 Å [2]. The Cu atoms are arranged in a fcc sub lattice and the O atoms are in a bcc sub lattice. The unit cell of Cu_2O contains four Cu atoms and two O atoms. It is cheap to produce, nontoxic, and environmentally friendly [2]. Its component elements are readily available in nature.

Cuprous oxide is a natural p-type semiconductor with a direct optical band gap of energy values between 2.1-2.6 eV depending on the fabrication method and stoichiometry [3]. Cuprous oxide is a potentially attractive material for applications in solar energy converting devices, and gas and humidity sensors [4]. It shows several interesting characteristics for photovoltaic applications such as good absorption coefficient for the light above the band gap and a good mobility for the majority carriers.

Cu_2O thin films have been prepared by various methods, such as electro-deposition [4], wet chemical etching, reactive magnetron sputtering [3], activated reactive evaporation [5], sol-gel technique and pulsed laser deposition [6]. In this study, Cu_2O thin films were fabricated using the cost effective electro-deposition technique.

First, in order to monitor light intensity, an n-type single thin film was employed. The variation of voltage in the film was measured with and without exposure of the film to normal light. However, the measurements did not show a significant change due to the variation in the light intensity. Then a Cu_2O/Cu_2S junction was fabricated and it showed improved photovoltaic performance. It was able to monitor light of very low intensities with the use Cu_2O/Cu_2S junction along with the proper electronics described in this paper. In order to display the monitored light intensities, a unit was built by using a PIC Microcontroller.

2. DESIGN AND CONSTRUCTION

2.1 Fabrication of Cu_2O thin films

Cu_2O thin films were deposited on titanium substrates. Before the deposition, substrates were cleaned with detergent by brush abrasion technique, and then with diluted HCl and finally with distilled water. Cleaning methods were designed to minimize substrate damage while removing any organic impurities or debris on the substrate. For electro-deposition 0.01 M Cupric Acetate and 0.1 M Sodium Acetate were added into electrochemical cell. A saturated calomel electrode, a Platinum plate and a Titanium plate were used respectively as the reference, counter and working electrodes of the electrochemical cell. The temperature of the electrolyte was maintained at 60 ^{o}C and the electrolyte was continuously stirred using a magnetic stirrer. Electro-deposition was carried out under a potentiostatic condition of -200 mV vs. saturated calomel electrode for 60 minutes. pH value of the electrolyte was adjusted by adding a dilute sodium hydroxide solution to the bath. The general trend is that for high cupric ion concentrations, the films deposited at low pH values are n-type and those deposited at high pH values are p-type [7].

Formation of a Cu_2O/Cu_2S junction is achieved by directly applying a Na_2S aqueous solution on to an n-type Cu_2O thin film followed by heating on a hot plate at 100 ^{o}C. When reacted with aqueous Na_2S, Cu_2O is converted in to Cu_2S which process is termed the sulphidation. After the suphidation, the sample was washed thoroughly with distilled water to remove the excess Na_2S and NaOH that is formed during sulphidation process. Subsequently, the sample was annealed in a pre heated oven at 150 ^{0}C for 10 minutes to increase the photo voltage. Contacts to the film were made using evaporated gold. The resulting samples produced high photo voltages and low photo currents. Then the sample was directly exposed to ammonium sulphide gas for shorter durations (lower than 2 Sec) in order to further reduce its resistance that results in a larger photo current. Finally it was washed by using distilled water and was annealed at 150 ^{0}C for 10 minutes.

2.2 Construction of the microcontroller based circuit to display the light intensity

The above junction that was in thin film form was used as the sensor of the device. The sensor was then connected to the circuit designed for the light detection. To connect the film to the circuit leads, a mechanically adjustable “sensor holder” was constructed. The Photo-voltage generated by the film was amplified by an INA122 amplifier. This system was electronically controlled by 16F877A microcontroller. The INA122 is a precision instrumentation amplifier for accurate, low noise differential signal acquisition. Its two-op-amp design provides excellent performance with very low quiescent current, and is ideal for portable instrumentation and data acquisition systems. Using the INA122 data sheet [8], the gain of the amplifier was set using R_G external resistor. R_G was connected between pin number 1 and 8 of the amplifier INA122. The gain of the amplifier is given by the equation (1).

$$G = 5 + \frac{200\text{k}\Omega}{R_G} \quad \text{……...…………………………………….} \quad (1)$$

Here, a 1 kΩ resistor was used as R_G in order to conveniently set the gain of the amplifier at 205. The PCB diagrams were designed by using Ivex software and corresponding circuits were constructed. The program was written by using MicrocPro software, mikroC, which is a powerful, feature rich development tool for PIC microcontrollers.

The block diagram as shown in Fig. 1 of the system is given below.

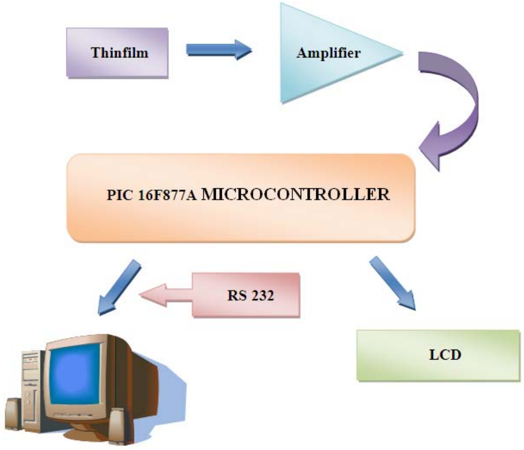


Fig. 1: Block diagram of the system

Output of the INA 122 was connected to RA0 analog input pin of the microcontroller. A 10 bit Analog-to-Digital converter module was used to gather the data. A 5 V supply voltage was used as the reference voltage of the A/D module. LCD was used to display the intensity. The data were also transmitted to PC by using an RS 232 cable. The following flow chart as shown in Fig. 2 illustrates the Algorithm to display intensity in a LCD and to send data into computer by using serial communication.

Start

Initialize AD module

Initialize LCD module

Initialize UART module at 9600 bps

Read AD data

Decode data into real data

Write data into LCD

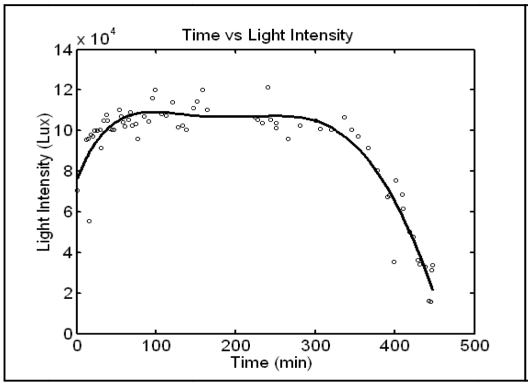
Write data into UART

End

Fig. 2: Ultimate device

3. RESULTS, ANALYSIS AND DISCUSSION

In order to study the photo sensitivity of the sensor, the light intensity was measured with a luminance meter simultaneously measuring the output voltage of the sensor. It was found that the temperature of the Cu_2O/Cu_2S hetero-junction had a major effect on the output voltage measurements. Thus the measurements were taken immediately after the sensor was exposed to the sunlight without keeping it exposed for a long time. Fig. 3 illustrates how the intensity of light varies as the day proceeds. The data were taken in one day from 9.30 am to 5.00 pm. Fig. 4 illustrates the variation of the output voltage of the sensor during the above time interval.



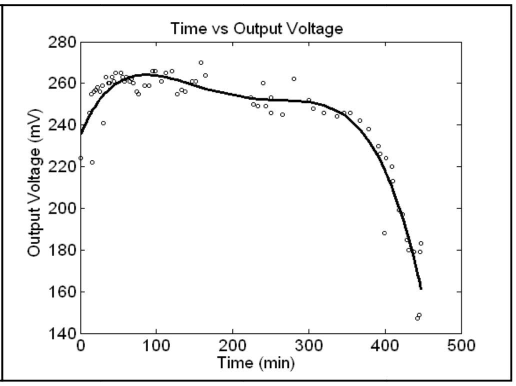


Fig. 3(a): Variation of light intensity of a day measured by using Luminance meter IM-3

Fig. 3(b): Variation of output voltage of the sensor measured simultaneously with the Luminance meter IM3 Measurements shown in Fig. 3(a)

The graph of Fig. 3(a) and Fig. 3(b) illustrates similarities in shape showing fluctuations in the middle of the day due to cloud movements. Hence one can assume that the sensor could be used to measure intensity of light effectively regardless of the time of the day.

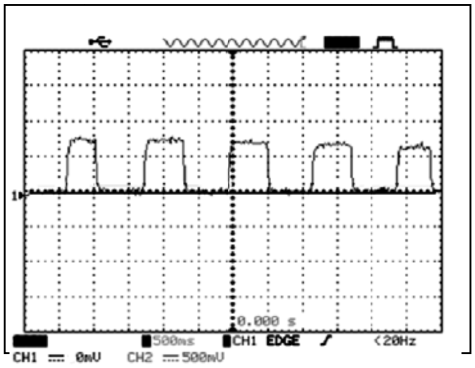


Fig. 4: Time Response of the Thin Film during exposure and closure to a 25 W light source of fixed intensity

Fig. 4 shows the time response of the sensor, which was exposed to a 25W filament bulb that switches on and off in rapid time intervals. The response of the sensor was instantaneous as the figure illustrates. An output voltage was observed instantly when the sensor was exposed to the light and the output dropped back to 0 when it's darkened. Therefore, it shows that this sensor has a quick response to light.

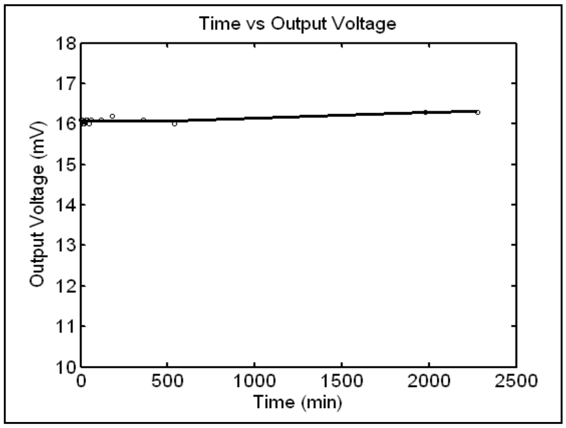


Fig. 5: Output voltage of thin film when exposed to light source of fixed intensity for a longer time interval

Fig. 5 provides the output voltage data at a given intensity when the sensor is exposed for a longer duration. The sensor was exposed to a fixed intensity (500 lux) light beam inside an air-conditioned laboratory where the temperature was maintained at 28 ^{o}C and the output voltage was observed. As the figure illustrates, the output voltage remained constant throughout its exposure.

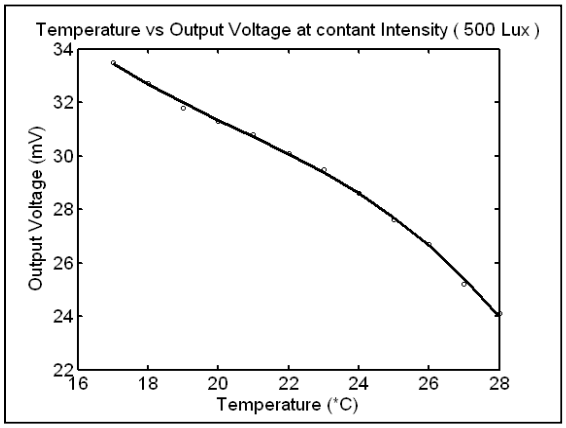


Fig. 6: Variation of sensor output voltage with the temperature at 500 lux

Fig. 6 illustrates variation of output voltage as a function of temperature while the sensor was exposed to 500 lux light source. Temperature variation was achieved by changing the temperature of the laboratory air conditioner from 17 ^{o}C to 28 ^{o}C. It can be observed that the output voltage decreases when the temperature increases due to the reduction in photo activity. Hence a temperature stabilizing techniques is necessary when creating a light intensity measuring device using the sensor.

3.1 Calibration of the device

In order to calibrate the sensor of the light detector, measurements were taken from a Luminance meter while reading the output voltage of the sensor simultaneously as the Fig. 7. Light intensity was varied by using a variable artificial light source.

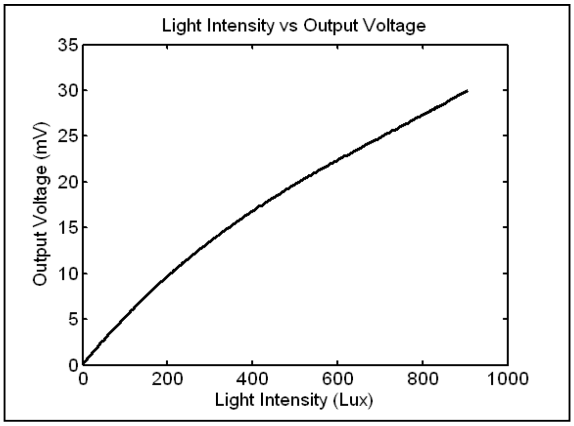


Fig. 7: Relationship between light intensity and output voltage of the sensor

3.2 Validating the device readings

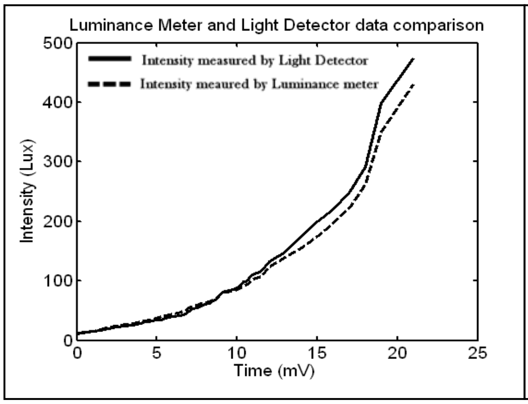


Fig. 8: Variation light intensity during a morning session of a day taken using the Luminance meter (dashed line) and the device (solid line)

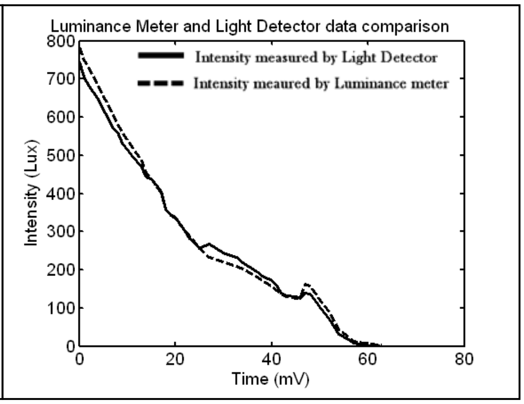


Fig. 9: variation of light intensity during an evening session of a day taken using the Luminance meter (dashed line) and the device (solid line)

Figs. 8 and 9 show that how the intensity varied in the morning session and evening session of a day. Measurements were obtained from the above calibrated device and luminance meter simultaneously. It shows some deviations with the calibrated device values and the luminance meter values. The deviations may be attributed to the variation of photoactivity and different responses that the luminance meter and the sensor show due to variation in the ambient temperature.

4. CONCLUSIONS

This study shows that a Cu_2O based thin films sensors can be practically used to construct a light detector. Cu_2S / Cu_2O thin film used in this device was observed to have a detection capability with a higher sensitivity leading to measurement of low light intensities. It could be conveniently used to measure the light intensity of the environment with intensities as low as 1 lux. The device requires a lower cost compared to commercially available light detectors.

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