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Development of a Microcontroller Based Conductivity Measurement Device for Semiconductor Thin-Films Application

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Abstract: *This work is aimed at developing a device to study the behavior of semiconductor thin-filmsamples using four-wire probes technique. The developed device is a four-point probes technique which consists of a 5 V DC regulated power supply, a current sensing unit, an arduino microcontroller unit, a digital liquid crystal display unit, a data logger and sets of probes for interfacing the semiconductor sample to the power supply and microcontroller units. The microcontroller is programmed using arduino C codes for current and voltage estimation. The resistivity of semiconductor of a given area and dimension is therefore determined using the current and voltage estimated from the developed device.*

Keywords: *Four-point probes, conductivity, arduino-microcontroller, semiconductors, current, voltage.*

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I. Introduction

The conductivity of a semiconductor device is one of the important electrical parameters which need to be investigated to properly understand the device behavior. Due to the flexible nature of semiconductor thin films, several growth parameters such as the growth temperature, pH of the electrolytic bath, annealing temperature, concentration of ions used for the thin film growth, concentration of donor / acceptor impurity atoms, and measurement temperature can influence the material conductivity. It is also of a great scientific interest to know that the conductivity of semiconductors behave differently depending on whether it is intrinsic or extrinsic. For intrinsic semiconductors, electrons are thermally excited from the valence band to the conduction band to improve conductivity while for extrinsic semiconductors, the conductivity is improved with dopants addition [1]. The resistivity of extrinsic semiconductor depends mainly on bulk doping and this can be achieved by using either p-type or n-type dopant impurity atoms[2]

Devices fabricated from semiconductor devices possess certain electronic features which are dependent on the material conductivity. Some of these features are: shunt resistance, series resistance, breakdown voltage, turn-on voltage,capacitance and Fermi level position[3]. In the higher institution of learning, undergraduate students perform a comprehensive study of devices fabricated from semiconductor materials and for this reason, it is essential that they measure the conductivity of the semiconductors experimentally. Two approaches have been proposed by researchers in determining the semiconductor conductivity; these are using the two-point probe and four-point probe technique[4]. However the use of two-point probe technique has been discouraged due to the fact that it permits the passage of direct and higher current into the semiconductor material during measurement thus changing the thin film properties[4]. In addition to the above, the two-point probe method does not make provision to reduce errors initiated by contact resistance between the semiconductor materials and the probe of the metals being used for measurement purpose [4]. The use of four-point probe technique has been suggested by researchers so as to obtain more precise conductivity values. Using the four-point probe method, the high current which passes through the semiconductor materials and the errors caused by contact resistance are drastically reduced.

It should be noted that the four-point probe technique is not a new method as several researchers have used this technique in thin film electrical characterization. However, the equipment is very expensive and the prices of purchase aretherefore not easily afforded by institutions most especially in the developing countries. For this reason, the present work describes the development of a portable, low-cost microcontroller based conductivity measurement instrument using arduino technology and principle of four-point probe technique. The present work is calibrated using standard conductivity measuring device and is further applied in measuring the electrical conductivity of in-organic thin films.

II. Materials and Methods

The device was simply built around arduinouno microcontroller with a four-wire probe technique. The four-wire probes were collinearly arranged with equal spacing of 1 mm (0.1 cm) between them over the surface of semiconductor thin-film samples as shown in Figure 1. The device was powered with a 5 V direct current (dc) power supply obtained from 240 V alternating current (ac) voltage source to supply current to the samples. In this case, a 240 V to 12 V ac transformer was used to reduce the high 240 V ac voltage to a low 12 V ac voltage. The low 12 V ac voltage was converted to dc voltage by a full-wave bridge rectifier using four silicon diodes (4 x IN4007) arranged in diamond configuration as shown in Figure 2. The result is unregulated voltage, therefore a voltage regulator using LM7805 integrated circuit (IC) was used to regulate the voltage to a standard 5 V dc voltage signal. The two capacitors 0.1μF and 0.01μF in the circuit were used to smooth out any ripples caused by ac signal.

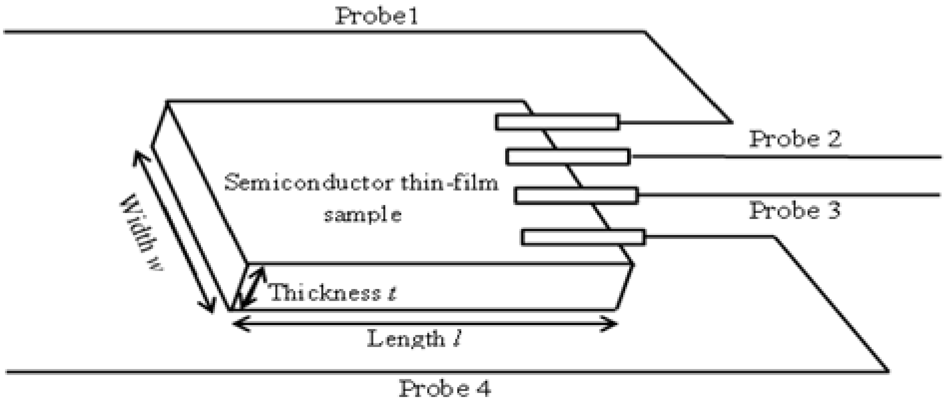

Figure 1: Arrangements of four-wire probes that measure voltage (V) and supply current (A) to the surface of the semiconductor sample.

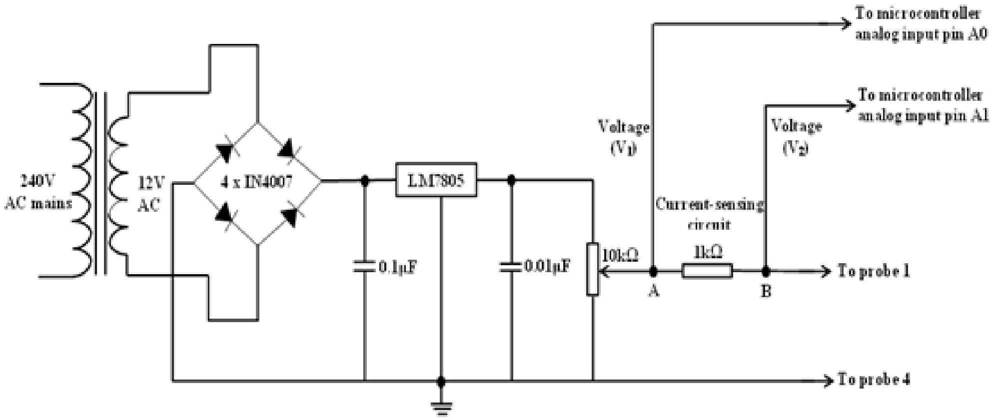

Figure 2: Circuit diagram of 5 V dc power sources that supplies current to the semiconductor sample.

Though use of dry cell is possible, but a dcvoltage obtained from an ac source was used in this work since it can provide more stable current and does not contribute contact resistance to the circuit. A 10 kΩ potentiometer was connected across the 5 V dc voltage signal, so that the voltage can be varied between zero potential voltage and maximum voltage level, that is, between 0-5 V range.This was done so that the behaviour of semiconductor thin-film samples can be studied at various voltage and current levels. In order to prevent a strong current from passing through the thin-film samples, a fixed 1 kΩ resistor was connected to the potentiometer wiper to limit the level of current flow rate and also, to detect the amount of current flowing through the circuit. The 1 kΩ resistor was selected in such a way that it should not affect the semiconductor samplethat the current is being passed to. As the voltage varies and applied to the resistor, current flows through the1 kΩresistor thus causing voltage V_1 at one end A and voltage V_2 at the other end B of the resistor.

The voltages at the two ends A and B of the resistor are fed to analog input pins A0 and A1 of the microcontroller respectively as indicated in Figure 2. The microcontroller was programmed using arduino C language to read and converts the voltages into corresponding digital values by its 10bits analogue-to-digital converter (ADC) between 0 and 1023, 0 being 0 volt and 1023 being 5 V.The voltage output from the two ends A and B of the resistor, which is V_1 andV_2 are calculated using Eq. (1).

$$V_1 \text{ or } V_2 = \frac{\text{ADC reading}}{1023} * 5\text{ V} \qquad (1)$$

where V_1 = voltage at end A of the resistor, and V_2 = voltage at end B of the resistor.
The difference between the two voltages at the ends A and B is equal to the voltage drop across the resistor which is proportional to the current flowing through the resistor. Therefore, the amount of current that flow through the resistor can be determined by Eq. (2).

$$I = \frac{\text{Voltage drop across the resistor } (V_1 - V_2)}{\text{Resistor value } (1000\ \Omega)} \qquad (2)$$

When the current is allowed to pass into a semiconductor thin-film sample through the two-wire probes 1 and 4 as shown in Figure 2, current flows from higher potential point to lower potential point over the surface of the sample; thus, this generates potential difference (voltage drop) across the surface of the semiconductor sample. The generated potential difference in the sample is detected by the other two-wire probes 2 and 3. The detected potential difference is fed to analog input pin A2 of the microcontrolleras shown in Figure 3. The microcontroller with its 10bits analogue-to-digital converter (ADC) also converts the potential difference into corresponding digital values in the range 0 and 1023. The microcontroller further processed the digital values obtained into a readable form by the conversion factor in Eq. (3).

$$V = \frac{\text{ADC reading}}{1023} * 5\text{ V} \qquad (3)$$

Knowing the value of current passed into the thin-film sample and voltage drop across the thin-film surface, then semiconductor thin-film resistance can be determined using Ohm’s law (V = IR).
Therefore,

$$R = \frac{V}{I} = \frac{\text{Voltage drop across the semiconductor thin - film}}{\text{Current passedinto the semiconductor thin - film}} \qquad (4)$$

where V is the voltage drop across the thin-film surface (mV), I is the current passed into the thin-film (mA) and R is resistance of the semiconductor thin-film in ohms (Ω).
Resistance R of the semiconductor thin-film can be re-consideredfrom the condition, that the resistance R of a material is proportional to its length land inversely proportional to its cross-sectional area A. That is,

$$R \alpha \frac{l}{A} \qquad (5)$$

Simplifying Eq. (5), R can be re-arranged as:

$$R = \rho \frac{l}{A} \qquad (6)$$

Also, $\rho = \frac{RA}{l}$

(7)

whereρ is the resistivity of the semiconductor thin-film sample in ohm-meter (Ωm). It should be noted that the samples of the semiconductor thin-films employed in this work are rectangular in shape with length l, width w and thickness t. The conductivity, σ of the semiconductor material measured in $(\Omega \cdot m)^{-1}$ or $(S \cdot m^{-1})$is determined by finding the inverse of ρ .

As illustrated in Figure 3, a 16x2 Hitachi’s HD44780 liquid crystal display (LCD) module was used to display the parameters measured by the device. The module is a thin flat screen that can display a total of 32 characters, which are divided into two lines of sixteen characters to produce output readings over its screen. The LCD module is connected to the arduino microcontroller by a 6bit data bus through pins 2, 3, 4, 5, 6 and 7 of the digital pins on the microcontroller. The microcontroller is separately powered with 9 V battery. Also, the device is integrated with data logger so that the measurements taken can be stored for offline analysis.

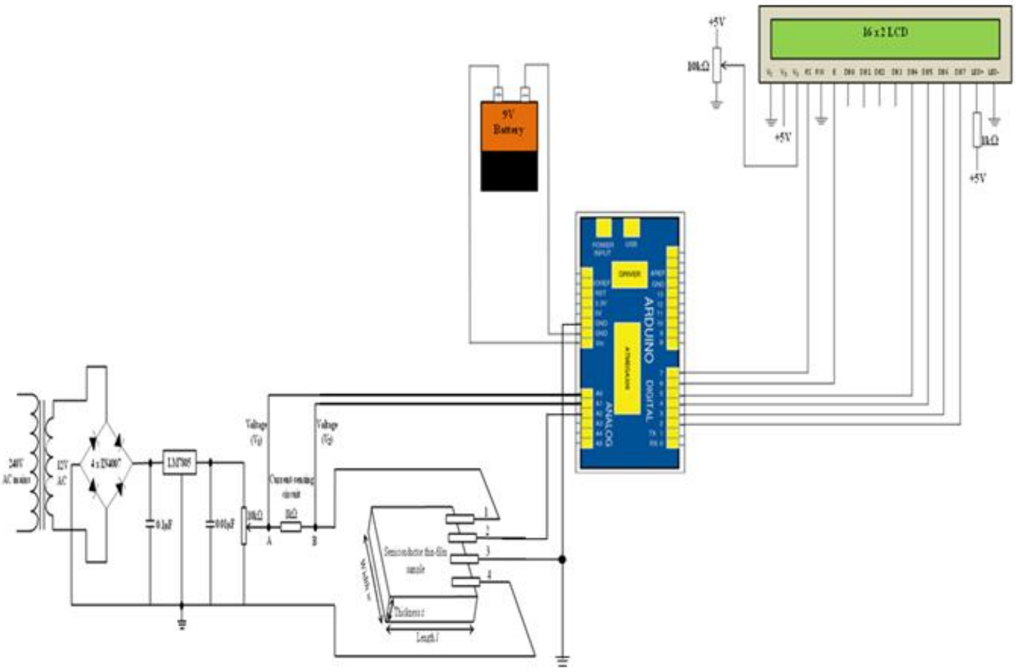

Figure 3: Complete circuit diagram of the developed device

III. EXPERIMENTAL SET-UP

An experimental setup was carried out to examine the conductivity of semiconductor thin-film samples using the same four-wire probes technique.In the set-up, the probes were arranged linearly in a straight line at equal distance from each other over the surface of semiconductor thin-film samples as it is in Figure 1. The probes were connected to the surface of the thin-film sample with crocodile clips and are separated by a distance of 1 mm (0.1cm) from each other and held firmly in position by mask tape to prevent them touching each other. A 5 V dc power supply obtained from alternating current transformer was used to pass current to the thin-film samples through the two-wire probes 1 and 4 as shown in Figure 4.

In order to prevent high current from flowing through the sample, a fixed 1 kΩ (1000 ohms) resistor was used in the circuit to limit the level of current flow. As current passed into the sample, voltage drop occur over the surface of the sample. Two digital multi-meters were used in the set-up as indicated in Figure 4, one for detecting current passed into the sample and the other for detecting voltage drop over the surface of the sample.By obtaining the values of current and voltage respectively, the resistance of the semiconductor sample isdetermined using Eq. (4),and as well as its resistivity using Eq. (7). By taking the inverse of the resistivity obtained, then the conductivity of the semiconductor thin-film can be determined.

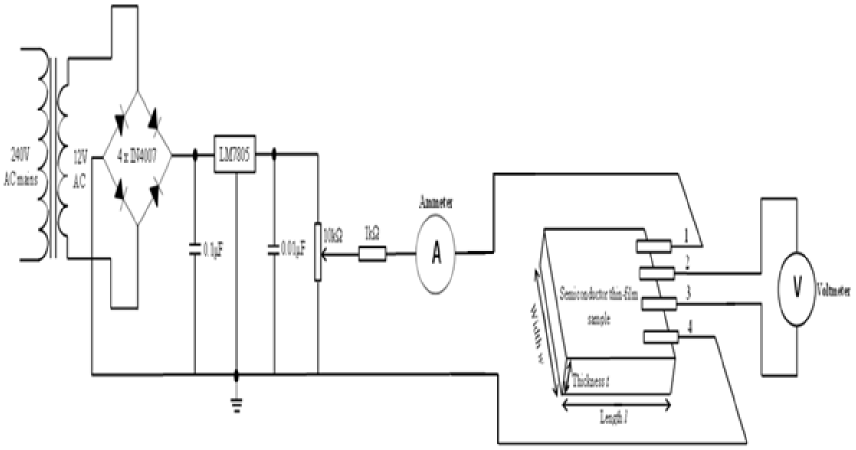

Figure 4: Schematic circuit diagram of the experimental set-up

IV. Calibration and Performance Tests

Each unit of the developed device shownin Figure 3 was coupled together using flexible cables. The device was used to measure the conductivities of three different semiconductor thin-film samples to test for itsfunctionality and performance. To ascertain the reliability of the device, subsequent measurement of the conductivities of the semiconductor samples were carried out using experimental set-up discussed in section 3. The results of the measurements obtained from the developed device were compared with that of the results obtained fromstandard instruments set up experimentally and the results are presented in Figures 5 to 7; this was executed to verify the accuracy and precision of the developed device.

The three semiconductors used to test the functionality of the developed device are binary compound semiconductors namely CdTe, CdSe and CdS of varying thicknesses 500 nm, 150 nm and 100 nm respectively.CdTe, CdSe and CdS aresemiconductor materials with energy band-gaps of 1.44, 1.80 and 2.42 eV respectively [5-7].

These materials behave differently as seen from the current-voltage (I-V) characteristics illustrated in Figures 5 to 7. Figures 5 (a) and 5 (b) show the I-V characteristic curves of CdTethin films obtained from developed and standard equipment respectively. The resistances obtained from the slope inverse of Figures 5 (a) and 5 (b) are 6.18 Ω and 6.34 Ω respectively. The deviation between these values lies within the range ±0.20 Ω.

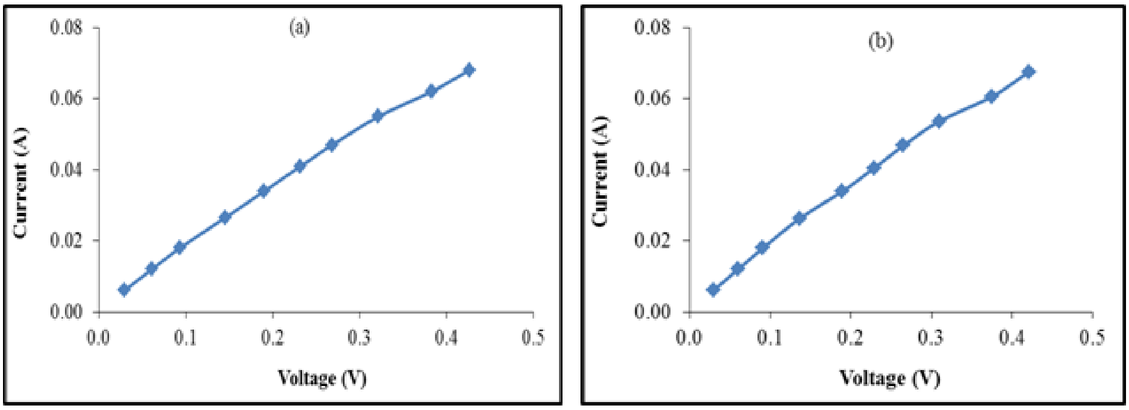

Figure 5: Current-voltage characteristics of CdTe thin films obtained from (a) Developed device and (b) Standard device.

Figures 6 (a) and 6 (b) reveal the I-V characteristic curves of CdS thin films obtained from developed and standard equipment respectively. The resistances obtained from the inverse of gradient of Figures 6 (a) and 6 (b) are 7.76 Ω and 7.94 Ω respectively. The deviation between these values also lies within the range ±0.20 Ω.

The I-V characteristic curves of CdSe thin films obtained from developed and standard equipment are shown in Figures 7 (a) and 7 (b) respectively. The resistances obtained from the slope inverse of Figures 7 (a) and 7 (b) are 10.16 Ω and 10.35 Ω respectively. The deviation between these values likewise falls within the range ±0.20 Ω.

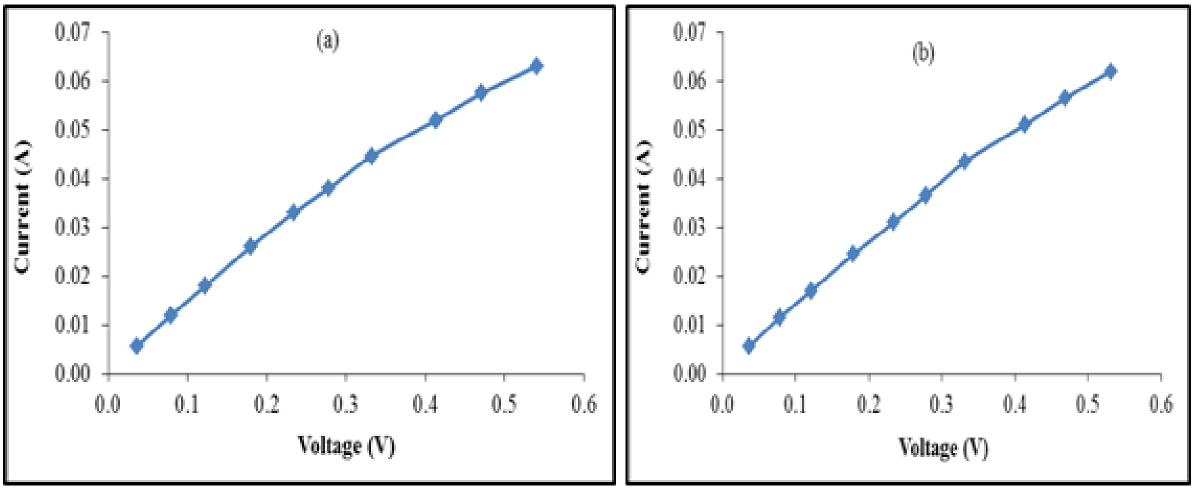

Figure 6: Current-voltage characteristics of CdS thin films obtained from (a) Developed device and (b) Standard device.

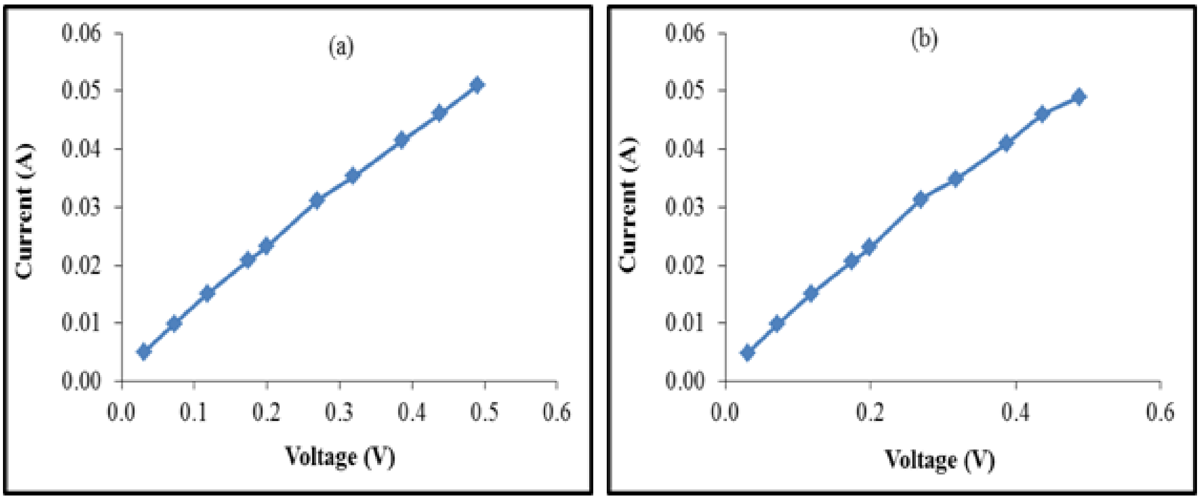

Figure 7: Current-voltage characteristics of CdSe thin films obtained from (a) Developed device and (b) Standard device.

The values of resistivities and conductivities deduced from the resistance of the three semiconductors used in the performance test are shown in Table 1. The result shows that the least resistivity was observed in CdTe thin film which is mostly used as an absorber layer in CdTe-based solar cell fabrication. On the other hand, CdS has a higher resistivity of $4.47 \times 10^6 \Omega$.cm. This is a typical characteristic of semiconductor materials which serve the purpose of a buffer layer[8,9]or window layer [10] in CdTe-based solar cell. The resistivity of CdSe thin films lies in-between that of CdS and CdTeas shown in Table 1. Also, the energy band-gap of CdSe lies in-between that of CdS and CdTethus showing that CdSe can be an intermediate layer between CdS and CdTe to form a graded band-gap device[11] with the structure: metal/CdS/CdSe/CdTe/metal contact.

Table 1: Comparison of some electronic parameters obtained from arduino-developed device and standarddevice.

	Data from arduino-developed device			Data from standard device		
Sample	R (Ω)	ρ (Ω.cm)	σ (Ω.cm)$^{-1}$	R (Ω)	ρ (Ω.cm)	σ (Ω.cm)$^{-1}$
CdTe (500 nm)	6.18	8.22×10^5	1.22×10^{-6}	6.34	8.47×10^5	1.19×10^{-6}
CdS (100 nm)	7.76	4.47×10^6	2.24×10^{-7}	7.94	4.57×10^6	2.19×10^{-7}
CdSe (150 nm)	10.16	2.03×10^6	4.92×10^{-7}	10.35	2.07×10^6	4.83×10^{-7}

A plot of resistance from standard device against developed device as shown in Figure 8 shows a regression (R^2) of 1 meaning that, there is a good correlation between the results obtained from the standard and developed devices.

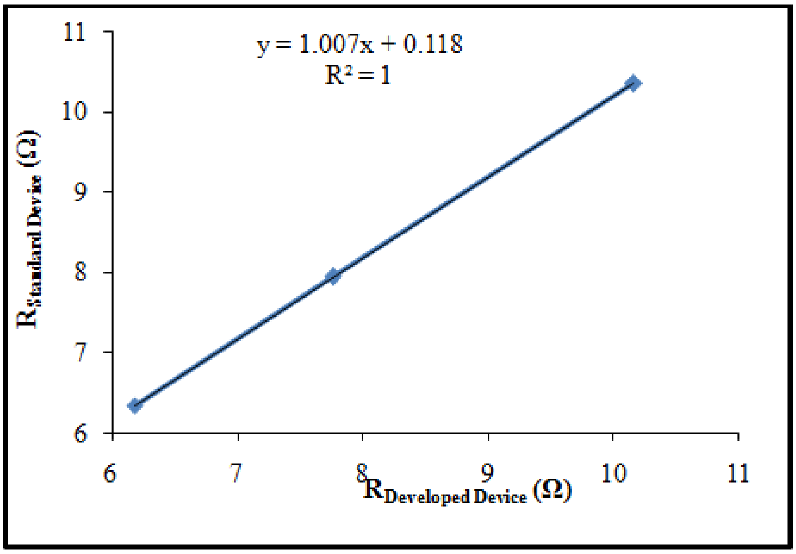

Figure 8: Graph showing the correlation between resistances obtained from developed and standard devices.

V. Conclusion

This paper has presented the development of a microcontroller based conductivity measurement device for semiconductor thin-films application. The results demonstrated in the graphs shown in Figures 5 to 7 has proven that the device work satisfactorily by using four-wire probes and arduino microcontroller as the core of the device. The device also proposed as a better replacement for the high cost convectional types available in the market as the device was made and assembled from inexpensive materials available within the environment. The device can be used in the laboratory for demonstration and research purposes as well as in allied industries. The device is cost-effective and much more feasible to buy and use because of its simple design.

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References

[1]. Koryta, J. Dvorak, L. Kavan, Priciples of Electrochemistry, second ed., John Wiley &Sons, Ltd., Chichester, West Sussex, England, 1993.

[2]. A. Garg, R. Sharma, V. Dhingra, Automating Energy Bandgap Measurements in Semiconductors Using LabVIEW, Eur. J Phys. Educ. 1 (2010) 2–14. doi:1309 - 7202.

[3]. O.I. Olusola, PhD Thesis “Optoelectronic Devices Based on Graded Bandgap Structures Utilising Electroplated Semiconductors,” Sheffield Hallam University, Sheffield, 2016. http://shura.shu.ac.uk/id/eprint/14127.

[4]. S. Seng, T. Shinpei, I. Yoshihiko, K. Masakazu, Development of a Handmade Conductivity Measurement Device for a Thin-Film Semiconductor and Its Application to Polypyrrole, J. Chem. Educ. (n.d.). doi:dx.doi.org/10.1021/ed500287q |.

[5]. O.I. Olusola, M.L. Madugu, A.A. Ojo, I.M. Dharmadasa, Investigating the effect of GaCl3 incorporation into the usual CdCl2 treatment on CdTe-based solar cell device structures, Curr. Appl. Phys. 17 (2016) 279–289. doi:10.1016/j.cap.2016.11.027.

[6]. O.I. Olusola, O.K. Echendu, I.M. Dharmadasa, Development of CdSe thin films for application in electronic devices, J. Mater. Sci. Mater. Electron. 26 (2014). doi:10.1007/s10854-014-2506-x.

[7]. H.I. Salim, O.I. Olusola, A.A. Ojo, K.A. Urasov, M.B. Dergacheva, I.M. Dharmadasa, Electrodeposition and characterisation of CdS thin films using thiourea precursor for application in solar cells, J. Mater. Sci. Mater. Electron. 27 (2016) 6786–6799. doi:10.1007/s10854-016-4629-8.

[8]. S.G. Kumar, K.S.R.K. Rao, Physics and chemistry of CdTe/CdS thin film heterojunction photovoltaic devices: fundamental and critical aspects, Energy Environ. Sci. 7 (2014) 45–102. doi:10.1039/C3EE41981A.

[9]. A. Morales-Acevedo, Can we improve the record efficiency of CdS/CdTe solar cells?, Sol. Energy Mater. Sol. Cells. 90 (2006) 2213–2220. doi:10.1016/j.solmat.2006.02.019.

[10]. M. Lakshmi, PhD Thesis “Studies on chemical bath deposited copper selenide and iron sulfide thin films useful for photovoltaic applications,” Cochin University of Science and Technology, 2001.

[11]. O.I. Olusola, M.L. Madugu, I.M. Dharmadasa, Investigating the electronic properties of multi-junction ZnS/CdS/CdTe graded bandgap solar cells, Mater. Chem. Phys. 191 (2017). doi:10.1016/j.matchemphys.2017.01.027.

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