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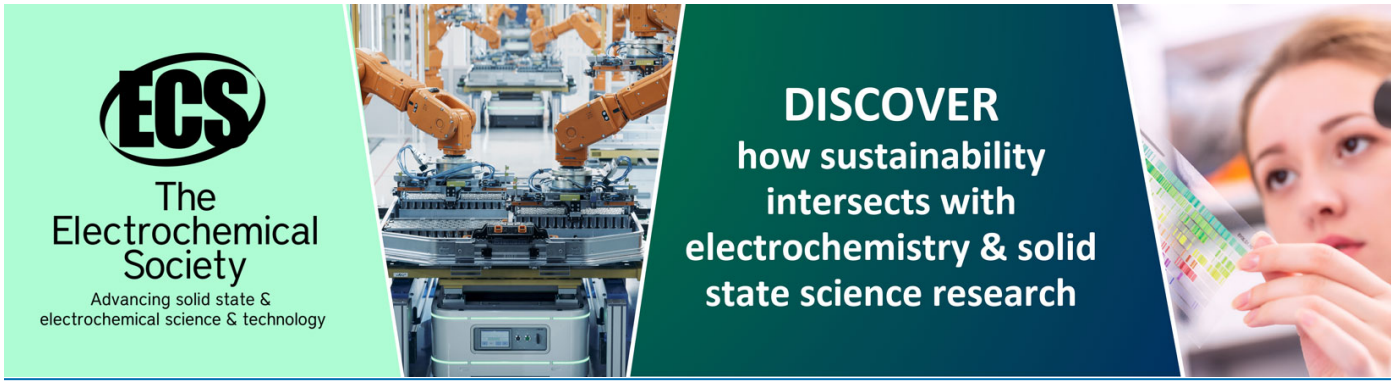

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Design of a simple and low cost electrical property tester for graphene material : a preliminary study

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Abstract. A simple and low cost electrical property tester for material has been designed and built using cheap components. This instrument consists of simple adjustable current source circuit using LM317, gold coated pin probe and multimeters. The circuit arranged has produced sufficient current to do an electrical property measurement. Value of current could be adjusted to select suitable current in measurement. Resistance vs current graph shows a reciprocal function that generated by a constant voltage of 1.25 volts in output pin. An experiment to examine sheet resistance of ITO glass was carried out to make sure the instrument work properly.

1. Introduction

In present day graphene has become a hot topic among the scientists. Graphene has remarkable properties that support the application into various field such as overpowering modulus young, high thermal conductivity, fantastic electron mobility, and high transparency.[1-3]. Drived by the fabulous characteristics, graphene has found as the main player in many devices. Touch screen, solar cell, LED, and transistor has use graphene as basis of the making in both as main constituent either as subtitute material in order to improve the performance. [4-12]. Furthermore, the latest research has attempt to apply graphene in electrochromic device, supercapacitor, electrochemiluminescent sensor, nanogenerators, loudspeaker and transparent conductive film. [13-18]

Graphene can be synthesized by varous kind of method such as mechanical exfoliation, epitaxial growth, chemical vapor deposition, and chemical methode. Mechanical exfoliation is run by using scotch tape to gather single layer graphene from natural graphite. Evaporating silicon carbide at temperature of 1000 C to desorb silicon and to create layer built of carbon atom is wrok priciple of epitaxial growth. This methode can produce pristine and single layer graphene. Chemical Vapor Deposition uses methane (CH4) as precursor to produce graphene. A complex and expensive cost is needed to operate this technique, but it can produce high quality graphene. Chemical metohode uses chemical reaction in mild temperature to produce graphene. This methode do not yield the pristine graphene but it allows to produce graphene in large number and low cost. [1, 19-21]

As synthesized graphene material is necessary to analyze to get information about the properties and quality. In typical characterization process, morphological property is analyzed using Scanning electron microscopy (SEM) and Atomic force microscopy (AFM). Optical property is studied by using Uv-Vis spectrometer. Atomic compound is determined by characterization of X-ray diffraction and X-

ray photoelectron spectroscopy. Electrical property of material is usually examined by using four point probe method.[22, 23]

Four point probe methode is a facile way to characterize the resistivity or surface resistance of the sample. Four point probe could measure two kind of sample which are bulk and film. Bulk material the sample thickness is assummed much bigger than the distance of the probes. Area affected by current would produce voltage. The integration was done by:

$$\Delta R = \rho\left(\frac{dx}{dA}\right) \tag{0.1}$$

The value of resistance is

$$R = \int_{x_1}^{x_2} \rho\left(\frac{dx}{2\pi x^2}\right) = \frac{\rho}{2\pi}\left(-\frac{1}{x}\right) = \frac{1}{2s}\frac{\rho}{2\pi} \tag{0.2}$$

Superposition of current gives $R = V / 2I$

$$\rho = 2\pi s\left(\frac{V}{I}\right) \tag{0.3}$$

While, for sample in film, would be discussed later in the next section.

In general four point probe has three main components which are current source, voltmeter, and probes. A stable current surce is injected into the sample material and voltage resulted by the resistance characteristic is analyzed. Many instruments have been built and have been sold in the market with a complex features. Unfortunately, the price of the fixed istruments are expensive.

To obtain this obstacles we study a more simple way to measure electrical property of material. We built a simple controllable current source based LM 317 integrated circuit. This device produces output reference voltage of 1.25 V emited from output and adjustment pins.

I_{adj} is kept constant by 100 μA regarded to load changes. To obtain the requirement, all not-moving current regulator returned to output terminal. Programable regulator designed by connecting a resistor between adjustment and output pins. In order to apllied this devide into a constat current source, the resistor R_1 could be set to the regulator. While the ground terminal R_2 is set near the ground of the load. [24]

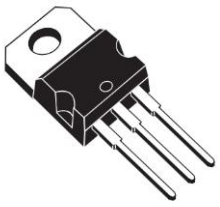

Figure 1 : LM 317

2. Experimental Setup

Design of circuit for constant and controllable current source were prepared to observe output current of the design. We vary the resistor to make sure the output current is obey the theoritical principle. Design of constant and controllable current source is presented by Figure 2.

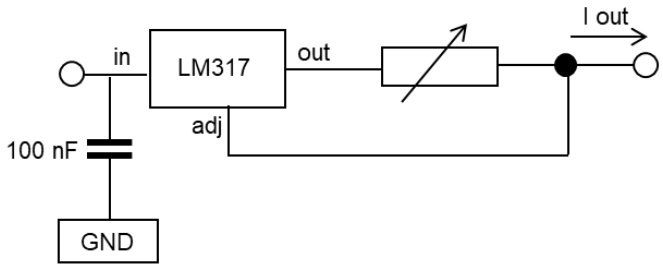

Figure 2 : Schematic Diagram of LM317 adjustable current source circuit

To obtain tinier output current, an additional resistance is intalled into the circuit. The resistance is arranged by series respect to a potensiometer. The design is showed in Figure 3.

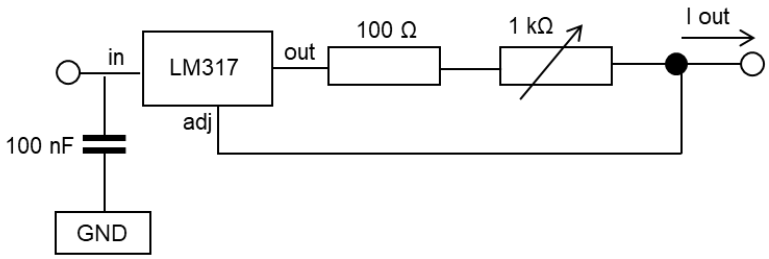

Figure 3 Schematic diagram of LM317 adjustable current with a resistor

The current from the circuit was used to evoke the voltage of analyzed sample. By adjusting the value of current gathered information from the voltmeter, the resistance value of the sample was obtained. The information of the resistance could bring to the value of rasistivity or sheet resistance as electrical property of materials.

To apply this circuit in electrical measurement, a sample of ITO glass was used to examine the validity of the tester. ITO glass is a kind of transparent electrode that used in many apllication such as solar cell [25]. A type of ITO glass used in the experiment has characteristic value of sheet resistance below 20 Ω/sq.

A voltage of 5 volt gathered from power supply was used to power the circuit up. By adjusting the potensiometer, a current output of the circuit was set and measure by an ammeter. Two jumper are connected and make the open circuit. End of the jumper was to the pin of test probe as shown in Figure 4.

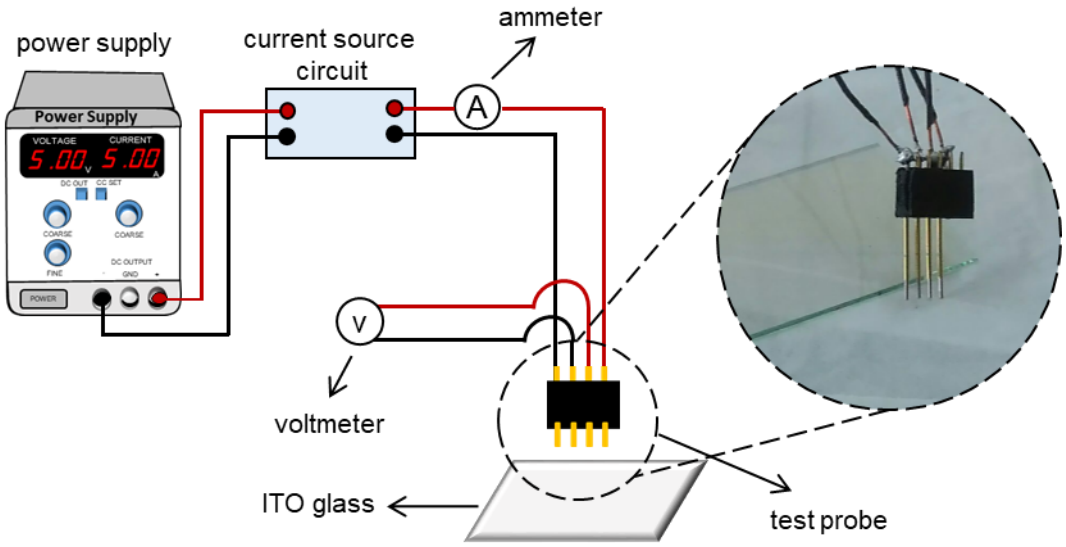

Figure 4 : Electrical propery of ITO glass measurement

To determine the value of sheet resistance, the formula of work principle of four point probe is applied. For sample in film, the layer thikcness is assummed much thinner than the distance of the probes. Expression for area created by current in sample is $A = 2\pi xt$. The integration was carried out as follows :

$$\Delta R = \rho\left(\frac{dx}{dt}\right) \tag{0.4}$$

$$R = \int_{s}^{2s} \rho\left(\frac{dx}{2\pi xt}\right) = \frac{\rho}{2\pi t}(\ln x) = \frac{\rho}{2\pi t}(\ln 2) \tag{0.5}$$

Superposition of current gives $R = V / 2I$

$$\rho = \frac{\pi t}{\ln 2}\left(\frac{V}{I}\right) \tag{0.6}$$

this expression independent of dimension of sample. Resistivity of a film is expressed in sheet resistance where $R_s = \frac{\rho}{t}$, thus

$$R_s = \frac{\pi}{\ln 2}\left(\frac{V}{I}\right) \tag{0.7}$$

More general expression is wrote the value of constant where $\frac{\pi}{\ln 2} = 4.53$, so the equation can be write as follows

$$R_s = 4.53\left(\frac{V}{I}\right) \tag{0.8}$$

3. Result and Discussion

The current produced was measured to investigate validity of data gathered from circuit.

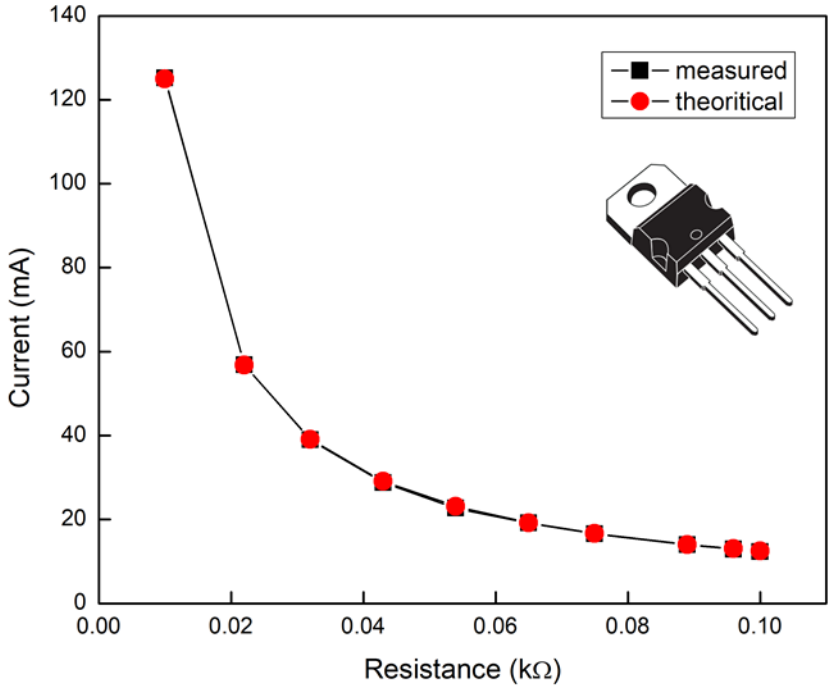

Figure 5 Resistance vs output current of LM317

Figure 5 shows the characteristic of output current affected by resistance intalled. The graph is a kind of reciprocal function that generated by a constant voltage of 1.25 volts in output pin [24]. Measured current shows almost exactly same value with theoritical one. As the basis for further steps, this data shows a good agreement with theoritical value wich gives maximum error up to 1.94%. This result indicate the constant current source has been produced using LM317 and could be controlled by applying a resistance. Complete measurement data gathered form experiment is shown in Table 1.

Table 1 Measurement of output current by varying resistance

R (kΩ)	I_{out} (mA)	$I_{theoritical}$ (mA)	Err (%)
0.01	125.2	125	0.16
0.022	56.8	56.82	0.03
0.032	39	39.06	0.16
0.043	28.8	29.07	0.93
0.054	22.7	23.15	1.94
0.065	19.12	19.23	0.58
0.075	16.58	16.67	0.52
0.089	13.93	14.04	0.82
0.096	12.9	13.02	0.93
0.1	12.33	12.5	1.36

Additional resistor installed into the circuit affects the output current by series law resistance. A 100 Ω resistor combined with 1 kΩ potensiometer produce equivalent resistance in range of 100 Ω – 1.1 kΩ. Despite of provided voltage between output and adjustmen pins was 1.25 V, the current produced by this configuration would be maximum and minimum of 12.5 to 1.05 mA respectively. To examine this arrangement follow the theoritical calculation, output current was measured. Value of maximun and minimum current measured from the circuit gave 12.41 – 1.07 mA respectively. This result is almost exactly agreed with the teoritical value, the difference produced error less than 2% and might be caused by the poor contact between components. With the value of this arragement, this design could investigate electrical property of material with tiny value of current. Typically graphene synthesized by using chemical reaction to get a low cost and allow mass production. Up till now, resistivity, a kind of electrical property that show intrinsic resistance of matter, has achieved 11 S/cm. [26]. A tiny current in order mA is conviniet to apply to examine this property,

To make sure this design of insrument tester was proper to examine property of samples, a validity experiment was carried out by measuring a sheet resistance of transparent electrode. ITO glass is one of transparet electrode that still plays role in energy and devide research. This kind of Transparent Conductive Oxide was made of In_2O_3 that consist 3-10% SnO_2 that was deposited onto substrate in 250 – 350 ^{O}C [27]. A typical ITO glass in 3 x 4 cm dimension gathered from local supplier was used in this experiment. Sales label informs the sheet resistance of the glass is below 20 Ω/sq. Variation of output current was injected into the ITO glass sample trough Au coated and spring equipped pins. Two other pins was connected to voltmeter to get information of voltage produced. Current and voltage was noted down to calculate the intrinsic resistance of the sampel as shown in table 2.

Table 2 Variation of current injected and voltage resulted in the ITO glass sample sheet resistance measurement.

I (mA)	V(mV)	R_s (Ω/sq)
1.50	2,90	8.76
1.80	3.20	8.05
2.00	3.80	8.61
2.20	3.90	8.03

2.40	4.40	8.31
2.50	4.70	8.52
2.60	4.80	8.36
3.00	5.34	8.06
3.50	7.60	9.84
4.02	8.70	9.80
4.52	2.10	9.12
Average		8.68

Table 2 shows 11 times measurements of varied current and voltage produced by sample as consequence of the current. Each pair of data could be analyze to find the measured sheet resistance of the sample. Value of sheet resistace obtained by instrument is in range of 9.84 -8.05 Ω/sq (3rd column) and produce average of 8.64 Ω/sq and variance 0.38. Besaide that graphical analysis was done by fitting the graph and investigate the slope of the line. The slope would be value of V / I that will lead to value of sheet resistance. By computing the data, the slope of fitted line is 2.26 which gives sheet resistace of 10.23 Ω/sq. The value is different with the average of measurement as stated in previous segment. The plotting and fitting of the data is showed in Figure 6.

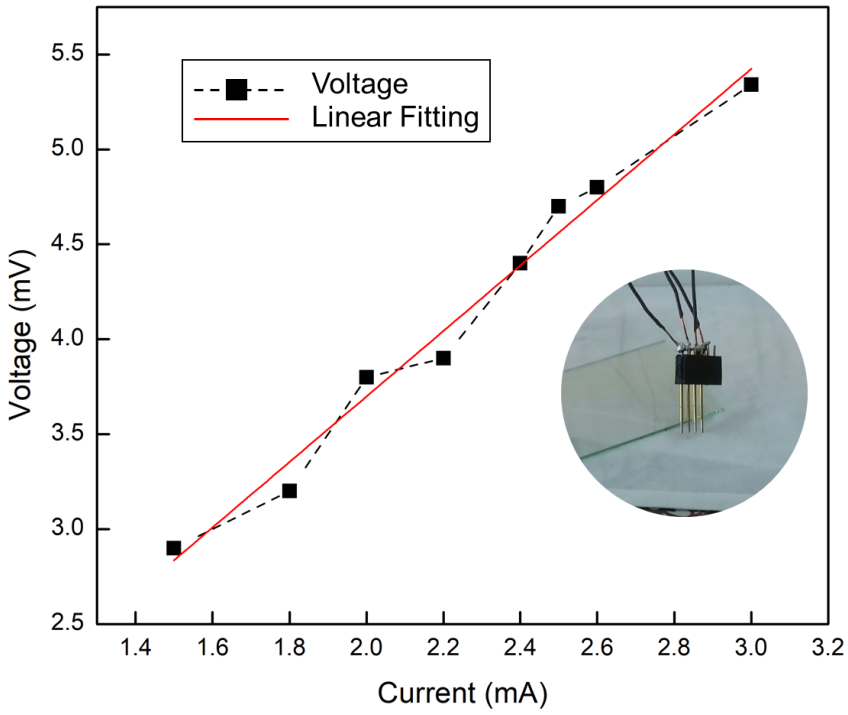

Figure 6 Current vs voltage plotting and fitting.

Inconcistency of average value and number obtaine from slope, gives sign that the instrumen was need to improoved in future. However a simple and low cost electrical property tester for material has been designed and built. Furthermore, a value gathered could be considered and near to real value.

4. Conclusion

A simple and low cost electrical property tester for material has been designed and built using cheap components. This instrument consists of simple adjustable current source circuit using LM317, gold coated pin probe and multimeters. The circuit arranged has produced sufficient current to do an electrical property measurement. Value of current could be adjusted to select suitable current in measurement. An experiment to examine sheet resistance of ITO glass was carried out to make sure

the instrument work properly. The sheet resistance gathered by instrumen near the actual value of the sample. A future improvement is necessary to do the instrument to increase the validity of measurement.

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