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 substitute 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 various kind of method such as mechanical exfoliation, epitaxial growth, chemical vapor deposition, and chemical method. 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 method 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 assumed much bigger than the distance of the probes. Area affected by current would produce voltage. The integration was done by:

\[
\Delta R = \rho \left( \frac{dx}{dA} \right)
\]  

(0.1)

The value of resistance is

\[
R = \int_{x_1}^{x_2} \rho \left( \frac{dx}{2\pi x^2} \right) = \frac{\rho}{2\pi} \left( -\frac{1}{x} \right) = \frac{1}{2\pi} \frac{\rho}{x_2}
\]  

(0.2)

Superposition of current gives \( R = V / 2I \)

\[
\rho = 2\pi s \left( \frac{V}{I} \right)
\]  

(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 source 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 instruments 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 emitted 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 applied this device 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](image)

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 theoretical principle. Design of constant and controllable current source is presented by Figure 2.
To obtain tinier output current, an additional resistance is installed into the circuit. The resistance is arranged by series respect to a potensiometer. The design is showed in Figure 3.

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 resistivity 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 application 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 2**: Schematic Diagram of LM317 adjustable current source circuit

**Figure 3**: Schematic diagram of LM317 adjustable current with a resistor

**Figure 4**: Electrical property 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 thickness is assumed 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:

$$\Delta R = \rho \left( \frac{dx}{dt} \right)$$  \hspace{1cm} (0.4)

$$R = \int \rho \left( \frac{dx}{2\pi xt} \right) = \frac{\rho}{2\pi t} (\ln x) = \frac{\rho}{2\pi t} (\ln 2)$$  \hspace{1cm} (0.5)

Superposition of current gives $R = \frac{V}{2I}$

$$\rho = \frac{\pi t}{\ln 2} \left( \frac{V}{I} \right)$$  \hspace{1cm} (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

$$R_s = \frac{\pi}{\ln 2} \left( \frac{V}{I} \right)$$  \hspace{1cm} (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

$$R_s = 4.53 \left( \frac{V}{I} \right)$$  \hspace{1cm} (0.8)

3. Result and Discussion
The current produced was measured to investigate validity of data gathered from circuit.

![Image](image.png)

Figure 5 Resistance vs output current of LM317
Figure 5 shows the characteristic of output current affected by resistance installed. 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 theoretical one. As the basis for further steps, this data shows a good agreement with theoretical 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.

| R (kΩ) | I_{out} (mA) | I_{theoretical} (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 theoretical 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 theoretical value, the difference produced error less than 2% and might be caused by the poor contact between components. With the value of this arrangement, 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 convinient to apply to examine this property.

To make sure this design of inrument 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 transparent electrode that still plays role in energy and devide research. This kind of Transparent Conductive Oxide was made of In$_2$O$_3$ that consist 3-10% SnO$_2$ that was deposited onto substrate in 250 – 350 °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.

| 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       |
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 resisitace 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. Besaid 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.](image)

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 instrument 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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References
[1] Q. Zheng and J. K. Kim, "Graphene-based Transparent Conductors: Synthesis, Properties and Applications (Authored monograph)," vol. 5, ed, 2015, p. 220.
[2] Z. Jing, Z. Guang-Yu, and S. Dong-Xia, "Review of graphene-based strain sensors," Chinese Physics B, vol. 22, p. 057701, 2013.
[3] S. Ghosh, W. Bao, D. L. Nika, S. Subrina, E. P. Pokatilov, C. N. Lau, et al., "Dimensional crossover of thermal transport in few-layer graphene," Nat Mater, vol. 9, pp. 555-558, 07//print 2010.
[4] S. Bae, H. Kim, Y. Lee, X. Xu, J.-S. Park, Y. Zheng, et al., "Roll-to-roll production of 30-inch graphene films for transparent electrodes," Nature nanotechnology, vol. 5, pp. 574-578, 2010.
[5] X. Wang, L. Zhi, and K. Müllen, "Transparent, conductive graphene electrodes for dye-sensitized solar cells," Nano Letters, vol. 8, pp. 323-327, 2008.
[6] W. Cai, Y. Zhu, X. Li, R. D. Piner, and R. S. Ruoff, "Large area few-layer graphene/graphite films as transparent thin conducting electrodes," Applied Physics Letters, vol. 95, p. 123115, 2009.
[7] M. Choe, B. H. Lee, G. Jo, J. Park, W. Park, S. Lee, et al., "Efficient bulk-heterojunction photovoltaic cells with transparent multi-layer graphene electrodes," Organic Electronics, vol. 11, pp. 1864-1869, 2010.
[8] Z. Yin, S. Wu, X. Zhou, X. Huang, Q. Zhang, F. Boey, et al., "Electrochemical deposition of ZnO nanorods on transparent reduced graphene oxide electrodes for hybrid solar cells," Small, vol. 6, pp. 307-312, 2010.
[9] X. Li, H. Zhu, K. Wang, A. Cao, J. Wei, C. Li, et al., "Graphene-on-silicon Schottky junction solar cells," Adv Mater, vol. 22, pp. 2743-8, Jul 06 2010.
[10] J.-P. Shim, M. Choe, S.-R. Jeon, D. Seo, T. Lee, and D.-S. Lee, "InGaN-based p–i–n solar cells with graphene electrodes," Applied physics express, vol. 4, p. 052302, 2011.
[11] L. Gomez De Arco, Y. Zhang, C. W. Schlenker, K. Ryu, M. E. Thompson, and C. Zhou, "Continuous, highly flexible, and transparent graphene films by chemical vapor deposition for organic photovoltaics," ACS Nano, vol. 4, pp. 2865-2873, 2010.
[12] X. Li, G. Zhang, X. Bai, X. Sun, X. Wang, E. Wang, et al., "Highly conducting graphene sheets and Langmuir–Blodgett films," Nature nanotechnology, vol. 3, pp. 538-542, 2008.
[13] A. Babichev, H. Zhang, P. Lavenus, F. Julien, A. Y. Egorov, Y. Lin, et al., "GaN nanowire ultraviolet photodetector with a graphene transparent contact," Applied Physics Letters, vol. 103, p. 201103, 2013.
[14] Y. Cao, Z. Wei, S. Liu, L. Gan, X. Guo, W. Xu, et al., "High-Performance Langmuir–Blodgett Monolayer Transistors with High Responsivity," Angewandte Chemie, vol. 122, pp. 6463-6467, 2010.
[15] Z. Fan, B. Liu, X. Liu, Z. Li, H. Wang, S. Yang, et al., "A flexible and disposable hybrid electrode based on Cu nanowires modified graphene transparent electrode for non-enzymatic glucose sensor," Electrochimica Acta, vol. 109, pp. 602-608, 2013.
[16] I. N. Kholmanov, S. H. Dominguez, H. Chou, X. Wang, C. Tan, J.-Y. Kim, et al., "Reduced graphene oxide/copper nanowire hybrid films as high-performance transparent electrodes," ACS nano, vol. 7, pp. 1811-1816, 2013.
[17] M. Wang, L. D. Duong, N. T. Mai, S. Kim, Y. Kim, H. Seo, et al., "All-Solid-State Reduced Graphene Oxide Supercapacitor with Large Volumetric Capacitance and Ultralong Stability Prepared by Electrophoretic Deposition Method," *ACS Applied Materials & Interfaces*, vol. 7, pp. 1348-1354, 2015/01/21 2015.

[18] S. Xu, B. Man, S. Jiang, C. Chen, C. Yang, M. Liu, et al., "Flexible and transparent graphene-based loudspeakers," *Applied Physics Letters*, vol. 102, p. 151902, 2013.

[19] X. Lu, M. Yu, H. Huang, and R. S. Ruoff, "Tailoring graphite with the goal of achieving single sheets," *Nanotechnology*, vol. 10, p. 269, 1999.

[20] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, et al., "Electric field effect in atomically thin carbon films," *science*, vol. 306, pp. 666-669, 2004.

[21] A. Reina, X. Jia, J. Ho, D. Nezich, H. Son, V. Bulovic, et al., "Large area, few-layer graphene films on arbitrary substrates by chemical vapor deposition," *Nano letters*, vol. 9, pp. 30-35, 2008.

[22] J. Banaszczyk, A. Schwarz, G. De Mey, and L. Van Langenhove, "The Van der Pauw method for sheet resistance measurements of polypyrrole-coated para-aramide woven fabrics," *Journal of applied polymer science*, vol. 117, pp. 2553-2558, 2010.

[23] S. I. Ahn, K. Kim, J. Jung, and K. C. Choi, "Large and pristine films of reduced graphene oxide," *Scientific Reports*, vol. 5, p. 18799, 12/22/online 2015.

[24] LM217, LM317 Datasheet 1.2 V to 37 V adjustable voltage regulators [Online]. Available: https://www.st.com/resource/en/datasheet/lm217.pdf

[25] S. Ngamsinlapasathian, T. Sreethawong, Y. Suzuki, and S. Yoshikawa, "Doubled layered ITO/SnO2 conducting glass for substrate of dye-sensitized solar cells," *Solar Energy Materials and Solar Cells*, vol. 90, pp. 2129-2140, 2006.

[26] H. Miftahul, A. F. Hafizh, F. Rohman, H. A. Akfiny, and I. Ferry, "A modified Marcano method for improving electrical properties of reduced graphene oxide (rGO)," *Materials Research Express*, vol. 4, p. 064001, 2017.

[27] E. Fortunato, D. Ginley, H. Hosono, and D. C. Paine, "Transparent conducting oxides for photovoltaics," *MRS Bulletin*, vol. 32, pp. 242-247, 2007.