INVESTIGATION ON ELECTRICAL PROPERTIES, MORPHOLOGICAL ANALYSIS AND SURFACE ROUGHNESS OF SILVER NANOPARTICLES-FILLED EPOXY CONDUCTIVE INK

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SUPERVISOR'S DECLARATION

I hereby declare that I have read this project and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:………………………..
Supervisor"s name	:………………………..
Date	:………………………..

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ROSHIDAH BINTI HAMIDI

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in fulfilment of the requirements for
the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

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2018

PENYIASATAN PADA SIFAT-SIFAT ELEKTRIKAL, ANALISIS MORFOLOGI DAN KEKASARAN PERMUKAAN DAKWAT KONDUKTIF NANOPARTIKEL PERAK YANG MENGANDUNGI EPOKSI

ROSHIDAH BINTI HAMIDI

Laporan ini dikemukakan sebagai
memenuhi sebahagian daripada syarat penganugerahan
Ijazah Sarjana Muda Kejuruteraan Mekanikal

Fakulti Kejuruteraan Mekanikal

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this project entitled "Investigation on Electrical Properties, Morphological Analysis and Surface Roughness of Silver Nanoparticles-filled Epoxy Conductive Ink" is the result of my own work except as cited in the references.

Signature	:…………………………….
Name	:…………………………….
Date	:…………………………….

DEDICATION

To my beloved mother, Rohani binti Ismail and
late father, Hamidi bin Mohd Nor

ABSTRACT

This study aspires to have an analysis of silver nanoparticles-filled epoxy conductive ink. Specifically, the parameters that were evaluated consist of sheet resistivity, surface texture and morphological analysis. In order to accomplish the analysis, four point probe is used to measure the sheet resistance value of the sample in ohms-per-square. Some of percentage of ink loading has detected the presence of resistivity and some percentage has not detected any presence of resistivity. The highest average resistivity is detected in low percentage of ink loading while the lowest one is found in high percentage of ink loading. In terms of surface texture, contact profilometer was used which resulted that the samples with lower filler percentage had consistent average value of surface roughness and smooth surface. Meanwhile, for the samples with high percentage of filler had inconsistent surface irregularities that contributed to rougher surface. In morphological analysis, light microscope is used to visualize the microscopic image of silver nanoparticles ink categorized by the electrical properties of the ink. Ink loading with high percentage of silver nanoparticles has conductivity while low percentage has no conductivity. At low percentage, the microstructure image shows no appearance of silver nanoparticles element while for high percentage; the image shows the content of filler loading. The future researchers can use different type of substrate or different materials of conductive ink in order to do the same analysis.

ABSTRAK

Kajian ini bercita-cita untuk menganalisis dakwat konduktif nanopartikel perak yang ,mengandungi epoksi. Secara khususnya, parameter yang dinilai terdiri daripada resistiviti lembaran, tekstur permukaan dan analisis morfologi. Untuk mencapai analisis, prob empat titik digunakan untuk mengukur nilai rintangan lembaran sampel dalam ohms-per-kuadrat. Beberapa peratusan kandungan dakwat telah mengesan kehadiran resistiviti dan beberapa peratusan lagi tidak mengesan kehadiran resistivitas. Purata resistiviti tertinggi dikesan dalam kandungan dakwat yang berperatusan rendah manakala resistiviti yang paling rendah didapati dalam kandungan dakwat yang berperatusan tinggi. Dari segi tekstur permukaan, profilometer sentuh digunakan di mana sampel yang mengandungi peratusan pengisi rendah mempunyai purata nilai kekasaran permukaan yang konsisten dan permukaan yang licin dihasilkan. Sementara itu, bagi sampel yang mengandungi peratusan pengisi tinggi, ia mempunyai kekasaran permukaan yang tidak konsisten lalu menyumbang kepada permukaan yang lebih kasar. Dalam analisis morfologi, mikroskop cahaya digunakan untuk memvisualisasikan imej mikroskopik dakwat nanopartikel perak yang dikategorikan oleh sifat-sifat elektrik dakwat. Kandungan dakwat dengan peratusan nanopartikel perak yang tinggi mempunyai kekonduksian manakala dakwat yang berperatusan rendah tidak mempunyai kekonduksian. Pada peratusan rendah, imej mikrostruktur tidak memperlihatkan unsur nanopartikel perak manakala peratusan yang tinggi; imej menunjukkan kandungan pengisi. Penyelidik masa depan boleh menggunakan jenis substrat yang berlainan atau bahan berlainan dalam dakwat konduktif untuk melakukan analisis yang sama.

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Thanks to Allah Almighty as with His Bestowment and His Mercy, I have completely succeeded this project. I revere the patronage and moral support extended with love, by my mother whose financial support and passionate encouragement made it possible for me to complete this project and not to forget my late father who is always in my prayers.

I want to express my heartiest gratitude to my supervisor, Dr. Mohd Azli bin Salim for his sincere guidance, support and help me with a lot of patience as well as provide me with valuable knowledge throughout the whole duration in completing this project.

I am deeply indebted to all concerned persons who cooperated with me in this regard for their valuable help in preparing this project. My joy knows no bounds in expressing my cordial gratitude to my friends as their keen interest and encouragement were a great help throughout the course of this project.

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LIST OF ABBREVIATIONS

ρ	-	Resistivity
A	-	Cross-sectional area of the ink
L	-	Length of sample trace from end to end
R	-	Resistance
l	-	Length of line in mm
W	-	Width in mm
R_{SH}	-	Resistivity of the sheet in *Ohm/sq,* Ω*/sq*
V	-	Voltage across the inner pins
I	-	Current between the outer pins
T_m	-	Melting point
E	-	Estimation of error
Ra	-	Average of roughness

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Conductive ink, ink printed to conduct electricity have been in some talk for a few years for their applications in Printed Electronics (PE) and Flexible Electronics (FE) as people will be able to print circuits on paper or some form of flexible surface through the inkjet printing technology. Although the early growth of the printed electronics industry is not drastic compared to the expected growth, due to high expectation, there are some great demands to use these products (conductive inks) in daily activities such as cell phones, displays, smart wearable, lighting, small packaging, labels, shipping, storage or any else.

Figure 1.1 Printed conductive ink (Savastano, "Conductive Inks Drive Growth in Flexible and Printed Electronics ", 2015)

Conductive ink has allowed some improvements in the electronics sector, thus enable the disposable electronics to develop in real world. Some factors such as good production performances, followed by reductions of material cost as well as environmental-wise (due to non-etching manufacturing procedures) lead to the alternative yet efficient way for end-use applications via conductive inks through PE and FE.

Material selection is one of critical success to take into consideration in formulating the conductive ink. Basically conductive ink consists of two main components; metal nanoparticles (usually silver), and liquid to carry the nanoparticles. When the mixture of both nanoparticles and liquid is printed to paper, it will dry, and the random connections of nanoparticles creating bridge to each other are put in place.

Electrical conduction is the electron movement via a material, providing an electric current. Conductive components are part of conductive ink that may consist of silver, carbon, graphite, or other precious metal coated base material. Some materials can naturally enable the electrons to travel through them, and they are known as electrical conductors. Metals are usually specialized in best conducting the electricity, but, in order to produce conductive ink, a liquid is needed, and most metals are in solid state at room temperature.

In other ways to produce conductive ink but still using metals, metal nanoparticles are chosen to realize it. These nanoparticles are in the form of tiny spheres of metal, where each of nanoparticles can conduct electricity, and when the strings of nanoparticles; pearls-in-a-necklace-like-chain are formed, electrons can flow from one nanoparticle to another.

In this study, silver nanoparticles are part of components in conductive ink that act as a filler material. Filler is used to fill the unfilled space between the particles which may lead to form conductive coating as silver is one of the best electric conductor.

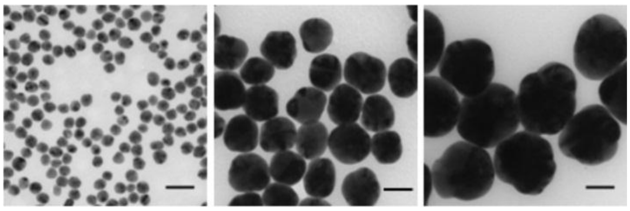

Figure 1.2 Transmission electron microscopy (TEM) images of silver nanoparticles (Oldenburg, "Silver Nanoparticles: Properties and Applications", 2017)

As for the liquid to carry the nanoparticles, there are two types of liquid with different viscosity, functioned as the binder and the hardener. Epoxy used as binder in this study is compatible to the viscosity behaviours of inks. It shows the anticorrosion properties when acting as coating ingredients. While for the hardener, it is an additional substance to the ink mixture to produce the ink finish strong or more durable, as well as the curing agent for epoxy. The final result of mixture from these three components is a conductive ink that maintains in liquid form until printed on certain surface at its drying point and succeed to conduct electricity.

In this study, troubleshooting problems in the characterization of conductive ink are elucidated to fabricate conductive ink which has high conductivity tracks or patterns. The characterization of conductive may consist of the parameters involved, the formulation of ink loading, the printing procedure, ink-substrate interaction, the temperature to cure and post-treatment of inks.

For the formulation of ink loading, the interaction between filler, binder and hardener is important as it is the preliminary step to find out which ink loading can be resulted to have high conductivity. The ink loading is printed on the glass substrate, and then they will go through preheating method where the ink loading is cured in the oven for specialized time and temperature. The characterization of conductive ink is investigated so that a proper understanding may be gained through various methods (analysis); four point probe for sheet resistivity, contact profilometer for surface texture and light microscope for morphological analysis.

All these described steps are repeated for the ink loading in accordance to the composition of element to produce conductive ink. This study highlights two research questions about the formulation of silver nanoparticles-filled epoxy to produce conductive ink and the relationship between all of the parameters investigated for silver nanoparticles-filled epoxy.

1.2 PROBLEM STATEMENT

The method of fabricating electrical circuits using conductive ink will take the place of the current method of creating circuit boards. The conductive ink depends on the formation ways of metal nanoparticles, thus the issues that need attention are the materials composition and its behaviour to have high conductivity ink as the drawback to conductive ink circuits is their resistance.

Choosing the right ink loading is a crucial success factor for quick, simple and affordable production of PE prototypes and electronically functional prints. One of the issues where the ink loading needs alteration is when the conductive inks are not fully dried after curing at certain temperature. Another issue is the ink-substrate interaction; the ink easily comes off of the substrate after printing or curing process which indicates that a compatibility issue may come in between the ink and substrate, or the ink may not be dried adequately.

Recently, most researchers around the world studied the effect of conductive ink for silver nanoparticles-filled epoxy by implementing measurement techniques to conductive ink in order to maximize the quality and reliability of conductive ink through three techniques (Samano, A., 2017). In this report, the measurements involved are sheet resistivity, surface texture and morphological behaviour for sheet resistivity; Samano described that four point probe measures the sample with no error produced by test lead resistance. Next, for the surface roughness, it is one of the main contributors that affect the electrical resistivity of printings on the substrate (Maattanen, A et al., 2010) and imaging methods from conventional microscope can contribute image with fine details that included elemental details of printed sample (Ikeda, O., Watanabe, Y., & Itoh, F., 2007).

After all, all of the issues of the conductive ink stated are linked to the formulation of ink loading, not being mentioned, another additional factors such as material selection, printing method, curing temperature and others. Therefore, the purpose of this study may come out with the solutions for the problems stated.

1.3 OBJECTIVES

The objectives of this study are:

1. To formulate silver nanoparticles-filled epoxy for conductive ink.
2. To investigate the relationship for silver nanoparticles-filled epoxy between sheet resistivity, surface texture and morphological analysis.

1.4 SCOPE OF PROJECT

In order to reach the objectives, several scopes have been decided:

1. Formulating silver nanoparticles for patterning conductive ink which consists of filler (silver nanoparticles), binder (epoxy) and hardener.
2. Evaluating the effect of silver nanoparticles conductive ink in constant temperature by using 4-point probe, microscope and contact profilometer.

1.5 HYPOTHESIS

From this study, the expected result is the optimum parameter will be obtained to improve the conductive ink by formulating the ink loading between filler and binder. The result should be found in the best conductivity of the ink in various patterns at constant temperature to cure.

1.6 REPORT OUTLINE

The structure of this report consists of five chapters. In Chapter 2, all of the related information from the literature review collection will be presented so that the comparison between the previous research, current and expected research can be made in order to ensure there is no similar research about this project has been made.

From Chapter 3, the research methodology will be displayed by stating the steps or procedures taken in the experiment based on the flowchart constructed. This chapter will present from the beginning of the experiment until the testing process; electrical testing, microscopy and surface roughness measurement so that the analysis can be made.

Then, in Chapter 4, when the results from the previous chapter has been obtained, the analysis will be discussed in this chapter in terms of the behaviour of the ink; mainly resistivity, and microstructure plus the surface roughness in order to answer the questions in this research.

Lastly, after the analysis has been carried out, only then the conclusion of this experiment will be revealed in Chapter 5; whether the objectives have been achieved or not.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, a review on conductive ink, methods of printing, heat treatment, material of substrates and the conductive ink characterization are being presented with the sources from previous studies in this field.

2.2 CONDUCTIVE INK

According to Bhore, inks are specially fabricated in accordance to the demand of a printing process. In 2006, Karwa, A. stated that the conductive inks are made of the composition of a filler with resin, solvents and additives; where the fillers are responsible for providing the conductive properties, while the binder is needed to produce the required adhesion to the substrate and cohesion to each other. The conductivity of an ink is affected by the filler loading amount, the particle size of the fillers, the percentage of binder used and the continuity of the printed layer after the processes of printing and drying (Joshi, S. S., 2011).