EFFECT OF SUSPENSION'S IONIC CONDUCTIVITY ON ELECTROPHORETIC DEPOSITION OF h-BN

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.)

by

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I hereby, declared this report entitled “Effect of Suspension’s Ionic Conductivity on Electrophoretic Deposition of h-BN” is the results of my own research except as cited in reference.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

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ABSTRACT

Hexagonal – Boron Nitride (h-BN) suspension used for Electrophoretic deposition (EPD) process is very sensitive to ionic conductivity. When the ionic conductivity of EPD suspension is high, the particle electrophoretic mobility becomes low due to the high concentration of free ions in the suspension. This results in a low deposition rate and the corresponding coating thickness is lower than the requirement of UL 1577 standard. Polycation is added as a binder for the h-BN particles so that the adherence and mechanical strength of h-BN coating is improved. Effectiveness of the polycation depends on the suspension processing parameters during and after the addition of polycation. Optimization of the processing parameters such as cleaning of the h-BN particles is needed to obtain low suspension's ionic conductivity. h-BN suspension's ionic conductivity functionalized with a polycation was successfully reduced by h-BN particles rinsing through filtration approach. h-BN particles functionalized using different concentration of polycation (0.3 wt%, 0.4 wt%, 0.5 wt% and 0.6 wt%) were prepared in two forms: (a) rinsed, (b) as - received particles to characterize the effect of h-BN suspension's ionic conductivity on the h-BN coating thickness and yield. The main results showed that the h-BN suspension underwent rinsing process produced higher h-BN yield and thickness. The highest h-BN thickness was measured at 17.4 µm, deposited using rinsed h-BN particles added with 0.6 wt% polycation.

ABSTRAK

Ampaian hexagonal – Boron Nitride (h-BN) yang digunakan untuk proses Penyaduran Electrophoretik (EPD) adalah sangat sensitif kepada kekonduksian ion. Apabila kekonduksian ionik ampaian EPD tinggi, mobiliti electrophoretik zarah menjadi rendah kerana kepekatan ion bebas yang tinggi dalam ampaian. Ini menyebabkan kadar penyaduran yang rendah dan ketebalan saduran yang lebih rendah daripada keperluan piawaian UL 1577. Polikation ditambah sebagai pengikat untuk zarah h-BN supaya kelekatan dan kekuatan mekanikal lapisan h-BN bertambah baik. Keberkesanan polikation bergantung kepada parameter pemprosesan ampaian semasa dan selepas penambahan polikation. Pengoptimuman parameter pemprosesan seperti pembersihan zarah h-BN diperlukan untuk mendapatkan kekonduksian ionik ampaian yang rendah. Kekonduksian ionik ampaian h-BN yang dicampur dengan polikation telah berjaya dikurangkan dengan membilas zarah h-BN melalui pendekatan penapisan. Zarah h-BN telah dicampur menggunakan kepekatan polikation yang berbeza (0.3 wt%, 0.4 wt%, 0.5 wt% dan 0.6 wt%) telah disediakan dalam dua bentuk: (a) dibilas, (b) zarah mentah untuk mencirikan kesan kekonduksian ionik ampaian h-BN kepada ketebalan dan hasil saduran h-BN. Keputusan utama menunjukkan bahawa ampaian h-BN yang telah melalui proses pembilasan menghasilkan ketebalan h-BN yang lebih tinggi. Ketebalan h-BN yang paling tinggi diukur pada 17.4 mikron, yang disadur menggunakan zarah h-BN yang dibilas dan ditambah dengan 0.6 wt% polikation.

DEDICATION

I hereby dedicate this to

my beloved mother, Sitirah Abdullah

my dearest father, Samsudin Morsid Dally

my friends and family.

Last but not least my Supervisor, Dr. Lau Kok Tee who had given me guidance and moral support in completing this research.

Thank you for giving me your support and advises to complete my studies in UTeM.

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LIST OF ABBREVIATIONS

CVD	-	Chemical Vapor Deposition
PVD	-	Physical Vapor Deposition
EPD	-	Electrophoretic Deposition
h-BN	-	hexagonal Boron Nitride
SEM	-	Scanning Electron Microscope
EDL	-	Electric Double Layer
ELD	-	Electrolytic Deposition
YBCO	-	Yttrium Barium Copper Oxide
HNO_3	-	Nitric Acid
NH_3	-	Ammonia
CaO	-	Calcium Oxide
SiC	-	Silicon Carbide
Al_2O_3	-	Aluminum Oxide
SiO_2	-	Silicon Oxide
A1N	-	Aluminum Nitride
PVA	-	Poly Vinyl Alcohol
PDADMAC	-	Poly (diallyldimethylammonium chloride)
PEI	-	Polyethylene Imine)
PEG	-	Polyethylene glycol-400
DI	-	Deionized

LIST OF SYMBOLS

W	-	Watt
ºC/W	-	Celcius per Watt
W/m-K	-	Watt per Meter Kelvin
µm	-	Micrometer
w	-	Deposited yield
E	-	Electric Field Strength
µ	-	Electrophoretic mobility
A	-	Surface area
C	-	Particle mass concentration
V	-	Voltage
S	-	Second
A	-	Ampere
Wt%	-	Weight percentage
µl	-	Microliter
g/l	-	Gram per Liter
M	-	Molarity
Rpm	-	Round per Minute
mg	-	Milligram
µS/cm	-	Microsiemen per Centimeter
a.u.	-	Arbitrary unit

CHAPTER 1

INTRODUCTION

1.1 Background

The electronic devices nowadays have becoming smaller in size compared to the old one and operating at a higher voltage. Thus, heat produced from the device increase and current leakage occurs. An excess heat generation may potentially damage the device such as transistors in a very short time. High electricity passes through power transistor causes generation of high amount of heat. Method have been discovered by researchers which is by developing a heat sink to increase the system cooling efficiency. Heat sink is investigated in environments containing natural and forced convection types. According to the specifications of heat sink, it is known that the dissipated power of heat sink is 11 W when the natural convection is used (Staliulionis et al., 2014). Also from specifications we know that the thermal resistance is equal to 5.45 ºC/W. As it can be seen from Table 1.1 the thermal resistance of the forced convection is equal 2 ºC/W which means that the dissipated power can be 2.72 times larger than under natural convection. So, the theoretical total dissipated power can be achieved around 30 W.

Table 1.1: Specification of the current used heat sink (Staliulionis et al., 2014).

Standard P/N	Dimensions of heat sink, (mm)	Number of fins	Natural convection, Power dissipation [W], 60 °C rise heat sink to ambient	Forced convection Thermal resistance at 300 ft/min, (°C/W)
517-95AB	57.9x61x24.1	8	11 W	2 °C/W

The thermal resistance exist due to the bad thermal contact occurs between the transistor and the heat sink (known as the interface region) (Sim et al., 2005). The transistor and the diode can only be chosen when the maximum dissipated power is known. Although the heat sink is designed on the power transistor to dissipate heat more effectively to the air, lifespan of transistor has not been increased. Therefore, a surface modification is needed for the heat sink to improve its thermal dissipation, to eliminate thermal contact resistance and to provide isolation at the interphase region so that the current leakage can be prevented. An example of transistor is shown in Figure 1.1.

Figure 1.1: Rear side of a transistor (Infineon Technologies A.G., 2012)

Surface modification of heat sink through coating process is performed to improve the thermal conductivity of the heat sink and to prevent the current leakage to occur which might fail the overall system of the transistor so that the requirement for the UL 1577 standard can be achieved. There are many coating methods that are available, which are chemical vapor deposition (CVD), physical vapor deposition (PVD), sol-gel, plasma spraying. Electrophoretic Deposition (EPD) method is chosen due to the low cost and simple equipment set up (Narayanasamy et al., 2016). Furthermore, EPD setup and materials can be modified easily compared to other coating techniques to obtain different coating materials on different shape and size with only minor change in counter electrode design and positioning. The EPD process requires charged particles in form of liquid dispersion before the particles are deposited onto the substrate by the DC electric field (Besra & Liu., 2007).

One of the potential coating material of the heat sink is Boron Nitride (BN). It has low density, high thermal conductivity and high dielectric strength which could enhance thermal conductivity of heat sink (Chemtronics, n.d.). BN exist in several crystallographic forms and it is known that bulk hexagonal boron nitride (h-BN) possess one of the highest basal plane thermal conductivities among other materials (up to 400 W/m-K at room temperature) (Zheng et al., 2016). Recent interest in h-BN has been motivated by the search for an electrically insulating counterpart of graphene suitable for thermal management applications (Balandin et al., 2008). Apart from excellent dielectric properties, few atomic layer h-BN crystals demonstrated high values of thermal conductivity approaching that of the bulk value (Jo et al., 2013). Considering the rare combination of the electrical insulating behavior with exceptionally high thermal conductivity, hexagonal boron nitride is a promising candidate for the next-generation of thermal management material. Hexagonal BN possesses the most excellent thermal conductivity thus, it is the most suitable material for the coating. Based on the theoretical calculation of Boron Nitride thick film with the minimum thickness of 20 µm (dielectric strength: 200 kV/mm) required to achieve targeted electrical isolation (Target: 4.5 kV/s) application under UL 1577 standard.

1.2 Problem Statement

EPD of h-BN particles are very sensitive to ionic conductivity of EPD suspension. When ionic conductivity is high, the h- BN particles deposition yield is low and a thin coating is formed. Previous study by (Narayanasamy, 2017) shows that only 8 μm thickness h-BN coating was achieved. One source of ionic conductivity contamination in the suspension was the addition of binder such as polycation in the EPD suspension. Polycation additive was used to improve the mechanical strength of coating by increasing the surface charge on the h-BN particles. Nevertheless, it increased the concentration of ionic charges in the suspension. The corresponding ionic conductivity was high and affected the electrophoretic mobility of the h-BN particles. It was proposed by Narayanasamy (2017) that the h-BN particles need to undergo rinsing process to reduce the ionic conductivity. One way of particles rinsing is filtration process to clean the h-BN particles.

h-BN rinsing process removes the excessive free ions in the suspension. This process avoids particles agglomeration and at the same time, will ease the movement of h-BN particles during EPD. When a large amount of free ions being removed, ionic conductivity of the suspension will be lowered and the deposition will be thicker due to the smooth particle motion. As for conclusion, the rinsing process of h-BN helps lower the EPD suspension's ionic conductivity and improved EPD yield.

1.3 Objectives

The objectives of this research are as follows:

i. To characterize EPD coating thickness (yield) as a function of suspension ionic conductivity of h-BN.
ii. To develop h-BN particles cleaning procedure in order to increase h-BN EPD coating thickness toward UL1577 standard requirement (20 µm minimum).

1.4 Scope of Research

For objective i, optimum concentration of polycation among all the different prepared concentration of polycation in fixed amount of h-BN and the stability of the suspension is identified using the sedimentation test. Particle analysis is performed to characterize the particles agglomeration in suspension with same concentration of polycation using as – received h-BN particles and rinsed h-BN particles. Polycation binders are functioning as a support medium to attract the particles to the cathode since the conductivity of the suspension is very sensitive which resulting in thin deposition or no deposition occurred. Besides, the ionic conductivity of the particles and the suspension will be determined using the conductivity meter and the pH meter addition of polycation process. Furthermore, the surface microstructure of the deposition is studied using the Scanning Electron Microscope (SEM) to determine the length and size of the coating for different concentration of polycation. The intensity of the h-BN added with different concentration of polycation is analyzed using Raman Spectroscopy. The amount of h-BN deposition is determined using the weight gain method and thickness measurement.

For objective ii, a cleaning process procedure for polycation added h-BN particles using filtration method are established, and compared with the previous study. Which are only use filtration method to clean raw h-BN particles.

1.5 Significant of Study

The study for the effect of suspension ionic conductivity on electrophoretic deposition of h-BN is important to improve the current problem that occur in the industries because it helps industries to make a perfect coating for electrical devices such as transistor to increase the lifespan of the devices. This is because, most of the electronic device has the same problem which is the devices will be damaged quickly if it is used for a long time due to the excessive heat and current leakage that occurred in the device. So it is important to improve the current problem and to achieve a solution due to this problem.

1.6 Organization of Report

Chapter 1 discussing mostly on the introduction. The content included is the background research of the heat sink, Electrophoretic Deposition (EPD) method and h-BN as the coating material. The problem statement, objectives, scope of study and significant of study are also included for chapter 1. As for chapter 2 which is literature review, details data relating to the objectives from journals and articles are gathered. The content is including basic mechanism of EPD, Hamaker's equation, Electric Double Layer (EDL), factor affecting aqueous based EPD, EPD process, properties of BN, Polycation and ionic conductivity issues. These content is connected to one another based on the objectives stated. Last but not least, chapter 3 focusing on the method used to achieve the objectives. The content is including the flowchart of the process, particle preparation, suspension preparation, sedimentation test. EPD method and characterization process.