Faculty of Mechanical Engineering

RELIABILITY PERFORMANCE OF EPOXY BASED ELECTRICALLY CONDUCTIVE ADHESIVE WITH VARYING MULTIWALLED CARBON NANOTUBE

Muhamad Muaz bin Nasaruddin

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MUHAMAD MUAZ BIN NASARUDDIN

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DECLARATION

I declare that this thesis entitled “Reliability Performance of Epoxy Based Electrically Conductive Adhesive with Varying Multiwalled Carbon Nanotube” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ……………..............................

Supervisor Name : ……………..............................

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DEDICATION

To my beloved family

ABSTRACT

Over the last twenty years, there is a rapid development in microelectronic industries to support sustainable manufacturing globally, which includes the use of more environmental-friendly interconnect materials. Carbon-based ECA is proposed to replace conventional materials such as lead solder alloy (Sn/Pb), lead-free solder alloy (Sn/Ag/Cu) and metal-based ECA. Carbon-based ECA such as MWCNT filled adhesive offer toxicity-free, low processing temperature and oxidation free which can benefit the ECA in many aspects. However, MWCNT is known to constraint the ECA performance in terms of electrical properties. In addition, a polymer-based binder such as epoxy could deteriorate under elevated temperature and humid conditions. Hence, the main objectives of this study are to investigate the effect of filler loading and aspect ratio of multi-walled carbon nanotubes (MWCNTs) on the volume resistivity of ECA, to evaluate the effect of filler loading and aspect ratio of multi-walled carbon nanotubes on the adhesion strength of ECA and to assess the effect of hygrothermal aging on the volume resistivity and adhesion strength of ECA with varying filler loading and aspect ratio. 112.5 (L-MWCNT) and 1750.0 (H-MWCNT) are MWCNT aspect ratios considered in this study. Meanwhile, the range of MWCNT filler loading considered for the ECA is between 3 to 8 wt.%. A four-point probe was employed to evaluate the volume resistivity of ECA using ASTM F390 as a guideline. Meanwhile, a universal testing machine (UTM) was utilized to conduct the single-bonded joint test to evaluate the ECA adhesion strength in accordance with the ASTM D1002. In addition, hygrothermal aging test was performed by using an environmental chamber to assess the influence of severe environmental conditions towards the volume resistivity and the adhesion strength of ECA. Regardless of the range of filler loading, it was found that H-MWCNT filled ECA exhibits superior performance than those of the L-MWCNT in terms of the electrical conductivity and adhesion strength when subjected to hygrothermal aging up to 504 hours. As an example, at 5 wt.%, the H-MWCNT recorded lower volume resistivity than those of the L-MWCNT filled ECA, which could be attributed to its great flexibility which increased the filler tends to be in contact with each other. Consequently, better electron pathway is established within the ECA system, which yields an improved electrical conductivity. Moreover, the H-MWCNT filled ECA is approximately 34% stronger in adhesion strength than those of the L-MWCNT filled ECA, possibly due to an efficient stress distribution with longer tube length of the MWCNT filler. Nonetheless, when subjected to hygrothermal aging, both types of ECA exhibit a similar trend in which the volume resistivity increased, with the H-MWCNT being more resistant, possibly due to greater humidity barrier towards the moisture ingression into the ECA composite system. Overall, it can be concluded that higher aspect ratio of the MWCNT filled ECA exhibit better functional performance with and without the hygrothermal aging conditioning.

ABSTRAK

Sejak 20 tahun lepas, terdapat pembangunan yang mendadak dalam industri mikroelektronik sebagai menyokong kelangsungan pembuatan di peringkat global, termasuk penggunaan bahan penghubung yang mesra alam. ECA berasaskan karbon telah dicadangkan untuk menggantikan bahan penghubung konvensional seperti pateri aloi plumbum (Sn/Pb), pateri aloi bebas plumbum (Sn/Ag/Cu) dan ECA berasaskan logam. ECA berasaskan karbon seperti perekat yang diisi MWCNT mempunyai sifat bebas toksik, suhu pemprosesan rendah dan bebas pengoksidaan yang boleh memberi manfaat kepada ECA dalam banyak aspek. Namun, bahan ini mempunyai kelemahan dari segi prestasi sifat elektrik. Tambahan pula, bahan pengikat berasaskan polimer seperti epoksi boleh terjejas di bawah suhu dan kelembapan yang tinggi. Oleh itu, objektif utama kajian ini adalah untuk mengkaji kesan perbezaan memuat pengisi dan nisbah aspek MWCNT terhadap isipadu keberintangan ECA, untuk mengkaji kesan perbezaan memuat pengisi dan nisbah aspek MWCNT terhadap kekuatan rekatan ECA; dan untuk mengenalpasti kesan penuaan higrotermal terhadap isipadu keberingkatan dan kekuatan rekatan ECA dengan memuat pengisi dan nisbah aspek yang berbeza. 112.5 (L-MWCNT) dan 1750.0 (H-MWCNT) adalah nisbah aspek MWCNT yang digunakan dalam kajian ini. Sementara itu, kadar memuat pengisi MWCNT untuk ECA adalah antara 3 hingga 8 wt.%. Empat titik kuar telah digunakan untuk menilai isipadu keberintangan ECA berpandukan ASTM F390. Sementara itu, mesin ujian semesta (UTM) digunakan untuk menjalankan ujian terikat tunggal bagi menilai kekuatan rekatan ECA berpandukan ASTM D1002. Tambahan pula, ujian penuaan higrotermal dijalankan dengan menggunakan kebuk persekitaran bagi mengkaji kesan keadaan sekeliling yang ekstrim terhadap isipadu keberintangan dan kekuatan rekatan ECA. Tanpa mengira kadar memuat pengisi, ECA yang diisi H-MWCNT memberikan prestasi yang luar biasa berbanding L-MWCNT dari segi keberaliran elektrik dan kekuatan rekatan apabila dikenakan penuaan higrotermal selama 504 jam. Sebagai contoh, pada 5 wt.%, H-MWCNT mencatatkan isipadu keberintangan yang rendah berbanding L-MWCNT, yang disebabkan kecemerlangan daya fleksibilitinya seterusnya meningkatkan kebarangkalian pengisi untuk bersentuhan antara satu sama lain. Hasilnya, laluan elektron yang lebih baik tercipta dalam sistem ECA, yang menyebabkan peningkatan dalam keberaliran elektrik. Tambahan pula, ECA diisi H-MWCNT dianggarkan mempunyai 34% lebih kekuatan rekatan berbanding L-MWCNT, berkemungkinan disebabkan oleh pembahagian tekanan yang lebih efisien hasil dari tiub MWCNT yang lebih panjang. Namun, apabila dikenakan ujian penuaan higrotermal, kedua-dua jenis ECA menunjukkan pola yang sama iaitu kenaikan isipadu keberintangan, dengan H-MWCNT yang mempunyai ketahanan yang lebih, berkemungkinan disebabkan oleh penghadang kelembapan yang baik daripada serangan kelembapan. Secara keseluruhan, ECA diisi nisbah aspek MWCNT yang tinggi menghasilkan prestasi fungsi dan ketahanan yang lebih baik dengan mahupun tanpa dikenakan penuaan higrotermal.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

L_{max} - Maximum allowable length for overlap area

F_{ty} - Yield point of substrate

t - Thickness of substrate

τ - 50% estimated lap shear strength

X_c - Composite property

X_m - Matrix property

X_f - Filler property

V_m - Matrix volume fraction

V_f - Filler volume fraction

W_m - Matrix weight fraction

w_m - Matrix weight

w_c - Composite weight

W_f - Filler weight fraction

w_f - Filler weight

ρ - Volume resistivity

V - Output voltage

I - Input current

G - Correction factor

t_s - Sample thickness

τ_{Lap} - Maximum lap shear strength

F_{max} - Maximum tensile force

A - Adhesive overlap area

L_c - Fibre critical length

σ_f - Fibre tension strength

d - Fibre diameter

τ_c - Shear strength of fibre-matrix interface

LIST OF ABBREVIATIONS

ACA	-	Anisotropically Conductive Adhesive
ASTM	-	American Society for Testing and Materials
BN	-	Boron Nitrade
CMC	-	Critical Micelle Concentration
COOH	-	Carboxyclic Acid
DSC	-	Differential Scanning Calorimeter
ECA	-	Electrically Conductive Adhesive
GNP	-	Graphene Nanoplatelets
HCL	-	Hydrochloric Acid
H-MWCNT	-	High Aspect Ratio of Multiwalled Carbon Nanotube
IC	-	Integrated Chip
ICA	-	Isotropically Conductive Adhesive
L-MWCNT	-	Low Aspect Ratio Multiwalled Carbon Nanotube
MF	-	Microflake
MWCNT	-	Multiwalled Carbon Nanotube
ND	-	Nanodiamond
NS	-	Nanosphere
NCA	-	Nonconductive Adhesive
NaOH	-	Sodium Hydroxide
PCB	-	Printed Circuit Board

PDA	-	Polydopamine
SEM	-	Scanning Electron Microscope
SWCNT	-	Singlewalled Carbon Nanotube
TAB	-	Tape-Automated Bonding
TEM	-	Transmission Electron Microscope
TGA	-	Thermogravimetric Analysis

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CHAPTER 1

INTRODUCTION

1.1 Background study

In the world that we live today, there is a great dependency on electrical devices for numerous activities and requirements, be it for personal life or for work. Therefore, with such a growing demand, the semiconductor electronic industries are working a long way to provide advancement in the manufacturing and assembly of electronic packaging. Several parts are identified to be critical in fulfilling the growing needs especially in higher performance computing that involves multi and complex tasks in a single computer, while at the same time, need to be maintained in a limited dimension. Consequently, evolution of technology especially in chip assembly and interconnect materials are extensively growing and improved to support the changes while not compromising the functionality and reliability of the electronic product (Trinidad, 2016).

On the other hand, a shorter product life cycle of electronic components as a result of mass production which is due to the hasty growing of technology has caused the electronic packaging to be thrown away in landfills as electronic waste (e-waste) (Lewis and Ryan, 2008; Ma and Suhling, 2009). At the initial stage of the electronic packaging industry, most of the interconnect materials used are consist of lead (Pb) which is high in toxicity, as one of the main constituent materials (Chew et al., 2014). Moreover, an abundance of e-waste with improper disposal which can harm the environment and human health (Abtew and Selvaduray, 2000; Yim et al., 2009).

Consequently, the key players in this field, either the electronic industries manufacturers or researchers are actively working on the solutions to overcome the pertaining issues. Therefore, the first alternative for the interconnect materials is the introduction of SAC solder alloys which consist of Tin, Silver, and Copper (Sn, Ag and Cu) and also known as lead-free solder alloys (Abtew and Selvaduray, 2000; Jiang et al., 2006). SAC solder is regarded as a reliable lead solder replacement material due to its toxicity free and available in the world market today. However, lead-free solder has a higher melting temperature, which is near 220 °C, compared to 183°C for lead solder. Furthermore, during solder reflows process, the temperature will be increased way above the melting temperature of solder materials. In such lead-free solder alloys cases, the reflow temperature can reach up to 260 °C or higher. This extremely high temperature will restraint its usage for specific applications, especially during the manufacturing of heat-sensitive electronic components such as organic/polymer packaging or low-cost PCBs. A common plastic substrate will deform its physical condition in the temperature range of 150 °C to 200 °C (Naghdi et al., 2018). This process will eventually increase the possibility of product defects even at the early stage of manufacturing processes. In addition, a high-temperature requirement for the processes will also increase the energy consumption in the industry which consequently expand the production cost, damage the environment and cause reliability problems (Ma and Suhling, 2009; Zhang and Agar, 2010), can be regarded as the major drawback of using such alternative material for the electronic packaging.

Due to the issues with both interconnect materials mentioned; lead and lead-free solder alloys, the effort has shifted towards polymer-based conductive materials to restore and become the leading materials as the interconnect materials in electronic packaging. The polymer-based conductive adhesive is commonly known as electrically conductive adhesives (ECAs), free from toxic material and also capable of being processed at low