DELAMINATION STUDY BETWEEN LEADFRAME SUBSTRATE AND EPOXY MOLD COMPOUND FOR SMALL OUTLINE SEMICONDUCTOR PACKAGING

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DEDICATION

This study is dedicated to my beloved wife, Dr Asmah and daughter, Asfa Shaheen who have been my source of inspiration and gave me strength when I thought of giving up, who continually provide their moral, guidance, writing skills, emotional, moral and financial support.

To my mother, Salasiah who share her word of encouragment to finish this study.

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ABSTRACT

Superior quality and reliable semiconductor integrated circuit (IC) packaging is required in electronic products especially for automotive applications due to the user safety concern. Therefore, improvement and controlling of IC package defects to reduce field application and reliability failure is essential. One of the defects that leads to this problem is package delamination. Delamination is a phenomenon where there is a gap or separation between two different interfacial surfaces. Poor adhesion between substrate and resin molding compound in IC packaging can cause serious quality issues which degrade the product and package quality. Hence, the purpose of this study is to identify the relation between surface texturing (roughening) on pre-plated leadframe (PPF) substrate and delamination issue in IC packaging assembly. The textured surface of pre-plated leadframe was prepared by the substrate supplier. In this study, four analyses were performed which analysis of surface morphology, wettability test (contact angle measurement), resin molding shear strength test and moisture-temperature reliability test. For surface morphology analysis, textured PPF substrate showed an average surface roughness of 284nm while standard copper (Cu) substrate showed only 174nm (average surface roughness). Meanwhile for the wettability test, textured PPF substrate showed the highest value of contact angle (71º) at room temperature compared to standard Cu substrate. However, at 175ºC temperature which was simulated according to inline IC assembly manufacturing condition (real manufacturing environment), the textured PPF substrate exhibited the lowest contact angle value which only 55º compared to standard Cu substrate (66º). Low contact angle value at inline simulation temperature (175ºC) indicated good wettability where the liquid was well dispersed on the solid surface (PPF substrate surface). Furthermore, high shear strength value was observed for textured PPF substrate (27-40kgf) compared to standard Cu substrate (8-13kgf). The final package reliability test revealed that no delamination was observed for textured PPF substrate samples. Nevertheless, this delamination issue was observed for standard Cu substrate samples. All the analyses findings agreed that the interfacial surface adhesion between substrate and molding compound was significantly improved via surface texturing. This pointed out that surface texturing (roughening) on PPF helps to eliminate and control the delamination by improving and providing good adhesion between mold compound and substrate surfaces. As a result, high quality and better reliability performance of IC package was produced and safe to be used in electronic products.

KAJIAN PELEKANGAN DI ANTARA SUBSTRAT KERANGKA DAN SEBATIAN ACUAN EPOKSI BAGI PEMBUNGKUSAN SEMIKONDUKTOR GARIS KECIL

ABSTRAK

*Pembungkusan litar bersepadu (IC) semikonduktor yang berkualiti tinggi diperlukan bagi produk-produk elektronik terutamanya dalam bidang automotif kerana melibatkan keselamatan pengguna. Oleh itu, penambahbaikan dan pengawalan terhadap kecacatan pakej IC bagi mengurangkan kegagalan perlaksanaan dan kebolehpercayaan di lapangan adalah penting. Salah satu kecacatan yang menyebabkan masalah kegagalan perlaksanaan ini ialah pakej yang mengalami delaminasi. Delaminasi ialah keadaan di mana lapisan di antara dua muka berbeza terpisah dan membentuk ruang kosong di antaranya. Lekatan yang lemah di antara lapisan substrat dan sebatian damar dalam pakej IC boleh menyebabkan isu kualiti yang serius dan merendahkan kualiti pakej dan produk. Tujuan kajian ini adalah untuk mengenalpasti perkaitan di antara proses pentekstur*an *permukaan (menjadikan permukaan lebih kasar) pada kerangka substrat pra-sadur (PPF) dan fenomena delaminasi dalam pembungkusan pakej IC. Substrat pra-sadur dengan permukaan bertekstur (kasar) disediakan oleh pihak pembekal substrat. Empat analisis dijalankan iaitu analisis morfologi permukaan, ujian kebolehbasahan (pengukuran sudut sentuhan), ujian kekuatan ricih sebatian damar dan ujian kebolehharapan suhu-lembapan. Untuk analisis morfologi permukaan, substrat PPF bertekstur kasar mempunyai kekasaran permukaan purata iaitu 284nm berbanding substrat kuprum (Cu) piawai iaitu 174nm. Bagi ujian kebolehbasahan, substrat PPF bertekstur kasar menunjukkan nilai tertinggi sudut sentuhan (71º) pada suhu bilik berbanding substrat Cu piawai. Apabila pengukuran dilakukan pada suhu 175ºC (simulasi keadaan pemasangan IC yang sebenar), substrat PPF bertekstur kasar menunjukkan nilai sudut sentuhan paling rendah iaitu hanya pada 55º berbanding dengan substrat piawai Cu (66°). Nilai sudut sentuhan rendah membuktikan tahap kebolehbasahan yang baik di mana cecair tersebar dengan baik di permukaan pepejal (permukaan substrat PPF). Seterusnya, nilai ujian kekuatan ricih lebih tinggi diperhatikan pada substrat PPF yang bertekstur (27-40kgf) berbanding substrat Cu piawai (8-13kgf). Ujian kebolehharapan pakej menunjukkan bahawa tiada delaminasi untuk substrat PPF bertekstur kasar manakala terdapat delaminasi bagi substrat Cu piawai. Hasil analisis menunjukkan bahawa kekuatan ikatan antaramuka di antara substrat dan sebatian damar telah bertambah baik dengan ketara melalui kaedah penteksturan permukaan. Ini menunjukkan perkaitan di antara penteksturan permukaan pada substrat PPF dan fenomena delaminasi. Penteksturan permukaan dapat mengawal dan menghapuskan delaminasi pada pakej IC melalui penambahbaikan dan penyediaan lekatan yang kuat di antara sebatian damar dan permukaan substrat. Dengan itu, pakej IC yang berkualiti tinggi dan prestasi kebolehharapan yang lebih baik dapat dihasilkan serta selamat digunakan di dalam produk-produk elektronik.*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

2D	-	Two-dimensional
3D	-	Three-dimensional
ACAD	-	Auto computer aid design
Ag	-	Silver
AMC UTEM	-	Advanced Manufacturing Centre Universiti Teknikal Malaysia Melaka
AV	-	Autonomous vehicles
BSE	-	Backscattered electron detector
C194	-	Copper alloy
C-SAM	-	Scanning acoustic microscopy
C-SCAN	-	Inspection with horizontally x-sectioned 2D image after focus)
CHE	-	Coefficient of hydroscopic expansion
CME	-	Coefficient of moisture expansion
COMP	-	Composition
CSP	-	Chip scale package
CTE	-	Coefficient of thermal expansion
Cu	-	Copper
DI water	-	Deionized water
DOE	-	Design of experiment
E-beam	-	Electron beam
EDS	-	Energy dispersive x-ray spectroscopy
EVAC	-	Evacuation
FESEM	-	Field-emission scanning electron microscope
HDS	-	Haesung DS
HEV	-	Hybrid-electric vehicle

IC	-	Integrated circuit
IPC/JEDEC STD 020	-	Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices
IPC/JEDEC STD 035	-	Acoustic Microscopy for Non-Hermetic Encapsulated Electronic Components
IR	-	Infra-red
IR 4.0	-	The fourth industrial revolution
JEDEC	-	JEDEC is an open standards setting organization with global membership that includes key technical individuals from most device, assembly, system and testing companies, which facilitates JEDEC's ability to publish standards with high value.
LED	-	Light-emitting diode
LF	-	Leadframe
LG	-	Liquid-gas
MSL	-	Moisture sensitivity level
N_2	-	Nitrogen gas
NiPd	-	Nickel/Palladium
NiPdAu	-	Nickel/Palladium/Gold
NiPdAu-Pd	-	Nickel/Palladium/Gold-Palladium
NiPdAu-Ag	-	Nickel/Palladium/Gold-Silver
OEM	-	Original equipment manufacturers
PB	-	Package-bond
PC-MSL 1	-	Pre-conditioning moisture sensitivity level 1
PCB	-	Printed circuit board
PDIP	-	Plastic dual inline package
PLCC	-	Plastic leaded chip carrier
PMC	-	Post mold cure
PPF	-	Pre-plated substrate leadframe
PTFE	-	Polytetrafluoroethylene
QFN	-	Quad Flat Non-Lead
QFP	-	Quad flat package
Ra	-	Average surface roughness
RH	-	Relative humidity

Rsar	-	Surface area ratio
Sa	-	Mean (average) surface roughness height
SAM	-	Scanning acoustic microscopy
SAT	-	Scanning acoustic tomography
SEM	-	Scanning electron microscopy
SG	-	Solid-gas
SiC	-	Silicon carbide
SiO_2	-	Silica
SL	-	Solid-liquid
SOIC	-	Small outline integrated circuit
TO	-	Transistor outline
TOPO	-	Topology
UV	-	Ultraviolet
VSI	-	Vertical scanning interferometry

LIST OF SYMBOLS

%	-	Percent
ε_{th}	-	Thermal strain
α_E	-	Encapsulant material
α_A	-	Adjacent material
ΔT	-	Temperature change
Tg	-	Glass-transition temperature
G*t*	-	Strain energy release rates due to temperature
G*p*	-	Strain energy release rates due to vapor pressure
θ	-	Angle / Contact angle
γ_{LG}	-	Surface tension at liquid and gas interface
γ_{SG}	-	Surface tension at solid and gas interface
γ_{SL}	-	Surface tension at solid and liquid interface
θ_{Young}	-	Contact angle at liquid-gas interface meets the solid-liquid interface
θ_{Wenzel}	-	Wenzel's apparent (measured) contact angle of the specific (true) surface
$\theta_{Cassie\text{-}Baxter}$	-	Apparent (measured) contact angle of the Cassie-Baxter area
k	-	Surface roughness ratio
k_1	-	Ratio of solid-liquid interface to the total area of liquid droplet
k_2	-	Ratio of liquid-gas interface to the total area of liquid droplet
θ_A	-	Advancing contact angle of the solid-liquid interface

δs	-	Surface tension for solid-air
δL	-	Surface tension for liquid-air
δsL	-	Surface tension for solid-liquid

LIST OF UNITS

nm	-	Nanometer
µm	-	Micrometer
°	-	Degree
°C	-	Degree celsius
kgf	-	Kilogram-force
mV	-	Millivolt
MPa	-	Megapascal
g	-	Gram
Å	-	Amstrong
mN/m	-	Millinewton per meter
PPM	-	Parts per million
mm	-	Millimeter
s	-	Second
N/m	-	Newton per meter
g/cm^3	-	Gram per cubic centimeter
W/m*K	-	Watts per meter Kelvin
µΩ-cm	-	microOhm-centimeter
kN/mm^2	-	Kilowewton per square millimeter
N/mm^2	-	Newton per square millimeter
kV	-	Kilovolt
µL	-	Microliter
MHz	-	MilliHertz
dB	-	Decibel
cm	-	Centimeter

LIST OF PUBLICATIONS

Journal

A.Suhaimi, G. Omar and M. T. Asmah, "Correlation between Surface Texturing on Pre-Plated Leadframe and Delamination Phenomenon in Automotive Packaging," *International Journal of Nanoelectronics and Materials*, 15(3), 2022, pp. 197-206 (SCOPUS indexed).

Conference Proceedings

A. Suhaimi, G. Omar and M. T. Asmah, "Influence of Textured Nickel/Palladium/Gold-Silver (Ni/Pd/Au-Ag) Layer on Pre-Plated Leadframe for Automotive Applications," in *2021 IOP Conf. Series: Material Science and Engineering*, 2021, pp. 1173-1182 (SCOPUS indexed).

A. Suhaimi and G. Omar, "Assessment of NiPdAuAg Leadframe Rough for Delamination Stable in Electronic Packaging for Automotive," in *2019 IEEE CPMT Symposium Japan (ICSJ)*, 2020, pp. 49-54.

CHAPTER 1

INTRODUCTION

This chapter provides information of the study background, problem statement, research objectives and research scope.

1.1 Background

Now in the days of the fourth industrial revolution (IR 4.0), the new trends of automotive electronics such as autonomous vehicles (AV), hybrid-electric vehicle (HEV) and in-car infotainment are accelerating the automotive industry (Ardebili et al., 2019). Thus, reliable and full capabilities of integrated circuit (IC) devices are necessary for these automotive applications. These automotive devices require high quality and robust packaging solutions. Any functionality impairment will lead to lifetime reliability and safety risk. Device components used in automotive systems such as air bags, door locks, power train, tire pressure monitoring sensors and emergency brake system require high performance and long lasting with zero failures. Many automotive original equipment manufacturers (OEM) demand that IC components should last for 18 years with zero failure. For instance, 4,000 cars have been produced every day by Audi which composes of 7,000 IC components in every single car. Meanwhile 10,000 cars have been produced for BWM every day (Sperling and Rambo, 2019). This report proofs that an enormous amount of IC components has been used in automotive industries. Therefore, reliability improvement in IC package components that satisfy the current automotive standard is vital.

One of the common failures in IC packaging is delamination which can cause serious problems such as degrading the package quality, influencing the package reliability and leading to safety performance issue (Danielle et al., 2018; Sukantharat et al., 2020). Many semiconductor companies such as Renesas, Sony and Toshiba provide their own quality handbook for users and customers that emphasizes the long-life span, quality and safety of their products (Renesas Electronics Corporation, 2017; Sony Semiconductor Solution Corporation, 2018; Toshiba Electronic Devices & Storage Corporation, 2018).

Delamination is interpreted as weak interfacial adhesion (or loss of adhesion) and separation of the encapsulant from an adjacent material at the interface. This issue is contributed by the mismatch of CTE (coefficient of thermal expansion) between two different types of dissimilar material interfaces at elevated or high temperature. In IC packaging, the occurrence of delamination is commonly observed between molding compound and metal leadframe substrate interfacial surfaces (Denoyo et al., 2018; Khanna, 2011; Sukantharat et al., 2020). In addition, post encapsulation delamination may also occur during IC packaging assembly manufacturing, board assembly and field application. There are several major factors that contribute to the delamination occurrence, for instance poor wetting, moisture ingression, high temperature and mechanical stress that induced during IC assembly processes (Garete et al., 2020; Tay et al., 1999; Tay et al., 1998).

In integrated circuit of semiconductor packaging, the leadframe (LF) subsrate provides mechanical support for chip attaching and for electrical connection between attached chips with external leads of the package (Liu et al., 2008). These days, pre-plated leadframe (PPF) is an option to the conventional standard copper (Cu) leadframe that offers various advantages to the semiconductor IC packaging. This PPF substrate helps in leadframe solderability improvement and enhances the adhesion of epoxy mold compound, die attach and wire bonds (Christopher, 2013). This Cu-alloy-based plated leadframe

comprises of several layer of metal plating, for example NiPd (nickel/palladium), NiPdAu (nickel/palladium/gold), NiPdAu-Pd (nickel/palladium/gold-palladium alloy) and NiPdAu-Ag (nickel/palladium/gold-silver alloy) (Li et al., 2011).

Surface texturing or roughening the plated metal layers is one of the alternative procedures to improve the adhesion strength between molding compound to the leadframe or between molding compound to the chip interface. Textured and roughed PPF surface helps to improve the mechanical interlocking between two different interfacial surfaces and subsequently resulted in higher and better adhesion between these dissimilar interfacial surfaces. This process helps to control delamination issue for better IC package quality and reliability (Christopher, 2013; Sukantharat et al., 2020; Wenjing et al., 2012). Nevertheless, optimum surface roughness is required to ensure adhesion between these different interfacial surfaces. This is due to a very rough surface will mismatch with the adhesion standpoint while a smooth surface reduces the adhesion tendency (Khanna, 2011).

1.2 Problem Statement

A reliable IC package is highly demanding in electronic automotive industries. A weak adhesion between leadframe substrate and molding compound can cause various serious issues that impact the reliability, quality and safety of the IC package device (Danielle et al., 2018; Sukantharat et al., 2020). Copper alloy metal substrates (leadframes) are widely used in electronics packaging industries (Vivet et al., 2020; Vivet et al., 2013). However, copper surfaces will easily oxidize when exposed to high temperature during IC assembly processing. The formation of oxide layer on the leadframe surface can lead to poor interfacial adhesion between leadframe and encapsulant compound during assembly process which can further accelerate the moisture-induced in the package component and degrade the bonding adhesion (Razali et al., 2018).