Faculty of Manufacturing Engineering

DETERMINATION OF ELECTRICAL MEASUREMENT TO DETECT POOR THERMAL DISSIPATION DEVICES USING TRIZ

Ong Ming Chung

Master of Science in Manufacturing Engineering

2017

DETERMINATION OF ELECTRICAL MEASUREMENT TO DETECT POOR THERMAL DISSIPATION DEVICE USING TRIZ

ONG MING CHUNG

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled “Determination of Electrical Measurement to detect Poor Thermal Dissipation devices using TRIZ” 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.

Signature : ....

Name : ....

Date : ....

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 Manufacturing Engineering.

Signature :………………..

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

Date :………………………...

DEDICATION

To my beloved parents, Ong Teck Lai and Phan Seow Lin.

Dedicated to my beloved wife, Deborah Chow Yen May.

Dedicated to my beloved brothers and sister in law.

Thank you for your support and encouragement.

ABSTRACT

Thermal dissipation of a microelectronic device is a topic of interest amongst the researchers because poor thermal dissipation may cause reliability problem during customer's application. Researchers found that Leadframe, Solder Paste Material, Chip Metalization and Die Attach process contributed to poor thermal dissipation of a device. The existence of air gap inside the package which was created during Die Attach process was found causing poor thermal dissipation for the device. Air gap blocks the heat dissipation path of the device, causing the heat to be entrapped inside the device which leads to poor reliability performance. X-Ray and Scanning Acoustic Microscopy (SAM) are widely used to identify air gap within microelectronic devices. However, these methods are only able to identify the poor thermal dissipation devices if it is related to the presence of air gap. Poor thermal dissipation can also caused by some weaknesses inherited from wafer processes. An alternative way to identify poor thermal dissipation devices is by using electrical measurement which has better advantages compared to X-Ray and SAM in terms of sampling size, time and effort. However, the challenge is on the effectiveness of the electrical measurement to identify poor thermal dissipation device because using low energy, the measurement may not be sensitive enough; but if using high energy, the device may become destructive. This is a typical contradiction found in this Inventive Problem which best solved by using "The Theory of Inventive Problem"-TRIZ because TRIZ deals with "Contradiction". Moreover, TRIZ stimulated new idea in solving the effectiveness problem in a structured approach. In this thesis, TRIZ proposed to use Parameter Change (PC) and Periodic Action (PA) as the solutions principle to increase the effectiveness of identifying poor thermal dissipation devices. Principle PC concluded that using V voltage, Y timing with 13.2Ampere as the input energy able to screen out device with poor thermal dissipation with 100% success rate; while Principle PA suggested that using input Energy of 900mJ able to achieve the same result. Experiment and data collection confirmed that TRIZ principle PC and PA are able to identify poor thermal dissipation in microelectronic device even though the device did not have air gaps. Such identification was not possible through traditional approaches, such as X-Ray or SAM.

ABSTRAK

Pelesapan haba peranti mikroelektronik adalah topik yang menarik di kalangan penyelidik kerana pelesapan haba yang lemah boleh menyebabkan masalah reliabiliti semasa aplikasi pelanggan. Para penyelidik mendapati bahawa Rangka Plumbum, Bahan Pateri Pes, Lapisan logam Cip dan Proses Pelekatan Cip menyumbang kepada pelesapan haba yang lemah. Kewujudan ruang udara di dalam pakej yang diwujudkan semasa Proses Pelekatan Cip didapati menyebabkan peranti mempunyai pelesapan haba yang lemah. Ruang udara ini menghalang jalan pelesapan haba peranti, menyebabkan haba akan terperangkap di dalam peranti ini sehingga peranti mengalami kerosakan dalaman. Secara umumnya, X-Ray dan Scanning Acoustic Microscopy (SAM) digunakan secara meluas untuk mengenal pasti jurang udara dalam peranti mikroelektronik. Walau bagaimanapun, kaedah ini hanya mampu untuk mengenal pasti peranti pelesapan haba yang lemah dalam peranti jika peranti mempunyai jurang udara. Pelesapan haba yang lemah pada peranti juga boleh diwarisi daripada proses wafer. Alternatif lain yang lebih baik untuk mengenal pasti pelesapan haba yang lemah dalam peranti adalah dengan menggunakan pengukuran elektrik yang mempunyai kelebihan yang lebih baik berbanding X-Ray dan SAM dari segi saiz persampelan, masa dan usaha. Akan tetapi, cabarannya adalah mengenai keberkesanan pengukuran elektrik untuk mengenal pasti pelesapan habayang lemah dalam peranti kerana jika menggunakan tenaga yang rendah, ukurannya tidak cukup sensitif; namun jika menggunakan tenaga tinggi, peranti mungkin menjadi musnah. Ini adalah percanggahan yang biasa terdapat dalam Masalah Inventive ini yang dapat diselesaikan dengan menggunakan "The Theory of Inventive Problem" - TRIZ kerana TRIZ berurusan dengan "Percanggahan". Selain itu, TRIZ merangsang idea baru dalam menyelesaikan masalah keberkesanan dalam pendekatan yang berstruktur. Dalam tesis ini, TRIZ mencadangkan penggunaan Parameter Change (PC) dan Periodic Action (PA) sebagai prinsip penyelesaian untuk meningkatkan keberkesanan mengenal pasti peranti yang mempunyai lemah pelesapan haba. Prinsip PC menyimpulkan bahawa menggunakan V voltan, Y masa dengan 13.2Ampere sebagai input tenaga dapat mengenal pasti peranti yang mempunyai pelesapan haba yang lemah setinggi 100% keberkesanannya; manakala Prinsip PA mencadangkan dengan menggunakan input tenaga sebanyak 900mJ dapat mencapai keputusan yang sama. Eksperimen dan pengumpulan data mengesahkan bahawa prinsip TRIZ PC dan PA dapat mengenal pasti pelesapan haba yang lemah dalam peranti di mana ini tidak mungkin dicapai jika melalui pendekatan tradisional, seperti X -Ray atau SAM.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Associate Professor Dr Md Nizam Bin Abd Rahman from the Faculty of Manufacturing Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to my superior, Mr Long Theng Chao from Infineon Technologies Melaka for his advice and suggestions in completing my thesis.

Special thanks to all my peers, my beloved parents, siblings and wife for their moral support throughout the years spent in this study. Lastly, thank you to everyone who had been to the crucial parts of realization of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Ag	– Silver
Ag–Al	– Silver–Aluminium
Al	– Aluminium
ANOVA	– Analysis of Variance
Au	– Gold
Au–Sn	– Gold–Tin
BSM	– Backside Metallization
Cu	– Copper
DC	– Direct Current
DI	– Deionised
DOE	–Design of Experiment
MOSFET	– Metal Oxide Semiconductor Field Effect Transistor
Pb–Sn	– Lead–Tin
PC	– Process Control
PCT	– Power Cycling Test
RSM	– Response Surface Modelling
SAM	– Scanning Acoustic Microscopy
SEM	– Scanning Electron Microscopy
SiC	– Silicon Carbide
SOA	– Safe Operating Area
TRIZ	– Theory of Solving Inventive Problem

LIST OF PUBLICATION

Ong, M.C., Abd Rahman, M.N., 2016. Microelectronics Thermal Dissipation Characterization Using TRIZ, *Journal of Advanced Manufacturing Technology (JAMT)*, Vol 10, No. 1, pp. 83-94.

CHAPTER 1

INTRODUCTION

1.1 Background

Microelectronics devices are being used in various applications, from consumer application such as smartphone to automotive application such as air bag module for safety aspect. Due to the various applications, microelectronics packaging is essential to protect the fragile silicon chips when they are operating under the extreme hot and cold environment. One of the packaging technologies that are widely used in Microelectronics manufacturing is the plastic packaging technology. In plastic packaging technology the silicon chip is attached to the lead-frame during die attach process and encapsulated by thermoset plastic material by means of transfer molding process. The function of the plastic package is not only to protect the silicon chip; it also provides a medium to dissipate heat generated by the silicon chip to the outer environment.

One of the inherent issues in plastic packaging technology is the presence of entrapped air inside the plastic package which causing the degradation of thermal dissipation capability of the Microelectronics device. The presence of air gap within the package forces the heat to be dissipated through another cooler and longer thermal dissipation path. Such longer thermal dissipation path would cause the package to have lower thermal impedance as suggested by Katsis and Daniel (2006). Therefore, the heat entrapped within the package would cause a temperature rise in the package and would result in higher junction temperature and weaker reliability performance. Subsequently, the device may become malfunction and risk end user's life especially when the device failed to operate in its normal operating mode. Such weak thermal dissipation devices need to be identified and isolated before reaching customer.

There are various research works done in minimizing the impact for weak thermal dissipation devices. Some of the researches being done are in the area of materials development such as lead-frame materials as discussed by Li et al. (2012); Yang et al. (1999) and Ohtaka et al. (1996). Improvement on lead-frame design to improve the thermal dissipation were shared by Lee and Chien (1997); Wu et al. (2012); Pardo et al. (2013) and Xian and Choon (2013). Aside lead-frame materials and lead-frame design, research works in solder paste materials were done by Li et al. (2010), Yussef et al. (2015), Siow (2012), Manikam et al. (2012) and Kim and Nishikawa (2014) in which solder paste material plays an important role to improve the thermal dissipation of a microelectronics device. Goran et al. (1990), Thang et al. (2005) and Olsen and Berg (1979) researched in chip metallization concluded the use of Au-Sn as chip backside metallization can achieve air gap free die attach process which contribute to the good thermal dissipation. Aside from materials development, process optimization works were also explored by Yu et al. (2008) and Thang et al. (2005) during die attach process while Yen et al. (2014) and Lee et al. (2008) research on molding process which utilize simulation tool to analysis and optimize molding design in reducing the air gap formation during molding process.

1.2 Problem Statement

Despite those research efforts to improve thermal dissipation, air gap formation still presents as one of the major issue in microelectronics packaging. Therefore, the ability to screen those weak thermal dissipation devices is important. Currently, most of the Microelectronics manufacturing operations still performing X-Ray or SAM (Scanning Acoustic Microscopy) in sampling basis to screen out potential weak thermal dissipation devices due to the present of air gap. These screening processes are cumbersome, complicated process, needs additional efforts and time consuming, often limited by sampling basis. Thermography or Infrared may be good in screening out weak thermal dissipation device, but different material has different emissivity, therefore, the interpretation of the captured data in images form becomes harder and complex. The image processing may still subject to certain inaccuracy due to some noise, and require additional process to segment and filter before producing the final desired outcome. Also, Thermography is not suitable to be used as one of the screening process in production due to the low Unit per hour (UPH) and its image processing inaccuracy. On the contrary, electrical measurement can fit in the gap because using electrical measurement as a screening method is less complicated yet effective and can have 100% screening compared to X-Ray, SAM and Infrared. Moreover, if the device inherits weaknesses from wafer process, the device may not have air gap, but still can have weak thermal dissipation as mentioned by Wolfgang (2007) and Schulze et al. (2013). Such weak thermal dissipation devices are not able to be screened out by traditional screening methods such as X-Ray or SAM but only by electrical measurement.

Electrical measurement provides more advantages over the X-Ray and SAM methods with 100% sampling to identify the weak thermal dissipation devices. However, the challenge is to determine the optimum level of energy to be used during electrical measurement process, if the measurement energy is too low, the measurement may not be sensitive enough; but if the measurement energy is too high, the device may become defective. Such typical contradiction found in Inventive Problem which is best solved by using “The Theory of Inventive Problem”-TRIZ because TRIZ deals with “contradiction”. Moreover, TRIZ is a structured inventive problem solving methodology and TRIZ can also stimulate new idea in solving the effectiveness problem. Due to limited research works or journals being published on the application of TRIZ in electrical measurement, this could be one of the challenges in this study. Nevertheless, in this study, the application of TRIZ in solving electrical effectiveness problem to identify the weak thermal dissipation device was demonstrated.

1.3 Objectives

Specific objectives to be achieved in this study are:

- To adopt Theory of Solving Inventive Problem (TRIZ) approach in exploring alternatives for weak thermal dissipation devices detection by electrical measurement.
- To prove that the cause of poor thermal dissipation device can be due to air gap within the device and device issue at silicon wafer level.
- To find the optimum energy level that can effectively identify poor thermal dissipation devices.

1.4 Scope of Study

This research adopted TRIZ approach which is a structured inventive problem solving methodology in electrical measurement to explore new idea in solving the effectiveness in identifying weak thermal dissipation devices on Metal Oxide Semiconductor Field Effect Transistor (MOSFET) device. Experiments were done in modifying the input energy of the parameter setting to validate the two TRIZ principles, "Parameter Change" and "Periodic Action". The device used in this study has chip thickness between 100µm to 130µm and the chip size between 20 mm^2 to 25 mm^2. Copper (Cu) leadframe material was used in this device. This MOSFET device was with eight pins where the pins connected to Gate, Drain and Source terminal for its switching functionality. The experiments were conducted in a controlled room temperature of 25˚C with tolerance of plus and minus 2 to 3˚C.

1.5 Significance of Study

- This study was reference to TRIZ systematic approach to solve the Inventive Problem. The steps which led to an alternative solution were provided in this thesis which served as a reference for other TRIZ application in any other field.

- This study was also to prove and correct the wrong concept of "Weak device is solely depends on air gap alone". In other words, many perceived that if there is no air gap exists within the package, the device should be considered as good device. Hence, proven by experiment data, this wrong concept was able to be corrected.

- With the effectiveness of this electrical measurement in identifying weak thermal dissipation devices, X-Ray or SAM process could be removed as one of the manufacturing process and in Failure Analysis process cycle.

1.6 Thesis Outline

This thesis was divided into five chapters. In Chapter 1, an introduction of this research was presented. Background, problem statement, objectives, scope of study, significance of study and the outline were discussed.

In Chapter 2, literature review on what cause weak thermal dissipation device and the improvement activities on heat dissipation were discussed, focusing on leadframe, solder paste, wafer metallization and die attach processes. Besides, the ways in identifying the solder air gap in assembly and their limitations were discussed in which electrical measurement was proven to have more advantages than the other options.

In Chapter 3, flow chart of the experiment was shown and explained. With this, a clearer picture on the whole experiment setup was clearly defined with some figures provided. Firstly, TRIZ approach was used and introduced. Secondly, Sample preparation process was discussed. Thirdly, the experiments to validate the TRIZ principles were discussed.

In Chapter 4, all data from sub experiments were compiled systematically. Basically, it was divided into two portions where the first portion was on validating the TRIZ principle "Parameter Change" while the second portion was about validation on TRIZ principle "Periodic Action". Several observations were made after analyzing the data.

Lastly, in Chapter 5, a summary of this study was presented as well as recommendation was provided for future study.