



**A DEVELOPMENT OF TIME DOMAIN REFLECTOMETRY (TDR)  
METHODOLOGY TO DETECT WIRE SWEEP DEFECT IN  
NEARLY SHORT CONDITION**



**DOCTOR OF ENGINEERING**

**2023**



**Faculty of Electronics and Computer Engineering**

A faded version of the UTeM logo and university name is visible in the background. The Arabic text 'اونيورسيتي تيكنيكل مليسيا ملاك' and the English text 'UNIVERSITI TEKNIKAL MALAYSIA MELAKA' are present but lighter in color.

**A DEVELOPMENT OF TIME DOMAIN REFLECTOMETRY (TDR)  
METHODOLOGY TO DETECT WIRE SWEEP DEFECT IN NEARLY  
SHORT CONDITION**

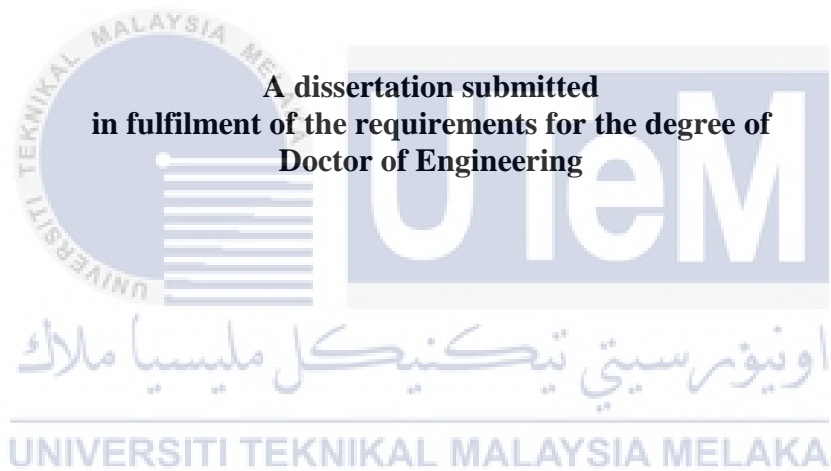
**Ng Kiong Kay**

**Doctor of Engineering**

**2023**

**A DEVELOPMENT OF TIME DOMAIN REFLECTOMETRY (TDR)  
METHODOLOGY TO DETECT WIRE SWEEP DEFECT IN NEARLY SHORT  
CONDITION**

**NG KIONG KAY**



**A dissertation submitted  
in fulfilment of the requirements for the degree of  
Doctor of Engineering**

**Faculty of Electronics and Computer Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2023**

## DEDICATION

To my beloved parents, Mr. Ng Heyau Jin and Madam Yeo Ai Chee; my wife Ms Swee Siew Fiew; my daughter Ng Shi Yi and lastly my son Ng Shi Hong.



## ABSTRACT

Wire sweep is a common defect observed in power semiconductor devices, especially when bonded with thin aluminium wire ( $< 100\mu\text{m}$ ). The conventional methods for detecting the wire sweep defect are Automatic Optical Inspection (AOI), Real-Time X-ray and Automatic Test Equipment (ATE). However, all three methods are having capability limitations to detect the wire sweep defect, especially in nearly short conditions. The objective of this research is to develop a new test methodology to detect the wire sweep defect using Time Domain Reflectometry (TDR) that can overcome the limitations of these conventional methods. The focus of the wire sweep defects is on the wire-wire sweep and wire-lead sweep. The research is using power semiconductor device bonded with  $75\mu\text{m}$  thin aluminium wire as test samples and consists of three experiments and a case study. The first experiment is to select the optimal TDR probe measurement methods that can be used to detect wire-related failure in a power semiconductor device. The second experiment is to study whether TDR can detect and respond when there is a wire sweep failure in the power semiconductor device. The last experiment is to characterize the response of the TDR curve with a statistical data analysis method and establish modelling with regression equations that can be used to predict the gap between the two wire sweeps. Lastly, a case study is performed to confirm that the proposed TDR methodology can detect the wire sweep defects and the gap for the wire sweep can be estimated using the regression equation model. By performing TDR measurement using Single-Pin Grounded method at the affected pin of the power semiconductor having a wire sweep defect and calculating the area under the TDR curve with a 4pSec time-range, the TDR curve shifts statistical significantly ( $p\text{-value} \leq 0.05$ ) to lower impedance in comparison to a good reference curve. This demonstrates that the proposed method using TDR can detect and respond to both types of wire-wire (WW) sweep and wire-lead (WL) sweep defects. By fitting the value for the area under the TDR curve into the regression equation established, the estimated gap between the wire sweep is within  $\pm 10\%$  tolerance in comparison to the actual gap. From this research, it is demonstrated TDR can detect both wire sweep defects in nearly short conditions on a power semiconductor device bonded with thin aluminium wire; and can overcome the limitation of conventional methods using AOI, X-ray and ATE electrical test. The area under the TDR curve together with the regression equation model can be used to predict the gap between wire sweep which is useful since it is a non-destructive method.

## **PEMBANGUNAN KAEDAH PEMANTULAN DOMAIN MASA UNTUK MENGESAN KECACATAN SAPUAN WAYAR DALAM KEADAAN HAMPIR LITAR PINTAS**

### **ABSTRAK**

*Sapuan wayar merupakan kecacatan biasa dalam pembuatan peranti semikonduktor kuasa terutamanya apabila menggunakan wayar aluminium yang halus ( $< 100\mu\text{m}$ ). Kaedah konvensional yang digunakan untuk mengesan kecacatan sapuan wayar adalah dengan menggunakan Pemeriksaan Optik Automatik (AOI), Sinaran-X dan Peralatan Ujian Automatik (ATE). Namun, ketiga-tiga kaedah tersebut mempunyai kelemahan dalam mengesan kecacatan sapuan wayar terutama dalam keadaan hampir litar pintas. Objektif penyelidikan ini adalah untuk mencari kaedah alternatif baru bagi mengesan kecacatan sapuan wayar dengan menggunakan Pemantulan Domain Masa (TDR). Fokus jenis kecacatan sapuan wayar adalah pada sapuan wayar-wayar dan sapuan wayar-pin. Penyelidikan ini menggunakan peranti semikonduktor kuasa yang diikat dengan wayar aluminium halus  $75\mu\text{m}$  sebagai sampel ujian dan mempunyai tiga fasa penyiasatan dan satu kajian kes. Penyelidikan pertama adalah untuk menentukan teknik pengukuran TDR terbaik yang boleh digunakan untuk mengesan kegagalan berkaitan wayar di dalam peranti semikonduktor kuasa. Penyelidikan kedua adalah melakukan kajian untuk mengetahui sama ada TDR dapat mengesan dan bertindak balas apabila terdapat kecacatan sapuan wayar dalam peranti semikonduktor kuasa. Penyelidikan terakhir adalah untuk mencirikan tindak balas TDR dengan cara menganalisa data secara statistik dan mewujudkan persamaan regresi yang dapat digunakan untuk meramalkan jarak di antara sapuan wayar. Akhir sekali, kajian kes dilakukan untuk mengesahkan sama ada TDR dapat mengesan dan mengganggu jurang sapuan wayar. Pengukuran TDR dilaksanakan dengan menggunakan kaedah Pembumian Pin Tunggal pada pin yang mempunyai kecacatan sapuan wayar, dan menghitung kawasan keluasan di bawah graf TDR dengan tempoh  $4\text{pSec}$ . Didapati graf TDR beralih secara signifikan (nilai  $p \leq 0.05$ ) ke impedan yang lebih rendah jika dibandingkan dengan sampel yang baik. Ini menunjukkan bahawa kaedah pengesanan yang dicadangkan dengan menggunakan TDR mampu mengesan kedua-dua jenis kecacatan sapuan wayar. Dengan memasukkan nilai untuk keluasan di bawah graf TDR ke dalam persamaan regresi, didapati ia dapat mengganggu jurang sapuan wayar dengan toleransi sebanyak  $\pm 10\%$ . Dari penyelidikan ini, jelas ditunjukkan bahawa TDR dapat mengesan kecacatan sapuan wayar pada peranti semikonduktor kuasa yang diikat dengan wayar aluminium halus dan dalam keadaan hampir litar pintas. Dengan ini, TDR dapat mengatasi kelemahan kaedah konvensional menggunakan AOI, sinaran-X dan ATE. Selain itu, kawasan di bawah graf TDR bersama dengan persamaan regresi dapat digunakan untuk meramalkan jurang antara sapuan wayar secara tidak merosakkan peranti semikonduktor kuasa.*

## ACKNOWLEDGEMENTS

First and foremost, I would like to extend my appreciation to Universiti Teknikal Malaysia Melaka (UTeM) and Infineon Technologies Melaka for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for the financial assistance.

My utmost appreciation goes to my main supervisor Associate Professor Dr. Soo Yew Guan from the Faculty of Electronics and Computer Engineering of 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 industrial superior, Mr. Chew Tat Tian from Infineon Technologies Melaka for his advice and suggestions in completing my thesis.

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



## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	i
<b>ACKNOWLEDGEMENTS</b>	iii
<b>TABLE OF CONTENTS</b>	iv
<b>LIST OF TABLES</b>	vii
<b>LIST OF FIGURES</b>	ix
<b>LIST OF ABBREVIATIONS</b>	xiii
<b>LIST OF SYMBOLS</b>	xv
<b>LIST OF APPENDICES</b>	xvi
<b>LIST OF PUBLICATIONS</b>	xvii
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem Statement	3
1.3 Research Objective	5
1.4 Scope of Research	6
1.5 Contribution of Research	7
1.6 Thesis Outline	10
<b>CHAPTER 2 BACKGROUND KNOWLEDGE AND LITERATURE REVIEW</b>	<b>13</b>
2.1 Introduction	13
2.2 Background of Research	13
2.2.1 Power Semiconductor Device	14
2.2.2 Manufacturing of Power Semiconductor device	15
2.2.3 Wire Bonding	18
2.2.4 Package Decapsulation	25
2.2.5 Wire Inspection	26
2.3 Literature Review	28
2.3.1 Investigation of Wire sweep	29
2.3.2 Conventional Methods of Wire Sweep Defect Detection	33
2.3.3 Package Defect Detection with Capacitance Test	40



2.3.4	Time Domain Reflectometry (TDR)	41
2.3.5	Application of TDR in Electronics and Semiconductor Devices	52
2.3.6	TDR Measurement Methods	62
2.3.7	Overall Summary	63
<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>70</b>
3.1	Introduction	70
3.2	Experimental Setup	70
3.2.1	Test Samples with Power Semiconductor Device	70
3.2.2	Time Domain Reflectometry Experimental Setup	71
3.2.3	Custom-Made Jig	72
3.2.4	Methods of Analysing the TDR Response	72
3.2.5	Data Analysis with Statistical Analysis Method	75
3.3	Experiment 1: Determine the Optimal TDR Measurement Methods to Detect Wire-Related Defects	80
3.3.1	Test Samples	80
3.3.2	Experimental Procedures	82
3.4	Experiment 2: Detecting the Wire Sweep Defect with TDR	85
3.4.1	Test Samples	86
3.4.2	Experimental Procedures	87
3.5	Experiment 3: Characterization of TDR Response for Wire sweep	88
3.5.1	Test Samples	88
3.5.2	Experimental Procedures	92
3.6	Case Study: Performance of Utilizing TDR to Detect Wire sweep	93
3.6.1	Test Samples	93
3.6.2	Experiment Procedures	94
3.7	Full Test Methodology Using the TDR Detection Method	95
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSION</b>	<b>97</b>
4.1	Introduction	97
4.2	Experiment 1: The Optimal TDR Measurement Method to Detect Wire-Related Failure	97
4.2.1	ATE Electrical Testing	97
4.2.2	TDR Measurement	98
4.2.3	Discussion	104
4.3	Experiment 2: Detection of Wire Sweep Defect with TDR	106
4.3.1	ATE Electrical Testing	107
4.3.2	TDR Measurement	107
4.3.3	Laser Decapsulation and SEM Inspections	109
4.3.4	Discussion	111
4.4	Experiment 3: Characterization of TDR Response for Wire sweep	112
4.4.1	TDR Measurement	113
4.4.2	Laser Decapsulation and SEM Inspection	121
4.4.3	Data Analysis	129
4.4.4	Discussion	140
4.5	Case Study	142
4.5.1	ATE Electrical Testing	142
4.5.2	TDR Measurement	143

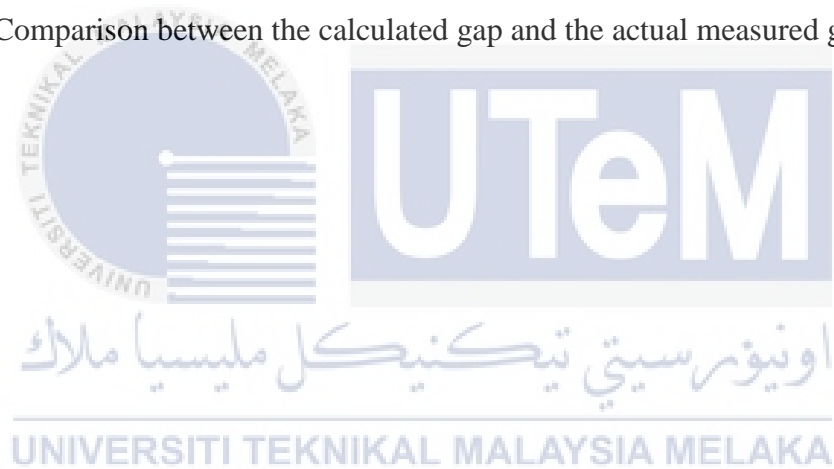
4.5.3	Laser Decapsulation and SEM	146
4.5.4	Comparing Calculated Gap and Actual Gap	147
4.5.5	Discussion	148
<b>CHAPTER 5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>150</b>
5.1	Conclusion	150
5.2	Suggestions for Future Work	152
<b>REFERENCES</b>		<b>154</b>
<b>APPENDICES</b>		<b>184</b>



## LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Overview of thermocompression, ultrasonic and thermosonic wire bonding mechanism	20
Table 2.2	Summary of the limitations of convention wire sweep defect detection methods	39
Table 2.3	Comparison of TDR, X-ray and SAM non-destructive failure analysis technique (Smolyansky, 2004)	53
Table 2.4	Summary of gaps and opportunities found with literature review	65
Table 2.5	Comparison of Wire Sweep Defect Detection Method Using AOI, X-ray, ATE and TDR	68
Table 3.1	Formula for common descriptive statistics	77
Table 3.2	Summary of all the sample groups for Experiment 1	81
Table 3.3	Sample group for case study	94
Table 4.1	Summary results from electrical	98
Table 4.2	Failure location detected using Single-Pin Grounded method	104
Table 4.3	Overall comparison of TDR and electrical test results	105
Table 4.4	Summary of ATE and TDR Measurement	107
Table 4.5	Summary of gap measurements with SEM for sample WW and WL	128
Table 4.6	Statistical analysis for the time-range	130
Table 4.7	Time-range selected	130
Table 4.8	Area under TDR curve for probe measurements	131
Table 4.9	Statistical analysis for probe measurements	131

Table 4.10 Area under the TDR curve for Good reference, WW and WL	132
Table 4.11 Summary of the p-value (significant test)	135
Table 4.12 Summary of the data analysis for Good reference, WW and WL	135
Table 4.13 Range for the area under the TDR curve on Good samples	138
Table 4.14 Area under TDR curve and gap measured for WW	139
Table 4.15 Area under the TDR curve and gap measured for WL	139
Table 4.16 Results of ATE electrical testing	142
Table 4.17 Area under the TDR curve (4 pSec time-range)	145
Table 4.18 Comparison between the calculated gap and the actual measured gap	148



## LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1	Typical semiconductor device manufacturing flow	1
Figure 1.2	Semiconductor device bonded with wire bonding	3
Figure 1.3	Semiconductor device with wire sweep defect	3
Figure 2.1	FE manufacturing process (Geng, H. et al., 2018)	16
Figure 2.2	Typical BE manufacturing process	18
Figure 2.3	Wire bonder used for wire bonding (Kulicke and Soffa, 2021)	19
Figure 2.4	Ball-stitch bonding and wedge-wedge bonding	21
Figure 2.5	Gold wire, copper wire and aluminium wire for wire bonding (Tanaka, 2022)	22
Figure 2.6	Thin and thick aluminium wire (Heraeus, 2022)	23
Figure 2.7	Wire sweep measurement (Ali et al., 2014)	24
Figure 2.8	Two types of common wire sweep defects	24
Figure 2.9	Laser decapper system	26
Figure 2.10	Typical low-power and high-power optical microscopes.	27
Figure 2.11	Typical SEM machine	28
Figure 2.12	AOI machine for wire inspection	34
Figure 2.13	Real-time X-ray machine	35
Figure 2.14	Typical ATE used in semiconductor device testing	35
Figure 2.15	X-ray images for gold wire (25 $\mu$ m) and aluminium wire (75 $\mu$ m, 250 $\mu$ m)	38
Figure 2.16	Test setup for Capacitance Testing (Ripin, 2018)	40
Figure 2.17	History of TDR	42

Figure 2.18 Typical setup of TDR (Tektronix, 2005)	43
Figure 2.19 Representative of a transmission line and the equivalent circuit	44
Figure 2.20 A section of lumped element model for transmission line	44
Figure 2.21 Transmission line with load at $z=0$	46
Figure 2.22 Typical response of TDR under different loads	48
Figure 2.23 TDR responses with different loads	49
Figure 2.24 TDR characteristic curve with different L-C-R load configurations (TDA, 2002b)	51
Figure 2.25 TDR curve with a signal transmitted via a transmission line with different width	52
Figure 3.1 Experimental setup with TDR	71
Figure 3.2 Dimension for the custom-made jig	72
Figure 3.3 Example of linear regression model	79
Figure 3.4 Sample groups with short-contact failures	81
Figure 3.5 Sample groups with open-contact failure at different locations	82
Figure 3.6 Experimental procedure for Experiment 1	83
Figure 3.7 TDR measurement setup with the Single-Ended method	83
Figure 3.8 TDR measurement setup with the Single-Pin Grounded method	84
Figure 3.9 Placement of the pin under investigation on the custom-made jig	85
Figure 3.10 TDR measurement setup with the All-Pin Grounded method	85
Figure 3.11 Sample with different wire sweep conditions	86
Figure 3.12 Experimental procedure for Experiment 2	87
Figure 3.13 Laser decapsulation to expose wire sweep at the lead area	88

Figure 3.14 Example of Group GU samples (GU1 to GU5) that are good reference sample	89
Figure 3.15 Example of Group WW samples (WW1 to WW5) with the wire-wire sweep	90
Figure 3.16 Example of Group WL samples (WL1 to WL5) with the wire-lead sweep	91
Figure 3.17 Experiment procedure for Experiment 3	93
Figure 3.18 Experimental procedure for Case Study	95
Figure 3.19 Full test methodology with the TDR detection method	96
Figure 4.1 TDR response for Group S-WL (wire-lead short-contact) measured with three different TDR measurement methods	100
Figure 4.2 TDR response for Group S-WW (wire-wire short-contact) measured with three different TDR measurement methods	102
Figure 4.3 TDR response for open-contact failure measured with three different TDR measurement methods	103
Figure 4.4 TDR response for Sample WS0, Sample WS10 and Sample WS20	109
Figure 4.5 SEM on the wire sweep and measurement of the gap	111
Figure 4.6 TDR hand probe measurement curves at different pins	115
Figure 4.7 Good reference samples (GU1 to GU5) measured at different pins	117
Figure 4.8 TDR response for wire-wire sweep (WW) measured at different pins	119
Figure 4.9 TDR response for wire-lead sweep (WL) measured at different pins	121
Figure 4.10 Optical inspection, SEM and gap distance for sample WW1	122
Figure 4.11 Optical inspection, SEM and gap distance for sample WW2	123
Figure 4.12 Optical inspection, SEM and gap distance for sample WW3	123
Figure 4.13 Optical inspection, SEM and Gap Distance for samples WW4	124

Figure 4.14 Optical inspection, SEM and Gap Distance for samples WW5	125
Figure 4.15 Optical inspection, SEM and Gap Distance for samples WL1	125
Figure 4.16 Optical inspection, SEM and Gap Distance for samples WL2	126
Figure 4.17 Optical inspection, SEM and Gap Distance for samples WL3	127
Figure 4.18 Optical inspection, SEM and Gap Distance for samples WL4	127
Figure 4.19 Optical inspection, SEM and Gap Distance for samples WL5	128
Figure 4.20 Typical method of analysing TDR response	130
Figure 4.21 Example of data extraction from TDR response on good reference (Pin1- Pin2)	130
Figure 4.22 Area under the TDR curve with time-range	131
Figure 4.23 Interval plot for Good reference, WW and WL at different pins	134
Figure 4.24 Example of two sample Welch's t-test	135
Figure 4.25 Statistical data analysis for the area under the TDR curve for Good samples (GU1 to GU5) at different pins	138
Figure 4.26 Regression modelling for wire-wire sweep (WW)	139
Figure 4.27 Regression modelling for wire-lead sweep (WL)	140
Figure 4.28 TDR response for Sample 4-1 to 4-4 measured at different pins	145
Figure 4.29 Optical inspection, SEM and gap distance for Sample 4-3	146
Figure 4.30 Optical inspection, SEM and gap distance for Sample 4-4	147



## LIST OF ABBREVIATIONS

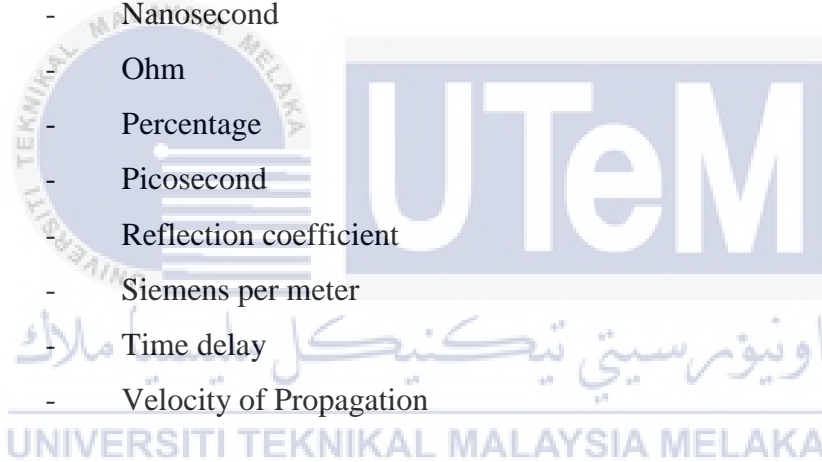
AELB	-	Atomic Energy Licensing Board
Al	-	Aluminium
AOI	-	Automatic Optical Inspection
ATE	-	Automatic Test Equipment
Au	-	Gold
BE	-	Backend
BGA	-	Ball Grid Array
CAGR	-	Compound Annual Growth Rate
CMOS	-	Complementary Metal-Oxide-Semiconductor
Cu	-	Copper
DB-FIB	-	Dual-Beam Focused Ion Beam
EBGA	-	Thermally Enhanced Ball Grid Array
fcBGA	-	Flip Chip Ball Grid Array
FE	-	Frontend
FEA	-	Finite Element Analysis
GaN	-	Gallium Nitride
GR&R	-	Gage Repeatability and Reproducibility
GTO	-	Gate Turn-Off Thyristor
IC	-	Integrated Circuit
IGBT	-	Insulated-Gate Bipolar Transistor
Laser	-	Light Amplification by Stimulated Emission of Radiation
LFBGA	-	Low-profile Fine-pitch Ball Grid Array
MCM	-	Multi-Chip Module
Mg	-	Magnesium
MOSFET	-	Metal-Oxide-Silicon Field Effect Transistor
NDA	-	Non-Destructive Analysis
OEF	-	Open-End Fixture
PCB	-	Printed Circuit Board

QFP	-	Quad Flat Package
RF	-	Radio Frequency
SAM	-	Scanning Acoustic Microscopy
SCR	-	Silicon Controlled Rectifier
SEM	-	Scanning Electron Microscopy
Si	-	Silicon
SiC	-	Silicon Carbide
SiO <sub>2</sub>	-	Silicon Dioxide
SQUID	-	Superconducting Quantum Interference Device
TDR	-	Time Domain Reflectometry
UV	-	Ultraviolet



## LIST OF SYMBOLS

$Z_0$	-	Characteristic Impedance
$^{\circ}\text{C}$	-	Degree Celsius
$d$	-	Distance
$\text{GHz}$	-	Giga Hertz
$Z_L$	-	Load Impedance
$\mu\text{m}$	-	Micrometre
$\text{mm}$	-	Millimetre
$\text{Nm}$	-	Nanometre
$\text{nSec}$	-	Nanosecond
$\Omega$	-	Ohm
$\%$	-	Percentage
$\text{pSec}$	-	Picosecond
$\rho$	-	Reflection coefficient
$\text{S/m}$	-	Siemens per meter
$T_d$	-	Time delay
$V_p$	-	Velocity of Propagation



## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
APPENDIX A	Summary of ATE Electrical Testing Result.	184



## LIST OF PUBLICATIONS

### Journal

Ng, K.K. and Soo, Y.G., 2022. Comparison Study of Time Domain Reflectometry (TDR) Measurement Methods for Detecting Wire Interconnect Related Open-Contact and Short-Contact Failures in Power Semiconductor. *Trends in Sciences*, 19(11), pp.4207-4207.  
(Published: May 16, 2022)

Ng, K.K. and Soo, Y. G., 2021, New Method of Wire sweep Detection in Plastic Moulded Semiconductor Component, Using Time Domain Reflectometry (TDR). *Solid State Technology*, 64(2), pp 2304 – 2314.  
(Published: February 12, 2021)



# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Figure 1.1 is showing the typical manufacturing flow in producing semiconductor devices with wire bonding as one of the important processes (Bard et al., 2015; Park et al.; Ye N., 2020). The purpose of wire bonding is to provide electrical connections in microelectronics as shown in Figure 1.2 (Harman, 2010). During wire bonding, the wire is attached to a bond pad or lead post by applying large amounts of heat or ultrasonic vibration (depending on wire bonding types), pressure and high force over a limited period on the wire (Shannon, 2019). Nowadays, wire bonding is performed with the wire bonder machine to achieve good bonding quality and high throughput (Levine, 2016).

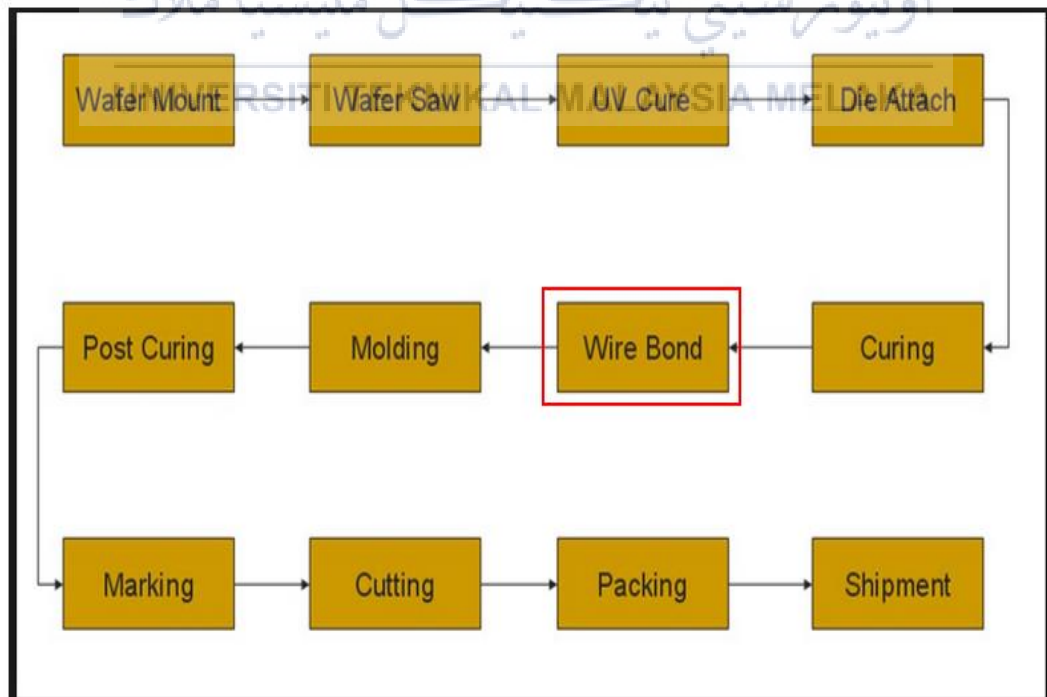


Figure 1.1 Typical semiconductor device manufacturing flow

There are three main types of wires used for wire bonding, namely: gold (Au) wire, copper (Cu) wire and aluminium (Al) wire (Harman, 2010; Lee, H. et al., 2019). Aluminium wire is widely used for wire bonding in power semiconductor devices because of its advantages over gold and copper wires (Pecht et al., 2017). With the shrinkage in size and increased integration density of semiconductor IC (integrated circuit), the pitch between bond pads is becoming closer and there is a need to use thinner wire during the wire bonding (van Driel, 2009). A thin wire is known to have a lower wire sweep resistance (Teh, S.S et al., 2010). Lower wire sweep resistance means the wires prone to shift during the manufacturing processes; before the semiconductor IC is being covered and protected with the plastic moulding compound. This is leading to one of the critical defects in the wire bonding process that is known as the wire sweep defect and is shown in Figure 1.3 (Liu, P. et al., 2012). If the wire sweeps and comes into contact with other wires, it will cause the device electrically to malfunction and fail at the final electrical test (Chen, H.S et al., 2008). However, if the wire only sweeps in proximity to neighbouring wires (known as a nearly short condition), this defective device may not always be able to remove during the final electrical test (Ming et al., 2015). As a result, it ends up with reliability failure where the defective semiconductor device failed later in the field applications (Tummala et al., 2013; Qu, F. et al., 2021). The worst-case scenario is the defective semiconductor device with a wire sweep defect failed in the field application and leads to the casualty of human life (Yun, G et al., 2018). For example, the malfunction of a semiconductor device used in automotive applications such as anti-lock braking systems (ABS) can cause serious car accidents. Therefore, the detection of a defective semiconductor device with a wire sweep defect in the nearly short condition is important.

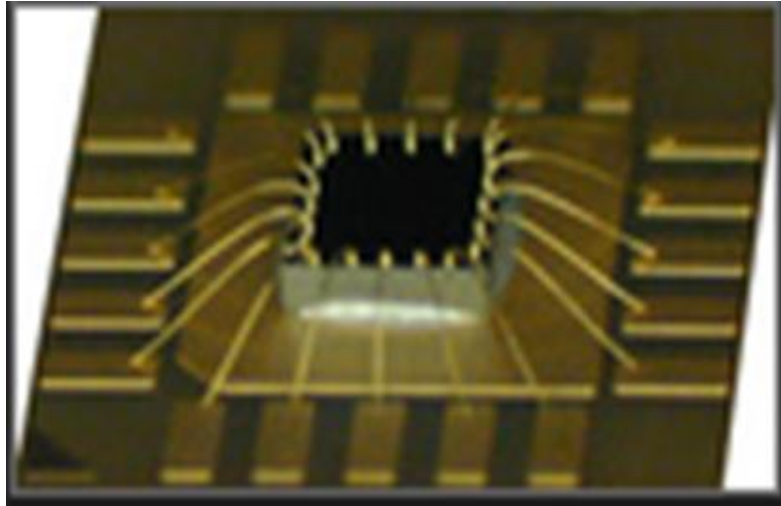


Figure 1.2 Semiconductor device bonded with wire bonding

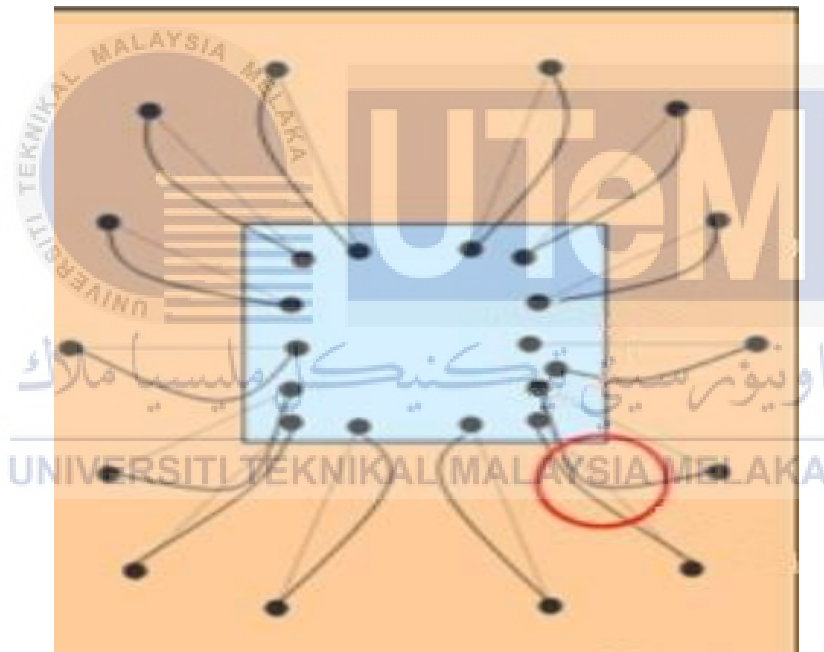


Figure 1.3 Semiconductor device with wire sweep defect

## 1.2 Problem Statement

There are three common methods used for detecting the wire sweep defect in a semiconductor device during the manufacturing process. These methods are by using Automatic Optical Inspection (AOI), Real-Time X-ray and Automatic Test Equipment