MICROELECTRONICS THERMAL DISSIPATION CHARACTERIZATION USING TRIZ

M.C., Ong[1], M.N., Abd Rahman[2]

[1,2]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

Email: [*1]bromingchung@yahoo.com; [2]mdnizam@utem.edu.my

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. One of the factors that caused poor thermal dissipation of a device is the existence of air gap inside the package. Air gap blocks the heat dissipation path of the device, causing the heat to be entrapped inside the device and to the extent of becoming malfunction. In this analysis, TRIZ was proposed through Parameter Change (PC) as one of the principle solutions to increase the effectiveness of identifying poor thermal dissipation devices. Experiment confirmed that TRIZ PC principle was 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 XRay or SAM.

KEYWORDS: *Air Gap, Thermal Dissipation, TRIZ*

1.0 INTRODUCTION

Ability to dissipate heat is one of the important elements in ensuring functionality of a microelectronic device. The thermal dissipation is mainly achieved by means of conduction from the die to the package and by convection from the package to the external environment. One of the common problems faced in thermal dissipation in such device is the presence of air gap between the die and package which significantly reduces its thermal impedance and thermal dissipation capability [1]. Such device potentially has poor reliability performance and has to be selected out. The presence of air gap will slower down the thermal dissipation of the device, but wafer process defects like ionization, inhomogeneous current distribution within a cell field or some parasitic capacitance and inductance may contribute as well to the poor thermal dissipation of the device even though the device is without the presence of air gap [2-3].

X-Ray and SAM are the traditional approaches that are widely used to identify an air gap inside microelectronic device which has potentially poor thermal dissipation. However, these approaches require lots of effort and time. Moreover, X-Ray and SAM are performed by sampling basis only. Nevertheless, electrical measurement may fit in the gap to identify such poor heat dissipation devices if appropriate condition is used as shown in Table 1. The challenge is on the effectiveness of the electrical measurement to identify poor thermal dissipation device because using too low Energy, the measurement may not be sensitive enough; but if using too high Energy, the device may become destructive. This is a typical contradiction found in this Inventive Problem which can be solved by using "The Theory of Inventive Problem"-TRIZ which is a well structured approach to stimulate new idea in solving the effectiveness problem [4]. Table 1 illustrates the advantages of electrical measurement compared to XRay and SAM.

Table 1: Advantages of Electrical Measurement compared to X-Ray and SAM

No	Area	X- Ray	SAM	Electrical measurement
1	Sampling Size	Sampling		100%
2	Time	~1 - 30mins		<1s
3	Effort	High(manual/semi-auto/auto setting)		Low
4	Effective ness	Medium(wafer process defect can't be identified)		Low if inappropriate condition is used
				High if appropriate condition is used

The effectiveness of using TRIZ is proven because many researchers have unanimously agreed that TRIZ is able to help them to solve Inventive problem and generate more ideas, patents in improving a certain product, process or a system design [5-7]. In this paper, TRIZ methodology was illustrated systematically and how Principle Parameter Change (PC) was used to improve the effectiveness in identifying the poor thermal dissipation device by using electrical measurement was demonstrated.

2.0 ME THODOLOGY

2.1 TRIZ Approach

TRIZ was chosen due to two reasons. Firstly, "Contradiction" was found in the problem itself. By increasing the Energy used, the effectiveness could be increased; however, this increased of Energy could bring reliability problems toward the device. This contradiction is best solved by using TRIZ because TRIZ deals with "Contradiction". Moreover, TRIZ is a well-structured approach to stimulate new idea in solving the effectiveness problem. This is very important especially in manufacturing and development field.

Figure 1 shows the flowchart of TRIZ. TRIZ begins by drawing the Functional Model Analysis for "Ineffective Electrical Measurement in identifying poor thermal dissipation device". Such diagram was to understand how the system, sub-system and the super-system of an "Ineffective Electrical Measurement in identifying poor thermal dissipation device" were connected. Cause-and-Effect analysis was provided after Functional Model Analysis to identify the root cause of ineffective electrical measurement in identifying poor thermal dissipation device. Next, based on the identified root cause, Engineering Contradiction statement was constructed. Specific improving and worsening system parameters were identified from Engineering Contradiction statement. When these improving and worsening System Parameters matched with the Contradiction Matrix, the related principles to improve the electrical measurement effectiveness in identifying poor thermal dissipation were proposed by TRIZ. In this study, Parameter Change (PC) principle was used to check the effectiveness of electrical measurement in identifying poor thermal dissipation device.

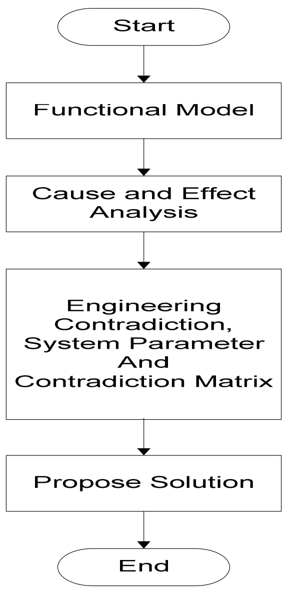


Figure 1: TRIZ Flow Chart

2.1.1 Functional Model

Functional Model analysis in Figure 2 was a modelling to analyze how the components of "Ineffective Electrical Measurement in identifying poor thermal dissipation device" interact with one another. From a typical "Function Model", the "Arrow (→)" is a function symbol that contains lots of information (Bold: Useful; Red: Harmful; Dotted line: useful but insufficient). Generally, if the function is useful, then it must be kept; otherwise it must be eliminated. For the function which is useful but insufficient, then improvement must be done to improve the insufficiency. The interpretation of Figure 2 was as follows: "*Measurement Condition*" was useful but insufficiently supplied to the "*Electrical Measurement*". Therefore, "*Electrical Measurement*" is not sensitive enough in measuring the "*Device*" and not able to distinguish between the good and poor heat dissipation device. In other words, "*Measurement Condition*" should be sufficiently applied to "*Electrical Measurement*" to increase the effectiveness of identifying poor thermal dissipation device.

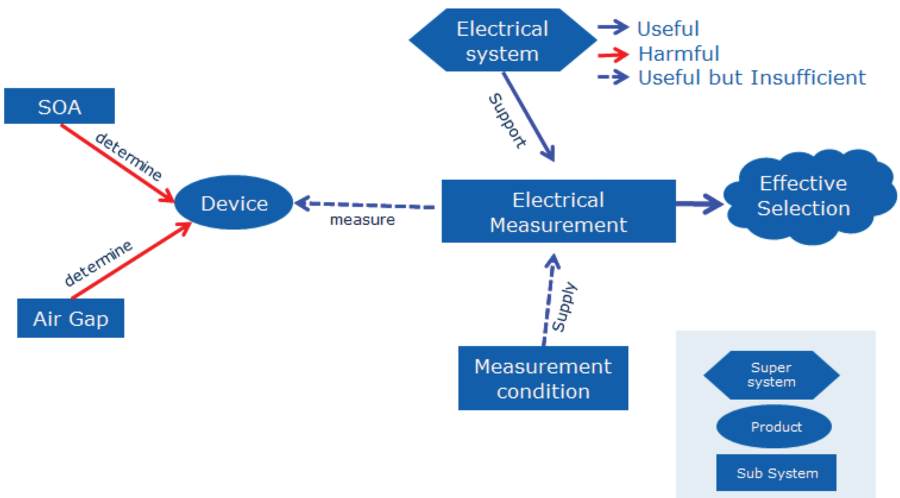


Figure 2: Functional Model of an "Ineffective Electrical Measurement in identifying poor thermal dissipation device"

2.1.2 Cause And Effects Analysis

By performing Cause-and-Effect (CAE) analysis, the root cause of ineffectiveness to identify the poor thermal dissipation device was found. By questioning on "Why the measurement is not effective in identifying poor thermal dissipation device?", the answer led to the root cause "Insufficient Measurement Condition" or "Inappropriate Measurement Condition". This again confirmed the observation seen in the Functional Model Analysis where the "Measurement Condition" is the root cause for "Ineffective Electrical Measurement in identifying poor thermal dissipation device".

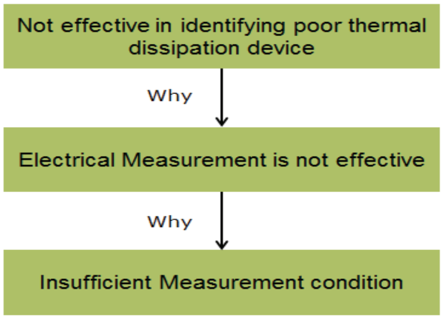


Figure 3: Cause and Effect Analysis for ineffective identification of poor thermal dissipation device.

2.1.3 Engineering Contradiction, System Parameter and Contradiction Matrix

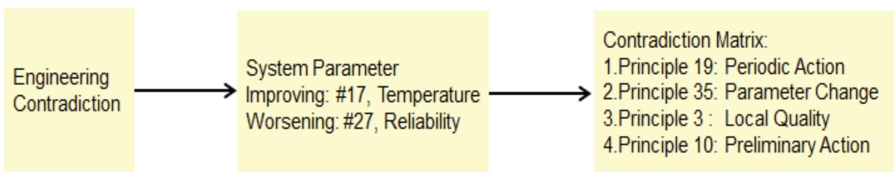


Figure 4: Engineering Contradiction, System Parameter, Contradiction Matrix

Next, based on the root cause mentioned above, Engineering Contradiction statement was constructed.

<u>Engineering Contradiction:</u>

Engineering Contradiction can be easily constructed using "If…then…but…" statement.

If the measurement condition is increased, then the *"Temperature"* of the device is increased, but this temperature rise might destroy the device or cause *"Reliability"* problem.

System Parameter:
From the above Engineering Contradiction statement, the improving and worsening system parameters were identified as follows:

Improving System Parameter: #17, Temperature
Worsening System Parameter: #27, Reliability

Contradiction Matrix:
By putting the improving system parameter #17, Temperature and worsening system parameter #27, Reliability in the Contradiction Matrix, TRIZ proposed the following principles to improve the effectiveness in identifying poor thermal dissipation device.

1. Principle 19: Periodic Action
2. Principle 35: Parameter Change
3. Principle 3 : Local Quality
4. Principle 10: Preliminary Action

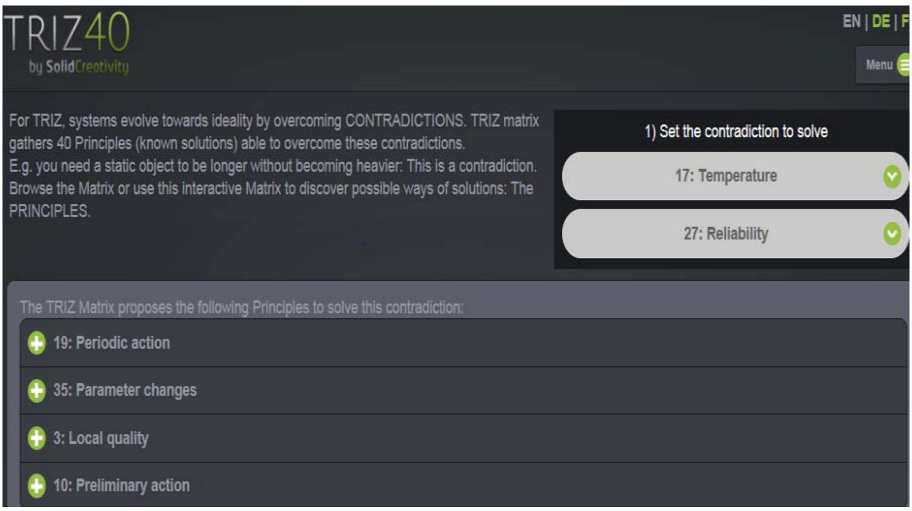


Figure 5: Solutions Proposed by TRIZ[8]

2.1.4 Propose Solution: Principle 35 "Parameter Change"

The solutions proposed by TRIZ must be carefully selected based on Engineering Judgement. Out of the principles proposed by TRIZ, only principle 19 "Periodic Action" and Principle 35 "Parameter Change" were more suitable to increase the effectiveness in identifying poor thermal dissipation devices. However, "Periodic Action" will not be discussed here due to the focus is on Principle 35, "Parameter Change".

In TRIZ context, the definitions for Principle "Parameter Change" were as follows:

a) Change an object's or system's physical state (e.g.: to a gas, liquid, or solid)
b) Change the concentration or consistency
c) Change the degree of flexibility
d) Change the temperature
e) Change other parameters

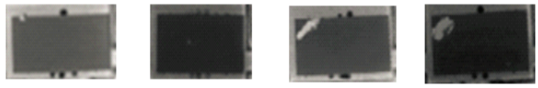
The definition of "D-Change the temperature" was most relevant in this study where the "Temperature" of the device can be increased by changing the Energy used to increase the effectiveness of identifying poor thermal dissipation device.

The experiment was carried out using with and without air gap device and using the existing measurement condition (Condition A, Before Changed of Energy) and new measurement condition (Condition B, After Changed of Energy). The results and findings were tabulated in the next section.

3.0 RESULTS AND DISCUSSION

3.1 Negligible Air Gap Device versus Air Gap Device

Figure 6 shows the SAM picture for 4 devices. A141 and A42 were with negligible air gap while B75 and B112 were with air gap. Theoretically, those devices with air gap would be having difficulty in thermal dissipation and therefore regarded as poor thermal dissipation device if compared to A141 and A42 which only had negligible air gap. The theory is proven through experiment and could be observed from Figure 8, Graph After "Parameter Change" where device B75 and B112 were showing "Elongated Non-Linear Curve" earlier than A141 and A42 when there was an increased in Current along X-axis. This "Elongated Non-Linear Curve" behavior was the "Curve line" in Y axis which happened especially on poor thermal dissipation device when heat was trapped inside the package and resulted in self - heating phenomena causing non-linear output response [9] before the device became malfunction. While the A141 and A42 still showed a stable linear graph, those poor thermal dissipation devices showed "Elongated Non-Linear Curve" Therefore, the quality performance between good and poor thermal dissipation devices was clearly distinguished. Device with air gap was poorer in thermal dissipation compared to device without air gap.



Device	A141	A42	B75	B112

Figure 6: SAM Picture for 4 Devices

3.2 Poor Thermal Dissipation Device in Negligible Air Gap Device

Although A141 and A42 were both devices with negligible air gap, the device quality performance between the two was not identical and can be clearly distinguished as illustrated in Figure 8. Device A42 was observed to have "Elongated Non-Linear Curve" earlier than A141 before it became malfunction while A141 survived at the end of the experiment and did not have any "Elongated Non-Linear Curve". Such observation could be due to the weaknesses inherited from wafer processes [2-3] which caused device A42 performed poorer in thermal dissipation than device A141.

3.3 The Attribute of Poor Thermal Dissipation Device

Based on the experiments, air gap contributed to the poor performance of the device. With the existence of the air gap in the device, the thermal dissipation was rather slow if compared to the good device. However, poor thermal dissipation device may not contribute from the air gap alone. Weaknesses from wafer processes could affect the performance of the device. Therefore, electrical measurement was the better way in identifying poor thermal dissipation devices compared to traditional X-Ray or SAM approach.

3.4 Before and After "Parameter Change"

Following the TRIZ Approach, Figure 7 and Figure 8 show the Graph before "Parameter Change" and the Graph After "Parameter Change" respectively. "Before Parameter Change" which used Condition A (Before Change of Energy) showed that the sensitivity of the electrical measurement was not significant. Therefore, straight curve could be seen and there was no difference between the good and poor thermal dissipation device. However, "after Parameter Change" which used Condition B (After Change of Energy), the effectiveness in identifying poor thermal dissipation devices increased. Good device could be seen with a straight curve while poor thermal dissipation device showed "Elongated Non-Linear Curve". Hence, good and poor thermal dissipation devices were distinguishable.

3.5 X-Ray/SAM and Electrical Measurement in identifying poor thermal dissipation

Based on Table 2, X-ray/SAM is only capable of informing the general relationship between the big air gap and the thermal dissipation; the bigger air gap, the poorer thermal dissipation. However, this statement was not 100% true because B75 device was confirmed having the worst thermal dissipation compared to device B112 although device B112 was having larger air gap. in addition, A141 device was confirmed having the best thermal dissipation compared to A42 device which used electrical measurement although both devices had negligible air gap. In other words, electrical measurement could identify device with poor thermal dissipation more effectively compared to X-Ray and SAM regardless of whether the thermal dissipation was contributed by air gap or by external factor-wafer process defects.

Table 2: Effectiveness of Electrical Measurement compared to X-Ray and SAM

Device	A141	A42	B75	B112	Remarks
Air Gap	small	very small	2nd Biggest	Biggest	NA
If X-Ray/SAM is used in identifying poor thermal dissipation	Fair Thermal Dissipation	Best Thermal Dissipation	2nd Worst Thermal Dissipation	Worst Thermal Dissipation	General Statement: Bigger air gap, poorer thermal dissipation. But not 100% true.
Electrical measurement is used in identifying poor thermal dissipation (Before Parameter Change)	Can't distinguish the good and poor thermal dissipation device				
Electrical measurement is used in identifying poor thermal dissipation (After Parameter Change)	Best Thermal Dissipation	Fair Thermal Dissipation	Worst Thermal Dissipation	2nd Worst Thermal Dissipation	Electrical measurement can identify device with poor thermal dissipation effectively compared to X-Ray and SAM

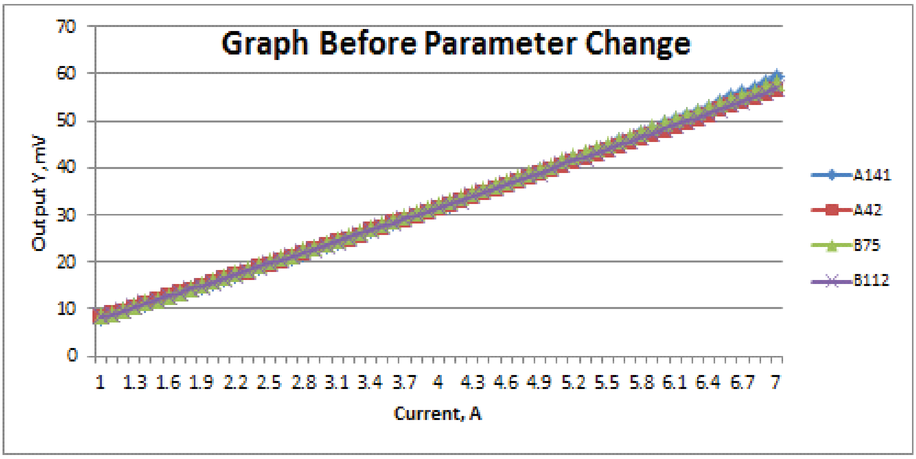


Figure 7: Graph Before "Parameter Change"

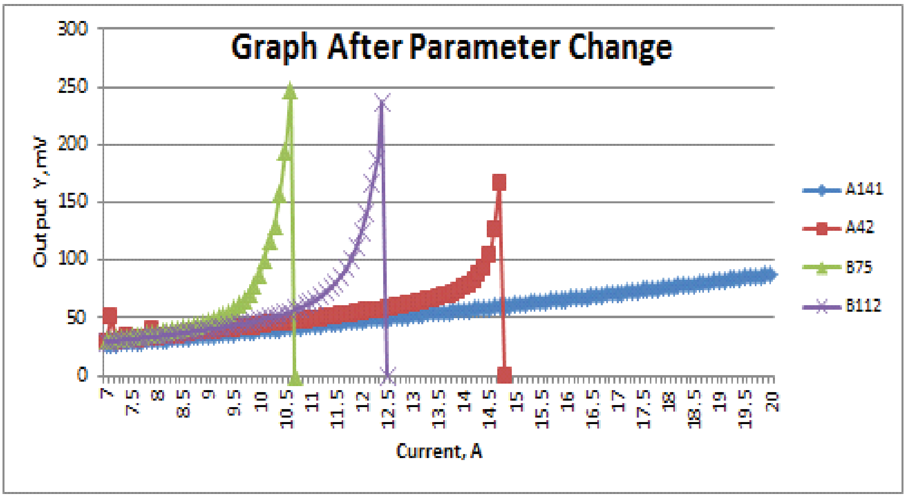


Figure 8: Graph After "Parameter Change"

4.0 CONCLUSION

In conclusion, the advantages of using Electrical measurement in identifying poor thermal dissipation device compared to X-Ray or SAM have been discussed. The inefficiency of electrical measurement in identifying poor thermal dissipation device was also solved using TRIZ approach which has been demonstrated systematically. Principle Parameter Change (PC) provides another perspective in solving the electrical measurement inefficiency problem. Device with air gap is poorer in thermal dissipation compared to device without air gap. However, devices with negligible air gap can have poor thermal dissipation due to some weaknesses inherited from wafer processes. Such identification of poor thermal dissipation in microelectronic device can be achieved by using electrical measurement with "Parameter Change" of TRIZ principle.

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