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REDUCTION OF LIFTED STITCH DEFECTS IN WIRE BONDING PROCESS THROUGH ROOT CAUSE ANALYSIS

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Abstrak

Pemeriksaan keandalan koneksi sangat penting untuk kualitas produk semikonduktor. Masalah yang sering terjadi adalah *stitch defects* selama pengikatan kawat. Untuk mengatasi hal ini, investigasi dilakukan dengan menggunakan diagram alir. Selain itu, dilakukan analisa dengan identifikasi penyebab mendasar menggunakan metode *Fishbone Diagram* dan teknik *5 Whys*. Setelah perbaikan termasuk pelatihan operator, terjadi penurunan signifikan sebesar 96,75% pada *stitch defects*. Studi ini menunjukkan bahwa kombinasi metode analisis akar penyebab dan pelatihan operator secara efektif meningkatkan keandalan proses pengikatan kawat dan kualitas produk semikonduktor. Studi ini tidak mempertimbangkan faktor lingkungan yang dapat memengaruhi proses pengikatan kawat, seperti variasi suhu dan kelembapan. Oleh karena itu, temuan ini mungkin terbatas pada kondisi lingkungan yang berbeda.

Kata Kunci: ***Wire Bonding Process, Fishbone Diagram, Quality Improvement, Lifted Stitch Defect***

Abstract

Reliable connection inspection is crucial for the quality of semiconductor products. A frequent issue is stitch defects during wire bonding. To address this, an investigation was conducted using flow charts. Additionally, an analysis was performed by identifying root causes using the Fishbone Diagram method and the 5 Whys technique. After improvements, including targeted operator training, a significant reduction of 96.75% in stitch defects was achieved. This study demonstrates that the combination of root cause analysis methods and operator training effectively enhances the reliability of the wire bonding process and the quality of semiconductor products. This study did not account for environmental factors that might influence the wire bonding process, such as temperature and humidity variations. Therefore, the findings may be limited in settings with different environmental conditions.

Keywords*: *Wire Bonding Process, Fishbone Diagram, Quality Improvement, Lifted Stitch Defect

1.0 INTRODUCTION

Wire bonding plays a fundamental role in microelectronics by forming electrical connections between semiconductor chips and external circuitry through the use of fine metal wires and carefully controlled bonding processes [1]. The back-end manufacturing flow for semiconductor devices typically includes wafer thinning, die singulation, die-attach, wire bonding, encapsulation, and final testing, with wire bonding recognized as a critical step that can significantly affect device reliability and yield [2]. A range of wire materials such as gold, copper, aluminum, and silver-are selected for wire bonding applications, with recent industry trends showing increased interest in copper and silver because of their advantageous electrical performance and lower material costs [3]. Among these, copper has become especially prevalent in advanced packaging due to its combination of affordability and excellent electrical conductivity [4].

Wire bonding defects such as broken wire, double wire, and lifted stitch are persistent challenges in power module manufacturing. Broken wire typically results from mechanical stress, improper bonding parameters, or material fatigue, leading to open circuits and device failure [5], [6]. Double wire defects, where two wires are unintentionally bonded to the same or adjacent pads, are often caused by misalignment or process errors and can result in electrical shorts and reduced reliability [7], [8]. The lifted stitch defect (Figure 1) is the most common in "*X*" modules of PT. YY, occurs when the wire fails to adhere properly to the pad, frequently due to surface contamination, poor metallization, or suboptimal bonding conditions, which can cause intermittent or complete connection loss. Several studies have shown that careful control of bonding parameters, maintaining a clean pad surface, and utilizing modern inspection techniques can significantly reduce the occurrence of wire bonding defects and help keep the reliability of power modules over time [9], [10]. Surface roughness, contamination, and improper bonding parameters are among the key factors that influence the formation of lift stitch defects and overall bond reliability [11].

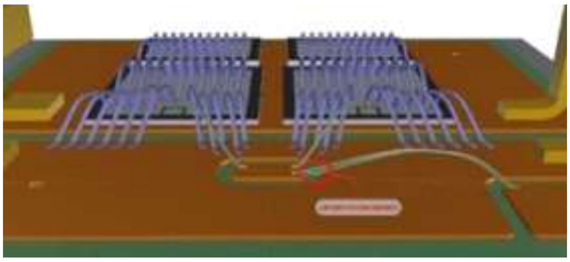

Figure 1: The Lifted Stitch Defect

This study employs the Fishbone Diagram (Ishikawa) and 5 Whys method to address lift stitch defects in wire bonding systematically. The Fishbone Diagram categorizes potential causes into a structured visual framework, enabling teams to identify interdependencies, such as machine vibration or bond pad contamination. The 5 Whys method then drills into each category through iterative questioning to isolate root causes like outdated calibration standards or uneven surface roughness. This dual approach balances breadth (holistic cause mapping) and depth (targeted root-cause analysis), making it ideal for multi-layered defects in precision manufacturing. Recent applications include a textile industry study that reduced defects by linking process factors to root causes using 5 Whys and Root Cause Analysis [12] and a rubber manufacturing project that used Fishbone and 5 Whys within Six Sigma to address high defect rates [13].

Alternative methodologies offer complementary strengths, such as DMAIC (Six Sigma) for data-driven process refinement, FMEA for proactive risk assessment, and Statistical Process Control (SPC) for real-time monitoring. For instance, DMAIC has been shown to significantly reduce defect rates in automotive and casting industries by combining Fishbone, FMEA, and control chart tools [14], [15]. However, the Fishbone and 5 Whys combination is prioritized here for its simplicity, cost-effectiveness, and proven success in resolving interconnected technical-operational failures. These traits align with studies in manufacturing industries, where similar frameworks reduced defects by 30–50% through structured categorization and iterative root-cause resolution [13], [15].

Although many studies have examined defects in wire bonding, limitations persist in effectively addressing specific defects such as lifted stitch, which significantly impact product reliability. Previous research has placed insufficient emphasis on systematic root cause analysis of these defects. Therefore, this study aims to fill this research gap by applying Fishbone Diagram and 5 Whys techniques in combination with targeted operator training.

2.0 METHOD

This study applies a root cause analysis (RCA) framework combining the Ishikawa Fishbone Diagram with the 5 Whys technique to explore the causes of lifted stitch defects in wire bonding. The approach connects process parameters to interfacial failures, offering a detailed diagnosis of the defects. It is consistent with established quality engineering practices in semiconductor manufacturing [16]. The Ishikawa diagram, also known as the fishbone or cause-and-effect diagram, helps organize and evaluate the potential causes of a problem. It is designed like a fish skeleton, with the primary issue at the head and contributing factors branching off the spine [17]. These factors are typically grouped into methods, materials, manpower, machinery, measurement, and environment [18]. After identifying possible causes within each category, the 5 Whys technique systematically drills down into each cause by repeatedly asking "why" until the fundamental root cause is uncovered [19], [20]. This process of asking "why" several times helps uncover deeper problems that might otherwise be missed. Grouping causes into categories also helps clarify complicated situations. As a result, this approach can highlight important issues that may not be obvious.

Within research methodologies, shown in Figure 2, the initial task of explicitly defining the central problem determines the direction and success of subsequent analytical procedures, especially in Ishikawa fishbone analysis. Discussing the issue with those involved to ensure the problem is understood and agreed upon from multiple perspectives. The problem statement should be framed in clear, measurable terms and supported by observable evidence. The team establishes a common reference point by placing this clearly defined issue at the head of the fishbone diagram, which helps maintain focus as potential causes are explored [17].

After defining the problem, the next step involves constructing the fishbone diagram. This diagram begins with the problem statement at the head and a horizontal line serving as the "spine." From this spine, several major categories branch out, typically including People, Process, Equipment, Materials, Environment, and Management. Within each category, possible causes are brainstormed and added as branches and sub-branches, allowing a clear visualization of all potential factors contributing to the problem. Once the diagram has been populated with potential causes, the team reviews and discusses these factors to prioritize those most likely significant. Focusing on the most probable or impactful causes ensures that subsequent efforts are directed toward areas where they will have the most tremendous impact [18].

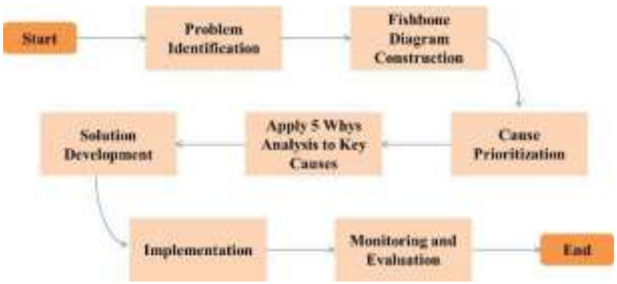

Figure 2: Methodology Flowchart

Attention then shifts to the prioritized causes, where the 5 Whys technique is applied. This technique asks “Why?” five times to underlying root causes. Each answer leads to the next “why,” continuing until a fundamental, actionable root cause is revealed. With root causes identified, targeted solutions are developed to address the core issue. Solutions are designed to eliminate the root cause, and preventive measures are considered to help ensure the problem does not reoccur [19].

Following the identification of solutions, an action plan is designed. A solid action plan spells out exactly what needs to happen, who’s handling each part, and when everything should be finished. Once everyone’s clear on their roles and the timeline, the next step is to put these ideas into practice. Once the changes have been made, it helps to see if anything is different. The last is monitoring and evaluation phase. Sometimes this means looking at results every so often, or just asking people how things are going. If the original problem is still hanging around, it might be worth going back and tweaking the steps or trying something new. This kind of ongoing check-in helps make sure improvements really take hold.

The fishbone diagram shown in the Figure 3 provides a clear overview of the various factors that can lead to wire bonding failures during manufacturing. It organizes these potential causes into four main categories: Material, Machine, Method, and Man. The materials category focuses on issues related to the raw materials used in the wire bonding process. Two main factors are identified: improper material selection and contaminated bonding pads. If the wrong type of wire is chosen or the wire is already damaged, contamination or using substandard materials can significantly compromise the strength and reliability of wire bonds. The machine category addresses challenges involving the equipment used in wire bonding. Problems such as a misaligned wedge or a damaged knife can negatively impact the precision and effectiveness of the bonding process. Moreover, issues like improper calibration or worn-out components can result in incorrect force, temperature, or alignment application, which are crucial for forming strong and reliable bonds.

Figure 3: Fishbone Diagram of Lifted Stitch Defect

The method category addresses challenges tied to procedural and operational practices. Incorrect bonding parameters, such as improper temperature, bonding time, or force, can result in weak bonds or even damage to the materials involved. Defects may go unnoticed and continue throughout production if quality control measures are insufficient. The man category highlights the impact of human influences in wire bonding. Mishandling wires or tools, like accidental bending or improper storage, can lead to physical defects or contaminants that weaken bond quality. Untrained operators might also skip steps, misadjust settings (e.g., temperature, pressure), or fail to spot subtle flaws during inspections. Prioritizing hands-on skill development and encouraging meticulous practices, such as double-checking work and adhering to protocols, helps minimize these risks and boosts consistency in the process.

Table 1: Potential Problems

Factor	Problem	Verification	Remark	Occurrence percentage
Machine	Equipment malfunction (bend wedge, knife tools damaged)	Tool condition assessment: Regularly check the condition of knife tools, ensuring they are sharp, properly aligned, and free from damage. Replace damaged or dull tools promptly.	Inspect equipment regularly for signs of wear and tear and Replace damaged or worn out parts	80 %
Method	Incorrect bonding parameters (e.g temperature, time, force)	Follow standardized bonding parameters based on material specifications and product requirements	The technician must set the proper parameters on the machine	70 %

The Table 1 list two primary sources of potential problems identified through a fishbone diagram: machine and method. For the machine factor, the issue is equipment malfunction, such as damage to band wedges or knife tools. If any tool is found to be damaged or dull, it should be replaced right away. Regular inspections help prevent bigger breakdowns and keep the process running smoothly. According to the table, this kind of machine problem happens about 80% of the time.

On the other hand, problems with methods usually involve using the wrong settings for bonding, like incorrect temperature, time, or force. The best way to avoid this is by always following the standard bonding parameters that fit the material and product being worked on. It is the technician's job to set these parameters correctly on the machine. This issue is also quite common in about 70% of cases. Focusing on these two areas, keeping equipment in good shape, and following proper procedures can reduce recurring problems.

Table 2: Technical Root Cause for Occurrence

Why did the lifted stitch occur?	
Why	Equipment malfunction (bend wedge, knife tools damaged)
Why	Operator not performing routine calibration or maintenance
Why	Operator unaware of calibration or maintenance procedures
Why	Inadequate training for operators on calibration or maintenance procedures
Why	Provide adequate training for operators on calibration or maintenance procedures

After analyzing the issue with a fishbone diagram and verifying the root causes (Table 2), it was found that raised seam defects stem from several factors: incorrect calibration, worn or faulty machine parts, damaged or contaminated materials, and operators lacking sufficient skills. To solve these problems, it is necessary to organize a training program that covers the required materials, teaching methods, trainers, schedule, location, and the number of attendees. Providing this training is crucial because it will help operators improve their knowledge and skills in wire bonding. As a result, better-trained operators are less likely to produce lifted stitch defects.

3.0 RESULT AND DISCUSSION

This study was conducted to identify the main contributing factors of lifted stitch defects in the wire bonding process and to evaluate the effectiveness of the interventions applied, particularly technical operator training and regular equipment supervision. With this approach, it is expected that appropriate solutions can be found to improve production process reliability and reduce defect rates.

3.1. Training Program

Based on the fishbone and 5 Whys analysis results, the appropriate corrective action is to conduct targeted training for the operators. The training program will cover several key topics, shown in Table 3, to address knowledge and skill gaps: understanding the wire bonding machine, material knowledge in the wire bonding process-including wire types, sizes, knives, and quality control specifications (QC), wire replacement procedures, and the replacement of cutters, wedges, and capillaries. These sessions will be delivered through lectures, discussions, and practical exercises, ensuring operators from Shift D are well-equipped to perform their tasks effectively and maintain process quality. This comprehensive approach aims to improve technical competency and adherence to quality standards in the wire bonding process.

The training program for Shift D operators has been completed, as evidenced by the attached verification of attendance and assessment results. The program consisted of five sessions covering essential topics: knowledge about the wire bonding machine, material knowledge in the wire bonding process (including wire type, size, knife, and wedge), quality control specifications (QC), wire replacement, and cutter, wedge, and capillary replacement. Each session used a combination of lectures, discussions, and practical exercises, ensuring comprehensive learning for all participants.

Table 3: Training Program

No	Training content	Duration
1	Knowledge about wire bonding machine	1 hour
2	Material knowledge in wire bonding process	1 hour
3	Quality Control Specification (QC)	1 hour
4	Wire replacement	1 hour
5	Cutter, wedge, and capillary replacement	1 hour

To verify the effectiveness of the training, operators were required to take the Kezdo test, a 45-question assessment designed to measure their understanding of the wire bonding machine and related processes. This test evaluates the operators' knowledge, skills, and abilities in operating the equipment and maintaining product quality, with a minimum passing score of 65 to confirm their readiness for heavy equipment operation. All Shift D operators attended the sessions and achieved satisfactory grades, as shown in the verification form (Figure 4), demonstrating their improved competency and commitment to maintaining high standards in the wire bonding process.

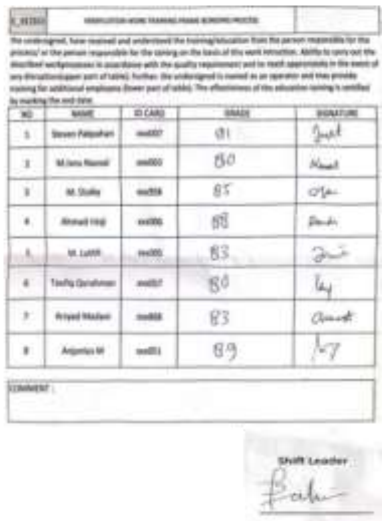

Figure 4: Verification Form

3.2. Quantitative Data of Lifted Stitch Defect

A comparative analysis was conducted to evaluate the effectiveness of the implemented treatment in reducing defects during the production process. Data were collected from two distinct periods: before and after the treatment (See Table 4 and Table 5). Each period comprised 30 production lots, with a consistent production quantity of 200 units per lot, resulting in a total of 6,000 units for both datasets.

Table 4: Data Before Treatment

No.	LOT	Production Quantity	Number of Reject
1	xxx891P0	200	18
2	xxx892P0	200	29
3	xxx893P0	200	12
4	xxx894P0	200	18
5	xxx896P0	200	9
6	xxx897P0	200	17
7	xxx898P0	200	24
8	xxx899P0	200	8
9	xxx900P0	200	4
10	xxx901P0	200	11
11	xxx902P0	200	17
12	xxx904P0	200	7
13	xxx905P0	200	31
14	xxx906P0	200	8
15	xxx909P0	200	24
16	xxx910P0	200	4
17	xxx911P0	200	14
18	xxx912P0	200	14
19	xxx913P0	200	14
20	xxx915P0	200	0
21	xxx917P0	200	12
22	xxx918P0	200	0
23	xxx919P0	200	0
24	xxx920P0	200	22
25	xxx921P0	200	27
26	xxx923P0	200	12
27	xxx924P0	200	3
28	xxx926P0	200	14
29	xxx927P0	200	10
30	xxx928P0	200	18
	Total	6000	401

Table 5: Data after Treatment

No.	LOT	Production Quantity	Number of Reject
1	xxx246P0	200	1
2	xxx247P0	200	0
3	xxx249P0	200	0
4	xxx250P0	200	2
5	xxx253P0	200	0
6	xxx254P0	200	0
7	xxx255P0	200	0
8	xxx256P0	200	0
9	xxx800P0	200	0
10	xxx842P0	200	1
11	xxx843P0	200	1
12	xxx846P0	200	1
13	xxx847P0	200	1
14	xxx851P0	200	0
15	xxx852P0	200	0
16	xxx963P0	200	0
17	xxx964P0	200	2
18	xxx965P0	200	0
19	xxx966P0	200	0
20	xxx967P0	200	1
21	xxx213P0	200	0
22	xxx214P0	200	0
23	xxx216P0	200	0
24	xxx217P0	200	0
25	xxx218P0	200	3
26	xxx220P0	200	0
27	xxx229P0	200	0
28	xxx235P0	200	0
29	xxx237P0	200	0
30	xxx239P0	200	0
	Total	6000	13

Before the treatment, 401 rejects were recorded out of 6,000 units produced. After the treatment, the number of rejects dropped substantially to 13 out of 6,000 units. The defect reduction (DR) percentage achieved through this improvement can be calculated as follows:

$$DR(\%) = \frac{Total\ Reject\ Before - Total\ Reject\ After}{Total\ Reject\ Before} \times 100\% \quad (1)$$

$$DR(\%) = \frac{401-13}{401} \times 100\% = 96.75\% \quad (2)$$

Following the implementation of the treatment, a substantial improvement in the production process was observed. The total number of rejects declined from 401 units before treatment to 13 units after treatment, while the production quantity remained constant at 6,000 units in both periods. This notable reduction in rejects reflects the effectiveness of the corrective actions in addressing process deficiencies. The consistent production volume across both datasets ensures the reliability of the comparison and underscores the positive impact of the treatment. The calculated defect reduction of 96.75% further demonstrates the success of the improvement measures in enhancing product quality.

Table 6: Defect Reduction and Margin of Error Analysis for Lifted Stitch Issue

Parameter	Before	After	Reduction (%)
Number of Units Inspected	6000	6000	-
Number of Defects	401	13	96.75
Margin of error	±0.63%	±0.12%	

Measuring the margin of error is an essential step in statistical analysis to understand the level of uncertainty in sample estimates compared to the true population. The table 6 illustrates how sample size affects the value of the margin of error at a given confidence level. As shown, increasing the sample size leads to a smaller margin of error, which indicates more precise and dependable estimates of the population. This information is crucial when research studies to ensure statistically reliable results. Margin of error is calculated using the formula [21]:

$$Margin\ of\ Error = z \times \sqrt{\frac{p(1-p)}{n}} \quad (3)$$

where p is the sample proportion, n is the sample size, and z is the z-score related to the confidence level (commonly z = 1.96 for a 95% confidence level). This formula measures the statistical uncertainty bounds for an estimated proportion in the population, assuming a binomial distribution that approximates normal. The margin of error decreases as the sample size increases, indicating more precise estimation.

3.3 Box Plot Graphic

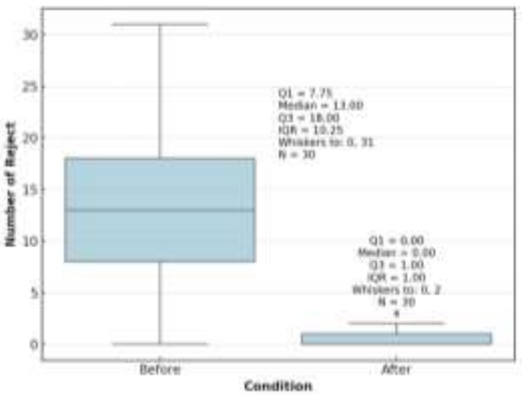

Figure 5: Box Plot Graphic For After-Before Treatment

The box plot provides a visual summary of the number of rejects per lot before and after the treatment. Before the treatment, the distribution of rejects was much wider, with a median of 13 rejects per lot. The first quartile (Q1) was 7.75 and the third quartile (Q3) was 18, indicating that half of the data fell between 7.75 and 18 rejects per lot. The interquartile range (IQR) was 10.25, and the maximum value reached 31 rejects, reflecting high variability and frequent defects across production lots. In contrast, after the treatment, the distribution became much more concentrated, with a median of 0 rejects per lot, Q1 at 0, and Q3 at 1. After the treatment, the IQR range decreased to 1, and the whiskers reached from 0 to 2, with only one lot showing a value of 3 rejects as an outlier. This marked decrease in both the spread and frequency of rejects indicates that the process became much more consistent and controlled, with most production lots experiencing very few or no defects.

A dramatic decrease in defects was observed following the training intervention: the total number of rejects dropped from 401 units before treatment to only 13 units after treatment, with the production quantity consistently maintained at 6,000 units in both periods. This represents a defect reduction rate of 96.75%, clearly indicating the effectiveness of the implemented quality improvement measures. These findings not only reflect a substantial improvement in production quality but also align with the fundamental principles of Total Quality Management (TQM), which emphasize the importance of continuous improvement and systematic workforce development as critical drivers of process excellence [22]. According to the Kirkpatrick model of training evaluation, effective employee training yields measurable behavioral changes and improved organizational results. The outcome of this study substantiates this model, demonstrating that structured, targeted training of operators can directly accelerate defect reduction and promote long-term process reliability. Similar outcomes have been noted in contemporary manufacturing quality improvement literature [23]. This result is consistent with recent international studies emphasizing the synergy between workforce training and quality enhancement in manufacturing environments.

This study has certain limitations that should be considered when interpreting the results. First, the analysis was conducted within a production environment with relatively stable temperature and humidity conditions, which might limit applicability to settings with more variable environmental factors. Second, the data sample was confined to a single production line and a specific group of operators, hence generalizing findings to other production lines or organizations should be done cautiously. Consequently, these findings are intended as an initial reference, and further research with broader scope and inclusion of additional variables is recommended to strengthen the conclusions and provide more comprehensive improvement recommendations.

4.0 CONCLUSION

This research achieved a remarkable 96.75% reduction in lifted stitch defects within semiconductor modules, a significant breakthrough in addressing a persistent quality challenge. This accomplishment resulted from a comprehensive approach that combined operator training, multiple quality checks, and routine equipment maintenance. These improvements not only enhance semiconductor module quality but also minimize the risk of failure, leading to potential cost reductions through less rework, repairs, and material waste.

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