The Failure Mode and Effects Analysis Implementation for Laser Marking Process Improvement: A Case Study

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Abstract

Failure mode and effects analysis (FMEA) is a preventive technique in reliability management field. The successful implementation of FMEA technique can avoid or reduce the probability of system failure and achieve good product quality. The FMEA technique had applied in vest scopes which include aerospace, automatic, electronic, mechanic and service industry. The marking process is one of the back ends testing process that is the final process in semiconductor process. The marking process failure can cause bad final product quality and return although is not a primary process. So, how to improve the quality of marking process is one of important production job for semiconductor testing factory. This research firstly implements FMEA technique in laser marking process improvement on semiconductor testing factory and finds out which subsystem has priority failure risk. Secondly, a CCD position solution for priority failure risk subsystem is provided and evaluated. According analysis result, FMEA and CCD position implementation solution for laser marking process improvement can increase yield rate and reduce production cost. Implementation method of this research can provide semiconductor testing factory for reference in laser marking process improvement.

Key Words: Failure Mode and Effects Analysis, Laser Marking, Semiconductor Testing, Charge Coupled Device

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1. Introduction

As the world economy recesses since 2000, the semi-conductor industry has been hit severely with none immune from loss. To make the matter worse, the so-called anti-dumping measures taken by America against Taiwan's semi-conductor manufacturers works together with the entry of WTO and other factors to weed out many lesser manufacturers and push the remaining ones to work on the next-generation developments, such as the research on 0.11 μm process and the construction of 12" wafer foundry plants. Advanced systems are also introduced to improve the production and the quality of products as well. Apart from the R&D design, processing capability, materials and system operation, technologies with high reliability are also required to produce products with excellent quality. As the upper stream plants (including wafer foundry plants and DRAM plants) witness resurgence since the beginning of 2003, the lower stream plants (such as packaging plants and testing plants) are still struggling to survive due to their redundant capacity built in 1999.

The lower stream plants, in particular the testing plants, are more prudent in making their production run at full throttle. As the testing systems are expensive, it was not until the end of 2003 that the testing plants began purchasing testing systems in a careful way. The marking process can be divided into ink marking and laser marking. Ink marking means to print the customers' logo, the type and speed of the IC on its colloid. However, this technology is no longer desirable as it causes environmental concerns. In comparison, the laser marking is to burn the Logo of the customer and other information of the IC on its surface, which is potentially destructive to the IC. Therefore the laser marking equipment requires effective maintenance, periodic service and replacement of components for fear of serious outcomes. The pin type testing is to inspect the appearance and pin type of the IC product to ensure IC's smooth adhesion in the SMT process. If the adhesion of the products is not reliable, the clients may claim for compensation or demand re-processing, causing much damage on the manufacturers' reputation. Recoiling packaging is to package the products in the recoiling mode instead of the traditional tray package to facilitate its use by different SMT equipment.

IC testing industry is a technology-extensive and investment-intensive industry providing IC testing for clients. As the function and quantity of IC products are directly linked with their values, great importance has been attached on the improvement of testing efficiency, reduction of overkill and underkill, and the maintenance of equipment. However, the equipment used in the later-stage processes is lack of their due share of attention. Take the company in the study as an example. Excerpt the due maintenance of the existing equipment purchased in 1999, there is no plan to buy new ones. The poor quality of such equipment directly affects the quality of the products. According to the statistics, the ratio of the total amount of burn-in and testing equipment and that of the later-stage equipment is 5 to 1. The average monthly maintenance expenses in 2003 were NT$3 million, among which those of the burn-in and testing equipment were NT$2.8 million which those for the later-stage equipment were merely NT$200,000. In respect of the maintenance staff, the number of those for the burn-in and testing equipment was about 90 while those for the later-stage equipment accounted for ten. It is evident that the later-stage equipment is lacking of maintenance. Therefore, this study intends to find an optimal way to ensure the success rate of the later-sage process of the IC testing despite the limitation of financial and human resources.

The product reliability is the base of semi-conductor manufacturers. Among all the quality control methods that ensure the reliability, the failure mode and the effect analysis are two indispensable ones, which could improve the process capability and stability of the equipment, enhance the yield, reduce the costs and increase the profit by reducing the failure repetition rate. The objective of this study is IC testing plants with the intention of improving the laser marking quality in the later-stage process. The failure the laser marking would cause the rejection of the IC, which is unacceptable.

The purpose of the failure mode and the effect analysis is to analyze the causes and possible affects of the potential failure modes of various systems, products, processes and equipment, make priority assessment in the order of their severity, and take effective preventative *measures to address them. The methods employed in this study are the reliability engineering* method, the statistic technology required by QS 9000, and the failure mode and effects analysis (FMEA). A project team of engineers and operators from relevant departments is called to assess the failure mode of the equipment and define the levels of various risk factors. The calculated risk coefficients would be submitted to the equipment units to decide the improvement orders, measures and dates. Hence the equipment stability and the product quality are improved.

2. Literature Review

Literature relevant to the failure mode and effects analysis will be discussed to serve as the theoretical basis of this study.

2.1 The Working Structure of FMEA

As a preventative reliability management technology [3, 7, 18, 20], the Failure Mode and Effects Analysis (FMEA) aims at determine the potential failure mode and cause of the failure of the system by making use of the structural procedures, analyze the relations between sub-systems and the main system, and allow the related units to take appropriate measures before the system failure to reduce or avoid the failure rate. See Figure 1 for the working structure of FMEA [1, 2, 9].

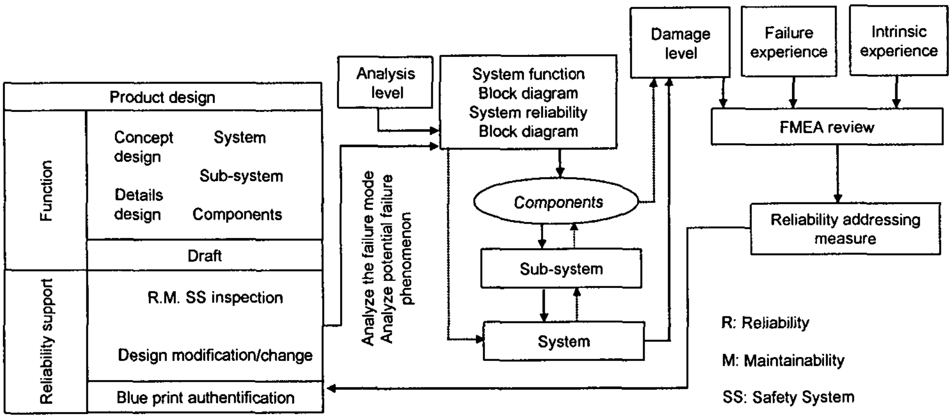

Figure 1. Working structure of FMEA

2.2 Definition of Related Concepts

Relevant concepts should be defined before the implementation of FMEA [11, 12]:

1. Reliability: refers to the capability of the product to perform its required function within the given time, under the given environmental stresses, or in performing the given task.
2. Failure: refers to the incapability of a system, sub-system, module or component to perform the scheduled tasks at the given time.
3. Failure Mode: refers to the causes of various failures, such as breaching, wearing-out, shaking, excursion, distortion or burnout.
4. Severity: refers to the affects of the system/module failure on the performance of the task, and the consequences on the product, the next process and the clients as well.
5. Occurrence: refers to the probability of such failure mode, usually defined by its frequency.
6. Detection: refers to the extent of discovering the failure mode of certain product, module or process, or the probability of being detecting by the clients.

2.3 The History of FMEA

With the appearance of jet planes in 1950s, the U.S.-based Grumman Co. developed the FMEA method to address the reliability of main controlling system of the ever-complicated jet planes. In 1957, Boeing and Martin Marietta officially introduced the FMEA into its operating procedures to ensure the reliability of their planes. As the National Aeronautics and Space Administration (NASA) worked on its APOLO plan in 1963, it demanded all the suppliers to carry out the FMEA, paving the way for FMEA to work in all the important space plans in America [13]. Witnessing the great achievement of such method, the American armed forces and the industry introduced the FMEA into the design inspection. In 1969, Crown defined the FMEA and pointed out that its working structure was usually used at the early stage of the lifecycle of products to improve the reliability of the product and the process as well. The pentagon published the military standard MIL-STD-1629 in 1974, which took the FMEA as the standard operation procedure [15, 17, 19].

In 1977, Ford Motors introduced FMEA to address the potential problems in the R&D and the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method. Later on the automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key check issue. As the FMEA regulations differed, the suppliers suffered a lot. To address this problem, the AIAGs of Ford, Chrysler and General Motor began to integrate various FMEA regulations and published the Potential FMEA Handbook in 1993, laying the foundation of FMEA in the industry. In the same year, America Automobile Engineering Association combined the FMEA with sychro-engineering and expert system to effectively improve the automobile quality.

2.4 Objectives of the FMEA

According to relevant literature, the FMEA could be divided into design FMEA and process FMEA.

2.4.1 Design FMEA

The designers used to work according to the performance requirements and the reliability was secondary. This method was greatly dependent upon the experience of the designers. With the FMEA, the design parameters could be analyzed, the design process is sound and complete and the quality is greatly improved, enhancing the product reliability.

2.4.2 Process FMEA

In a finished system or module, as the design concept, system function and chosen materials are set; any problems may cause much damage on the products. Without the FMEA, the user has to repair the sub-system and no preventative measures could be taken. In comparison, the FMEA enables the user to take measures to prevent such failures, or reduce their occurrence.

2.5 The Operation Procedures of FMEA

Usually the FMEA is employed in the development of new products, process or equipment and its operation procedures are similar. It could be divided into fifteen procedures, which is respectively described as follows [1, 9, 10, 15, 21]:

1. Establish a cross-department FMEA project team: A cross-department project consisting of

senior technicians or directors of various processes should be established.

2. Carry out the FMEA operation exercise: The members of the team should understand in depth the objectives, methods, operation procedures and the data required of the FMEA before it is implemented.
3. Define the flows of various systems: The first step of FMEA operation is to define the sub-systems of the system in question. Such sub-systems should include all the basic functions, specifications of the whole system and process.
4. Determine the tasks of various systems: To understand the tasks of systems and differentiate the functions of various sub-systems is an important step in the FMEA. It is impossible to determine whether the systems or sub-systems encounter failure ff the tasks are unclear or unable to determine whether they are achieved.
5. Determine the system analytic level: This is to determine to what extent the systems should be differentiate in the FMEA. Usually it has four levels, namely the system, sub-system, single component and various parts. In practice, the levels could be reduced or increased according to the size of the system or the complexity of the tasks.
6. Draw out the system function block diagram or reliability block diagram: The reliability block diagram describes the series or parallel connections between system, sub-systems, single component and various parts in the reliability calculation, and encodes them on different levels to facilitate recognition. See Figure 2 for details [2, 8].

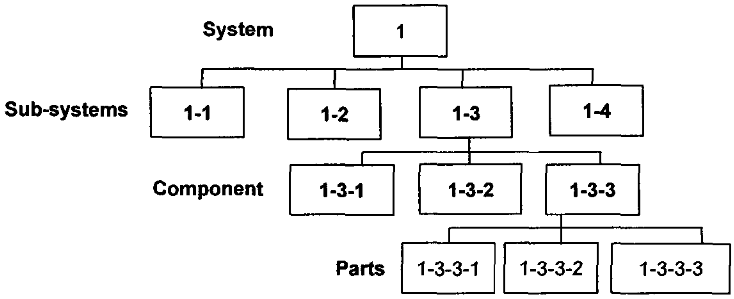

Figure 2. System Series No. Chart

7. Analyze the potential failure modes of various sub-systems, components and parts: As the FMEA is an analysis work aiming at preventing failure; the team members may deduce the potential failure factors of each sub-system, component and part by historical record, experience, system specification and various related research data.
8. Determine and sort out the critical failure modes in the system: List out all potential failure modes in the previous procedures and pick out the critical ones by group discussion for the FMEA.
9. Assess the affects of various failure modes (severity): Assess the critical failure modes

and their affects on the system, and rank them in the order of severity (failure mode) from 1 (the weakest) to 10 (the most severe).

10. Analyze the causes of each failure mode (occurrence): The project team determines the assessment of the occurrence on the basis of the causes of real failure modes and by reference to various historical records. Usually the lowest occurrence is ranked as 1 and the highest one 10.
11. The status quo assessment of FMEA (detection): Determine the detection of the failure modes in the current operation on the basis of the current system. The 1 indicates the failure mode is the easiest to be detected and 10 the most difficult to be detected.
12. Determine the failure mode for improvement by Risk Priority Number (RPN): After determining the severity, occurrence and detection of each failure mode, multiply them to acquire its RPN. The failure mode with the highest RPN (usually above 80) should be the prioritized target for improvement.
13. Propose improvement or regulatory measures: Relevant departments should carry out the measures proposed by the project team to address the failure mode. A schedule should be set up for the project team to monitor the progress.
14. Review: The project team should review the implementation of the measures, monitor the advancement, and review whether the measures are helpful in addressing the failure problems.

Hence the FMEA is roughly completed by carrying out the above steps. The project team should fill out the FMEA format with analysis report, measures, date, results and key analytical conclusion for future improvement. See Figure 3 for the operational flow chart of FMEA [4, 5].

2.6 Risk Assessment of FMEA

The employment of FMEA requires the determination of the severity, occurrence and detection of various failure modes and rank the problems need to be addressed in the order of the RPN. There are several methods to acquire the RPNs or criticality values, which are described as follows:

2.6.1 Criticality Analysis and Criticality Matrix

The criticality analysis is conducted in the order of the fields, and then the criticality matrix describing the criticality components of the system of equipment is drawn out accordingly for relevant departments to make out the preventative or remedy plans. The determination of the severity of component failure in MIL-STD-1629A makes use of quantitative or qualitative criticality matrix as Figure 4 [1]. The execution of the criticality analysis is in the order of the fields in the criticality analysis table, which includes: (1) name of the plan, system description, reference No. and page No.; (2) unit/series No.; (3) function specification; (4) failure mode; (5) cause of failure' (6) severity level; (7) failure probability/source of the failure probability; (8) failure rate of the part; (9) probability of the failure mode (β); (10) occurrence of the failure mode (α); (11) operational time of the system (t); (12) failure rate of the failure mode (Cm); (13) the failure probability of the system (Cr); (14) remarks; (15) filling date and signature of the analyst; (16) signature of the checker. See Table 1 for the criticality analysis table [1, 7].

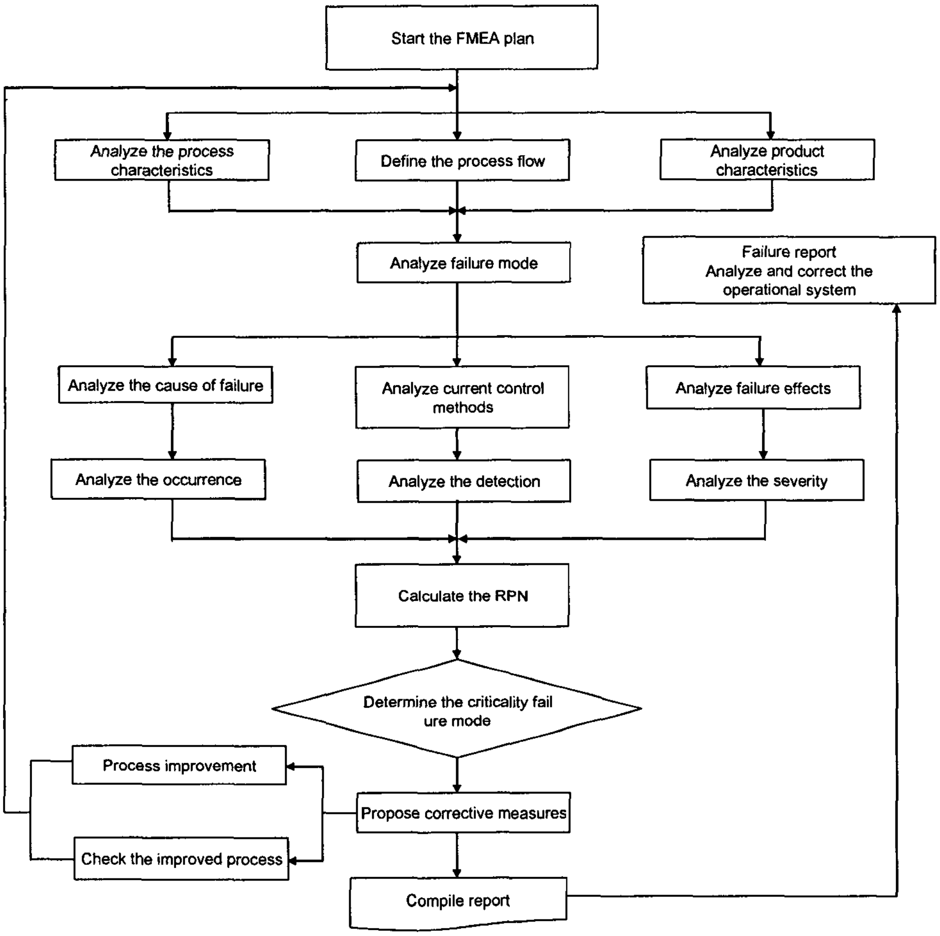

Figure 3. The FMEA flow chart

According to the quantitative method, acquire the Cr value of each component and part by criticality analysis, and then establish the criticality matrix by classifying the Cr values and severity. In comparison, according to the qualitative method, the criticality matrix is established by classifying the occurrence and severity of components' failure modes. The upper-right part of the matrix indicates higher severity of the failure mode, which requires immediate preventative measures [1, 7, 14, 21]. The Cr values could be acquired by adding all the failure mode criticality numbers. The Cm is acquired by multiplying the failure effect probability (β), failure mode ratio (α), the part failure rate (λp) and the operational time of the part.

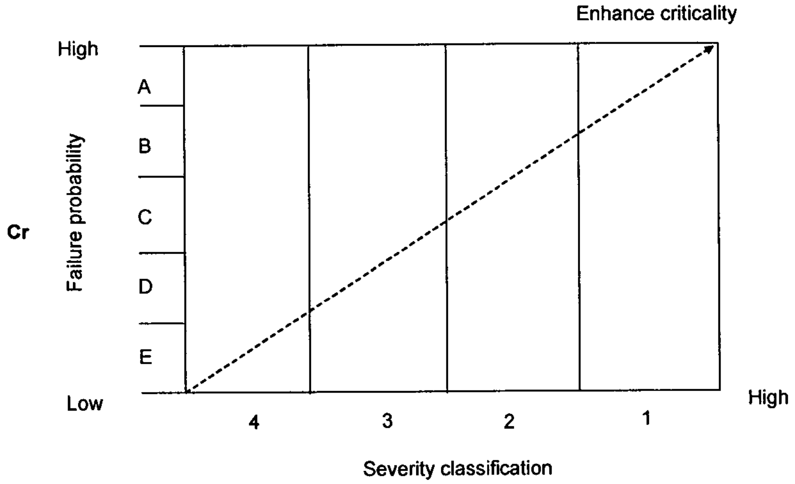

Figure 4. The criticality matrix

Table 1. The Criticality analysis table

function/ SN.	Function specification	Failure mode	Cause of failure	Severity level	Source of Failure rate	Failure Rate λ	Failure Mode Probability β	Failure Mode Ratio α	Operational Time t	Failure Probability Cm	System Failure probability Cr	Remark

2.6.2 RPN

In 1997, Ford Motors [15] successfully introduced FMEA into the R&D and early stage production to define the potential failures, and employed RPN to determine the priority of problems need to be addressed. RPN first determines the risk priority index, then conduct risk assessment in the order of the index. The risk factor consists of parameters of occurrence (Sf), detection (Sd) and severity (S), which given a score from one to ten. See Tables 3 to 4 for the extents and scores of the three factors.

Table 2. The Occurrence (Sf)

Chance	Score	Probability
Almost impossible	1	0
Low	2	1/20000
	3	1/10000
Middle	4	1/2000
	5	1/1000
	6	1/200
High	7	1/100
	8	1/20
Very high	9	1/10
	10	1/2

Table 3. The Detection (Sd)

Failure detection level	Score	The probability of the defection reaching the clients (%)
Almost impossible	1	0~5
Very low	2	6~15
	3	16~25
Middle	4	26~35
	5	36~45
	6	46~55
High	7	56~65
	8	66~75
Very high	9	76~85
	10	86~100

Table 4. The Severity (S)

Severity level	Score
Neglected by customers	1
Little upset of the customers	2 3
Not satisfactory to customers	4 5 6
Highly unsatisfactory to customers	7 8
Put the customers in peril	9 10

RPN is acquired by multiplying the scores of above three factors. The score assessment is dependent on the circumstances of FMEA. See Figure 5 for the RNP map [6].

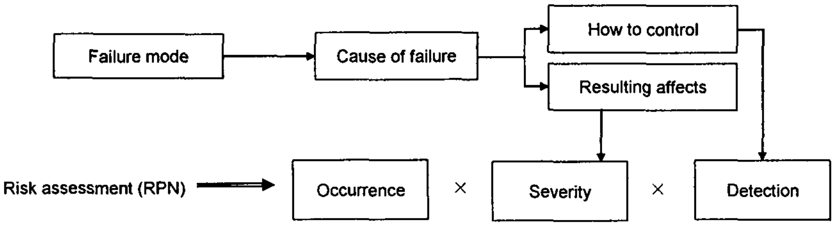

Figure 5. The RPN map

2.6.3 Level of Risk

According to DINV 19250, the level of risk is assessed by four factors (S-A-G-W), which are respectively determined as Table 5.

Table 5. The Principle of determining the factors

Item	Principle
S: severity of harm	– S1: light damage – S2: serious damage or loss of one life – S3: loss of a few lives – S4: major disaster or heavy loss of lives
A: frequency of exposure	– A1: seldom or periodic – A2: often to continuous
G: degree of inevitability	– G1: may not be avoidable – G2: unavoidable
W: probability of causing harmful accidents	– W1: low (little chance) – W2: middle (sometimes) – W3: high (often)

See Figure 6 for the assessment of risk. Take S2-A1-G2-W2 for example, its level of risk is 2. High level of risk means urgent and complete improvement is required.

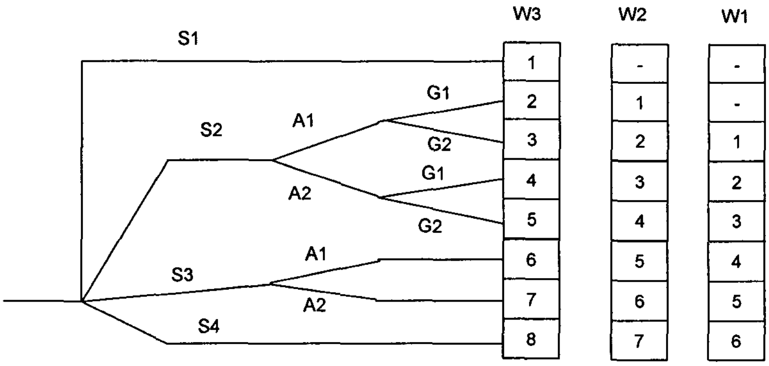

Figure 6. Level of risk

3. Establishing the FMEA of Laser Marking Equipment

According to the description of Section 2, FMEA first disintegrates product, system or process into different sub-systems and defines their respective tasks and inter-relations accordingly. In this section, the operational procedures of laser marking equipment are disintegrated as required by the FMEA for the understanding of the system tasks and the inter-relations between its sub-systems.

3.1 Feeding Part

The feeding part of laser marking equipment consists of pin, connecting rod and transporting belt. The pin is to ensure that the tray is fed into the equipment one by one. Then the connecting rod takes the tray slowly down to the transporting belt, which in turn, sends it to the marking part.

3.2 Laser Marking Part

The laser marking part consists of positioning connecting rod, descending and ascending motor, vibrating device and laser marking device. The positioning connecting rod fixes the tray on the holding tray down the marking part. The ascending and descending motor moves the tray to the marking part. The vibrating device is meant to achieve better positioning effect for the IC in the tray. Then the laser-marking device marks the required Logo and codes on the surface of IC.

3.3 Failure Mode Analysis of Each Sub-system

In the feeding part, an air-pressure cylinder controls the bearing pin while the connecting rod and the transporting belt are controlled by a servomotor. The failure of bearing pin may lead to the wrongly positioning of IC and jam the tray. In the laser marking part, the failure of the positioning connecting rod, the malfunction of ascending and descending motor as well as the vibration of vibrating device could result in wrongly placed marks: the failure of positioning connecting rod would not fix the tray at the correct holding tray; the failure of the motor would cause failed positioning of the tray in the marking part; over-vibration of the vibrating device may shake the IC out of the place and under-vibration is not up to the positioning.

3.4 Establishing the FMEA of Each Sub-system

The FMEA analysis table of the laser marking equipment is made out to describe the occurrence, severity and detection of each sub-system as well as their RPN. According to Step

3 to Step 13 of Figure 3, the project team makes out the table of risk factors (Sf, Sd and S) by RPN. After discussion, it is decided that the extent-score table proposed by Gilchrist [16] is appropriate for direct reference. The FMEA project team points out six potential failure modes in the two sub-systems of the equipment. The three risk factors (occurrence, detection and severity) of the failure modes are respectively determined, and the RPNs are acquired. See Table 6 for the results. It can be observed that the first three failure modes all lie in the marking part. Meanwhile, as the detection is very difficult in all sub-systems, the improvement is hard to achieve.

Table 6. FMEA analysis table of laser marking equipment

Failure mode	Occurrence	Severity	Detection	RPN	Priority ranking
Malfunction of the bearing pin	3	3	4	36	4
Malfunction of the bearing connecting rod	2	3	3	18	5
Malfunction of the transporting belt	1	2	3	6	6
Malfunction of the positioning connecting rod	3	4	7	84	3
Malfunction of the descending & ascending motor	4	4	8	128	2
Malfunction of the vibrating device	4	5	8	160	1

4. Improvement Measures

4.1 Discussion on the Cause of Deviation and Proposed Measures

It could be observed by FMEA that most of the deviations are caused by the malfunction of the components in the marking part, and their detection is highly difficult. Engineers and related dealers work together to discuss the possible improvement on the structure of the marking part and the introduction of new technology or system. As the IC is moved to the marking part, those deviation not detected by sensors could result in improperly marked products. The vibrating device, which is meant to align the IC toward the same direction, could cause problems too if the vibration is too strong or weak. Furthermore, the long-term vibration could result in the loosening of various components, which, in turn, lead to the mal-positioning of the IC. Finally, the FMEA project team proposes the CCD positioning system.

4.2 Introduction of the CCD Positioning System

In the discussion aiming at addressing the deviation problem, the manufacturer proposes to introduce the CCD positioning system, which is already proven in the pin-testing equipment.

It could effectively address the error caused by the equipment structure or the aging problem. The CCD positioning system could detect the exact position of the IC on the tray by its intrinsic characteristics, such as the position of Pin 1 point without the interference caused by the errors of the tray, the limitation of vibrating device or the aging problem. After the introduction of the CCD positioning system, the project team assesses the risk of the failure mode. See Table 7 for the modified RPN and the improvement effects.

Table 7. FMEA Table after the Improvement

Failure mode	Occurrence	Severity	Detection	RPN	Improvement effects
Malfunction of the positioning connecting rod	2	3	7	42	50%
Malfunction of the descending & ascending motor	2	3	8	48	62.5%
Malfunction of the vibrating device	4	3	8	96	40%

4.3 The Benefits of the Improvement

To demonstrate that the introduction of the CCD positioning system could effectively reduce the occurrence of deviated markings, this study makes a comparison between the rate of deviated marking before and after the improvement. See Table 8 and Table 9 for the results.

Table 8. Before the improvement

Customers	Number of fed-in IC	Number of qualified IC	Number of unqualified IC	Unqualified products (ppm)
Customer N	2,364,189	2,363,577	612	259
Customer H	1,089,452	1,089,214	238	218
Customer P	648,519	648,372	147	227
Customer S	846,927	846,762	165	195
Total	4,949,087	4,947,925	1162	235

Table 9. After the improvement

Customers	Number of fed-in IC	Number of qualified IC	Number of unqualified IC	Unqualified products (ppm)
Customer N	1,973,624	1,973,520	104	53
Customer H	1,134,069	1,134,003	66	58
Customer P	871,985	871,945	40	46
Customer S	763,201	763,165	36	47
Total	4,742,879	4,742,633	246	52

It could be observed that the installation of the CCD positioning system could effectively diminish the deviated markings, and reduce the number of unqualified products accordingly. However, as it is a costly improvement, this study makes a rough cost-benefit analysis. The market price of DDR 400 wafer at the end of May 2006 was NT$ 86.4. The laser marking equipment discussed in this study has a daily production of 130,000 IC, making a monthly production of 3,900,000 IC. The difference of unqualified products before and after the improvement is 183 (ppm), which makes the number of IC account for 714 per month, saving NT$ 61,664 on a monthly basis. Therefore the cost of the CCD positioning system could be paid off in 25 months. Furthermore, the benefit for the manufacturer's reputation is another important factor. Therefore it is quite a bargain to implement the improvement.

5. Conclusions

As the semi-conductor industry revives with the economy, the price of IC is rocketing high. The cost caused by the wrong marking becomes even more unacceptable and pushes the testing plants to work on it. By field investigation and with the employment of FMEA, this study assesses the failure modes, ranks them, and works out the improvement measures. With experimental data, RPN, and concrete facts, it is established that the proposed measure could effectively reduce the deviated markings. It could be drawn to the following conclusions:

1. The mechanical damage at the feeding part and laser marking part could both lead to the deviated markings.
2. The deviation caused by the misplacement of IC at the feeding part is so great that the CCD positioning system could help little. The user may install a sensor at the feeding part to detect the misplaced IC and prevent the deviated markings accordingly.
3. Despite that the CCD positioning system is costly; it could effectively address the deviation problem. According to the data of this study, the extra cost could be paid off in two years. Therefore it is quite economic.
4. The filling-out of FMEA table is a complicated work. However, the combination of relevant software and the computer system could computerize the data, saving time and reduce the errors.

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