Application of FMEA and KT Method on Fab Daily Management

Tie Liu Chi-Liang Lin* Johnson Liu

United Microelectronics Corporation (Singapore Branch)

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Abstract

Due to the complicated process and huge cost of a modern semiconductor wafer foundry fab, how to ensure its smooth operation through daily management is very important. In daily management, fab engineers often encounter risky and urgent issues. In this paper, we have introduced a new application to integrate FMEA (failure mode and effect analysis) and Kepner-Tregoe (KT) method to help engineers handle urgent daily management issues of a fab in an efficient and effective manner. The application basically follows the steps of QC story. After problem was defined, background and status analysis were conducted. The possible causes for the certain failure mode with respect to the problem were identified from the established FMEA database. Based on the possible causes from the given FMEA table, we used KT method to narrow down the most probable cause. The possibilities of all possible causes were analyzed by using 3W1H (What, Where, When and How Many) together with "IS" and " IS NOT" method. The priorities of possible causes were further discussed by considering possibility, feasibility, and cost. Then we choose the top one or three to verify first based on the final priority. The root cause verification is conducted in a structure way including suspect, action, evidence and conclusion, and further explained by failure mechanism analysis. FMEA method was then used to calculate Risk Priority Number (RPN) of the failure mode, and the recommended actions were proposed based on SOD analysis (severity, occurrence and detection) to reduce the RPN. Finally, not only the issue has been solved, but also the risk has been reduced. Furthermore, we apply such a new idea to handle an urgent daily management case in a fab, which is a PCM (Process Control Monitor) test abnormal issue caused by High Current (HI) implanter. From the real case application, it is proved that FMEA and KT method have been integrated successfully. This application has great potential to extend to other complicated and urgent fab daily management issues.

Keywords: FMEA, KT method, QC story, daily management, risk assessment

1. INTRODUCTION

A semiconductor fabrication plant, which is generally called a fab, is a factory where devices such as integrated circuits (IC) are manufactured. A fab is known as a foundry as it is for the purpose of fabricating the IC chips of fabless semiconductor companies or IDM (Integrated Devices Manufacturers). The semiconductor device fabrication process is a multiple-steps sequence including lithography, etching, thin film deposition, diffusion and implantation during which electronic circuits are gradually formed on a wafer. As the semiconductor technologies evolve rapidly from 130 nm to 90 nm and even 65 nm, the smaller the device, the more complicated the process. A wafer may pass through more than one thousand manufacturing steps before it is sent for pakaging and testing.

For a modern fab, it usually requires hundreds

* Correspondence: United Microelectronics Corporation (Singapore Branch)
No. 3, Pasir Ris Drive 12, Singapore 519528
E-mail: chi_liang_lin@umc.com

of very expensive manufacturing and metrology equipments, especially for a new 300-mm fab. Due to the complicated process and huge cost, how to ensure the smooth operation of a fab through daily management is very important. In general, daily management consists of scheduled and unscheduled activities such as routine pass down, Statistical Process Control (SPC), standard operation procedures (SOP), daily/weekly/monthly management index monitor, prevention maintenance (PM), change management, and trouble shooting, etc.

In daily management, fab engineers often encounter risky and urgent issues such as process variation, equipment down, wafer defects, wafer scrap, line excursion, Process Control Monitor (PCM) test failure and even yield loss. These kinds of issues may have high potential risk to cause great loss if they are not handled in an efficient and effective manner. Different kinds of methods, such as SPC (Wheeler and Chambers, 1992), QC Story (Ando, 1994), Failure Mode and Effect Analysis (FMEA) (Stamtics, 2003), Kepner-Tregoe (KT) method (Kepner and Tregoe, 1981), 8 Disciplines (8D) report (Rambaud, 2006), and Six Sigma (Brue and Howes, 2006) are proposed to solve the daily management issues mentioned above.

Kepner-Tregoe (KT) method, a rational thinking process, is one of the most unique, documented analysis and decision-making methods, and is widely used for fab daily management issues by both problem solving (Lumsdaine and Lumsdaine, 1994) and decision making (Judith, 1999). KT method is a step-by-step approach for systematically solving problems, making decisions, and analyzing potential risks. It helps the decision maker to maximize critical thinking skills, systematically organize and prioritize information, set objectives, evaluate alternatives, and analyze impact. However, it is not easy for fab engineers to use full-scale application of KT method directly to handle urgent cases due to tight schedule.

FMEA is an engineering technique used to define, identify, and eliminate known and/or potential failures, problems, errors, and so on, from the system, design, process, and/or service before they reach the customer. In fab daily management, process FMEA is widely used by process engineer for risk prevention. A process FMEA is a disciplined analysis/method of identifying potential or known failure modes and providing follow-up actions before the first production run occurs (Stamatis, 2003). It is widely used to prevent potential process risk on production, but few people use it during trouble shooting stage.

In this paper, we introduce a new application of FMEA integrated with KT method to solve complicated fab daily management issues efficiently and effectively. The application basically follows the steps of QC story. When solving a daily management issue with respect to a certain failure mode, the potential causes are given in the FMEA table. The most probable cause is narrowed down by using KT method based on the given FMEA table. After root cause verification and risk assessment, the recommended actions are proposed to solve the issue and reduce the risk.

This paper is organized as follows: A methodology, which combined FMEA with KT method, will be described first in Section 2. Then, Section 3 will give an application of FMEA integrated with KT method on a real fab daily management issue. Finally, a conclusion is drawn in Section 4.

2. METHODOLOGY

The methodology is shown in Figure 1. It starts from problem statement. The problem needs to be described clearly using a short statement including the object and deviation. The problem statement is the same as a failure mode in FMEA. After problem statement, a detailed background analysis is necessary to have a better understanding of the problem. At this step, we list out the facts and impacts of the problem. The facts describe the phenomena which mean what findings you have seen in different perspectives while the impacts describe the severity which means what results the issue causes.

Next, refer to FMEA database, we check the possible causes of the problem or failure mode. Actually, in order to prevent the risk, the FMEA for a given failure mode has been established already based on experts' experiences and knowledge in a fab. Therefore, for saving time, the possible causes of the given failure mode can be identified from FMEA database. Then, we combine KT approach and FMEA to conduct status

analysis. 3W1H table, which is the analytic technique of KT method, is used to help engineers analyze the status of the problem. 3W are what, where and when, and 1H is how many. Based on 3W1H table, fab engineers can analyze the status of the problem by asking at least 11 questions which are object and deviation for "What"; geography and location for "Where"; when first, when reoccurred, continuous or not, which step for "When"; how many objects, how big, and trend for "How Many".

Then, we need to analyze the possibility of potential causes. During root cause analysis, we use KT method to narrow down the problem scope based on the possible causes from the given FMEA table. The possibilities of all possible causes are analyzed by using 3W1H together with "IS" and "IS NOT" method. "IS" means it happens on a certain thing or event while "IS NOT" means a similar thing or event should happen but not happen with respect to each question in 3W1H table. For example, for the question of object of "What", why "is" it happening on such an object but "is not" happening on another similar object? That is, for each question in 3W1H table, we use "IS" and "IS NOT" to check the explanation capability of all possible causes given in FMEA table for the certain failure mode. The possible cause, which can explain the certain question in 3W1H table, will be marked by a "Star". The possible cause, which can not explain the certain question, will be marked by a "cross". The possible cause, which is unknown for the certain question, will be marked by a "triangle". Based on 3W1H and IS/IS NOT analysis, we can evaluate and grade the "possibility" of all possible causes. That is, the one with the most number of "star" is the most probable cause. By sum all grades for each possible cause, we can list the priority of the most probable causes.

However, it is not enough to consider the possibility only for root cause verification. We also need to take feasibility and cost into account. The rating scale for each most probable cause is 5-Very Good, 4-Good, 3-Average, 2-Poor, 1-Very Poor in terms of possibility, feasibility and cost. The final priority of the most probable causes is evaluated based on possibility, feasibility and cost by multiplying the grades for each cause. Hence the final priority can be decided. Once the final priority is identified, we can choose top one or three of them to verify first. The verification should be done in a more structure way and at least includes description of "suspect", "action", "evidence", and "conclusion". After root cause verification, failure mechanism analysis may help

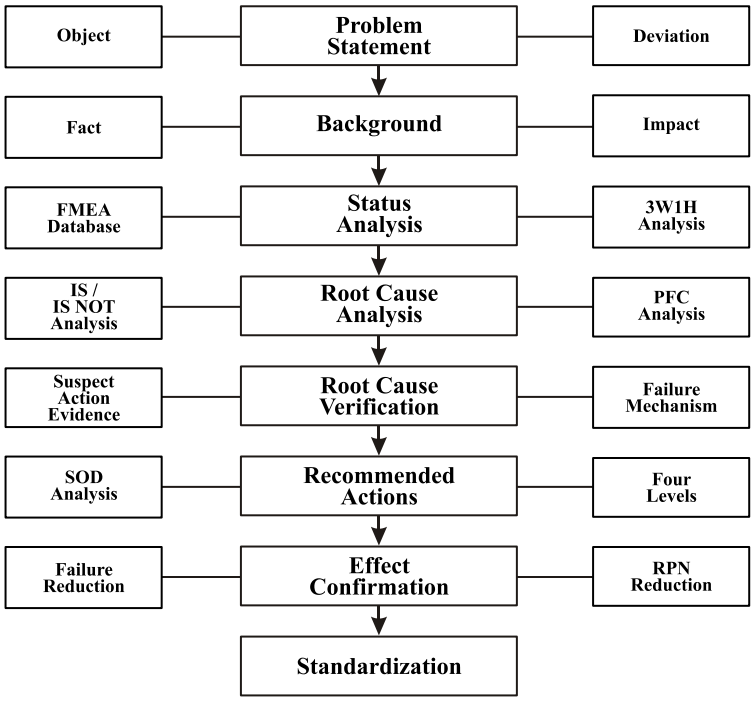

Figure 1. The integrated methodology

to further understand the root cause. It is noticed that if the possibilities of all possible causes are very low, perhaps there exists another new root cause which is not listed in the given FMEA table. Then we have to go back to the step of status analysis to identify the possible causes again instead of choosing from FMEA database directly.

After root cause verification, the recommended actions can be proposed based on severity, occurrence and detection (SOD) analysis from the given FMEA table. The rating scales of severity, occurrence and detection are ranged from 1 to 10. The lower the rating, the lower the risk for severity, occurrence, and detection. For example, rating 1 for severity means the severity of the failure effect is very low, while rating 10 means the severity of the failure effect is very high. Rating 1 for occurrence means the occurrence of the failure cause is very low, while rating 10 means the occurrence of the failure cause is very high. Rating 1 for detection means the detection capability is very good, while rating 10 means the detection capability is very poor. The product of these 3 ratings of severity, occurrence and detection is so called Risk Priority Number (RPN). The bigger the RPN, the higher the risk. Therefore, we can choose the item with higher RPN to reduce the risk by taking recommendation action to reduce the rating of severity, occurrence or detection. Therefore, to reduce the risk for the given higher RPN, we can firstly choose severity, occurrence or detection, which is with higher rating, to take recommended action or choose all of them to take recommended actions depending on the resource condition and actual situation.

Finally, by implementing the recommended actions, the RPN can be effectively reduced to a satisfied level, which means the risk drops. We classified the recommended actions into four levels: containment actions, detection actions, prevention actions, and prediction actions. Containment actions need to be implemented immediately to prevent further suffers. Detection actions are used to detect the failure when happening and take necessary actions in time. Prevention and prediction actions are used to prevent similar failure to happen again and even predict the problem in advance. After the recommended actions are implemented, proper index can be used to confirm the effectiveness of the recommended actions. PDCA (Plan-Do-Check-Action) loop should be used to continue monitoring and improving the process. Finally, a standard operation procedure (SOP) or best known method (BKM) could to be proposed to standardize the solution.

3. APPLICATION

In this section, we would like to follow the methodology mentioned above to give an application of FMEA integrated with KT method on a real fab daily management issue. A production wafers' PCM test out of specification (OOS) issue was investigated. The problem statement is: several wafers of lot A for customer X suffer PCM test parameter Y OOS (12.5% higher than the baseline), and need to be scrapped. Figure 2 shows the trend chart of PCM test parameter Y of lot A. Each point in Figure 2 represents a PCM test parameter Y of a wafer. We measure 9 sites of a wafer to calculate the average value of PCM test parameter Y for each wafer.

Then we conduct the background analysis

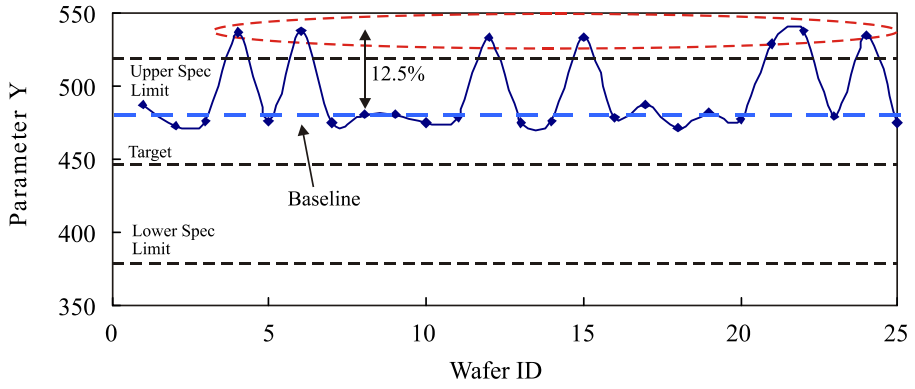

Figure 2. The trend chart of PCM test parameter Y of lot A

Table 1. HI process FMEA table

Process	Step	Potential Failure Mode(s)	Potential Effect(s) of Failure	Severity	Class	Potential Causes(s)/Mechanism(s) of Failure	Occurrence	Current Controls		Detection	R.P.N.
								Preventive Controls	Detective Controls		
Pre-process	Beam Tunning	Can not get required beam I	Implant interrupt	6		Recipe setting wrongly	3	Recipe audit	EQ alarm / PDS	1	18
						Source and beam line condition bad	3	PM / daily monitor	EQ alarm / PDS	1	18
						PM quality bad	3	Daily monitor	EQ alarm / PDS	1	18
		Poor uniformity	PCM test fail / CP drop	6		Source and beam line condition bad	3	PM / daily monitor	EQ alarm / PDS	1	18
						PM quality bad	3	Daily monitor	EQ alarm / PDS	1	18
		Poor Beam Angle / Spread	PCM test fail / CP drop	6		Source and beam line condition bad	3	PM / daily monitor	EQ alarm / PDS	1	18
						PM quality bad	3	Daily monitor	EQ alarm / PDS	1	18
		Beam energy shift	PCM test fail / CP drop	6		Extraction electrode	3	PM / daily monitor	EQ alarm / PDS	1	18
		Dose shift	PCM test fail / CP drop	6		Dose controller fault	2	PM / daily monitor	EQ alarm / PDS	1	12
						Beam condition bad	3	PM / daily monitor	PCM test	8	144
	Vacuum pumping	Dose shift / Particle	Implant interrupt / PCM test fail / CP drop	6		Pump error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Guage error	3	PM / daily monitor	EQ alarm / PDS	1	18
	Wafer loading	Wafer drop / scratch	CP drop / line yield drop	6		Robort error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Aligner error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Load port error	2	PM / daily monitor	EQ alarm / PDS	1	12
Processing	Wafer implanting	Poor Beam stability	Implant interrupt / PCM test fail / CP drop	6		Source and beam line condition bad	3	PM / daily monitor	EQ alarm / PDS	1	18
						PM quality bad	3	Daily monitor	EQ alarm / PDS	1	18
	Vacuum pumping	Dose shift / Particle	Implant interrupt / PCM test fail / CP drop	6		Pump error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Guage error	3	PM / daily monitor	EQ alarm / PDS	1	18
	Wafer scanning	Dose shift	Implant interrupt / dose shift	6		linear motor error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Scanning controller error	3	PM / daily monitor	EQ alarm / PDS	1	18
	Angle control	Implant angle shift	PCM test fail / CP drop	6		Platen error	3	PM / daily monitor	EQ alarm / PDS	1	18
	Wafer cooling	PR harden	PCM test fail / CP drop	6		Cooling wafer flow low	2	PM / daily monitor	EQ alarm / PDS	1	12
						Wafer contact bad	2	PM / daily monitor	EQ alarm / PDS	1	12
	Wafer holding	Wafer drop	CP drop / line yield shift	6		E-clamp error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Wafer backside uneven	2	Recipe setting / PM	EQ alarm / PDS	1	12
Post-process	Wafer unloading	Wafer drop / scratch	CP drop / line yield drop	6		Robot error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Aligner error	2	PM / daily monitor	EQ alarm / PDS	1	12
						Load port error	2	PM / daily monitor	EQ alarm / PDS	1	12

including fact and impact. The facts are:

- HI (High Current Implanter) is used mainly for source/drain (S/D), lightly doped drain (LDD) and poly implant.
- Parameter Y is sheet resistance of P+ S/D, and it is related to parameters of P+ implant.
- Lot A ran at HI-02 with a certain recipe for P+ implant. And there is no abnormality at other steps.
- The first 7 wafers of Lot A suffer PCM test OOS, but other wafers' test data is fine.
- The PCM test parameter Y of the first 7 wafers is about 12.5% higher than the baseline.
- SPC non-lot monitor of HI-02 during that period is fine.
- PCM test of lots ran before and after Lot A at HI-02 is fine.
- PCM test of lots ran at other HI tools during that period is fine.

And the impacts are:

- Yield loss, 7 wafers scrapped due to PCM test OOS.
- Affect customer satisfaction.

The HI process FMEA table as shown in Table 1 is used to list the possible causes and 3W1H as shown in Table 2 is used to list the status with respect to IS and IS NOT. From the given FMEA table, failure mode of dose shift is related

to this problem. There are totally six potential causes can cause this failure mode. 3W1H and IS/IS NOT methods are used to analyze the possibility for every possible cause as shown in Table 2. Each cause can be marked by "Yes", "Don't know", or "No", in terms of IS/IS NOT. By summarizing the mark of every cause, we found the most probable causes are: Beam condition with 7 stars followed by Dose controller with 5 stars. Other causes' possibilities are relatively low with 3 or 4 stars. The more stars, the more possible. Besides, the priority of each possible cause is further evaluated based on possibility, feasibility and cost as shown in Table 3. Then, the product of these three factors gave us the final priority of each possible cause. From Table 3, we see that the possible cause with the first priority is "beam condition".

Next, we choose the possible cause with the first priority, "beam condition drift", to verify first based on the final priority evaluation result. Following the verification structure, the suspect is beam condition drift. The action is to check the beam condition records during that period. The evidence is the bean condition trend chart as shown in Figure 3 which shows that the beam

Table 2. Possibility evaluation for all possible causes by 3W1H and IS/IS NOT method

Yes ★ **Don't Know** ▲ **No** ✖

		IS	***IS NOT***	*Possible root cause 1*	*Possible root cause 2*	*Possible root cause 3*	*Possible root cause 4*	*Possible root cause 5*	*Possible root cause 6*
				Dose Controller	**Beam Condition**	**Pump**	**Gauge**	**Linear Motor**	**Scanning Controller**
What	Object	X Product	Other Products	✖	★	✖	✖	✖	✖
		SS302	Lots ran before and after SS302	▲	▲	▲	▲	▲	▲
		First 7 wafers of SS302	Rest wafers of SS302	▲	▲	✖	✖	▲	▲
	Deviation	RS OOS	VT, ION, IOFF and etc.	★	★	★	✖	★	★
Where	Location	HI-02	HI-01, HI-03 to HI-10	★	★	★	★	★	★
		All 9 measurement sites on each wafers	wafers edge, center and etc.	★	★	★	★	▲	▲
When	First time	31-Jan-07	Before or after 31-Jan-07	★	★	★	★	★	★
How Many	Many	1 lot	more than one lot	▲	★	✖	✖	✖	✖
	Big	12.5% high	Small difference	★	▲	▲	▲	★	★
	Trend	Single event	Trend up, down or stable	▲	★	✖	✖	✖	✖
				5★	7★	4★	3★	4★	4★

Table 3. Priority evaluation for possible causes

	Possibility	*Feasibility*	*Cost*	*PxFxC*	*Priority*
Dose Controller	4	3	2	24	2
Beam Condition	5	4	4	80	1
Pump	3	4	2	24	2
Gauge	2	3	2	12	4
Linear Motor	3	2	2	12	4
Scanning Controller	3	3	2	18	3

Notes: 5-Very Good, 4-Good, 3-Average, 2-Poor, 1-Very Poor.

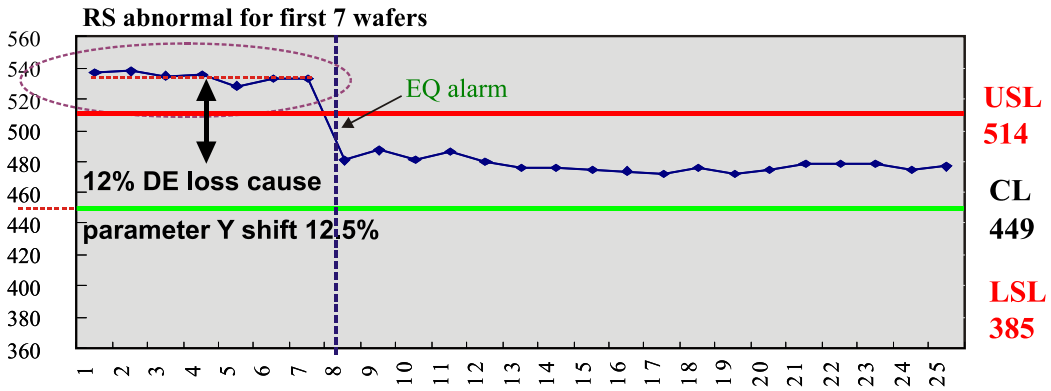

Figure 3. Root cause verification

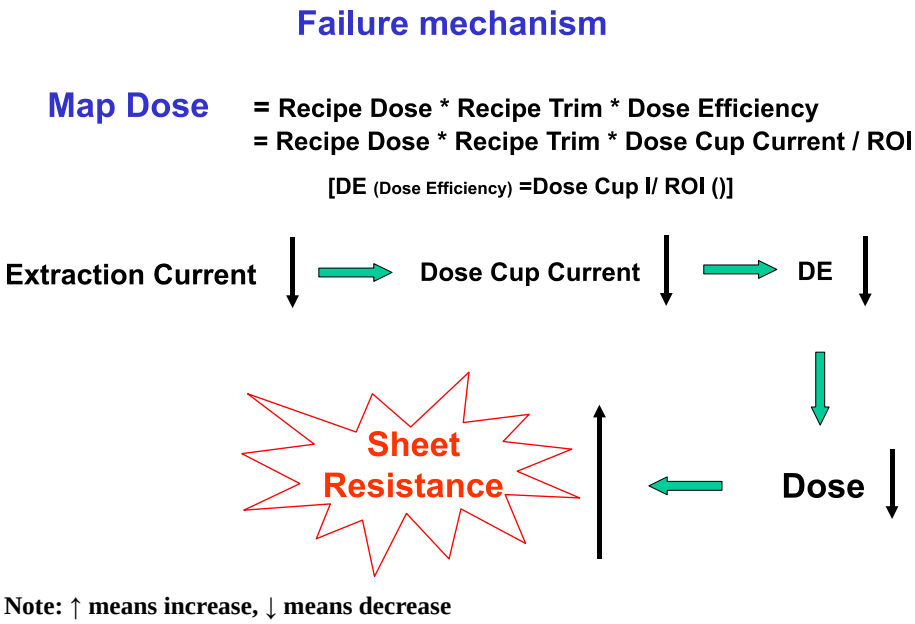

Figure 4. Failure mechanism analysis

Process	Step	Potential Failure Mode(s)	Potential Effect(s) of Failure	Severity	Class	Potential Causes(s)/Mechanism(s) of Failure	Occurrence	Current Controls		Detection	R.P.N.	Recommended Artian(s)	Area / Individual Respansible & Completion Date	Action Taken	Severity	Occurrence	Detection	R.P.N.
								Preventive Controls	Detective Controls									
Pre-process	Beam Tunring	Dase shift	PCM test fail / CP drop	6		Beam condmon bad	3	PM / daly monter	PCM test	8	1.44			RPN降低	6	1	3	18

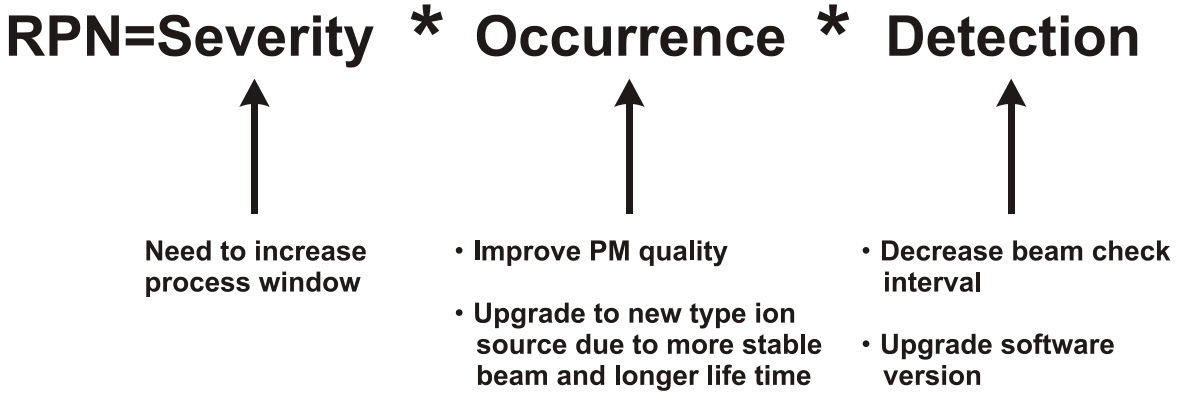

Figure 5. Recommended actions to reduce RPN

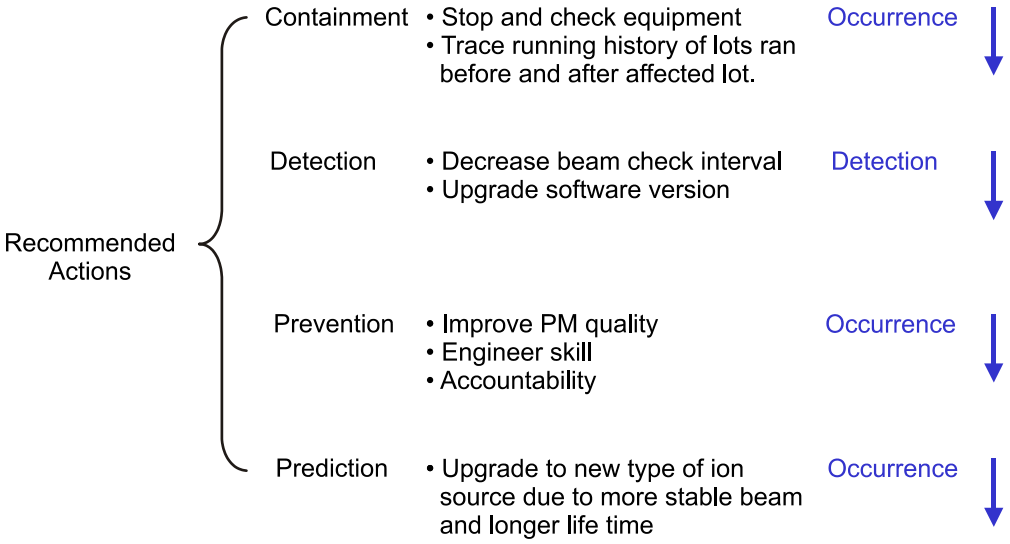

Figure 6. Four levels recommended actions

condition drifted after first seven wafers had implanted. The conclusion is "beam condition drift" is the root cause. This root cause can also be verified by failure mechanism study as shown in Figure 4.

As mentioned earlier, recommended actions were proposed based on SOD analysis. Figure 5 shows SOD analysis in FMEA and relative actions for severity, occurrence and detection. All these recommended actions could be divided into four levels as shown in Figure 6. By implementing these actions, the PRN of this failure mode can be effectively reduced from 144 to 18 as shown in Figure 5. PCM test OOS due to beam condition drift was used as an index to monitor this issue. The index trend showed that after the recommended actions had been implemented, there was no more similar case happening again which indicated the potential risk was significantly reduced.

4. CONCLUSION

In this paper, we introduce a new application of FMEA integrated with KT method to solve complicated and urgent fab daily management issues in an efficient and effective manner. The application basically follows the steps of QC story. During the steps, we use the established FMEA database to list possible causes for a certain failure mode and then use 3W1H table of KT method to list the status of the issue. Next, the possibilities of all possible causes are analyzed by using 3W1H together with "IS" and "IS NOT" method. Besides possibility, we also take feasibility and cost into account for verification purpose to determine the final priority of possible causes. Then we choose the top one or three to verify first based on the final priority. The root cause verification is conducted in a structure way and further explained by failure mechanism analysis. After verification, the recommended actions with four levels are implemented and the RPN was reduced based on SOD analysis. Finally, not only the issue has been solved, but also the risk has been reduced. Furthermore, we apply such a new idea to handle an urgent case of bean condition drift of HI in a semiconductor wafer foundry fab very efficiently, which proves that FMEA and KT method have been integrated successfully. From the real case application, after implementing the recommended actions, the RPN can be reduced from 144 to 18, which means the risk of this issue has been significantly reduced. This application has great potential to extend to other complicated and urgent fab daily management issues.

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失效模式效應分析與 KT 手法於半導體晶圓代工廠日常管理之應用

劉鐵　林啓良* 劉智強

聯華電子新加坡分公司

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摘　要

由於現代半導體晶圓代工廠的製造過程非常複雜，加上高額的投資成本，如何透過有效的日常管理，以確保工廠順利營運，是極其重要的課題。在每天的日常管理中，工程師經常會碰到高風險的緊急日管問題。針對這類問題，本論文提出一種新的應用手法，整合失效模式效應分析 (FMEA) 與 KT 手法，來協助工程師有效而快速地處理緊急日管問題。該應用手法基本上遵循品管改善流程 (QC story)的步驟。首先是定義問題，然後是進行現況掌握與現況分析，接著根據既有的 FMEA 資料庫，界定出針對特定失效模式的失效原因，再利用 KT 手法收斂到最可能的原因。我們主要是利用 KT 手法中的 3W1H (何物、何處、何時、何量)，以及 IS/IS NOT (是／不是) 來分析各種可能原因的可能性。並進一步透過可能性、可行性與成本需求性的討論，安排出各種可能原因的優先順序，再從中選取第一名或前三名優先進行眞因驗證。驗證的方式必須以結構化的方式來進行，包括懷疑的對象、驗證的對策、收集的證據、以及得到的結論，並以失效機制分析進行綜合佐證。接著，再針對該特定的失效原因與失效模式，利用 FMEA 方法計算其風險優先係數 (RPN)，然後再根據 SOD (嚴重度、發生度、檢測度) 分析，提出建議改善對策以降低其 RPN。最終不僅解決該問題；同時也降低了風險。最後，我們將這個新的構想，應用在半導體晶圓代工廠一個實際的日管問題，亦即高電流離子植入製程管制監測異常問題。透過該眞實案例的應用與說明，證實本文成功地整合 FMEA 與 KT 手法，並可推廣應用至半導體晶圓代工廠其他的日管問題。

關鍵字：失效模式效應分析、KT 手法、品管改善流程、日常管理、風險評估

* 聯絡作者：聯華電子新加坡分公司。
E-mail: chi_liang_lin@umc.com