The Effective Use of Process Control Plans and Process Failure Mode Effects Analysis in a GaAs Semiconductor Manufacturing Environment

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ABSTRACT

The effectiveness of a wafer fab is sometimes measured in its ability to react to problems in a timely manner as they arise during the manufacturing cycle. Sophisticated process controls are developed and deployed with the hope that process variation will be minimal and that the manufacturing processes will be predictable.

When one of those process controls fails and scrap is created, a series of actions take place to contain the problem, uncover root cause and develop a corrective action plan. The effectiveness of the corrective action is verified and when successful, everyone is satisfied that a process improvement has been achieved.

Fortunately, the same types of process improvements can be made in a more controlled environment without the costs associated with scrap, containment and rushed process engineering activities.

The use of process control plans coupled with a dynamic failure mode effects analysis can spot potential high-risk process failures before they occur allowing the process engineer to take action proactively at a much lower cost.

INTRODUCTION

The use of Process Control Plans (PCP) or Failure Mode Effects Analysis (FMEA) is nothing new. FMEA has its roots in the US military as described in *MIL-STD-1629A Procedures for performing failure mode, effects, and criticality analysis (FMECA)* [1]. This standard was initially released in 1949. The objective of the standard was to classify failures "according to their impact on mission success and personnel/equipment safety".

FMEA achieved prominence in the automotive industry in 1972 when Ford used this tool after it was discovered that the Ford Pinto model had a fault that caused the fuel tank to leak and potentially cause a fire after a crash.

Process Control Plans are an automotive and aerospace quality tool and are considered an output of the Advanced Product Quality Planning (APQP) process [2], as is the FMEA [3].

PROCESS CONTROL PLAN CONCEPTS

The process control plan provides a documented "summary description" of the methods used to minimize process and product variation. It provides a structured approach for the design, selection and implementation of value added control methods. It is not intended to replace the detailed information contained in operator work instructions.

Table 1 below provides an example of a typical process control plan layout. The columns are completed as follows:

Process Operation: process step being considered

Machine, Tool or Device: equipment used to perform this particular process step or operation

Control Characteristic: process parameter being controlled. In the case of wafer fab equipment this list can become quite lengthy however, the work done during this phase will become invaluable during the generation of the FMEA.

Method: means used to control the particular process parameter

Frequency: how often the process control takes place

Control Method: manner in which evidence of the process control is recorded

Reaction Plan: actions that will take place if the process control fails

Performance Measurement: standard against which the success of the process control is measured

Process Operation	Machine, Device or Tool	Control Characteristic	Method	Freq	Control Method	Reaction Plan	Performance Measurement
Photo develop	Oven	Bake time Bake temp	Timer Thermocouple	1 / lot	Tool log	Strip and rework	Work instruction
Photo expose	Stepper	Reticule type	Visual	1 / lot	Check	Strip and rework	Work instruction

Table 1: Process Control Plan Layout

FMEA CONCEPTS

There are several types of FMEA. The most common are design and process FMEA. This paper will focus on the process FMEA.

The process FMEA asks a series of questions: What can go wrong with the process? What effect would this have on the product? How severe would this be? What could cause the failure to occur? What is the probability of occurrence? What controls are already in place? How effective are these controls?

It is important to note that most of these questions are hypothetical and are not based on the fact that a process failure has actually occurred.

Much like the process control plan, an FMEA is arranged in a table format as shown in Table 2 below. The columns are completed as follows:

Process Operation: process step being considered

Process Failure: manner in which the process could fail to meet the process requirements. This is where the work done during the process control baseline preparation pays off. Every process parameter failure should be taken into account even if this parameter is recipe controlled.

For example if bake time is an equipment parameter, bake time too long and too short should be considered. Similarly, temperature would be considered as too high and too low. Other parameters such as environmental factors should also be included as applicable (i.e. ambient temperature, humidity, particle count).

There is typically a one-to-two relationship between the process control plan parameters and the process failure modes in the FMEA.

Effect: effect of the failure mode on the product, process parameter or customer

Sev (or Severity): rank associated with the most serious effect for a given failure mode on a scale of 1 to 10 with 10 indicating a safety concern (very high) and 1 indicating no concern (very low). The assumption must be made that the process failure has occurred. Do not presume that the severity ranking is low because occurrence is low or because detection is extremely effective.

Note: A reduction in severity ranking can only be achieved through a design change to the system or sub-system that uses the device.

Cause: description of how the failure could occur in terms of something that can be controlled

Occ (or Occurrence): rank associated with the likelihood that the process failure will occur on a scale of 1 to 10 with 10 meaning the failure is sure to occur and 1 meaning the failure is unlikely.

Controls: description of controls that currently either prevent the process failure from occurring or detect the effect(s) of the process failure.

Operator certification programs, preventive maintenance, operator work instructions or recipe controls are examples of preventive controls. Measurements or electrical tests taken after a process step are examples of detection controls.

Det (or Detectability): rank associated with the probability that the process controls will detect either the process failure (i.e. prevention) or the effect of the process failure (i.e. detection). The scale is 1 to 10 with 10 meaning there is absolute certainty of non-detection and 1 meaning the control is certain to detect the failure (i.e. error proof in design). The assumption must be made that the process failure has occurred. Do not presume that the detection ranking is low because occurrence is low.

Note: A reduction in the detection ranking can only be achieved by improving the planned process controls.

RPN (or Risk Priority Number): ranking between 1 and 1,000 that quantifies the risk associated with a particular process failure mode. The RPN is the product of the severity (S), occurrence (O) and detection (D) rankings:

RPN = (S) x (O) x (D)

Actions: activity generated due to a high-risk (i.e. high RPN) item. Typically a threshold is selected and any RPN beyond that threshold automatically generates the need to take action. Although this threshold is somewhat arbitrary, this number is typically in the 125 to 150 range which represents an above average risk as illustrated in Figure 1 below:

Sev	1..	2..	5..	7..	10
Occ	1..	2..	5..	7..	10
Det	1..	2..	5..	7..	10
RPN	1	8	**125**	343	1,000

Figure 1: RPN Risk Calculation Scale

To reduce the probability of occurrence, process and/or design revisions are required. To reduce the probability of severity, a design revision must be made. To reduce the detec-

Process Operation	Process Failure	Effect	Sev	Cause	Occ	Controls	Det	RPN	Actions
Photo develop	Bake temp too high	CD too small	6	Wrong recipe selected	1	CD SEM	2	12	None required
	Bake temp too low	CD too large	6	Wrong recipe selected	1	CD SEM	2	12	None required
	Wrong reticule	Incorrect layer imaged, circuit improperly defined, no gates on wafer	6	Failure to follow work instructions	3	CD SEM	2	72	None required

Table 2: Failure Mode Effects Analysis Layout

tion ranking, the preferred method is the use of error/mistake proofing. Generally, improving detection controls is costly and ineffective for sustainable quality improvements. Increasing the frequency of quality controls is not an effective preventive action and should only be used as a temporary measure.

Action items must have assigned responsibility with target dates. After the action has been implemented, it must be reviewed for effectiveness, the occurrence and detectability rankings must be revised and the resulting RPN recalculated. The impact on the control plan must also be considered. If further action is considered necessary, the analysis should be repeated. The emphasis should always be on continuous improvement (see Figure 2).

Once all items above the threshold have been reduced to a reasonable risk, the threshold should be lowered and the improvement process repeats itself.

RANKING GUIDELINES

The AIAG manual includes a series of tables that define raking guidelines for severity, occurrence and detectability. These are heavily geared towards the automotive industry and as such will not translate well into a wafer fab environment. A set of guidelines should be developed that is more applicable to the wafer fab. It is important to note that the ranking activity is an inexact science and consistency should be emphasized over accuracy.

RELATIONSHIP BETWEEN THE PROCESS CONTROL PLAN AND FMEA

In order for the FMEA to consider all potential process failure modes, a complete inventory of process parameters needs to be established. The initial process control baseline plan provides this list. The traditional approach is to establish the FMEA first and subsequently, generate the process control plan based on the risks identified. Figure 2 below shows that it is possible to start this cycle at any one point and still achieve the desired result:

The wafer fab in Woburn has chosen to generate the process control plan as the means of identifying all process parameters. It is the author's opinion that this ensures all process parameters are addressed during the initial FMEA generation and limits the number of iterations required to capture the significant process risks.

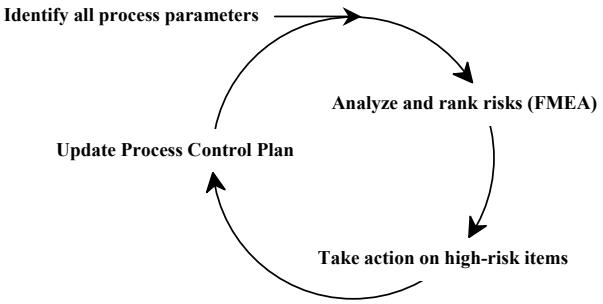

Figure 2: Continuous Improvement Cycle

In any case, it is extremely important to update the FMEA and process control plans whenever process controls are improved or modified or when internal / external failures indicate that a certain process failure mode was overlooked or underestimated.

APPLICATIONS IN THE WAFER FAB

Skyworks has developed a database to manage their FMEA activity. The use of a database provides several advantages including database and document level security, consistency with the AIAG format, includes ranking guidelines, allows individual action items to be generated, tracked and managed and addresses the requirements for automotive customers to maintain FMEA records.

The following are some examples of actions that were taken for high-risk process failure modes before they caused scrap:

- Ambiguous work instructions were rewritten or modified
- Preventive maintenance schedules were modified
- A water flow sensor was added in the grind area when it was noted that a water supply interruption would have caused extensive damage to the equipment
- Bar code readers were introduced in the shipping area to prevent shipping wafers to the wrong assembly house
- Additional HEPA filtration was introduced in certain areas in the fab
- Water temperature controls were introduced in wafer saw
- Color coded tapes were introduced in the wafer mount operation at scribe and break

The examples above represent tens of thousands of dollars in scrap prevention savings but were insignificant investments in time or equipment to deploy.

CONCLUSIONS

Significant improvements can be achieved in a controlled, proactive manner when process control plans and a dynamic FMEA are deployed and maintained.

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REFERENCES

[1] US Military, *MIL-STD-1629, Procedures for performing failure mode, effects, and criticality analysis (FMECA),* (Revision: A 08/04/98)

[2] AIAG, *Advanced Product Quality Planning and Control Plan,* (2001).

[3] AIAG, *Potential Failure Mode and Effects Analysis,* (2001).

ACRONYMS

APQP: Advanced Product Quality Planning
FMEA: Failure Mode Effects Analysis
PCP: Process Control Plan
RPN: Risk Priority Number
AIAG: Automotive Industry Action Group