Getting to Zero – Methods of Reducing Defects

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Abstract

This recount of a quality improvement journey will start at the top. First, two key philosophies of management will be explained. Next, several processes will be described which provided the framework for individual examples of improvement techniques. Ten specific improvement examples will be presented, each resulting in significant reductions in measured DPMs.

I. Introduction

Everyone wants better quality. Nobody likes defects, but how do you prevent them? Typically, this is a difficult subject for public discussion, since one might need to expose how many defects they have (or had). Nonetheless, the journey is what's important to document here, not the starting point. For most semiconductor companies, quality is measured in parts per million, or "defects per million" (DPMs). For these types of units, "zero" is a level that's relative to the denominator – where zero DPMs might be as high as 500 parts per billion! For the sake of this work, zero DPM is a "good enough" level of quality to mention in front of your customers, so we can get past the stigma of talking about defects in public.

II. Purpose

The intent of this work is to provide information on 1) what viewpoints in management are helpful in supporting defect reduction activities? 2) What are the processes that are effective in reducing defects? and 3) What specific activities have reduced defects?

III. Results

Improvements are referenced in terms of effective management support, methodology, and progress in overall reduction of defectives. The units of measure will be DPMs - as measured.

Figure 1 shows the overall improvement in internally measured DPMs over the past two years. This involves the generic quality defect, and not just the type of physical process defects familiar to fabrication folks. It is important to note Fig.1 is plotted on a log scale, and the data actually does go below "1". For our measurement resolution, the result is zero DPM.

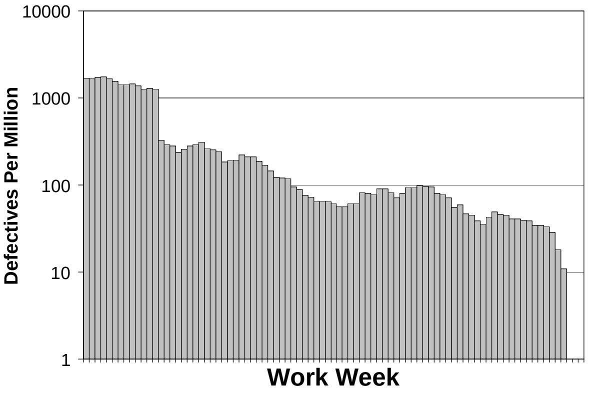

Figure 1. Improvements in Defectives Per Million (DPMs) Over Time.

Management. There are two key enabling actions by management that made this overall improvement effort possible. First of all, the overriding philosophy of continuous improvement provided the framework and sponsorship of the defect reduction process. Under the continuous improvement umbrella, the specific teams could work in a sanctioned environment. In a more general sense, management identified DPM reduction as a key corporate metric – making reduction a "target" for improvement, as well as making it a visible yardstick to all employees of the company. Until these two key management actions, DPM reduction efforts were only partially successful and they typically had very narrow scope. Without the management participation, significant gains were not possible.

The management effects were exactly as expected. Traditional quality programs will only succeed if they are sponsored from the very top. Without the key management sponsorship – the effort is unlikely to follow. The corporate "culture" of improvement was inspired with an initiative named "Continuous Process Improvement." The initiative includes training of all managers to be improvement team facilitators. Training involves team leader skills, traditional quality improvement tools, and leadership management skills. This training includes five full days for team facilitators, and an additional half-day of training for all employees of the company.

The second key method of support was the identification of goals and methods to measure progress towards the goal. The key quality goal was the reduction of DPMs. This goal was reiterated on the divisional, group, section, and personal levels.

Another key part of management support is the publicity and celebration of success. The individual improvement teams are recognized through quarterly meetings where results are presented to the top management of the corporation. Progress on the metrics is presented personally by top management (vice presidents) on a quarterly basis, and the overall results are presented by the President in his quarterly address to the employees. Additionally, completion of major milestones, such as demonstrating defective improvement at each decade, are recognized by a celebratory feast of cake.

Systems. The involvement of system activities became very effective after the management actions mentioned above. Truly cross-functional teams are formed. The first successful process to impact the reduction of defects was to reach agreement on the "official" measurement of defects. The simple act of measuring defectives in the factory led to the first breakthrough – electrical measurements of quality on ICs are difficult. This acknowledgement resulted in a classification methodology of measuring DPMs in two groups: "1st submit" and "confirmed." The 1st submit classification refers to devices that don't pass a production electrical test with a single socket attempt. The confirmed classification refers to fallout devices that are verified as defective regardless of the type or number of socketing attempts. These classifications have proved to be psychologically important. This is because once the classification was made, folks began to focus on improvement rather than attacking the measurement itself. (see Example 3)

The second most important system of improvement is the use of a "Pareto chart." Named after Vilfredo Pareto, the chart is simply a ranking of variables from most to least important. For most of the various parameters measured during an improvement process, such a chart will identify the "important" parameters for improvement. In general, the first one or two variables will emerge as significantly more important than the remaining variables. Below is an example of charting for one particular improvement team.

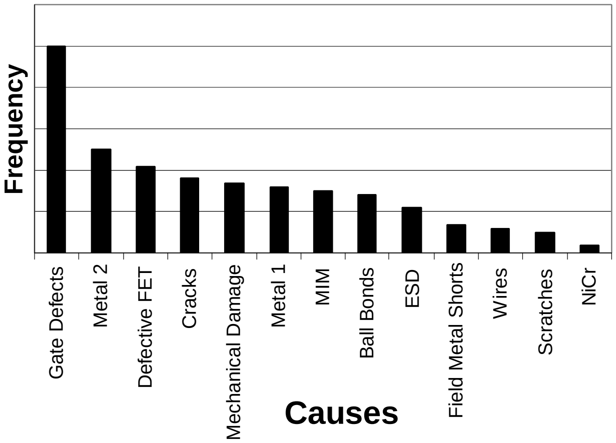

Figure 2. Pareto Chart for the Causes of Defectives Measured in a Yield Investigation

Examples. This work provides ten specific examples of DPM reduction and improvement. Each example involved a team of folks working on the project for approximately three months. Typically, the project would not be a top priority – but an ordinary part of the job. The following table lists the examples and the approximate improvement for each specific example.

Table 1. Improvement Teams and Results.

#	Description	Improvement
1	Change the Sampling Order	30,000 DPMs to 30 DPMs
2	Mitigate #1 Process Defect	20,000 DPMs to 1,000 DPMs
3	Identified Confirmed Vs. 1st Pass	5000 DPMs to 300 DPMs
4	Stop Hot Socket During Test	10,000 DPMs to <1 DPM
5	Purchase New IC Handler	20x and 12x reduction
6	ESD Robustness	10x reduction
7	Remove ESD Sources From Tester	2000 DPMs to 500 DPMs
8	Shorted DC Blocking Capacitors	21.88 DPMs to 3.1 DPMs
9	Intelligent Guard Bands	132.08 DPMs to 6.99 DPMs
10	Change in Sampling Method	Test Cost (DPM Metric)

Example 1. This improvement is an example of a psychology change instead of a material change in the test process. Basically, the test process was influenced to the extent of identifying anomalies and resolving them. The original process was capable of performing screening of anomalies, but the remedy was allowed to become too “automatic”, instead of requiring intervention and root cause elimination.

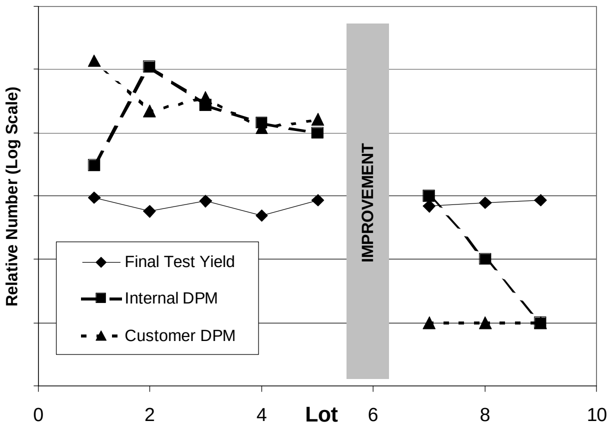

Figure 3. Improvement results from a change to the sequence of sampling during production electrical test.

Example 2. This improvement is a classic example of how removal of defects helps in more ways than expected. For a particular power amplifier design, compliance to requirements on some of the noise parameters was causing excessive fallout. After several attempts at correlating the packaged part noise to DC parameters, a dramatic improvement was obtained by eliminating the top cause of manufacturing defects (Fig.2). At the time of this particular project, the defect was a type of lift-off anomaly on the gate metallization. A change in photolithography, resulted in the improvement shown in Figure 4.

Example 3. It is human nature to be defensive about performance parameters, and DPMs are no exception. One of the typical defense mechanism is to attack the credibility of the data. This is especially true of DPMs since most folks will not accept that defective parts (at any level) actually exist. For more than a year, the DPM data was subject to question. However, instead of defending the data, or attempting to gather more, a successful remedy was to divide the problem. In this example, the folks didn’t want to believe the sample testing results at final QA test. This challenge was particularly effective since many of the “failures” could indeed eventually pass re-test after multiple attempts. The problem was in successfully contacting the devices within the test fixtures for measurement. The questioning about the socket data was especially potent since the end customer didn’t use a socket either, and would instead normally solder the device for use. The “division” methodology was simply to temporarily remove the socketing question from the DPM measurement. This was accomplished by replacing DPM measurements with two alternate measurements labeled “1st pass” and “confirmed.” This method was successful because it effectively set-aside the problem of contacting high performance devices. The method of dividing the DPM definition was successful because even when the socket was eliminated, other causes of DPMs were immediately obvious.

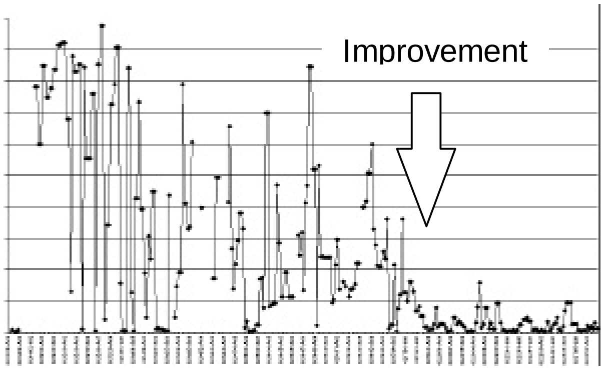

Figure 4. Reduction in Percent Fallout per Lot for Photolithography Improvement in Example 2.

Example 4. The solution of this project is one of those examples that look obvious in hindsight. A power amplifier experienced decreasing final test yields. The test fallout was classified as shorted. Additionally, many lots failed a sample test and the associated defective metrics were increasing anomalously. Failure analysis determined that multiple Fab runs had identical failure signatures.

The failed devices had output FETs that appeared shorted, but were fully functional when isolated from the bias circuit. However, failure analysis determined that a particular nearby FET and/or diode were destroyed in all the failures. The test equipment was investigated. The handler was examined but no issues were found. The functional and diesort testers were also investigated and no problems found. Then the power supplies were examined for transient effects. No “spikes” could be produced, however it was determined that the power supplies were not all sequenced off during the die sort test. However, the damage signature was not found when die sort failures were analyzed. One wafer was then die-sorted multiple times, and the number of failures did increase. Additionally, devices were assembled from wafers that had completed die sort and had been spared from the die-sorting step. It was found that the die sort was indeed causing latent overstress damage that resulted in shorted amplifiers during final test. The die sort test was changed to power down the supplies before moving to the next die. Multiple die sorts did not cause any failures after correction. Yield improved and DPMs dropped on lots utilizing the improved power supply sequence during die sort.

Example 5. This improvement is a straightforward upgrade in equipment. It was found that a particular brand of handler was not adequate to test a particular device. Rather than re-engineer the handler, a different brand was purchased. The new handler improved DPMs by a 20x reduction and improved yield by a reducing one type of fallout 15%.

Example 6. The leading cause of failures in sample testing, field returns, and reliability aging is ElectroStatic Discharge (ESD). This data is clearly shown in Figure 5.

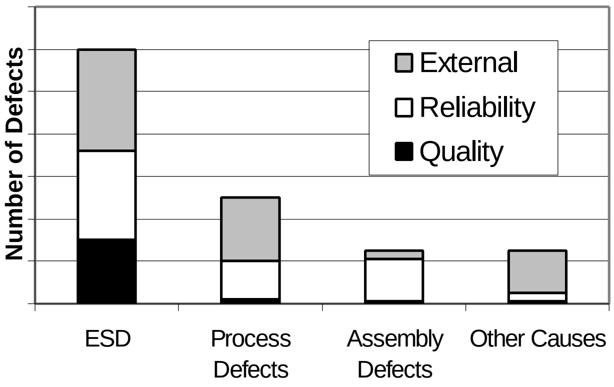

Figure 5. Root Cause of Failures by Source.

ESD can be mitigated in several ways. First, the sources of ESD can be reduced by well-known countermeasures such as wrist straps, heel straps, conductive smocks, ESD workstations, shielded bags, air ionizors, humidifiers, and others. Alternately, the device design can be modified to reduce susceptibility. The following two graphs show examples of each type of improvement. Figure 6. Shows how relative number of DPMs are observed through duplicate lines where some of the countermeasures have been inadvertently disengaged at a high volume manufacturer. Figure 7 shows how a design modification to improve ESD robustness can reduce the DPM levels at a factory.

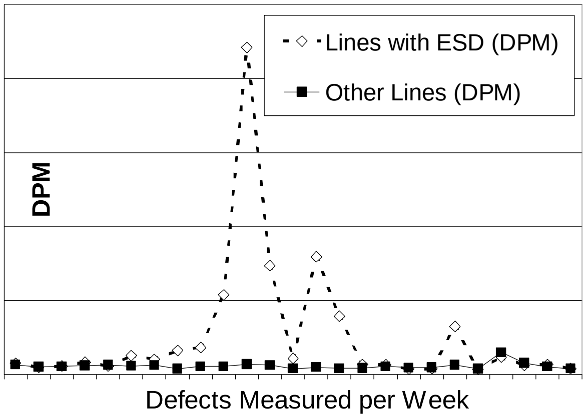

Figure 6. Effect of ESD Countermeasures at a Factory.

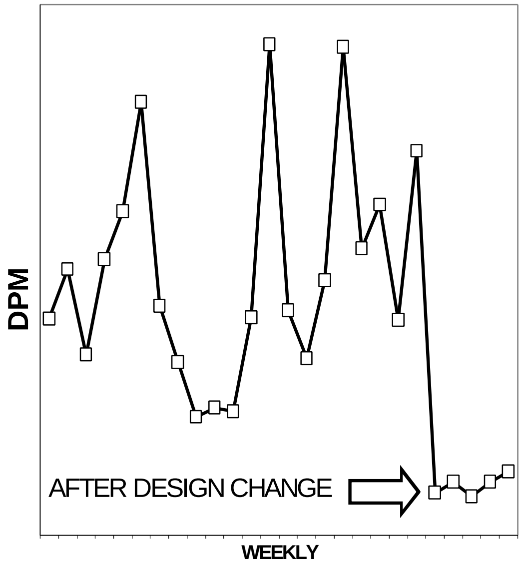

Figure 7. Effect of a design change on DPMs caused by ESD (Measured at a Factory).

Example 7. This improvement is the result of a specific team to evoke ESD countermeasures on a specific part handler. The team began with a similar Pareto chart as shown in Figure 5. ESD was known as the leading cause of DPMs during final test. The team performed an audit of the test area and found the handler was a source of ESD fields. In an effort to improve the handler, metal parts were fabricated to replace some of the non-conductive parts that contact the devices during testing. The results of this simple upgrade are shown in Figure 8.

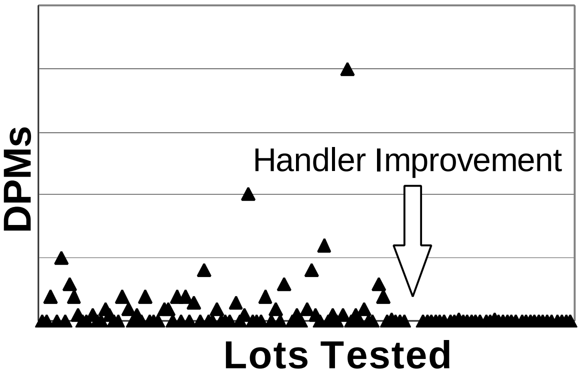

Figure 8. Lot-by-Lot DPMs measured before and after countermeasure improvement to a handler.

Example 8. This is another hardware improvement to the test methodology, but also includes an ESD influence. Examination of some ESD failures discovered that DC blocking capacitors are sometimes damaged. In conjunction, it was found that some of the devices with damaged capacitors would pass electrical test. Test coverage of capacitors can be overlooked since most of the RF test equipment provides it's own DC blocking capacitors and many ports operate with RF, not DC signals. Although this seems like a trivial example, it is representative of the kind of improvements necessary to progress once the DPMs have been reduced. For this product, the resulting improvement was a reduction of DPMs of only 18 DPM, but those defects caused levels to drop from 21 DPM – down to three DPM – an 86% improvement!

Example 9. All of the improvements up to this example have been obvious choices for implementation because of the reduction in DPMs. To the contrary, many actual improvements come at the cost of something else – in other words, a tradeoff. A classic tradeoff comes in setting guardbands for test parameters. A guardband is simply a built-in margin. See Figure 9.

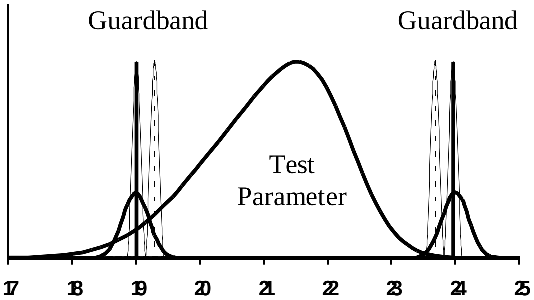

Figure 9. Description of Guardbands.

The tradeoff is simple: if the guardbands are too large, many good devices will be thrown out needlessly, resulting in lost yield. If the guardbands are inadequate, bad devices may actually pass tests, resulting in lost quality or reliability. The tradeoff can be represented graphically by curves as shown in Figure 10.

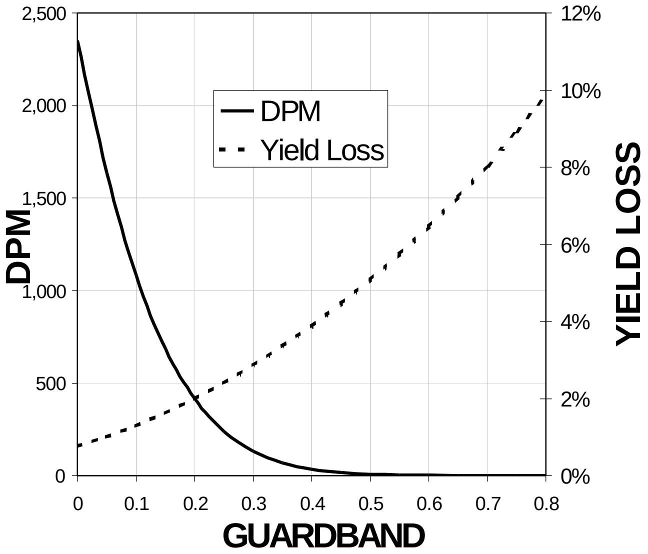

Figure 10. Guardband Tradeoff, DPM Vs. Yield.

If the data exists for a tradeoff graph, then the cost can be calculated for each risk, making the decision more objective. While the cost of yield is usually very simple to quantify, the cost of a DPM may be very subjective. The advantage in converting yield and DPMs to dollars is obvious from Figure 11. First of all, yield and quality can both be plotted on the same axis (dollars), and secondly, the minimum cost can be determined.

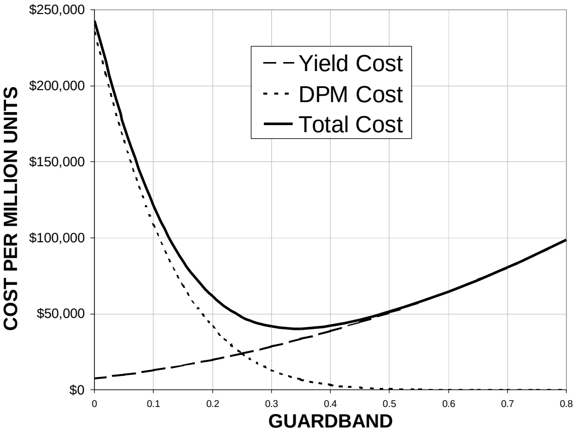

Figure 11. Cost Analysis Curve.

Example 10. This final example is simply an improvement by eliminating "redundant" tests and reducing test time. It is a case where DPMs were not actually reduced, but the level of DPMs observed was used as a metric for selecting sample sizes. It is also used as an example of repeating prior improvements. Since the 1st example involved the sampling methodology, the improvement of revisiting the sampling issue came up again in Example 10 because DPMs were used here as criteria (just like dollars) in selecting the optimum solution. For this example, individual test parameters were examined against each other for correlation. Once parameters with high correlation were identified, they were tested by monitoring DPMs over special samples 15 times larger than normal. If enough samples were screened with a shorter test without producing any failures, the test was considered acceptable with respect to potential DPMs. This method is shown graphically in Figure 12. In this example, a sample of 60,000 parts tested without a screening failure was considered adequate to prove that DPMs would not be adversely impacted by a reduction in the tests.

IV. Summary

This is a discussion on improving quality. This work advances the knowledge of GaAs quality by showing the importance of management and methodology on several specific defect reduction project examples. These ten examples represent the projects causing the most change on a percentage basis. In reality, these were just a small representation of more than 120 improvement teams operating over a 24 month time frame. Although many of the teams were focused on improvements other than the reduction of DPMs, the work of many more teams than the ten described here resulted in overall factory DPM improvement of three orders of magnitude over a two year time span.

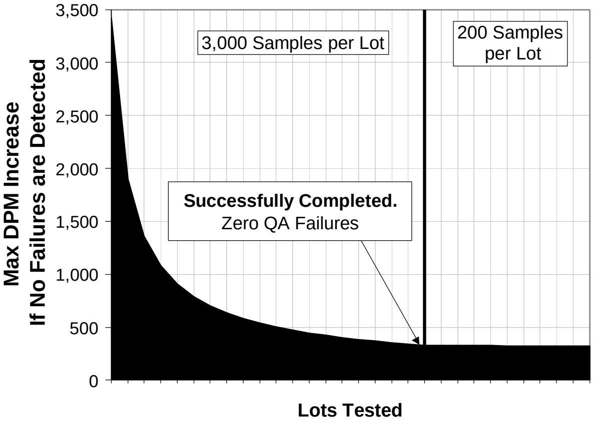

Figure 12. Use of DPMs as a Metric for Improving Sampling and EvaluatingTest Time Reductions.

V. Acknowledgement

The author would like to acknowledge the management support for the methodology employed and described in this paper. The following people lead the improvement teams responsible for the improvements described: Andy Ross, Aaron Koslowski, Dee Byrd, Steve Brockett, Fong Wang, Mike Armentrout, and Mike Sajec.

Reference

The importance and interrelationships of increasing volumes and yield on improved quality on reliability was previously discussed in the reference below.

Volume & Quality Impacts on Reliability: A New Game for GaAs, William J. Roesch, 15th Annual GaAs REL Workshop, Seattle, Washington, November 5, 2000.