Six Sigma in Semiconductor: Continuous Improvement in Production Floor Area

S J S Velu¹, M S Jusoh¹², D H Muhd Yusuf¹², A G M Rosli¹² and M S Hj Din¹

¹Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, Malaysia.
²Center of Excellence Social Innovation & Sustainability, Universiti Malaysia Perlis, Malaysia.

Email: shahar@unimap.edu.my

Abstract. This study addresses the improvement of first pass yield on the production floor of ABC Semiconductor. ABC is a company running a multiple volume complex product in aligning with memory business in the operation. First pass yield refers to the proportion of fully built product that pass testing without the need for additional rework. The first pass yield (FPY) project showed steady progression for its first five years. But over the following one year, the primary yield metric which is first pass yield has stayed stagnant. The goal of the paper presented here is to analyze the reasons for the current performance and propose novel ways of improving the metric again using quality management tools. The most common is using 7QC tools method by categorizing failure pareto that will lead to targeted corrective action to reduce the recurrence of pre-identified failure modes. A DMAIC methodology is establish on how to define an efficient corrective action, along with a top three major defect on data acquired from ABC organization. From the exercise, the yield loss was able to be reduced from 17.4% to 3.52%.

1. Introduction

ABC Semiconductor specializes in their area of research and develops and manufactures memory and storage technologies applied in various applications such as personal computers (PC), networks application, data centers, and the automotive industry. Across its global brands, including ABC semiconductor, the organization produces memory cards, drives, and infrastructure technology. As one of the leading semiconductor companies in the storage and memory business in this earth, ABC faces major competition from other semiconductor companies, and other chip producers. A significant changed has been discovered for self-storage businesses around COVID-19. During the COVID-19 pandemic, business operations have less onsite traffic as many as 52% customers have been reported to avoid going outside and online shopping and other e-commerce activities online has recorded a whopping 74% increase [1]. Working has also been transformed where lockdown during the pandemic has forced as high as 90% employees to work from home [2]. This resulted in changes to the mechanism of their working procedures and strategy. A study has shown new way of life will involve IoT, 5G and automation in every angle of life not limited to personal, works, health care, autonomous, and big data. Align with that, ABC board of director’s has instructed all the department to go for cost improvement initiative as much as possible in this pandemic situation. In fact, all top-level executive teams are working on the cost competitiveness
across the industry not only the semiconductor industry. This is because among the effect due to lockdowns implemented all over the world, costs of production has increase due to increase in freight and shipping costs, shortages of supply, and increase in lead time [3]. Thus, the ABC manufacturing department decided to address the problem of yield improvement in production. Among the widely used solutions to improve quality is the Lean Six Sigma DMAIC methodology [4]. The DMAIC process was implemented to seek how quality can be improved by reducing rejects/defects, thereby improving production yield, and subsequently, reducing costs.

2. Lean Six Sigma DMAIC approach
The crucial approach in Six Sigma is the DMAIC framework problem-solving methodology. DMAIC stands for Define, Measure, Analyze, Improve, and Control among others by preventing duplication process and continuously improve quality performance [5-6]. The DMAIC process can be illustrated as per Figure 1 [7].

![Figure 1. A typical Lean Six Sigma DMAIC process](image)

2.1 Define (D)
This initial stage focuses on analysis of all the parameter categorized as critical to quality (CTQ) and cost of quality (COQ) that need to be addressed keeping in mind by defining project or process scope statement and budget associated. It is critical to define precise problem statement tied with the scope to enable the project team to invest time, skills, and resources in the desired direction accompany with corporate goal. In this case study, the problem is to address yield improvement in the test area.

2.2 Measure (M)
The measure phase involves collecting information and data pertaining to the area understudy. They types of data collected include volume scales, and impacts or loss. All type of metrics of the business impacts are established to measure and realize the intense of the issue.
2.3 Analyze (A)
Usually, the measure and analyze stages are inter-related between each other. All the factor, dependency, variables, hypothesis assessment, potential root cause evaluation using cause will take place. The team also use seven Quality Control (QC) tools such as fishbone/Ishikawa diagrams to drive in our case study yield improvement in production.

2.4 Improve (I)
The fourth stage which is the improvement stage heavily involved in improving or optimizing the current process based on the data analysis from previous stage. The team will recognize on the optimum factor influence in the causing factor by using design of experiment (DOE) method. The case refers a design of 3 factor and 2 level DOE to identify the significant causing factor influencing to improve the production yield.

2.5 Control (C)
Control is the last phase in the DMAIC approach. The purpose in this last phase is to sustain the process to ensure minimum variation involved and defects in the control way. In the case study the parameter has been defined and to be place in the spec to ensure control limit and spec limit has been revised according to the studies outcome.

3. Methodology
In the context of DOE (design of experiments) the design take part in full factorial. DOE is also the design of any experiment that intends to define and explain the variation involved in the process. In this research the team decided for the full factorial design to take place in two level, three factors, eight runs with one replicate. The term mentioned here is generally associated with experiments in which the experiments has been introduces that the conditions that directly influence the variation. The pre six sigma data of defect sample was collected which is as per Table 1. The data drive for a total of 17.04% losses in the production output which has been categorized as reject in form of contamination, overflow, insufficient, and under cure whereby good units are categorized as pass unit (1,712 units, 82.96%). Table 1, show unit of measurement of sample size and translate into percentage.

| Defect          | No. of Sample | %    |
|-----------------|---------------|------|
| Contamination   | 9             | 0.43%|
| Overflow        | 45            | 2.17%|
| Insufficient    | 206           | 9.94%|
| Under cure      | 93            | 4.49%|
| Pass Unit       | 1,719         | 82.96%|
| Total           | 2,072         | 100% |

Table 1. Pre six sigma data

Data has been analyzed using seven QC tools [8-9] and the results are displayed in the forms of bar chart and pie chart to visualize the impact on the performance and translate into percentage measurement. By having this quality management tools (7 QC), this enables the six sigma project team members to understand the independent variable of the study and the factor influence each independent variable.
Figure 2. Visual Inspection for Pre Six Sigma Data

Figure 3. Yield Results for Pre Six Sigma Data

In its simplest form, this experiment is been after understanding the variable involve which is influencing the factor and resulted as outcome. Here the DOE has identified 3 major factor, plasma process, volume of Titanium Oxides (TiOx) and staging temperature which is classified as independent variable is hypothesized to result of the study as per Table 2.
Table 2. DOE leg

| Std Order | Run Order | Center Pt | Blocks | Plasma | Vol of TiOx | Staging |
|-----------|-----------|-----------|--------|--------|------------|--------|
| 7         | 1         | 1         | 1      | Non Plasma | Half       | 23     |
| 3         | 2         | 1         | 1      | Plasma   | Half       | 23     |
| 5         | 3         | 1         | 1      | Non Plasma | Normal     | 23     |
| 1         | 4         | 1         | 1      | Plasma   | Normal     | 23     |
| 8         | 5         | 1         | 1      | Non Plasma | Half       | 60     |
| 4         | 6         | 1         | 1      | Plasma   | Half       | 60     |
| 6         | 7         | 1         | 1      | Non Plasma | Normal     | 60     |
| 2         | 8         | 1         | 1      | Plasma   | Normal     | 60     |

Each of the independent variable listed is being influence by 2 major levels mentioned. In the plasma process, the levels are non-plasma and plasma, while volume of TiOx is influence by half volume or normal volume, and finally, staging temperature is influence by low temperature 23 degree and 60 degrees.

Figure 4. Minitab statistical approach (full factorial design)

Key concerns driving this experiment are the institution of validity, reliability, and reproducibility of the results. For an example, all these concerns are being tackled by carefully choosing the most critical independent variable, reducing the risk of measurement error in each level of data, and ensuring that the documentation of the method is has been discover in all the engineering context. All data has been analyzed in suitable levels of statistical approach and sensitivity as per to Figure 4 Minitab statistical approach (full factorial design).

Yield loss data is collected for a period of two quarter time frame. Rolling data of 26 weeks has been collected and monitored

4. Results & Discussions
Results for each process and process are as per Figure 5, 6, 7 and 8. Based on Figure 5, factor of Plasma and Staging Temp does show a significant different between the 2 levels of factorial. On the other hand, for the volume of TiOx does not contribute a big impact in the effects of the half and normal volume. Based on Figure 6, there is no significant different interaction between staging temp and TiOx volume. While Plasma plays a big role in TiOx flow where the behavior is different when applied with 2 types of staging and volume.
Based on Figure 7, half volume, 60 degrees staging temperature with plasma shows a flux drop <5% and meet the CTQ’S requirement. The lowest flux drops 4.02 shows a nonstandard production mode.
Based on Figure 8, TiOx volume shows a big impact in the side coating process where it is found to interact with 2 levels of plasma and temperature.

Given the demand of strong volume has been forecasted in this process, the team has produced a significant improvement result by institute quality management tools (7 QC tools). The calculation methodology outlines the post six sigma results. The data drive for a total of 13.52% yield improvement in the production output which has been categorized as pass unit. Table 1, consist in unit of measurement of sample size and translated into percentage. However, the improvement can be seen in Table 3 where the percentages of pass unit have increased from 82.96% (pre-Six Sigma) to 96.48%. As a result, improvement has also been noted in productivity, cost per unit (CPU) and as well as cost of nonconformance (CONC) and cost of poor quality (COPQ).
Table 3. Post six sigma data

| Defect      | No of Sample | %   |
|-------------|--------------|-----|
| Contamination | 8            | 0.40% |
| Overflow    | 33           | 1.66% |
| Insufficient | 22           | 1.11% |
| Under cure  | 7            | 0.35% |
| Pass Unit   | 1,919        | 96.48% |
| **Total**   | **1,989**    | **100%** |

The post Six Sigma data were analyzed using seven QC tools in form of bar chart and pie chart to visualize the impact on the performance and translate into percentage measurement as per Figures 9 and 10.

Figure 9. Post six sigma data
In this experiment, by using the DMAIC approach, the yield losses was reduced from 17.4% to 3.52% as shown in Figure 11.

Figure 10. Post six sigma data

Figure 11. Yield loss (Pre and post six sigma)
5. Conclusion
Based on the yield loss data collected for 26 weeks, the yield lost was able to be controlled to be below 4% (average of 3.52%). This has been achieved by implementing the Lean Six Sigma DMAIC approach by identifying the major independent factor that influence the yield losses. The continuous improvement proposed aligned with Lean Six Sigma objectives of identifying the waste and eliminate the non-value added in the production floor.

References
[1] A. Bhatti, H. Akram, H. Basif, A. Khan, A. Naqvi and M. Bilal 2020 International Journal of Future Generation Communication and Networking 13(2) pp. 1449-1452
[2] M. Singh and V. Kumar 2020 Journal of Xi'an University of Architecture & Technology 12(5) p. 3176
[3] C. Rumbaugh, J. Hrbek, M. Hickey, N. Markowitz, T. Howell and M. Awwad 2020 Proceedings of the International Conference on Industrial & Mechanical Engineering and Operations Management
[4] S. Bushell 1992 The Journal for Quality and Participation 15(5) p. 58
[5] S. Ahmed 2019 Rev Environ Health 34(4) pp. 427-434
[6] Salvaragh I.R., Jusoh M.S., Salleh S.S.M.M., Ahmad R. and Din M.S.H. 2021 AIP Conference Proceedings 234721(July), article number 020286
[7] G. Impromta, G. Balato, P. A. Romano, E. Raiola, M. Russo, P. Cuccaro, L. Santillo and M. Cesarelli 2017 Journal of Evaluation in Clinical Practice pp. 1-7
[8] Sargunan S.A., Jusoh M.S., Yusuf D.H.M. and Din M.S.H. 2021 AIP Conference Proceedings 234721(July), article number 020224
[9] Yogeswary Y., Jusoh M.S., Yee C.S., Shyang T.C. and Din M.S.H. 2021 AIP Conference Proceedings 2347(July), article number 020201

Acknowledgments
The authors wish to thank the Ministry of Higher Education (MOHE), Malaysia, for their financial support of this study through Fully Integrated Students Entrepreneurial Mapping & Entrepreneurial Knowledge Management System (FISEM) Grant, 9007-00039.