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# Particle Reduction at Metal Deposition Process in Wafer Fabrication

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## 1. Introduction

Metal Deposition or metallization process is one of the processes in fabricating a wafer. A wafer is a thin slice of semiconductor material, such as a silicon crystal, used in the fabrication of integrated circuits and other micro-devices. Due to the nature on the process, it creates lot of particles, which would impact the next process if it were not removed. Particle deposition on the wafer surface can cause the circuit to malfunction; leading to a loss of yield. Cleaning process needs to be done after metal deposition process in order to remove the particles

Metal deposition, which has been constructed by several metal layers, allows the flow of current between interconnections. Each metal layers consist of three types of metal films such as Ion Metal Plasma Titanium (IMP Ti), Titanium Nitride (TiN) and Aluminum. The metal deposition started after the wafer has completed the "Tungsten Chemical Mechanical Polishing" (CMP) process.

Metal layers are deposited on the wafer to form conductive pathways. The most common metals include aluminium, nickel, chromium, gold, germanium, copper, silver, titanium, tungsten, platinum and tantalum. Selected metal alloy also may be used. The metal layer is shown in Figure 1 and the interconnection between metal layers is shown in Figure 2.

The deposited metal(s) offers special functionality to the substrate. Typically, the metal aqueous solution is employed for the wet metal deposition process due to the consideration of its low cost and operation safety.

Metallization is often accomplished with a vacuum deposition technique. The most common deposition processes include filament evaporation, electron- beam evaporation, flash evaporation, induction evaporation and sputtering. There are also two types of wet metal deposition processes – electrolytic and electro-less plating.

Sputtering and evaporation are well established as the two most important methods for the deposition of thin films. Although the earliest experiments with both of these deposition techniques can be traced to the same decade of the nineteenth century (Grove, 1852; Faraday, 1857), up until the late 1960s evaporation was clearly the preferred film-deposition technique, owing to its higher deposition rates and general applicability to all types of

materials. Subsequently, the popularity of sputter deposition grew rapidly because of the need to fabricate thin films with good uniformity and good adhesion to the substrate surface (demand driven by the microelectronics industry) as well as the introduction of radio-frequency (RF) and magnetron sputtering variants.

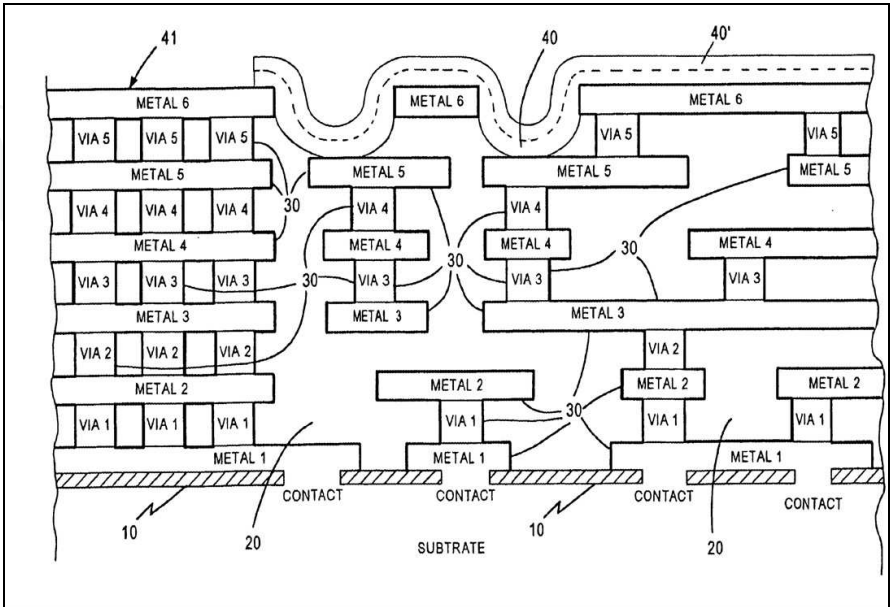


Fig. 1. The Metal layers

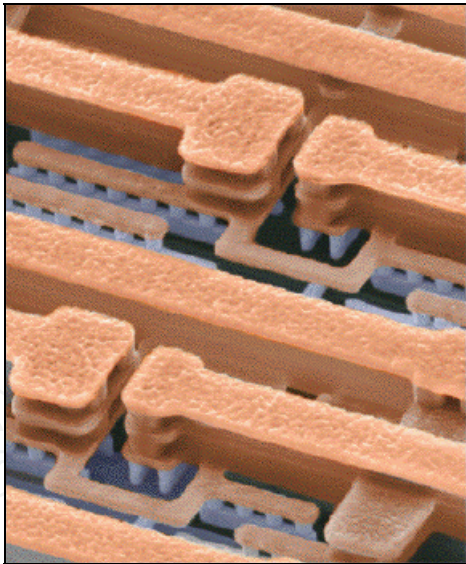


Fig. 2. The interconnection between metal layers

In this chapter, a thorough investigation was carried out to improve shut down event problem at Metal Deposition process during wafer fabrication. Particle contamination on wafer surface can cause the circuit to malfunction and leading to machine shut down. Data of shutdown event versus sputter target life showed that the rate of machine shutdown increased by the increment of sputter target life. The sputter target life was further investigated to determine the appropriate sputter target life to be used in order to avoid particles generation during metal deposition process.

## 2. Particles

Particles can be defined as “suspension of solid or liquid mass in air”. Particles can originate from a variety of sources and possess a range of morphological, chemical, physical and thermodynamic properties. The particles could be combustion generated, photo-chemically produced, salt particles from sea spray or even soil-like particles from re-suspended dust. Particles may be liquid; solid or could even be a solid core surrounded by liquid.

Particles are represented by a broad class of chemically and physically diverse substances. Particles can be described by size, formation mechanism, origin, chemical composition, atmospheric behavior and method of measurement. The concentration of particles in the air varies across space and time, and is related to the source of the particles and the transformations that occur in the atmosphere. Some of the more generalized characterization of particles is:

- i. Primary and secondary particles: A primary particle is a particle introduced into the air in solid or liquid form, while a secondary particle is formed in the air by gas-to-particle conversion of oxidation products of emitted precursors.
- ii. Particle characterization as per size: Particle can be classified into discrete size categories spanning several orders of magnitude, with inhalable particles falling into the following general size fractions-  $PM_{10}$  (equal to and less than 10 micrometre ( $\mu m$ ) in aerodynamic diameter),  $PM_{2.5-10}$  (greater than 2.5  $\mu m$  but equal to or less than 10  $\mu m$ ),  $PM_{2.5}$  (2.5  $\mu m$  or less), and ultra fine (less than 0.1  $\mu m$ ).
- iii. Particle characterization depending on requirements of study: Some of the particle components/ parameters of interest to health, ecological, or radiative effects; for source apportionment studies; or for air quality modeling evaluation studies are particle number, particle surface area, particle size distribution, particle mass, particle refractory index (real and imaginary), particle density and particle size change with density, ionic composition (sulphate, nitrate, ammonium), chemical composition, proportion of organic and elemental carbon, presence of transition metals crustal elements and bioaerosols

### 2.1 Particle contamination

Particle contamination can be defined as the act or process of contaminating by particulates. Particle contamination is problematic for many industries. They can appear unexpectedly mixed in solids, liquids and gases. Particles can be from many sources i.e.- metals, biological (skin, hair etc), polymers, building dusts etc. They all have different characteristics and properties such as shape, size and chemistry, which assist in identification. Scanning Electron Microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDX) coupled with optical microscopy provides a powerful machine for unambiguously identifying such particles. The technique is frequently coupled with Fourier transform infrared spectroscopy (FTIR) when identifying the source of organic contamination (Stephen, 2010).

#### 2.1.1 Particle contamination in semiconductor

Deposition of aerosol particles on semiconductor wafers is a serious problem in the manufacturing of integrated circuits. Particle deposition on the wafer surface can cause the circuit to malfunction, leading to a loss of yield. With the circuit feature approaching 1  $\mu m$  in

size of one-megabit memory chips, particle control is becoming increasingly more important (Benjamin et al., 1987). Particle contamination during vacuum processing also has a significant impact in Very Large Scale Integration (VLSI) process yield (Martin, 1989) and has motivated most manufacturers to adopt particle control methods base on sampling inspection.

According to Bates (2000), semiconductor memory chips are very sensitive to the particles because the circuitry is so small. In a typical clean room manufacturing environment, particles are deposited on the wafer surface by sedimentation, diffusion, and/ or electrostatic attraction. Sedimentation usually occurs for large particles, particularly those larger than 1  $\mu\text{m}$  in diameter, whereas diffusion occurs for small particles below 0.1  $\mu\text{m}$  in diameter.

In the intermediate size range, both sedimentation and diffusion may occur and must be considered. When particles are electrically charged, enhanced deposition can take place. The rate of particle deposition on a wafer surface depends on both the size of the particle and their electrical charge. In addition, the deposition rate is also influenced by the airflow around the wafer, which in turn are affected by the size of the wafer, the airflow velocity, and the orientation of the wafer, with respect to the airflow. Although the mechanisms of particle deposition on semiconductor wafers are reasonably well understood and approximate calculations have been made (Cooper, 1986; Hamberg, 1985), no detailed quantitative calculation has been presented.

### 2.1.2 Particle contamination in wafer processing

As the chip density increases and semiconductor devices shrink, the quality of fabrication becomes more crucial. The composition, structure, and stability of deposited films must be carefully controlled and the reduction of particulate contamination in particular becomes increasingly crucial as device sizes shrink and densities increase. As the devices grow smaller, they become more sensitive to particulate contamination, and a contaminant particle size that was once considered acceptable may now be a fatal defect. Voids, dislocations, short circuits, or open circuits may be caused by the presence of particles during deposition or etching of thin films. Yield and performance reliability of microelectronic devices may be affected by the mentioned defects (Alfred, 2001).

Often, the process gases will react and deposit material on other surfaces in the reactor besides the substrate. The walls of the processing chambers may be coated with various materials deposited during processing, and mechanical and thermal stresses may cause these materials to flake and become dislodged, generating contaminated particles. In processing steps that use plasma, many ions, electrons, radicals, and other chemical "fragments" are generated. These may combine to form particles that eventually deposit on the substrate or on the walls of the reactor (Alfred, 2001). Particulate contamination also may be introduced by other sources, such as during wafer transfer operations and backstream contamination from the pumping system used to evacuate the processing chamber.

In plasma processing, contaminated particles typically become trapped in the chamber, between plasma sheath adjacent to the wafer and plasma glow region. These particles pose a significant risk of contamination, particularly at the end of plasma processing, when the power that sustains the plasma is switched off. In many plasma-processing apparatuses, a focus ring is disposed above and at the circumference of the wafer to enhance uniformity of processing by controlling the flow of active plasma species to the



wafer, such as during a plasma etch process. The focus ring, and the associated wafer clamping mechanism, tends to inhibit removal of the trapped particles by gas. Thus, there is a need to provide a reliable and inexpensive process to remove such particles from the wafer-processing chamber (Alfred, 2001).

Similarly, in chemical vapor deposition and etching, material tends to deposit on various parts of the apparatus, such as the susceptor, the showerhead, and the walls of the reactor, as the by-products of the process condenses and accumulates. Mechanical stresses may cause the deposited material to flake and become dislodged. These mechanical stresses are often caused by wafer transfer operations, but may also be caused by abrupt pressure changes induced by switching gas flow on and off and by turbulence in gas flow. Thus, process by-products at the end of the processing stage must be flushed from the chamber to prevent them from condensing and accumulating inside the chamber.

Typically, the flow of the processing gas is shut off at the end of a processing stage, whereupon the pressure in the chamber rapidly falls to zero as the vacuum pump continues to run. Idle purge may be used; in which purge gas is introduced into the chamber at intervals while no processing is taking place. Nonetheless, pressure spikes occur with the cycling of gas flow, causing disruption of particles, which may then contaminate the wafer surface. This limits the particle reduction benefits from the idle purge. A large portion of device defects is caused by particles disrupted by pressure change during wafer loading and moisture on the pre-processed wafer surface (Alfred, 2001).

Three types of particle contamination can be defined, which are under the deposited film as shown in Figure 3, in the deposited surface as shown in Figure 4 and deposited Film as shown in Figure 5. Particle under the deposited film will cause the surface of the wafer to become dirty. The particle may come from the previous process. Particle in the deposited surface will cause gas phase nucleation, leaks into the system, contamination in gas source/flow lines and sputter off walls. The particle may come from the gas phase nucleation, system leak or contaminated gas line. Particle on the deposited film will cause film build-up on the chamber walls. The source may come from the process chamber or from the wafer handling.

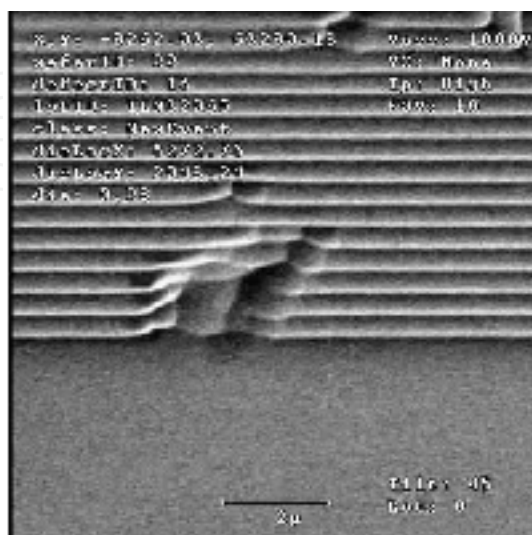


Fig. 3. Particle under the deposited Film

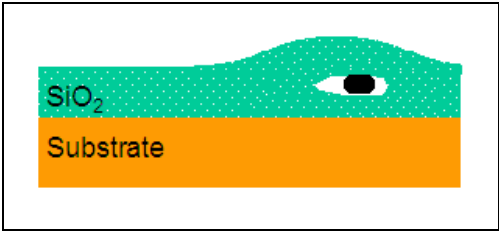


Fig. 4. Particle in the deposited surface

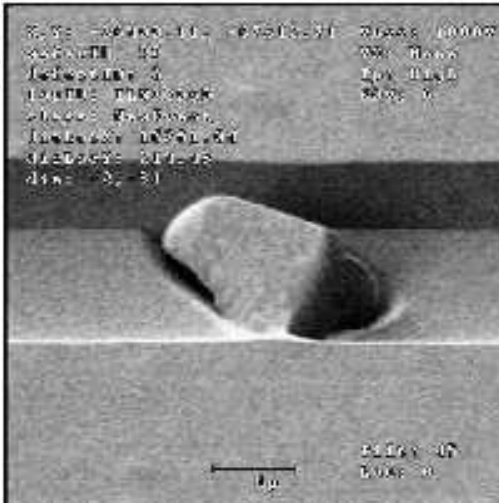


Fig. 5. Particle on the deposited Film

Example of TiN particle transformation is shown in Figure 6. From this figure, the particle was dropped on the wafer’s surface. The source of the particle may come either form previous process or from current process. After the deposition process done, the particle will be covered underneath the metal layer, which cause the damage of the interconnection.

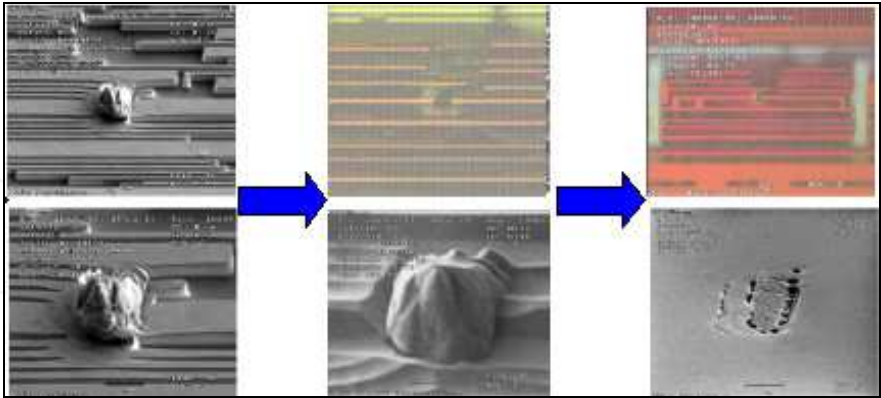


Fig. 6. The transformation of TiN particle

The particles entrained in the load lock air volume by turbulence during pumping are either carried in through the handling of the wafer, generated within the camber from causes such as wear or residual from previous pumping and venting cycles. Particles are removed as they are drawn out during pumping or as they are carried out of the surface of the wafers. Additional particles may bind to the walls of the chamber or machining to tightly that they are agitated free by subsequent pump/ vent cycles (Peter Bordon, 1990).

An equilibrium background level is reached because the number of particles carried out by pumping and deposition on the wafer surface is proportional to the number of particles entrained into the gas volume. For example, if the number of particles entrained doubles, twice as many particles land on the wafer and twice as many flow out the pump line (Bordon, 1990). The effectiveness of these mechanisms has long been recognized. For example, it is a common practice to pump/ vent clean process chambers in high- current ion implanters and other process machines or to run getter wafers after a chamber has been contaminated.

Low levels of particulate contamination can be obtained in process gas systems by using careful system design, high-quality compatible materials, minimum dead legs and leak rates, careful start-up and operating procedures, etc. Low particle levels can also be obtained in gas cylinders through careful selection of cylinder materials, surface treatment and preparation, and through close attention to gas fill system design and operation (Hart, et al., 1994).

Particle levels in flowing gas systems may be steady or (as in machine vent lines) cyclic over time. In machine feed lines, the gas is usually well mixed and particles are uniformly distributed. However, particle levels in gas cylinders can vary by orders of magnitude over time due to such effects as liquid boiling, gravitational settling, and diffusion to internal surfaces. Such effects may also produce non-uniform particle distributions, including stratification, in gas cylinders (Hart, et al., 1995). Levels of suspended particles in filled cylinders can be measured with a high-pressure Optical Particle Counters (OPC). Data obtained directly from cylinders show that careful attention to quality can result in low cylinder particle concentrations.

Cylinder and bulk gases are frequently reduced in pressure with an automatic regulator before entering the flowing distribution system. Automatic regulators may produce increased particle levels (through regulator shedding, impurity nucleation, and condensational droplet formation) that are sometimes followed by system corrosion (Chowdhury, 1997) or suspended nonvolatile residue formation. Gases are therefore filtered after pressure reduction and before entering the distribution system. Ceramic, metal, or polymer membrane filters are selected for compatibility with the process gas. Such filters can produce a low particle level as well as a low degree of variability in contamination over time.

CNC data for particles as small as  $0.003\mu\text{m}$  in  $\text{O}_2$  and  $\text{H}_2$  can also be obtained using an inert gas CNC with a special sample dilution device developed by Air Products (McDermott, 1997). These data showed that membrane filters can be used to produce high-cleanliness gases to  $0.003\mu\text{m}$  in large-volume gas systems. Well-designed distribution systems should contribute a minimum of additional particulate contamination to the flowing gas.

As the particle may impact the wafer quality, which result in wafer scrap, corrective and preventive action must be made immediately to stop the particle contamination from becoming catastrophic. Thus, a systematic problem solving method is needed to solve the issue.

## 2.2 Particle failure

In this step, the types of particle failure were studied. Data from Daily Particle Qualification process was analyzed. TiN particle have highest standard deviation  $\sim 4.0$  compared to Aluminium (Al) and Ion Metal Plasma Titanium (IMP Ti) as shown in Figure 7. This showed



that TiN particle performed the most inconsistent compared to Al and Imp Ti particle in the Metal Deposition process. Data for each films particle qualification was obtained and then Pareto Analysis was made. From the Pareto Chart, TiN defect has the highest failure rate compare to other films as shown in Figure 8.

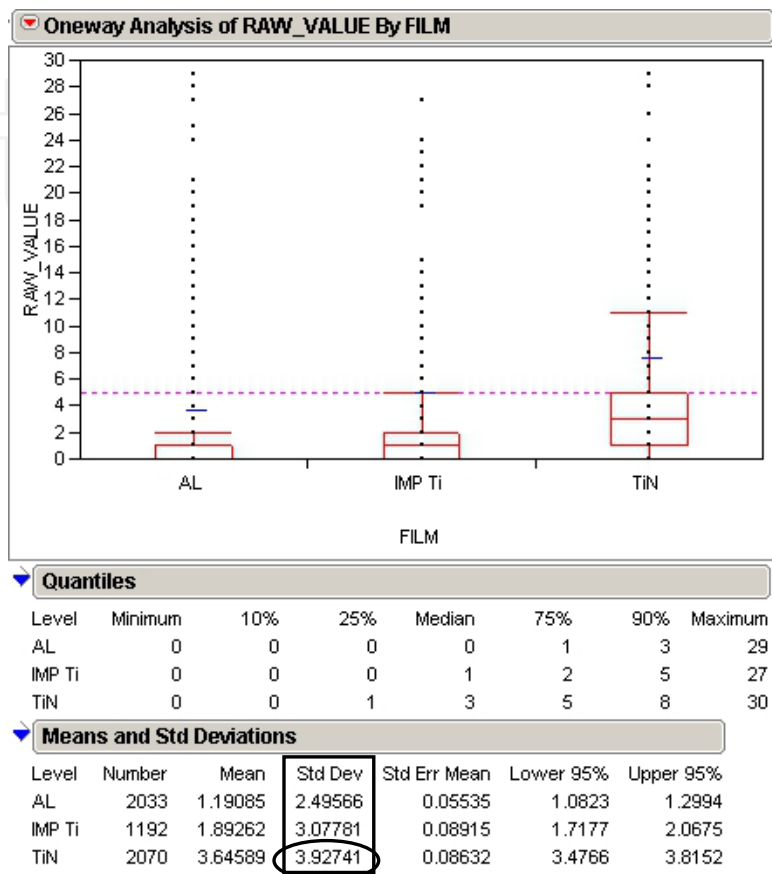


Fig. 7. Comparison between Al, IMP Ti and TiN

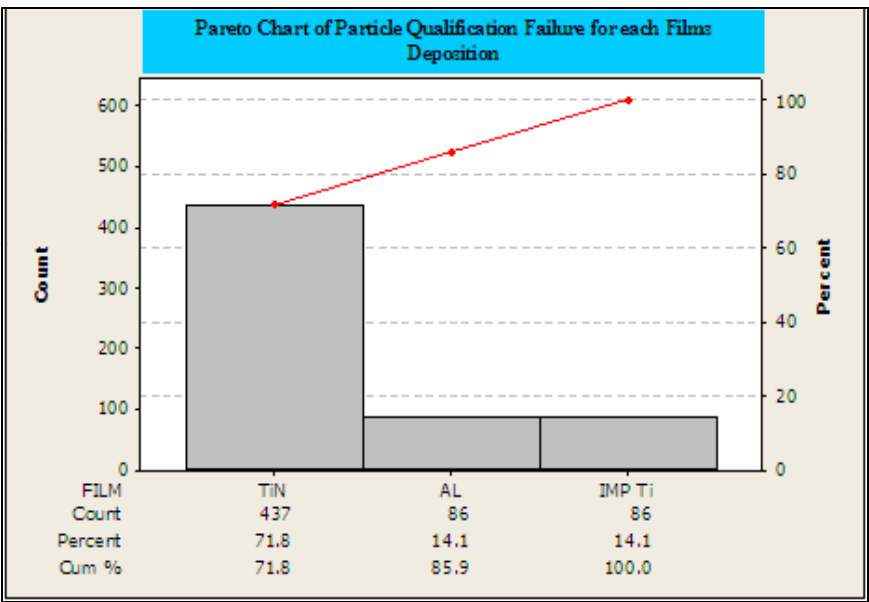


Fig. 8. Pareto Chart of Particle Qualification Failure for each Films Deposition

2.3 Chamber configuration and wafer processing sequence

Chamber configuration for metal deposition machine is shown in Figure 9. From below chamber configuration, the wafers which inside the cassette are placed at cassette Load lock, which consist of Load lock A (LLA) and Load lock B (LLB). Wafer will pass through form Buffer camber to transfer chamber in Chamber A. Then, wafer will be cooled down in Chamber B. At the end of the process, wafers will be vented to Atmosphere condition in Load lock A or Load lock B, depending to which Load lock the wafers origin.

Wafers in a production pod will be pumped down to vacuum condition from atmospheric pressure in load lock A or load lock B, depending on where the lot is placed. Degas and notch alignment occurred in Chamber E and F. The deposition process begins with IMP Ti deposition in Chamber C. The wafers will move into the transfer chamber in Chamber A. Metal deposition will occur in Chambers 1, 2, 3 and 4. Depending on the application, multiple metal films can be stacked without breaking the vacuum. After the deposition process, wafer will be cooled down in Chamber B and vented back into the atmosphere in the production pod at Load lock A or B.

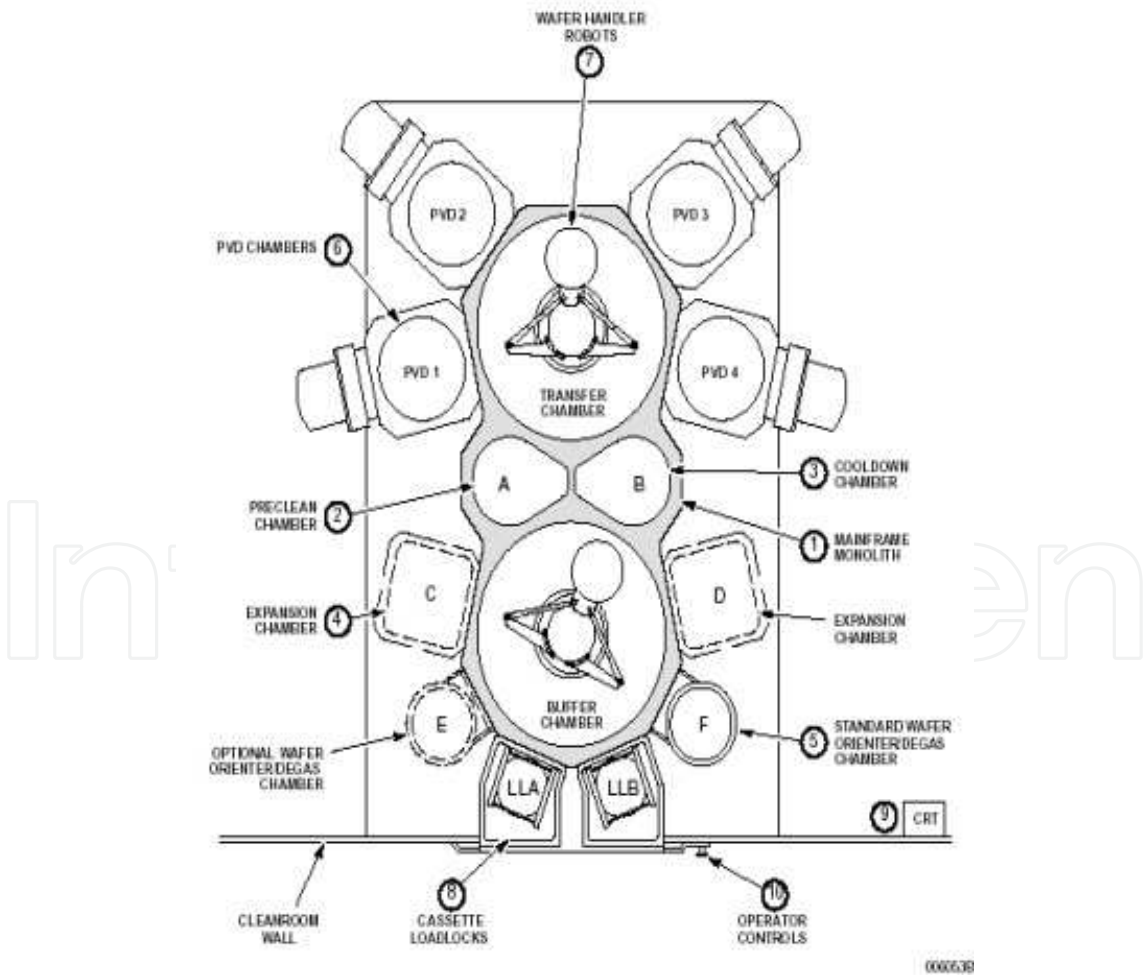


Fig. 9. Chamber Configuration of the Metal Deposition Machine

3. Cause and effect analysis diagram

A case study has been conducted in one wafer fabrication company. Downtime reduction at Metal Deposition process is being focused in this work. In average, three cases of Metal Deposition machines have been shutdown every week. Shutdown criteria is based on more than “10-area count per wafer” or well known as “adders”. The machine will be shut down if the post scan result shows particle increase more than 10 adders.

Brainstorming session has been done with the team members and root causes have been identified and classified under six main sectors, which are machines, material, methods, measurements, environment and personnel. Figure 10 is the fish bone diagram for cause and effect analysis.

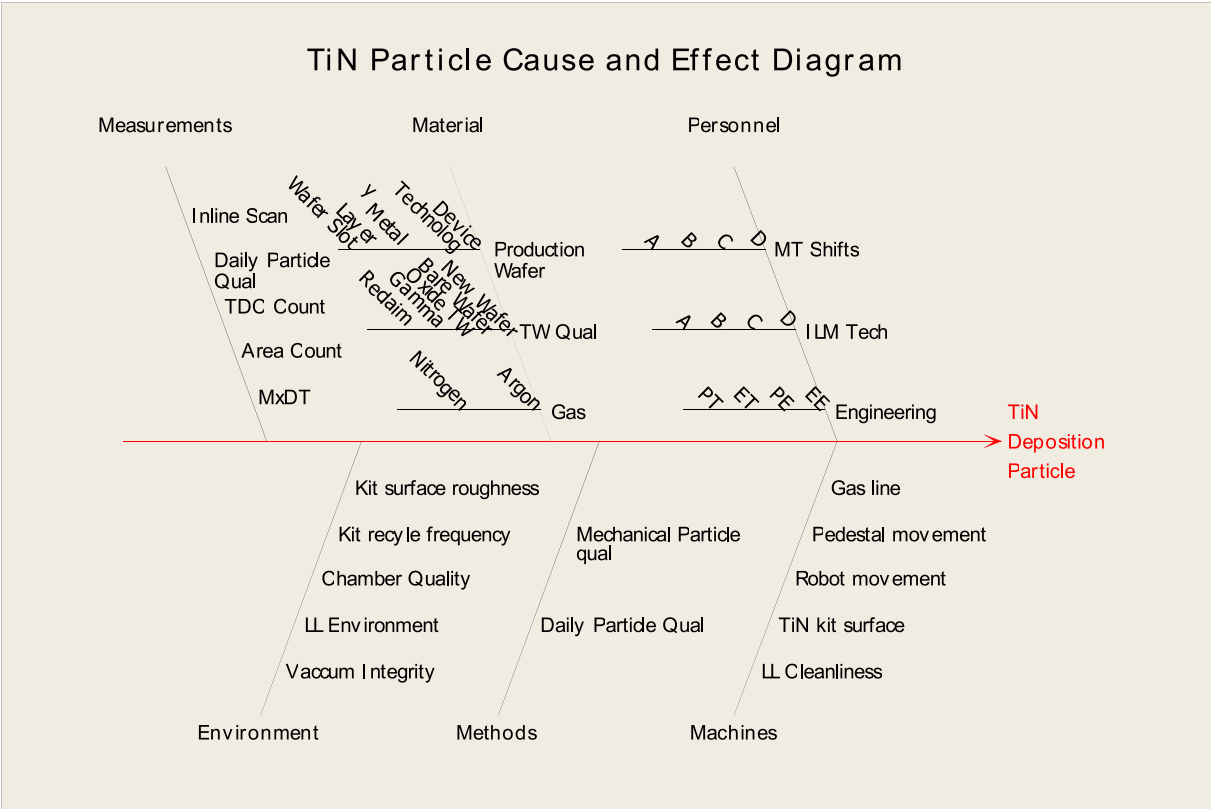


Fig. 10. The fish bone diagram of cause and effect analysis

3.1 Measurement systems

Particle measurement is performed by using the SP1 machine as shown in Figure 11. SP1 is the machine, which is measuring the particle by scanning and counting the existing particle on the wafer. Besides that, SP1 also is capable to show the wafer map, which can tell either the particles are clustered on the wafer, saturated, mild signature and others.

Percentage of Gage Repeatability and Reproducibility (GRnR) was done on SP1 in the production floor, which is used for particle scanning purpose. Gage RnR study is conducted to determine the measurement system variability in term of Repeatability and Reproducibility. TiN particle count is our KPOV that causing machine shutdown by ILM due to metal deposition particle existence in the machine.

Based on the GRnR study, the result proves that the SP1 is capable to measure the TiN Dep particle counts cine the total GRnR is less than 30%. The result of GRnR study is shown in Figure 12.



Fig. 11. The SP1 machine which measure the particle

Gage R&R		
		%Contribution (of VarComp)
Source	VarComp	
Total Gage R&R	0.67500	6.88
Repeatability	0.38333	3.91
Reproducibility	0.29167	2.97
Day	0.14722	1.50
Day*Slot	0.14444	1.47
Part-To-Part	9.13519	93.12
Total Variation	9.81019	100.00

		Study Var (6 * SD)	%Study Var (%SV)
Source	StdDev (SD)		
Total Gage R&R	0.82158	4.9295	26.23
Repeatability	0.61914	3.7148	19.77
Reproducibility	0.54006	3.2404	17.24
Day	0.38370	2.3022	12.25
Day*Slot	0.38006	2.2804	12.13
Part-To-Part	3.02245	18.1347	96.50
Total Variation	3.13212	18.7927	100.00

Number of Distinct Categories = 5

Fig. 12. The result of GRnR study for SP1

3.2 In-line monitoring and systematic machine excursion monitoring

There are three methods of inspecting and measuring the particle, which are using production wafers through Systematic Machine Excursion Monitoring (STEM), production wafer that went to In-line monitoring process (ILM) flow and test wafers which is being used during machine qualification process.

In-line monitoring (ILM) is a process to detect any defect in real time. It is done in many ways, such as in line inspection, upon request from user, from production lots which go to ILM flow and also Systematic Machine Excursion Monitoring (STEM) lots. Machine-related defect excursions are controlled by systematically checking process machines. Production wafers are being used for STEM purpose. Each of Metal Deposition machine need to do STEM activity once every two days. STEM is a process where the lot which is already completely processed from one machine, will be held for ILM scan. The scan is done to check for any defects that may be caused by the processing machine at previous process. STEM will provide faster detection and containment of the defect excursion. All major process machines are monitored in a systematic manner.

For STEM activity, Manufacturing Technician will hold the lot for ILM Technician after run through the metal deposition machine. ILM Technician will scan four wafers/ machine using Complus or AIT machine. If the scan result shows particle signature and above the control limit (more than 10 counts), they will shutdown the whole machine and the machine owner need to verify the shutdown prior to release the machine back to production.

For production wafers, there will be about 30% of the WIP will go to ILM inspection step. This is the random sampling in line scanning that has been designed to detect any defects along the process of fabricating the wafers from first process until end on the process. It has been designed in the process flow, where lots that are needed for this sampling will have ILM inspection flow compare to the other 70% of the lots that do not have ILM flow. Lots that have ILM flow will arrive at ILM inspection step after completing metal deposition process. ILM technician will scan the lot and if found particle and above the control limit (more than 10 counts), machine will be shutdown and same verification need to be done prior to release the machine back to manufacturing.

For qualification process, bare wafers or known as test wafers is used to check the machine's condition and performance. Qualification process is done based on schedule. Basically, every metal deposition machines need to perform qualification process once everyday. This is to ensure the machine is fit to run and not causing any defect later. Qualification process is carried out by manufacturing technician using SP1.

The qualification process is started with the pre particle measurement. Qualification wafer (bare wafer) will be selected and pre particle measurement is done using SP1. After pre-measurement is completed, the wafer will go inside the machine and process chamber for machine and chamber qualification purpose. After the process is completed, the wafer is again brought to SP1 for post particle measurement. The differences between pre particle value and post particle value will determine the machine and chamber's condition. For qualification process, the control limit is tightened to five count only. If particle is found more than five count, chamber will be shut down and pending verification from machine owner is needed prior to release the machine back to production.

Example of the pre particle and post particle measurement is shown in Figure 13. In Figure 13, two wafer maps were shown, which are pre particle wafer map and post particle wafer map. In Pre Particle wafer map, two particle counts were detected as circled. In post particle wafer map, four particle counts were detected. Two count were the existing particles and the other two were new particles, which were detected during post particle measurement. From Figure 13, the adders were two counts (post particle value- pre particle value).



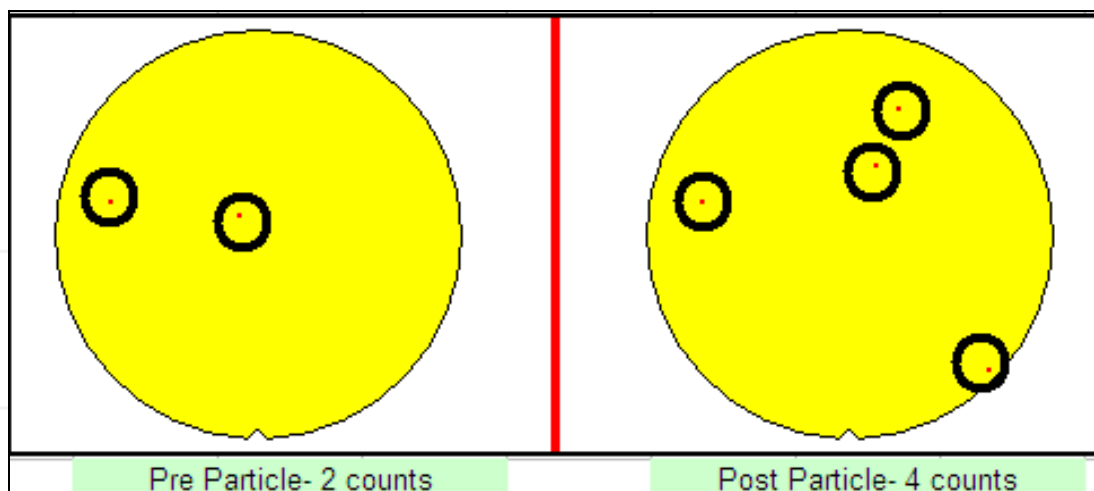


Fig. 13. Pre Particle and Post Particle Wafer Map

### 3.3 Possible root cause

From Ishikawa Diagram, possible root causes will be screened out to get the actual causes. From actual causes, potential corrective and preventive actions will be determined and implemented.

### 3.4 Personnel

There are four shifts in the studied company, which are shift A, B, C and D. Manufacturing technician (MT) for every shift is responsible to perform the daily qualification job daily. Since there are four shifts running in the production, the level of experiences between shifts to shift differs. The level of experiences of the MT is very important since they need to perform the qualification process. Experienced MT will know and easily catch the particle issue inside the chamber by looking at the qualification result, but less experienced MT may take some times. Study has been done to check the Manufacturing Technician's efficiency. Their year of services and also certification were referred. The data were obtained from Human Resources Certification Record. Level of certification is from one to three. Level one is the minimum certification level, while level three is the maximum level of certification.

Study has been done to check the ILM Technician's efficiency. Their year of services and also certification were referred. The data were obtained from Human Resources Certification Record.

Process technician, process engineer, equipment technician and equipment engineer also play their roles during machine shutdown. When machine detected unwanted particle and need to be shutdown, process technician normally will follow the Out of Control Action Plan (OCAP) in order to release the machine back to manufacturing group as soon as possible. Process engineer also will take a look on the issue and do analysis and then come out with the release plan. Equipment technicians and engineers need to ensure proper maintenances job been carried out as per checklist. This is to ensure the cleanliness of the machine after Preventive Maintenance (PM) was done. Study has been done to check the Equipment and Process Technician's efficiency. Their year of services and also certification were referred. The data were also obtained from Human Resources Certification Record.

Beside MT, In-Line monitoring (ILM) technician also play big responsibility to determine the particle rate. It is important to have a proper scanning and analyzing of the STEM lot, so that the decision to shutdown the machine is base on real issue.

### 3.5 Material

For production wafers, different technologies will give different impact of the particle. This is mainly related to the process recipes, which different devices will have different process recipe, thus the deposition rate and thickness will be different from one device to others. Study has been done to see the relationship between particle issue and technologies. From the shutdown event, list of lots that have been scanned was obtained. From the list, product technologies were segregated and the relationship between them with the particle is studied.

Beside the technology, the metal layers also have impact to the particle issue since more metal layers means more times the lot will go to metal deposition process and the chances for expose to particle issue is more. Example for lot with four layer metal will go four times metal deposition process compare lot with five metal layers, will go five times metal deposition process. Study has been done to see the relationship between particle issue and the metal layers. From the same list from shutdown event, metal layers were obtained to see if there is any relationship between metal layers and particle.

Test wafer also have some impact to the particle issue. For new test wafer, the performance is better compared to wafers that sent to rework and reused. This is because the rework wafer normally will have remaining particle, which can not be removed due to saturated at the surface of the wafer and needs stronger cleaning recipe to remove them. Brand new wafers normally will have a lot less particle. In this study, the incoming particle for 50 lots of new test wafers was measured using SP1 to get the potential incoming particle. From here, any existing particle from test wafers itself that may contaminate the process chamber later during qualification process can be seen.

### 3.6 Method and measurement

Correct methods, which are used during both particle and mechanical qualification, were studied and observed. Judgment was made base on observation across all four shifts on the procedures during the qualification process.

The particle measurement is done based on In-line scan and during particle qualification process. For inline particle scanning, it is done after the lot has completed the metal deposition process. The job of in-line scanning is known as Systematic Machine Excursion Monitoring (STEM), which been done once in two days. Lot will be on hold for in line monitoring (ILM) scan.

Four wafers will be scanned for each machine to check for particle performance. The wafers will be scanned using Scanning Electron Microscope (SEM) machine. If particle signature exists, ILM personnel will notify the Metal Deposition machine owner to check for the machine's health. If the particle level exceeds the limit, which is more than 10 particle counts, the machine will be shut down and need to follow procedures in order to bring the machine back up to the production.

For production lots that go to ILM flow, the lot will be scanned for scratches and particle. If scratches or particle are found to exceed the limit, which is more than 10 particle counts, machine will be shutdown and need to follow the procedure as well. Wafers will be scanned using Complus or AIT machine also.

Qualification process is a process to check for the machine's performance, so that it always performs same as the baseline. One of the important factors in qualification is the particle performance. Particle value is measured based on the different value between pre particle measurement and post particle measurement. Differences of both values will determine the particle existence inside the machine. If particle count is more than five area count/ wafers, machine will be shutdown and need to be followed up by machine's owner before release back to production.

### 3.7 Machine

Machine is the main focus of the particle issue. This is due to the mechanical movement such as pedestal and robot movement inside the machine that can generate particle. Beside that, gas line also can create particle.

Load lock cleanliness is also very important since this is the place where the lot is transferred into the machine from its base. Load lock is a chamber that is used to interface a wafer between air pressure and the vacuum process chamber. According to Borden (Borden, 1988), Wu (Wu, et al., 1989) and Chen (Chen, et al., 1989), in the absence of a water aerosol, the dominant source of wafer contamination is the agitation of particles during the pumping (venting) of the entry (exit) load lock.

In this study, 100 lots were selected to check the particle level in the cassette. Since wafers are inside the vacuum state inside the cassette, particle inside the cassette need to be measured. It was measured using mini- environment tester. The cassettes were opened in Wafer Start room and the particle was measured for all the 100 lots. The particle count that obtained from the testing is captured.

To study for particle during wafer handling and robot movement, mechanical qualification process was carried out. Before it was done, chamber was cleaned first to eliminate the potential source of particle coming from process chamber. One lot, which consists of five test wafers, was selected. Wafers inside the cassette were arranged in slot 5, 10, 15, 20 and 25. Pre particle measurements were obtained for all the five wafers. The lot then was vented inside the load lock and also into the deposition module. Without running the deposition process, the lot was moved out back into the load lock and cassette. Post particle measurement was done to check for the adders. This cycle is repeated for 10 times for the entire machine and data is captured and analyzed.

Particle in gas line also was focused in this study. Particle in gas line is measured by referring to the data that is obtained from the particle sensor. The particle sensor is mounted at the gas line as shown in Figure 14. This is to ensure any particle in the gas line can be detected and the amount of particle entered to the process chamber can be monitored and recorded.

Sputter target also been studied to check the correlation between sputter target life and also shutdown. Example of sputter target that been used inside metal deposition machine is

shown on Figure 15. The event of shutdown and the usage of target life is captured and analyzed.

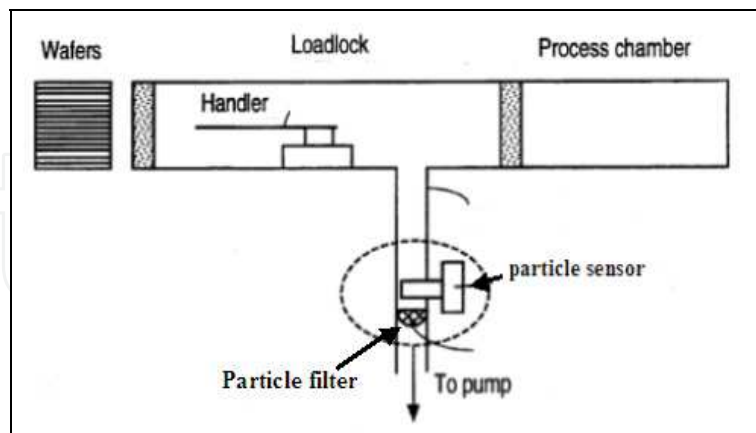


Fig. 14. Particle Sensor that Mounted at Gas Line



Fig. 15. Example of Sputter Target

### 3.8 Environment

The machine environment also has been studied to see any contribution to shutdown event. Load lock environment has been checked. Airborne particle measurement was conducted over metal deposition machines to collect the particle count. One hundred lots were prepared in this study. Wafers inside the cassette were arranged in slot 5, 10, 15, 20 and 25. Pre particle measurements were obtained for all the five wafers. The lot then was vented inside the load lock and left for five minutes. After five minutes, lot was moved out back from load lock move into cassette. Post particle measurement was done to check for the adders.

## 4. Results and discussion

From the fish bone diagram, all the possible causes have been screened out and verified to find the actual true causes. From actual true causes, corrective actions and preventive actions will be defined, identified and will be implemented to eliminate the particle issue.

4.1 Personnel

Verification have been made to people who directly working at metal deposition machine and related to the shutdown. Summary of the possible causes, which related to personnel, is shown in table 1.

Causes		Verification & Validation Process	Result	True/ False
Personnel	Manufacturing Technician (MT) in shift	1. To check the level of experiences of the MT 2. To check the capability of MT to perform qualification job correctly	1. Base on the study, all shift have dedicated MT > 2 years of experience to handle Metal Deposition tool 2. All the Manufacturing Technicians also capable to perform qualification job correctly	FALSE
	In Line Monitoring (ILM) Technician in Shift	To check the capability of ILM Technician to handle to scanning tool and catch the particle	Base on the study, all shift ILM Technician also having > 2 years of experience and capable to handle the scanning tool	FALSE
	Engineering Personnel (Process/ Equipment)	1. To check the capability of shift Equipment Technician (ET) and Equipment Engineer (EE) to perform Preventive Maintenance (PM) job efficiently. 2. To check the capability of Process Technician (PT) and Process Engineer (PE) to follow up on the ILM Shutdown issue to avoid re-shutdown	1. All shift ET/ PT and Engineers (PE/ EE) are well trained and have experiences > 3 years in average. 2. Equipment & Process team have their own checklist to be followed and verified by Section Head.	FALSE

Table 1. Summary of verify possible root causes related to personnel

4.1.1 Manufacturing technician (MT)

A validation and verification have been done to check the level of experiences of the MT and also the capability of MT to perform qualification job correctly. From the study, all shifts have dedicated MT more than two years of experience to handle Metal Deposition machine due to the criticality of metal deposition process. All the Manufacturing Technicians are also capable to perform qualification job correctly based on the checklist. The dedicated MT is summarized in table 2.

Shift	Person in Charge	Date Join	Years of Experiences	Certification level
A	1. NEDUMARAN A/L MEGAWARNAM	2004	> 5 years	3
	2. LIYANA HANIM BINTI AKBAR	2006	> 3 years	3
	3. MUHAMAD TERMIZI BIN AHMAD TAJUDIN	2006	> 3 years	3
B	1. ROZI BIN MD HASSAN	2003	> 6 years	3
	2. NOOR JANNAH BINTI MAHADZIR	2007	> 2 years	3
	3. ANUAR BIN MAT ISA @ ABDUL AZIZ	2007	> 2 years	3
C	1. MOHD ASRIZAL BIN AHMAD	2003	> 6 years	3
	2. KASMINI BINTI TUKOL	2007	> 2 years	3
	3. MAIMUNAH BINTI HASHIM	2007	> 2 years	3
D	1. MOHD YUSRI BIN YUSOF	2007	> 2 years	3
	2. MOHD IZHAM BIN MOHD IZHAR	2004	> 5 years	3
	3. ZAIDA BINTI AHMAD	2007	> 2 years	3

Table 2. Manufacturing Technicians in-charged of Metal Deposition Machine



4.1.2 Inline monitoring (ILM) technician

Based on the study, all shift ILM Technicians are also having more than two years of experience and capable to handle the scanning machine and captured defect images. The shift ILM Technician is summarized in table 3. Conclusion can be made that all the MT who handle the medal deposition machines are capable to perform qualification process and mistake that can lead to particle generation is almost zero.

Shift	Person in Charge	Date Join	Years of Experiences	Certification level
A	REDZUAAN BIN ABDUL RAHIM	2002	>7 years	3
	BALAKRISNAN A/L A.MUNIANDI	2007	> 2 years	3
B	RUZAINI B. ADZHA	2006	> 3 years	3
	CHAREN A/L KHAN	2007	> 2 years	3
C	SUNTHARA MURTHI S/O RAMAN	2003	> 6 years	3
	ERUAN BIN ABU SEMAN	2007	> 2 years	3
D	VASANTHAN A/L VELOO	2007	> 2 years	3
	IBRAHIM BIN IDRIS	2005	> 4 years	3

Table 3. In-line monitoring (ILM) Shift Technicians

4.1.3 Engineering personnel (process/ equipment)

Verification and validation made to check the capability of shift Equipment Technician (ET) and Equipment Engineer (EE) to perform Preventive Maintenance (PM) job efficiently. Also validation made on the capability of Process Technician (PT) and Process Engineer (PE) to follow up on the ILM Shutdown issue to avoid re-shutdown due to incorrect qualification job done prior releasing machine during shutdown.

The summary of PT is shown in table 4 and summary of ET is shown in table 5. Based on the verification, all shift ET/ PT and Engineers (PE/ EE) are well trained and having experiences to perform their job efficiently. Equipment and Process team have their own checklist to be followed and verified by Section Head during performing PM activities and also releasing the machine from shutdown.

Shift	Process Technician	Date Join	Years of Experiences	Certification level
A	NOR AZELINA BINTI ISMAIL	2002	>7 years	3
	HARYANI BINTI ABDULLAH	2007	> 2 years	3
B	NORMALA BINTI NAPIAH	2006	> 3 years	3
	MOHD SYUKRI BIN CHE HASSAN	2007	> 2 years	3
C	KHAIRUL ANWAR BIN ABU BAKAR	2003	> 6 years	3
	CANITTHA A/P IEKIN	2007	> 2 years	3
D	PUTERI SURINAEDAYU BINTI MEGAT ISMAIL	2007	> 2 years	3
	NOR ADILA BINTI ABDUL RASHID	2005	> 4 years	3

Table 4. Shift Process Technicians for Thin Film Metal Module

Conclusion can be made that PT who work at metal deposition process is capable to perform machine recovery as per procedure during the event of ILM shutdown. Particle generation during recovery or re-occurrence of shut down due to wrong recovery is zero. Conclusion also can be made that all ET who working with metal deposition machines are capable to

perform preventive maintenance jobs effectively and mistake that can lead to particle generation is almost zero.

Shift	Equipment Technician	Date Join	Years of Experiences	Certification level
A	MOHAMMAD RIDZAL BIN ABDULLAH	2002	>7 years	3
	MOHD KHADAFI BIN MAHAMOD	2007	> 2 years	3
B	AYUB BIN AHMAD	2006	> 3 years	3
	FRANCIS SELVAN A/L SINNAYAH	2007	> 2 years	3
C	MOHD ABDUL WAFI BIN AHMAD NADZIR	2003	> 6 years	3
	MOHD AZHUZAIRI BIN ABDULL AZIZ	2007	> 2 years	3
D	KHAIRUL HYFNI BIN NOORDIN	2007	> 2 years	3
	MOHD FAHMI BIN MOHD TAIB	2005	> 4 years	3

Table 5. Shift Equipment Technicians for Thin Film Metal Module

4.2 Material

Validation and verification were made in order to study the relationship between materials used in metal deposition process, with the shutdown rate related to particle, as shown in Table 6. The number of shutdown event (weekly) versus output (wafer move out from equipments) is shown in Figure 16. In average, three machines will be shutdown for every 27,900 wafer output from metal deposition process.

4.2.1 Relationship between shutdown event and output (weekly)

By using Minitab, correlation test between shutdown event and output has been conducted. The Pearson correlation between shutdown and output is 0.005, which means no correlations between both variables.

Regression analysis between shutdown event versus output was made using Minitab. The result of R square ( $R^2$ ) is zero, which means no relation between shutdown event and output.

Causes		Verification & Validation Process	Result	True/ False
Material	Production Wafers	To check the relationship between shutdown and moves	1. Correlations test between shutdown and moves had been done. The Pearson correlation between shutdown and move is 0.005, which means no correlations between both variables. 2. Regression analysis between shutdown versus Moves was made using Minitab as shown in Figure 4.3. From the result, the R square ( $R^2$ ) is zero, meaning no relation between shutdown and moves.	FALSE
		To check the relationship between shutdown and moves by technologies	1. Pearson Correlation test was done between shutdown and each of the moves by technologies as shown in Figure 4.6. 2. From the Pearson Correlation test, conclusion can be made that no correlation is exist between shutdown and technologies. 3. Base on the regression analysis, no significant relationship between the technologies and the shutdown event. The $R^2$ also showed 0%, which meaning no relationship between the shutdown and technologies	FALSE
		Relationship Between Shutdown and Technologies (STEM Failed)	1. From the Pearson Correlation shown in Figure 4.8, conclusion can be made that no strong correlation between shutdown and technologies. 2. Regression analysis was made between the shutdown and technologies as shown in Figure 4.9 and no strong evidence to conclude that the shutdown is influenced by the technology.	FALSE
		Relationship Between Shutdown and Metal Layers (LM)	1. From Figure 4.11, no strong evidence to say that the shutdown is influenced by the four layer metal lots 2. From Regression analysis in Figure 4.12, also indicates no strong correlation between shutdown and layer metal.	FALSE
	Test Wafers	Relationship Between Incoming Particle from New Test Wafer and Shutdown	All the 50 lots of new test wafer were passed the incoming particle screening. From this study, conclusion can be made that the particle generation is not coming from the new test wafers that were used during qualification process.	FALSE

Table 6. Summary of possible root causes related to materials used in metal deposition

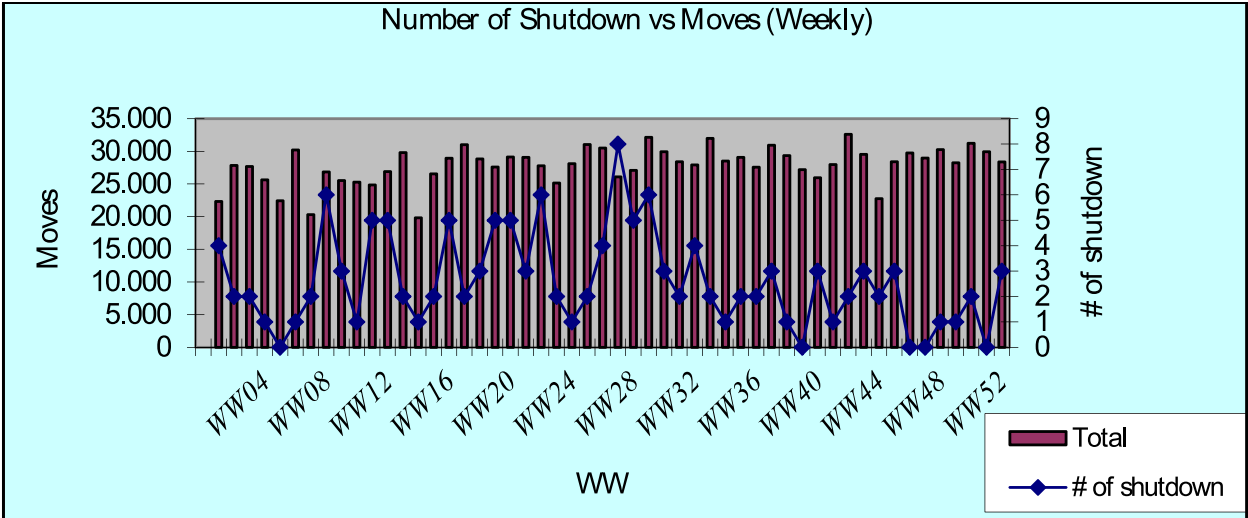


Fig. 16. Number of Shutdown Event versus Machines Output (Weekly)

4.2.2 Relationship between Incoming particle (from new test wafer) and shutdown event

Incoming particle screening was performed for 50 lots of new test wafers. Histogram was generated as shown in Figure 17. From the results, the mean is 1.18 with standard deviation of 1.24. Out of 50 lots of new test wafer that have been measured, 23 lots resulted in zero count of incoming particle, 6 lots showed one count of incoming particle, 10 lots showed two count and 11 lots showed three counts of incoming particle. Since the specification for the incoming particle is five count, all the 50 lots of new test wafer passed the incoming particle screening. From this study, conclusion can be made that the particle generation is not caused by the new test wafers that were used during qualification process

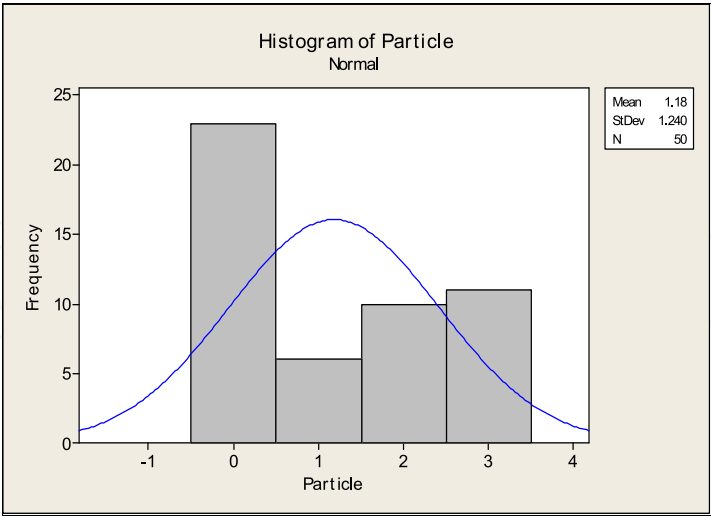


Fig. 17. Histogram for Incoming Particle in New Test Wafer

4.3 Method and measurement

Method of executing the qualification process were observed and summarized. Since the entire MT whose handle metal deposition machines were at level three, therefore they are

considered as competent to perform the task efficiently. This is proved by the qualification data that is available in the spreadsheet and also in the CIM system. By looking at the shutdown trend, conclusion can be made that STEM is effective to detect particles that generated at Metal Deposition process.

4.4 Machines

The relationship between shutdown event and machine was studied and the summary of the result is shown in table 7.

Causes		Verification & Validation Process	Result	True/ False
Machine	Vacuum Cassette	To check the particles that may enter a cassette from the cleanroom	Particle and mechanical qualification was done to check the particle existence. Result was clean and no particle was found during wafer loading from production pod to the loadlock	FALSE
	Wafer Handler/ Robot movement	To check the particle that may be created during wafer transfer from vacuum cassette to deposition module.	Particle and mechanical qualification was done to check the particle existence. Found that particle was created during wafer loading from vacuum cassette to deposition module	TRUE
	Gas Line	To check the particle in the gas line	Base on the particle data which is obtained from the particle sensor, no partilce can escape through the particle filter.	FALSE
	Sputter Target	To check the relationship between Sputter Target Life with ILM Shutdown	Base on the correlation analysis, there is relation between Sputter Target Life and ILM Shutdown	TRUE

Table 7. Summary of verify possible root causes related to Metal Deposition Machine

4.4.1 Relationship between shutdown event and particle in vacuum cassette

Results of particle existence in vacuum cassette are shown in Figure 18. From the bar chart, 82 lots detected zero particle count, 13 lots showed particle with one count and five lots showed two counts of particle. Conclusion can be made that particle almost not exist and can be considered as negligible in vacuum cassette, as the production is running under clean room environment of class one category.

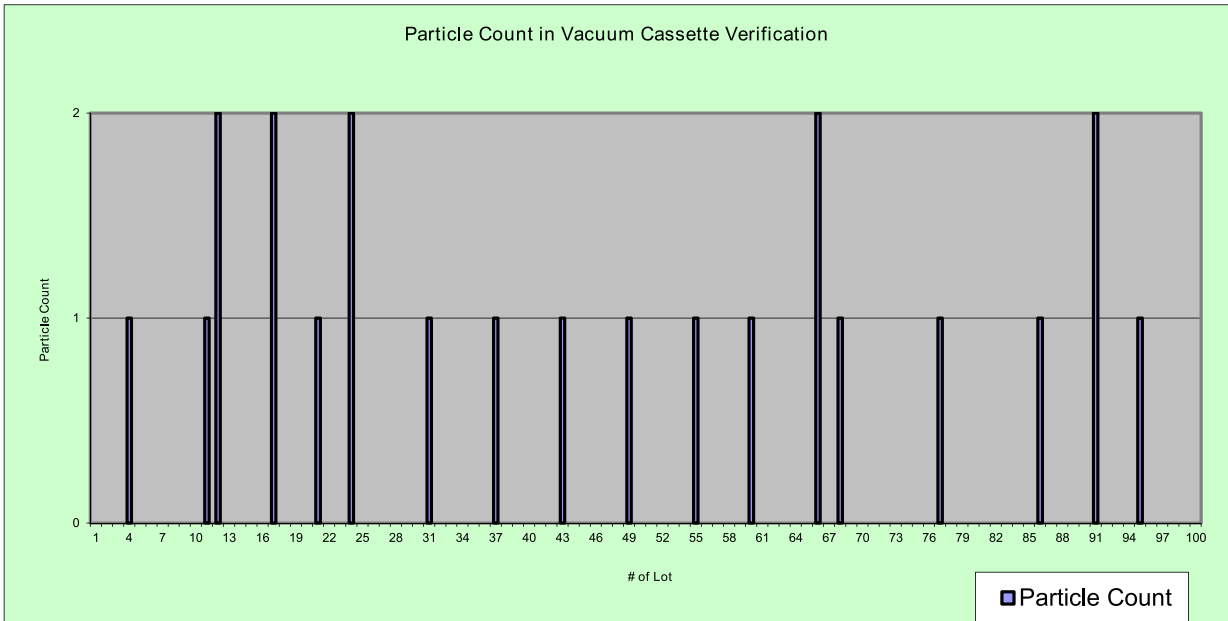


Fig. 18. Bar Chart for Particle Existence in Vacuum Cassette

4.4.2 Relationship between shutdown event and particle generation during mechanical movement

Results for mechanical qualification process are tabulated in table 8. From the data, bar chart was generated as Figure 19. From the bar chart, each of the machines showed particle generation inside the load lock. From the data, conclusion can be made that particles can be generated during wafer handling and mechanical movement.

Tool	Particle Count (adders) for mechanical Qualification Process for all Metal Depositon Tool									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Metal Dep 01	8	1	5	11	2	1	5	5	9	4
Metal Dep 02	12	3	8	2	2	4	12	5	9	8
Metal Dep 03	3	7	7	14	9	1	7	11	1	7
Metal Dep 04	15	1	7	2	10	2	5	8	2	9
Metal Dep 05	6	7	14	7	5	4	12	6	12	8
Metal Dep 06	3	2	1	3	5	13	9	3	7	11
Metal Dep 07	13	9	4	13	4	1	7	2	15	7
Metal Dep 08	5	3	9	4	2	7	9	3	1	5
Metal Dep 09	4	7	5	4	3	13	1	9	5	9

Table 8. Result for Mechanical Qualification Process for all Metal Deposition Machines

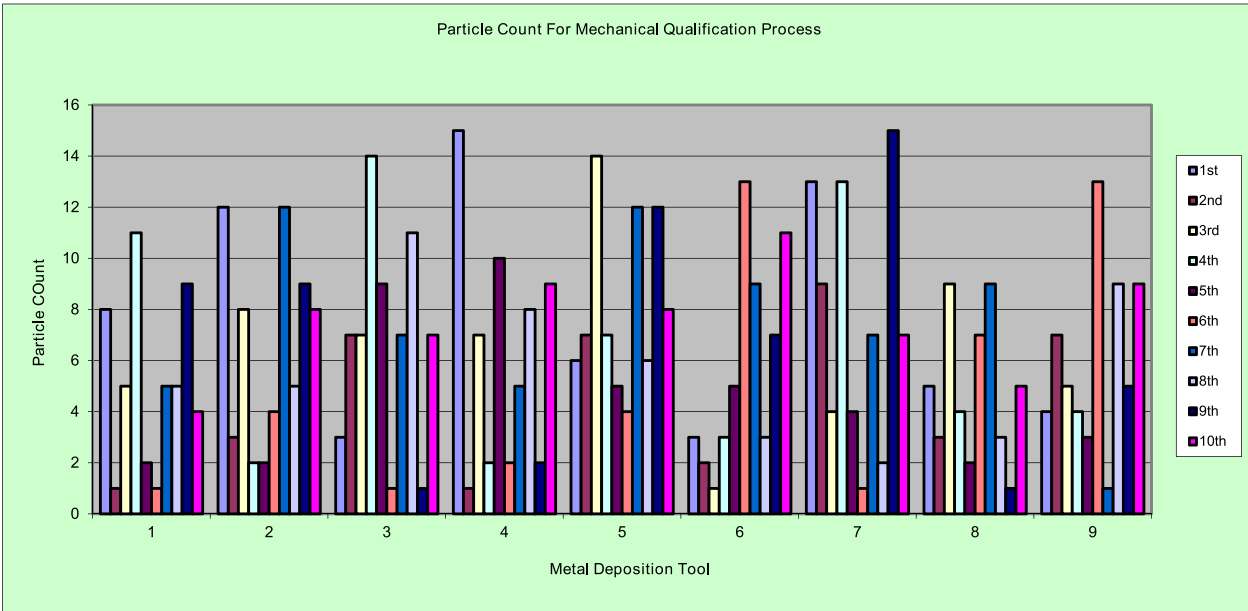


Fig. 19. Particle Count For Mechanical Qualification Process

4.4.3 Relationship between shutdown event and particle generation in gas line

Particle sensor is mounted at the gas line as shown in Figure 14 in section 3.7, to monitor particle existence in gas line. Since the gas lines are equipped with in-line gas filters, the particles are trapped in the filter. Zero reading was captured from the particle sensor. From this study, conclusion can be made that particle is not caused by the gas lines.

4.4.4 Relationship between shutdown event and sputter target life

Result for weekly shutdown event versus target life in Kilowatt per Hour (KW/H) is measured (refer Figure 20). By using Minitab, normality test was done for the target life as shown in Figure 21. The result shows the data is normal and valid to be studied.



Correlations test between shutdown and average sputter target life have been done. The Pearson correlation between shutdown and move is 0.981, which means strong correlations between both variables.

Regression analysis was made between shutdown event and sputter target life. Result for  $R^2$  value of 96.3% indicates strong relationship between shutdown event and sputter target life. Conclusion can be made that shutdown is highly influenced by sputter target life.

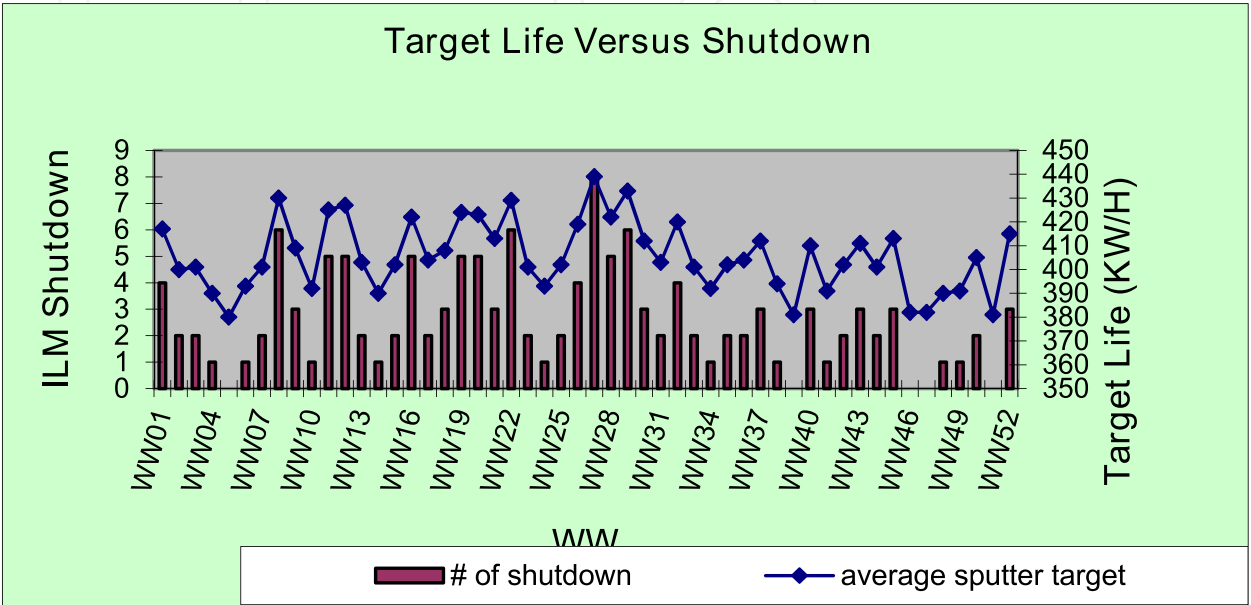


Fig. 20. Average Target Life (KW/H) versus ILM Shutdown (weekly)

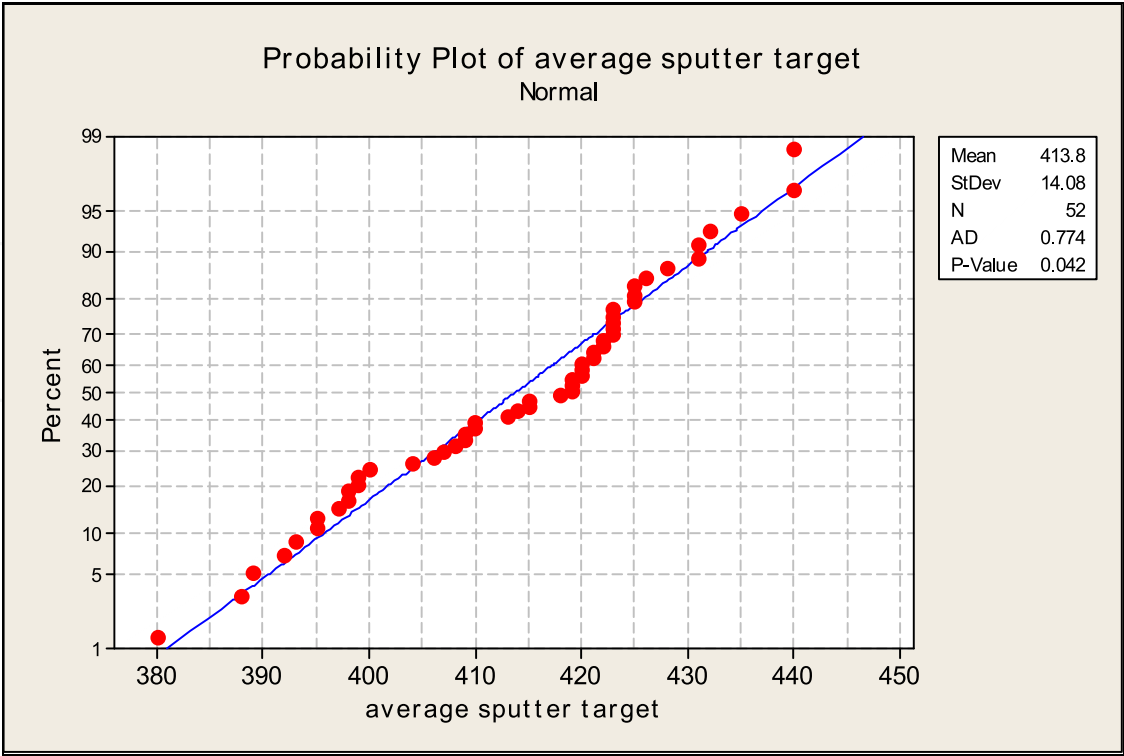


Fig. 21. Normality Test for Sputter Target Life

4.5 Environment

Result for the load lock environment is shown in Figure 22. Zero lots were captured with particle count more than three in the test. Since the specification is less than three counts, it can be concluded that load lock environment is free from particle.

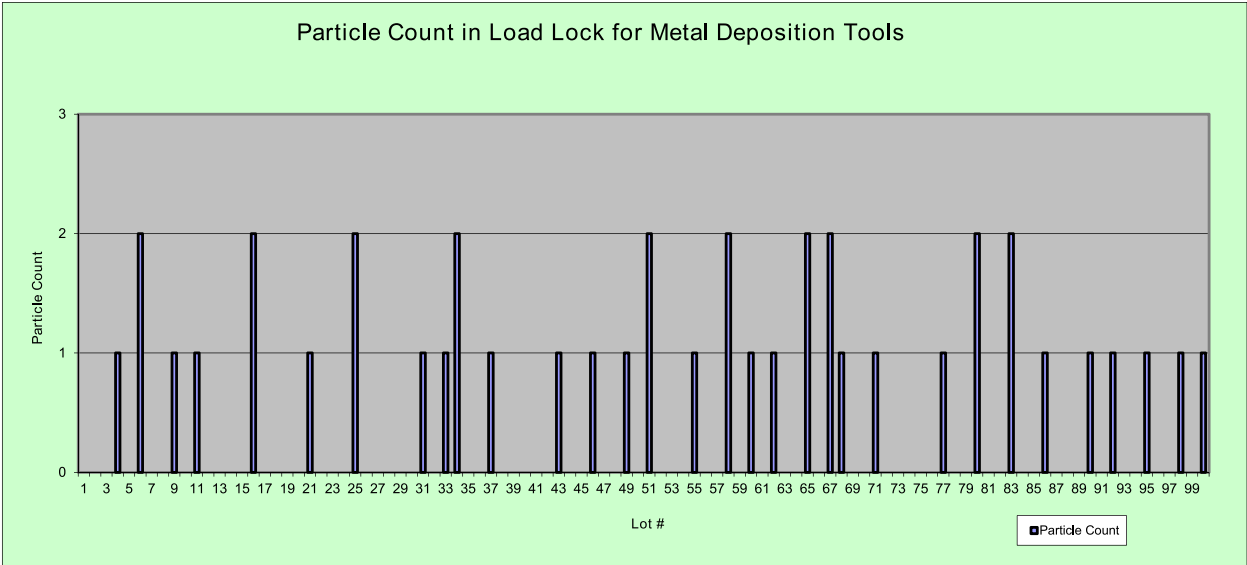


Fig. 22. Particle Count in Load Lock at Metal Deposition Machines

5. Analysis of true causes

From the verification process of potential true causes, wafer transfer in load lock and sputter target life has the most significant relationship to shutdown event. Since the most significant root cause is the sputter target life, this project will only focus on the improvement of sputter target life.

5.1 Sputter target life improvement

From the data of shutdown event versus sputter target life, observation can be made that the rate of machine shutdown is increasing by the increment of sputter target life. Even though the specification for the maximum sputter target life is 450KW/H, however in the study conducted, it shows that the chances of machine shutdown is higher if the sputter target life reach more than 410 KW/H. Zero shutdown per week was observed for sputter target life less than 390 KW/H, ten cases of one shutdown event per week were observed for sputter target life between 390 KW/H- 400 KW/H and 15 cases of two shutdown events per week were observed for sputter target life between 401 KW/H- 410KW/H.

In this study, three machines were selected to be improved by reducing the life of sputter target. Sputter target life is limited to 400 KW/H only, before replace with another new sputter target. Observation of the shutdown event versus the new sputter target life was monitored for three months, and the result is shown in Table 9.

From the data obtained, shutdown event was significantly improved. Three cases of shutdown event were observed within 12 weeks, however the cases were not related to metal deposition machine, but more to incoming particles from previous process.

Since the changes showed significant improvement in the shutdown event related to the particle issues, the new sputter target life reduction from 450 KW/H to 400 KW/H is introduced to the other six machines. Machine specification was updated with this new improvement and Preventive Maintenance job has also been revised to change the sputter target life when it reaches ~ 400 KW/H.

WW	Tool			Total	# of shutdown
	1	2	3		
WW01	2,875	2,790	2,698	8,363	0
WW02	2,650	2,923	2,596	8,169	0
WW03	2,748	2,866	2,777	8,391	1
WW04	2,931	3,257	2,956	9,144	0
WW05	3,096	2,385	2,343	7,824	0
WW06	2,386	3,397	2,248	8,031	0
WW07	2,847	2,711	3,464	9,022	1
WW08	3,186	3,290	3,355	9,831	0
WW09	3,727	3,513	3,628	10,868	0
WW10	3,726	3,053	3,972	10,751	0
WW11	3,527	3,331	3,319	10,177	0
WW12	3,459	3,175	3,736	10,370	1

Table 9. Shutdown versus Move base on new Sputter Target Life

6. Conclusion

Significant improvement can be seen in terms of In-Line Monitoring (ILM) shutdown event after the improvement of new sputter target life. Even though tool shutdown event still appear, it is mainly related to incoming process factors and not due to metal deposition machine. Therefore it is crucial to change the sputter target life when it reaches ~ 400 KW/H.

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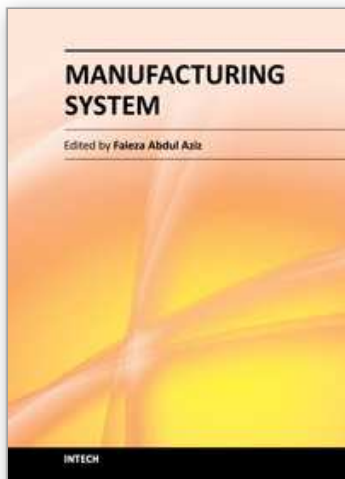
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This book attempts to bring together selected recent advances, tools, application and new ideas in manufacturing systems. Manufacturing system comprise of equipment, products, people, information, control and support functions for the competitive development to satisfy market needs. It provides a comprehensive collection of papers on the latest fundamental and applied industrial research. The book will be of great interest to those involved in manufacturing engineering, systems and management and those involved in manufacturing research.

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