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Research Article

Identification of Failure Modes on Electrostatic Chuck through Reliability Centered Maintenance: A Case Study

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Abstract: Quality of any reliability analysis depends strongly on the analyst's ability to identify all required functions. Failure is a basic concept of any reliability analysis. Also, the plant equipment's reliability is of vital importance in any production operation. The objective of the present study was to investigate the failure modes of critical systems in the manufacturing process of micro-chips by using Reliability Centered Maintenance (RCM) technique. In industries, RCM is employed to decide maintenance strategies using reliability data. The most critical component of the system was found to be Electrostatic Chuck (ESC) used in etching process. This technique was helpful in reducing the failure modes of critical equipment. Analyses were performed to observe the improvement in the system's efficiency. Downtime data was collected due to various faults in critical equipment. In the current research, various RCM analysis were performed on electrostatic chuck to ensure that shifting the maintenance technique to RCM would increase the revenue generation for the industry. This analysis was performed in Texas Instruments, UK. The results for optimum life of equipment, obtained after performing RCM, were quite high. Proper scheduling and planning improved the time of productive maintenance from 25% to 35%. Planning through Computerized Maintenance Management System (CMMS) boosted the efficiency up to 90%. The obtained results were compared with the current maintenance techniques; e.g., corrective maintenance. Solutions were recommended for the identified modes of failures and ways to eliminate the factors that cause failures on ESC.

Keywords: Backside cooling, computerized maintenance management system, decision making grid, dry vacuum pump, electrostatic chuck, reliability centered maintenance

1. INTRODUCTION

The corrective maintenance analyses were of no use for augmenting the life and reliability of the Wafer Etching System (WES), if it is not integrated into an operative preventive maintenance program successfully. The aim of this research was to find out how the RCM analysis could be performed for the ESC (LAM4520). The key struggle was to achieve the aims by collecting the life data of electrostatic chuck and dry vacuum pump and its downtime due to numerous faults. RCM analysis was carried out for increasing the availability of the ESC and DVP. Investigation of transformation processes of wafer disc into final product was performed on ESC (LAM-4520). The research determined the ways by which the ESC and DVP failed to fulfill their functions then the RCM analysis to determine the cause of failures. The objective of RCM was to improve maintenance actions in the most economical and technical way.

RCM to guarantee that equipment continues to perform its functions as their operators require doing in its present operating environment [1]. It is a well-organized process that focuses on aspects of reliability while determining plans of maintenance. It helps to create equilibrium

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between preventive and corrective maintenance [2]. The research was extended and applied to the railway, manufacturing, electricity, petrochemical and various other industries [3]. It was originated from the extensive examination of some specific questions about the equipment [4]. RCM incorporates reactive maintenance, preventive maintenance, predictive maintenance and proactive techniques of maintenance in an assimilated mode in order to escalate the probability of the equipment that performs its functions as required by the user for at least its designed life period [2].

The process for development of RCM requires about a failure on a given asset [5]. Performance standards and functions of a given asset were studied to describe the failure due to which asset is not properly functioning [6,]. After that causes, effect and result of each functional failure were observed on the basis of this information tasks to prevent each failure were predicted and performed. Analyses were carried out to recognize the most applicable and economical maintenance way in order to cut down the impact and risk of failure in system. Results were compared with the other maintenance techniques which are being used at present. Solutions to avoid failure mode were recommended accordingly. This helps to maintain the system and equipment in the most economical manner. The outcomes of suggested RCM planning direct the plant to a saving of at least 80% of the total downtime-cost as compared with the strategy used in plant i.e. Run to Failure or reactive maintenance. Decrease in the labor cost increased the reliability of system. The program was developed for the spare parts of plant (boiler, feed water pump and turbo-generator). The results showed that about 22.17% of the yearly spare parts charges were saved when RCM is implemented [7-10].

2. MATERIALS AND METHODS

2.1 Method of Data Collection

The data was collected from the company's personnel, interviews with skilled and experienced plant workforce in order to get their details about the plant. Time constraints, availability of personnel and asset, schedules and operating conditions of the asset were considered for analysis. The manuals of the assets and reports of past six months were examined to analyse. The data was collected from CMMS to carry out the RCM analysis. It is German system for the analysis and program development. The component for maintenance planning is unified with the components and sub-components of the SAP that includes the components for application for plant maintenance i.e. lists of maintenance activities, orders for maintenance, and notifications of maintenance along with work clearance management, the components for application for customer services After the collection of data from SAP, tables, graphs and reports were generated to get the required results. An early review was conducted by using maintenance and strategy techniques. SAP generates the failure reports whenever fault detected in the system in real time.

2.2 Decision Making Grid

Decision making grid (DMG) guides to choose the type of maintenance, i.e., RCM, TPM or CBM and its proper use by tracking the condition of worst machines in terms of performance, which were segregated on the base of different criteria. The information for the development of DMG was mainly extracted from SAP. DMG anticipated model was applied on the ESC (LAM 4520) which reduced the total breakdowns hours. To construct DMG, the data of last twelve months was collected. The data was calibrated through LAM Bench Viewer (LBV) which shows the number of failures w.r.t. time. The collected data shows that the number of failures increased with the passage of time. The investigation to find the reason of failure of LAM-ESCs revealed that the main reason of failure was problem in backside cooling of the wafer and improper vacuum in the chamber due to the dry vacuum pump that is attached directly to the ESC. Fig. 1 shows the breakdown trends of 12 months of a typical facility closed for the analysis.

Frequency of failures and downtime hours of wafer etcher (LAM-4520) failures were used to evaluate the classifying information using criterion evaluation method on DMG. Fig. 2 shows the categorization on frequency of machines failures. Both electrostatic chucks LAM4520-2 and LAM4520-7 failed 21 and 15 times respectively in 12 months, but LAM4520-3 was categorized in medium level group while LAM4520-6 in Low level group. The categorization of downtime was carried

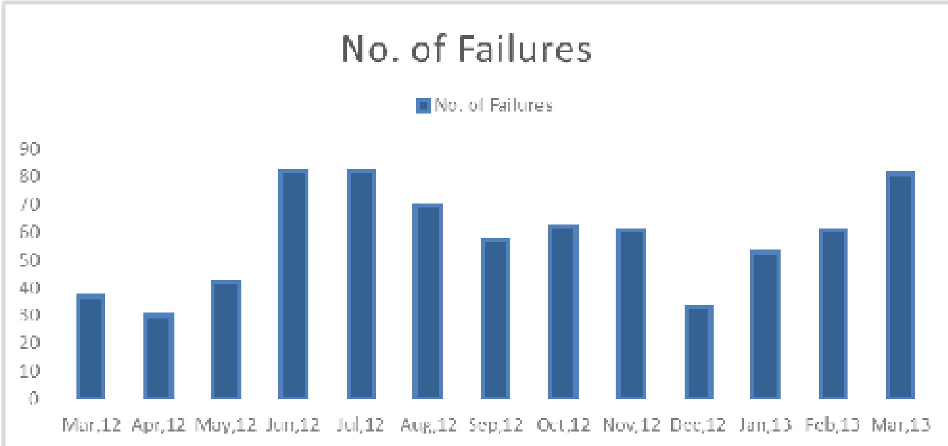

Fig. 1. Breakdown trend of ESC

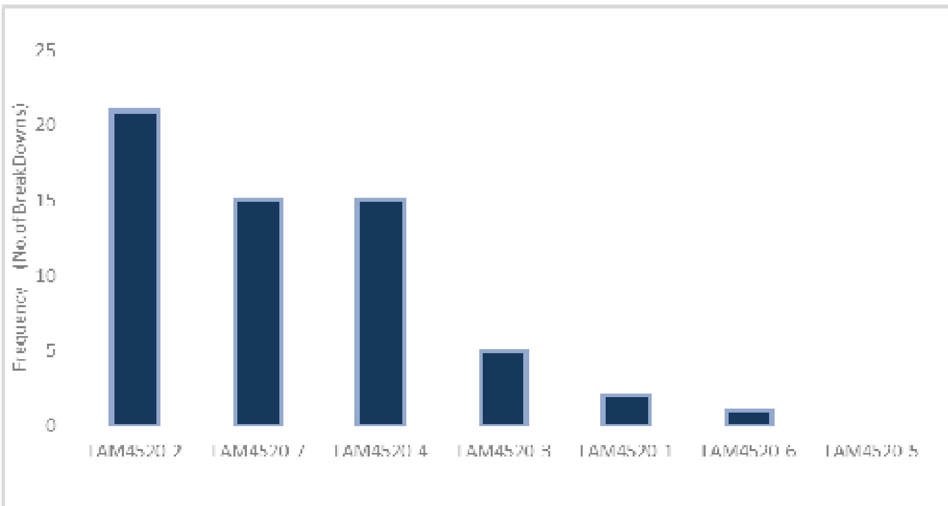

Fig. 2. Criterion analysis on frequency of failure

out using query selection method. LAM4520-4 categorized in the high downtime. Note that LAM4520-2 downtime is more than LAM4520-4 & 7 but both categorized in the same cluster.

Fig. 2 shows the misleading on the interval of high, medium, and low categorization and confusing categorization on LAM4520-7 and 4.

2.3 LAM4520 (Electrostatic Chuck) Availability and Failures History

Fig. 3 shows the availability of LAM4520 electrostatic chuck of one year with breakdown. The objective was to get 100% availability which means even not a single breakdown out of 85 events. However in 12 months breakdown trend has increased and maximum number of breakdowns occurred from October, 2012 to March, 2013. This research focused on the reason of unavailability of ESC and recommended solution using RCM analysis**.**

Etching performance found declined due the production stoppage of microchips. Six of the electrostatic chucks exhibited major defects. Data of the failure was collected and electrostatic chucks (LAM) were sorted by wafer sizes (150mm and 200mm diameters). The failure data obtained from LAM viewer exhibited that 85% of back side cooling (BSC) failure attributed to 150mm tools i.e. 51 out of 59 failures were attributed to LAM 4520-3, 4 and 7. It was witnessed that the maximum breakdowns occurred in LAM 4520. Fig. 4 shows that out of 7 ESC of the same model named as LAM-4520 electrostatic chuck. The maximum

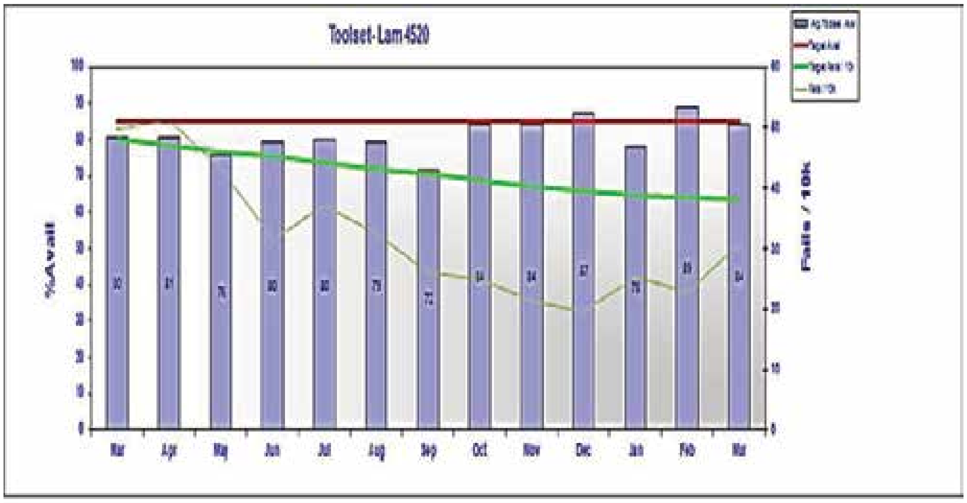

Fig. 3. Availability of ESC (LAM4520)

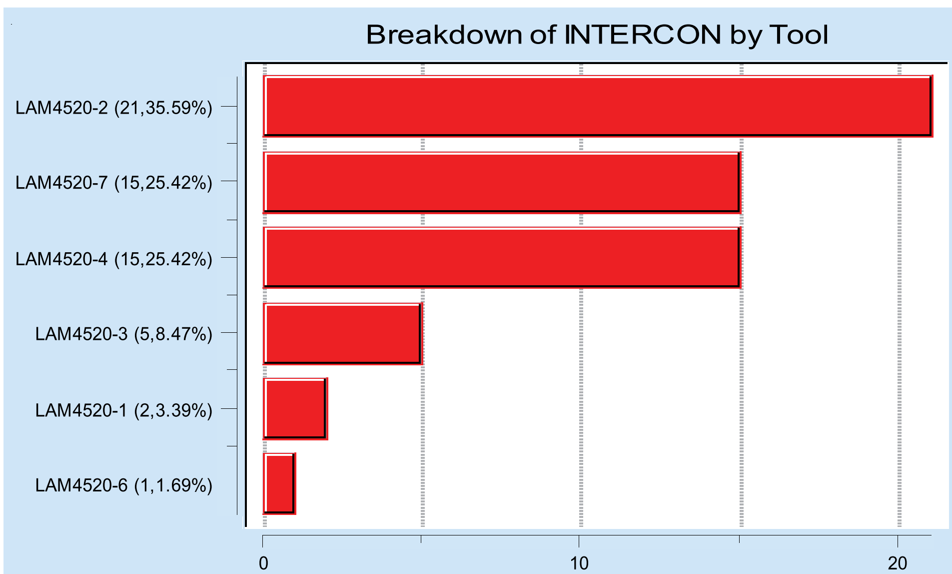

Fig. 4. ESC (7-LAMs) breakdown of INTERCON by tool

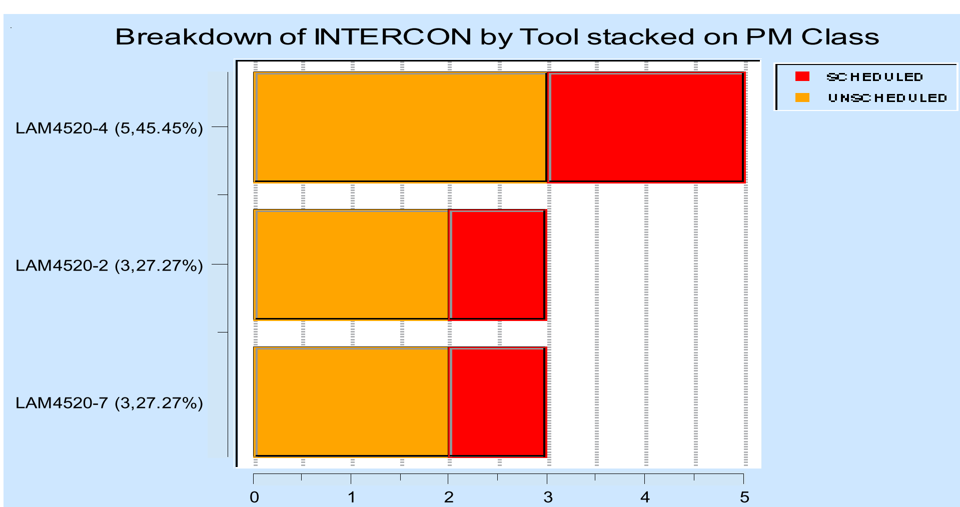

Fig. 5. Scheduled-unscheduled maintenance of INTERCON by tool

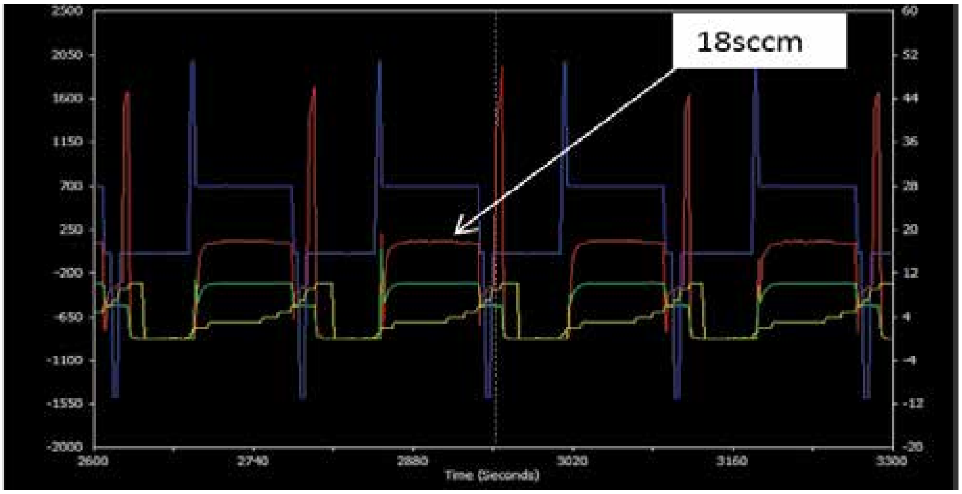

Fig. 6. Normal pressure of helium using graphs

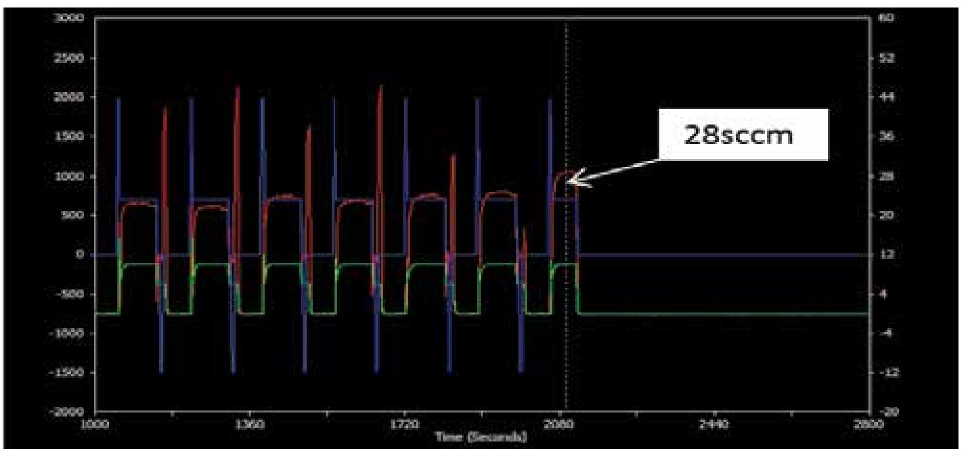

Fig. 7. Exceeded pressure of helium using graphs

failures occurred in LAM4520-2, 4 and 7 which was obtained directly from the LAM-Viewer and SAP-Intercon software.

Most of the maintenance tasks performed was unscheduled rather than scheduled. This unscheduled maintenance was carried out due to the failure of large part of 3 LAM4520 which can be evaluated by using the bar chart as shown in Fig. 5. The total 11 PMs were performed and 66% of those 11 PMs were unscheduled activities. The most common failures of all electrostatic chuck were due to the excess of helium flow, ESC voltage, and manometer pressure. Failure common to three LAM4520 of 150mm Electrostatic systems was hardware confirmed well, red: helium flow, green: helium manometer pressure and blue: ESC voltage as shown in Fig. 6. When the pressure went up more than 3-time of normal pressure, ESCs failed as shown in the pulse graph of SAP below: Helium flow > 25 sccm (unit of pressure) limit.

2.4 LAM4520 BSC Failures By Occurrence Last 12 Months

The Table 1 shows that maximum failures were due to BSC of wafer disc. The specific criteria that the process satisfied about wafer grip input and sense output standards were high. The wafer grip input was pulled to low value in order to command grip. When the wafer was sensed, then the wafer sense line was pulled low. These conditions were vital before gripping. For this research, the gripping of wafer was started upon sensing, before it hit the surface of chuck. This produced trifling lateral position shift of wafer. When wafer grip was achieved, then the output of “wafer gripped” is pulled low. After that the potentials of chuck electrode to curtail grip forces were enhanced. The lift pins before/without clamping a substrate/

Table 1. Backside cooling failures

Fails / Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
BSC	37	30	42	38	37	36	26	36	30	19	40	54	59
Endpoint				12	11	10	14	5	4	4	5	1	5
Handling				30	30	22	11	2	9	4	4	2	7
RF				2	4	2	6	5	6	3	1	1	0
Gap					0	0	0	10	7	1	1	1	3
Control stem PSU, Lam PC)								4	5	2	2	2	7
Intensity											10	3	2
PM01 work orders	153	170	170	119	133	100	76	82	74	51	84	75	101
Wafers processed	30704	33293	39411	37914	35638	30730	29195	33002	34784	25978	33191	33101	33054
Fails / 10k	50	51	43	31	37	33	26	25	21	20	25	23	31
Target Fails / 10k	48	47	46	45	44	43	42	41	40	39	39	38	38
PM02 work orders				48	52	40	42	37	32	26	41	32	29
PM02's / 10K	0	0	0	13	15	13	14	11	9	10	12	10	9
	20%										10%		

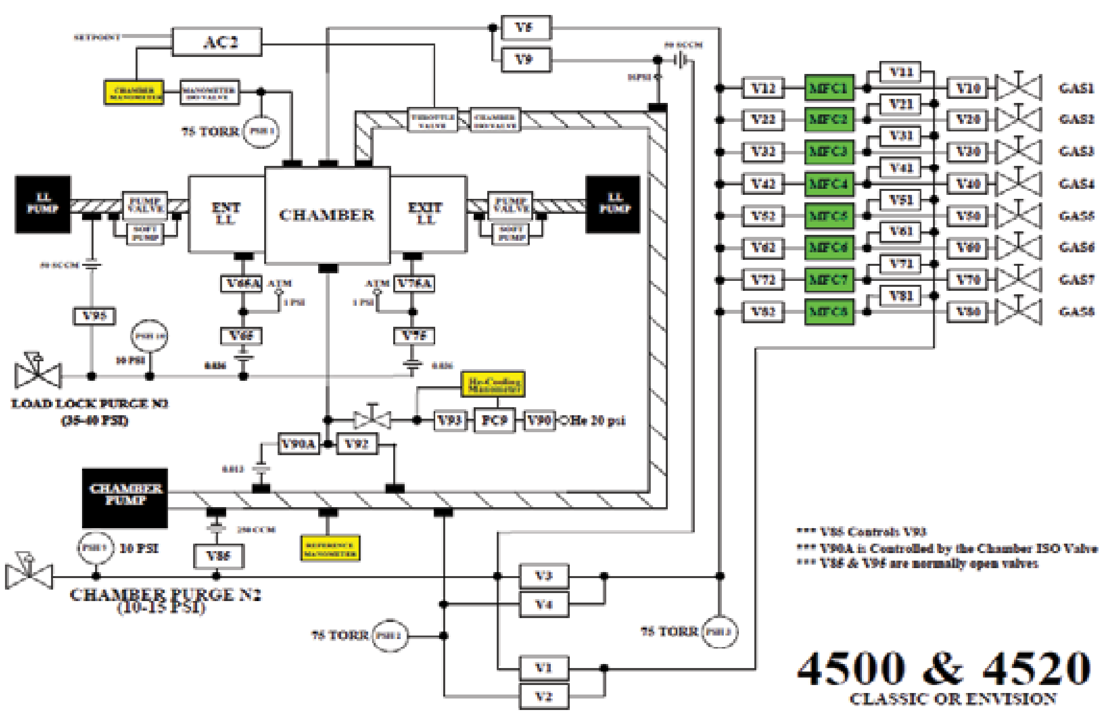

Fig. 8. Functional block diagram of ESC

wafer to an ESC surface was dropped throughout wafer acceptance. Small wafer discs astride onto a bigger electrostatic chuck by a carrier film made up of polyester, with a supporting ring of Silicon. Cooling was poor due deficiency of backfill gas under the wafer that was being processed. Wafer discs became heat sunk on the carrier Silicon wafer with the help of silicon diffusion pump wax or oil for small remains. Proper cleaning was done to avoid any sort of contamination. Wafer grip and lift was harmonized to curtail lateral shift.

Then the backpressure was smeared. Initially the gas flow was high, then it felled to the steady state leakage amount. The amount was higher than directed in the datasheet of electrostatic chuck due to the high stiffness of substrate, dirt particles, substrate bow, and damage to chuck. After plasma processing ended, wafer popping was caused by wafer release due to backfill pressure and was eliminated before release. After that RF processing was commenced by an indication from the host control computer. The two valves V90 and V 93 were used for helium supply at 15 to 20 psi. Backside pressure of wafer was measured by using a manometer of rang 10 Torr. The output achieved from 10 Torr manometer was then fed back into a Unit Pressure Controller (UPC). At the very same instant, the helium entered on two other valves operates V92 and V90A. The functional block diagram for the procedure is introduced in the Fig. 8

3. RESULTS AND DISCUSSION

3.1 Root Cause Failure Analysis (RCA) of System

RCA is used for analyzing severe adverse events in the equipment. RCA of Electrostatic Chuck (LAM-4520) covers failure mode, reason and root cause of failure for equipment. This root cause analysis was done by finding the answers to certain questions to complete the data of the failures occurred in ESC. For the electrostatic chuck, a lot of problems were identified while performing root cause analysis.

The subsystems becoming reasons of failure of ESC were identified to be Backside cooling system (BSC), water handler, vacuum chamber, plasma production chamber, helium pressure and vacuum stabilizer and RF stabilizer. Analyses were then further performed to find the reason of failures of these subsystems. The reason obtained by RCA for BSC failure was the stoppage of water etching process. When the detailed study was done the reasons pointed out for this were insufficient clamping voltage, insufficient Helium Flow, inaccurate measurement of Backside Manometer and a fault in Unit Pressure Controller (UPC).

Water handler caused a problem because of the wafer in the entrance cassette did not pick up by the water shuttle and the wafer lost in the chamber or got stuck up with the donut of ESC. To improve the optimum life of the equipment it was very necessary to find the main reason of these failures which by performing RCA were found to be the improperly loaded wafer e.g. cross slot in the cassette, Photo-resist on top of the wafer not properly hard-baked, sticking of Soft photo-resist to the helium clamp after plasma heating, sticking of wafer to the helium clamp which cannot be unloaded and most majorly the sticking of wafer to the lower electrode after plasma heating.

RCA was performed on other subsystems of ESC to find even the minute causes of failure and were identified. The vacuum chamber stopped working as the back side of wafer was too rough or contaminated with particles/film. Along with wafer Shuttle vacuum problem which created a default in alarm of vacuum chamber. There were few errors due to improper working of chiller which caused error in plasma production chamber ultimately making a role in ESC failures. Hence after performing RCA we can identify all the major failures of a system to the minutest details.

3.2 Failure Mode and Effect Analysis (FMEA) / Primary Information Sheet

A Failure Mode Effect Analysis was accomplished to recognize the possible modes of failure for a process or a product. The RPN technique requires the team for analysis to use past know-how and engineering decision to rate each possible problem. Primary FMEA sheet along with RPN analysis for the electrostatic chuck and dry vacuum pump were generated by further observing the functions and failure modes of sub systems and components and then the effect of these failure modes on that

Table 2. List of functions of ESC and DVP

Item	Function
Back Side Cooling System	To Provide Cooling at backside of wafer with Helium gas at pressure 18 SCCM and balance wafer in ESC
Check Valves (V90,V92,V93)	To stop the backward flow of air after creating Vacuum in the chamber
Helium Cooling Manometer(UPC)	To control the Helium flow up to 1 sccm accurate pressure this is directly flow from Helium Chamber to ESC chamber.
Chamber Pump	To rapidly create vacuum in the chamber and sucks extra Helium from etching process chamber to Pumping chamber
Air Filter	To purifier air by removing contaminants from the air to avoid dirt in the ESC donut
Four Pin Wafer Lifter	To Lift the wafer up at distance of 0.005 inch to 0.025 inch from the surface of chuck
ESC Power Supply	To apply the voltage of 700v to clamp wafer and -1700V to de-clamp wafer.
Clamp Ring	To hold pieces of glassware above the Head after/during process and to make separate EMI Gasket and ring to avoid failure of gasket.
Dielectric Material	To maintain the electrostatic attraction even with high Voltage from -350 to +1700 with no failure of dielectric
Safety Valve	To release the pressure when it exceeds above 18Sccm
(V90A, V85)	To make capacitor by charging donut and base +350 and -350 respectively to produce plasma.
Electrodes (Donut & Base)	To Pick the wafer from Etcher system and drop on the next system to process
Wafer Handler	To supply the Helium gas inside the ESC
Piping System	To exhaust the harmful gases and by- products out of the system
Exhaust Piping System	To prevent reverse flow of gas from the exhaust through the pump to the vacuum chamber, when pump is stopped
Exhaust Check Valves	To prevent reverse flow of gas from the exhaust through the pump to the vacuum chamber, when pump is stopped
Pump casing	To protect the pump
Bearings	To bear the thrust loads
Eye Bolts	For loading and unloading of the pump

component itself, the system ESC or dry vacuum pump and to the whole plant. Then the RPN was calculated by each of the failure modes. Higher RPN shows higher risk factor and vice versa. It was seen that the most risks are due to Backside Cooling of single wafer etcher and this finding was verified by the RPN analysis.

The RPN of ESC due to failure of BSC mechanism was greater than 100 because of its higher severity, higher rate of occurrence and almost unlikely detection of fault. When the pressure exceeded too much i.e. about 23 sccm then due to much more severe effects and low detectability of fault the risk priority number reached above 200, thus stopping the production and causing very drastic effects on plant. Failure mode and effect analysis is a technique that inspects process failures, estimates priorities of risks, and helps to determine corrective actions to evade identified problems. A detailed FMEA analysis was performed on FMEA sheet which is attached as Table 3. On the basis of FMEA “the final information sheet” was generated and is given in the table below.

3.3 Generation of Information Sheet and Decision Worksheet

The final information sheet was generated according to the item no. of the component. This information sheet was developed so that one may have a complete overview of the failure history of the ESC just by going through the information sheet and finally on the basis of all the information of equipment we formulated a decision sheet on what maintenance task should be performed on

Table 3. FMEA analysis of ESC

Item	Function	Function Failure	Failure Mode	Effect			
				RPN	Local	System	Plant
Back Side Cooling System	To Provide Cooling at backside of wafer with Helium gas at pressure 18 SCCM and balance wafer in ESC	Failed to maintain pressure and balance of wafer	Pressure exceeds to 23sccm	24	Wafer balancing failed	Etching Process Failed	Production Stopping
			Pressure exceeds to 23sccm	144	Wafer balancing failed	Etching Process Failed	Production Stopping
			Cooling System Failed	70	Wafer wasted	LAM-donut failed	Production Stopping
			Failed to maintain gap b/w wafer & Donut	80	Wafer wasted	No effect	Production Stopping
			Insufficient clamping voltage	64	Wafer Wasted	LAM-donut failed	Production Stopping
			Backside Manometer Faulty	28	Manometer Failed	Etching Process Failed	Production Stopping
Check Valves 90,V92,V93)	To stop the backward flow of air after creating Vacuum in the chamber	Valve is not acting as non-return stop valve	Fails to Open	135	Low Effect	High Effect	Low Effect
			Remain Open	84	Low Effect	Low Effect	No Effect
			Crack Valve	20	Low Effect	Low Effect	No Effect
Helium Cooling nometer(UPC)	To control the Helium flow upto 1 sccm accurate pressure which is directly flow from Helium Chamber to ESC chamber	Failed to control Helium flow from Helium chamber to ESC or failed to send signal back to UPC	Incorrect measurement of Pressure	24	ESC Trip	Full LAM-Etcher Shut Down	No Effect
			Failed to send signal to Computer PC9	120	ESC Trip	LAM- Etcher Slow Down	Low Effect
			Insufficient supply of Helium	32	ESC Trip	LAM Shut Down	No Effect
			He Flow Full more than 50 sccm but the maximum flow is set at below 50 sccm the UPC flow sensor can sense	144	UPC Collapsed	LAM Shut Down	Low Effect

equipment to get the optimum life. The generation of Decision Worksheet dealt with consequences of failure and preventative tasks. The decision work Sheet was generated by Logic Tree analysis. Then after getting the information about failure and its consequence preventive or proactive tasks were suggested for the better performance of the equipment and this all information is given in decision work sheet. The decision Worksheet spots the Consequences of failure by dividing it into the following headings:

- H : Hidden Failure Consequences
- S: Safety & Environmental Consequences
- O: operational Consequences
- N: Non-Operational Consequences

The information sheet and decision making sheets are attached in table 4 and 5 respectively. As the maintained is quite a neglected field all over the world and still not much work is done on RCM

Table 4. Final Information sheet of ESC

	Site: GFAB Plant TI		**Unit: 1**		**RCM INFORMATION SHEET FOR Texas Instruments, UK**	
	Main Assembly : Wafer Etcher Assembly				Date:	Sheet 1 of 1
	Sub Assembly: LAM-4520				Carried out by:	Mehroz, Umer
	Component: Electrostatic Chuck				Signed off by:	
NO.	Function		Function Failure		Failure Mode	Failure Effects
1	To Provide Cooling at backside of wafer with Helium gas at pressure 18 SCCM and balance wafer in ESC	A	Failed to maintain pressure	1	Pressure exceeds to > 25 SCCM	The whole batch of wafers will be wasted which causes the Electrostatic chuck stop. A 12 In. wafer has 113 Sq. In. to be used for chips at $200 that's only $1.77 per Sq In. only 17 cents more than 2 times the ammount lost. Total loss of production > $1000
				2	Surge in Helium Cooling flow	ESC takes time to set it to normal condition which causes the Etching Process system stop ultimately there will be more loss in Production once it set up permanently.
				3	Helium Flow is not consistent wafer to wafer	ESC is at low performance which causes the Etching system trip hence Lower production leading lower profit per wafer.
		B	Failed to balance the wafer	1	Wafer is not clamped even on 700Volts	ESC trip, Steam system trip, Production stooping
				2	Helium Pressure is very low (<18sccm)	same as 2-A-3
				3	Wafer unbalanced during etching process	ESC trip, Steam system trip, Lower production, downtime of 1 day
2	To stop the backward flow of air after creating Vacuum in the chamber		Valve was not acting as non-return stop valve	1	Fails to Open	Low effect on ESC and on system but there will be no effect on overall plant until Full etching process fails. Downtime for changing check valve is 3.5 hours
		A		2	Remain Open	ESC trip, Etching system trip, Production stooping
				3	Crack Valve	Once valve is cracked ESC will trip, Etching system trip and Production will be stopping. Downtime to change valve =1 hour

Table 5. RCM Design sheet for ESC

RCM DECISION WORKSHEET			Item LAM-4520 Wafer Etcher							System: Etching Process				Sheet No. 1 of 1	
			Component: Electrostatic Chuck							Unit No: 1					
Information Reference			Consequence Evaluation				H1 / S1 / O1	H2 / S2 / O2	H3 / S3 / O3	Default Task			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O	N1	N2	N3	H4	H5	S4			
1	A	1	N	N	N	Y	N	Y					Implement Extended Precoat on Novellus 150mm Tool	Weekly	Tech Op
1	A	2	N	N	N	Y	N	N	Y				Fix BSC Spacer Etcher for LAM4520- ESC	Weekly	Tech Op
1	A	3	Y	N	N	Y	Y						Generate OCAP (Out of Control Action Plan)	Weekly	Tech Op
1	B	1	Y	N	N	Y	Y						Check previous process (Dopping-Undopping), Change Novellus System	Weekly	Tech Op
1	B	2	Y	N	N	Y	Y						Vent the main reaction chamber	Weekly	Tech Op
1	B	3	N	N	N	Y	N	N	Y				Verify that the Chamber Clamp Flow (Envision) or He Flow Full Scale (sccm) is set to 50 sccm	4 Weekly	LAM-Engineer
2	A	1	Y	N	N	Y	Y						Replace check valve	Six monthly	Tech Op
2	A	2	Y	N	N	Y	Y						Replace check valve	Six monthly	Tech Op
2	A	3	N	N	N	Y	N	Y					Replace check valve	Six monthly	Tech Op

as the analysis seemed to be quite simple but these analysis make a major difference in the availability of plant.

4. CONCLUSIONS

This research revealed that when reliability-oriented maintenance was carried out at the production facility, it maximized the life and utility of plant and critical equipment for a much longer time. Even in today's world, maintenance is considered as a necessary evil and is thought be a simple process and a wastage of time. However, this study proved that by implementation of RCM at the production facility, the production in the prevalent conditions was achieved in a most cost-effective way. The decrease in downtime clearly revealed that the research proved fruitful; however, little betterment in future such as replacement of LAM-4520 unit with advance LAM 6 Rainbow etcher or replacement of dry vacuum pump model may lead to more economical and greater levels of production. Results of the RCM technique implemented on the plant suggested that the management must go for advanced predictive maintenance techniques.

This study also suggested to curtail reactive maintenance and encouraged to perform maintenance tasks at regular intervals. The planned labor program was also proposed, which showed that the labor cost falled from 295200 $/year to 220800 $/year which was 25.2% of the total labor cost. Insufficient maintenance and operational procedures and flaws in designs were exposed and corrected while constructing the fault tree. RCM planning directed a saving of about 80% of the total downtime cost as compared to pre-existing maintenance (RTF). Decreasing the labor cost increases reliability of system. The planned spare parts program for the components of plant was generated. The results showed that about 22.17% of the yearly spare parts charges were saved by implementing RCM. The whole plant underwent predictive maintenance and gave maximum from the given input.

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