Comparison of Relative Risk before and after SEMI S2-93A Implementation: Using a Semiconductor Plant in a Taiwan's Science Park as an Example

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Abstract

The objective of this study is to evaluate the equipment risk before and after SEMI S2-93A implementation, thus providing a guideline for safety improvement. Semiconductor Plant A located in Taiwan's Hsinchu Science Based Industrial Park with 147 manufacturing machines was used for risk assessment. This study was carried out in three steps. First, a preliminary hazard analysis was conducted. A detailed process safety evaluation was conducted (Hazard and Operability Study, HAZOP); and finally, the equipment risk comparison before and after Semiconductor Equipment Manufacturing Instruction (SEMI S2-93A) implementation. The preliminary hazard analysis results showed high risk in 21.77% of the manufacturing machines under risk assessment at Plant A. The largest percentage existed in the Diffusion Department. The machine types specified by the hazardous work site review and inspection according to Article 26 of Labor Inspection Regulation (the machines that use such chemicals as, SiH_4, HF, HCL, etc. and that are determined to be highly hazardous through preliminary hazard analysis) were added to the detailed process analysis and evaluation. In the third part of this evaluation, the machines at Plant A used for detailed process safety assessment were divided into two groups based on the manufacturing data before and after 1993. The severity, possibility, and actual accident analysis before and after SEMI S2-93A implementation were compared. The Semiconductor Equipment Manufacturing Instruction (SEMI S2-93A) implementation can reduce the severity and possibility of hazard occurrence.

Key Words: Semiconductor, Risk, HAZOP, SEMI S2-93A

1. Introduction

As semiconductor-manufacturing technology becomes more sophisticated, the complexity associated with the potential occupational hazards and asset loss has increased. The chemical reserve and usage in the semiconductor manufacturing process are both less than the amount handled in the chemical or petrochemical industries, however, due to flammable, toxic, and oxygen-deficient hazards, any leak that occurs into manufacturing units may cause casualties and serious asset losses. The United Nations Environmental Safety Symposium [1] pointed out that safety, hygiene, and environmental protection will significantly influence industrial development in this century. Immediately after trade barrier and tariff reductions, employee-employer relationships, must be recognized cultivated and the required social investments made. In view of the increasing importance of semiconductor hazard prevention, the U.S. Semiconductor Equipment and Materials International created semiconductor-related equipment and materials safety standards guidelines in 1991. This included safety, hygiene and environmental protection in the regulations for semiconductor equipment manufacturing processes, called SEMI S2-93A [2]. In recent years, many Taiwanese semiconductor manufacturers have invested in new plants, however, a large number of existing factories were built before SEMI S2-93A was published and implemented, for example, Macronix Plant 1, Winbond Plants 1 and 2, TSMC Plants 1 and 2, and so on. Therefore, this research identifies the hazardous areas in old semiconductor plants and provides a direction for prevention from exceptional accidents. The purposes of this research are to: (1) analyze and compare the degree of semiconductor hazard before and after SEMI S2-93A implementation and study the exceptional events that have occurred to Plant A in past years; (2) combine the experience from process safety assessments with operational practices by systematically identifying the potential hazards to the manufacturing process, prevention and response capacity. The identified risks are ranked to increase the requirements for production safety and environmental protection in semiconductor plants; (3) establish a practical model suitable for manufacturing process safety assessment that will enable continuous process safety evaluations in the right direction during future factory expansion or manufacturing equipment changes.

2. Research Methodology

The common acknowledgement of reducing risk or potential hazard is developed based on the department of machinery/equipment using chemicals in wafer factories. Qualified or senior engineers are then selected to participate in process safety assessment and analysis, coupled with analysis of the types of chemicals used by the machinery/equipment system by process, equipment, and administrative engineers, safety and hygiene engineers. Since numerous types of chemicals are used, preliminary hazard analysis is conducted to determine if the machinery hazard index rank qualifies as high level potential hazard. The results are analyzed using a detailed hazard safety assessment process and operability study (HAZOP) [3] to understand the risk rank distribution and the manufacturing year of the machinery/equipment at Plant A (6" wafer factory). SEMI S2-93A application can reduce the risk associated with the machines under study. The relative risks are assessed on the basis of a qualitative analyses of the detailed process severity and possibility. Regardless of the individual differences, semiconductor wafer manufacturing systems can be divided into five fundamental machinery equipment areas such as diffusion, etching, developing, thin film, and factory administration for independent assessment and risk rank analysis.

2.1 Description of Risk Analysis Structure

Semiconductor machines use many highly toxic, flammable, or explosive chemical substances (as shown in Table 1). Leaks from these chemicals will cause severe damage. No preliminary risk evaluation method has ever been developed by the semiconductor industry in Taiwan until now. Therefore, the chemical exposure indexes [4, 5] proposed by the Center for Environmental, Safety and Health Technology Development of the Industrial Technology Research Institute (Taiwan) with reference to the Tao Chemical Company are studied and modified based on the semiconductor manufacturing process, machinery, and administration properties, expressed using a simple and empirical ranking system based on the quantitative comparison method. This approach is further developed into a relative hazard ranking analysis methodology applicable to semiconductor machinery that provides quick and simple quantitative evaluation of the relative risks associated with these machines.. The semiconductor manufacturing process can be divided into such three parts; supply end, user end, and handling end (as shown in Figure 1). In general, the supply end is responsible for several user ends. After the chemicals are applied, according to the chemical properties involved, the chemicals are processed and categorized. Based on the chemical characteristics, coupled with the allocation to each processing equipment, this analysis occurs at the secondary chemicals/air control panel and the machine exit end, which is divided into three segments: the first segment is from the chemicals/air supply system to the secondary control panel. The second segment is from the secondary control panel to the machine exit end (including the machines' individual exhausted air handling equipment). The third segment is from the machine exit into the central air exhaust handling system.

Table 1. The major toxic substances and inflammable substances in semiconductor plants

Toxic Substances	Inflammable Substances
SiH_2Cl_2, CO, SiH_4, PH_3, Cl_2, HBr, BCl_3, NF_3, WF_6, N_2O, H_2SO_4, HCl, NH_4OH, HF, PH_3, B_2H_6, C_2F_6, SF_6, CHF_3, CF_4, $NaOCl$, Na_2SO_3, $NaOH$, IPA, $EKC265$, $PGMEA$, HNO_3, NMD-W, H_3PO_4, NBA, NH_4OH, C_4F_8, WF_6, NH_3, O_3, *Ethyl Lactate*, $EKC800$, Cl_2, CHF_3, KOH, BF_3, $POCl_3$, TLC	SiH_4, IPA, H_2, SiH_2Cl_2, PH_3, *Ethyl Lactate*, NH_3, CH_4, CO, $EKC800$, $TEOS$, $EKC265$, $PGMEA$, NBA, B_2H_6

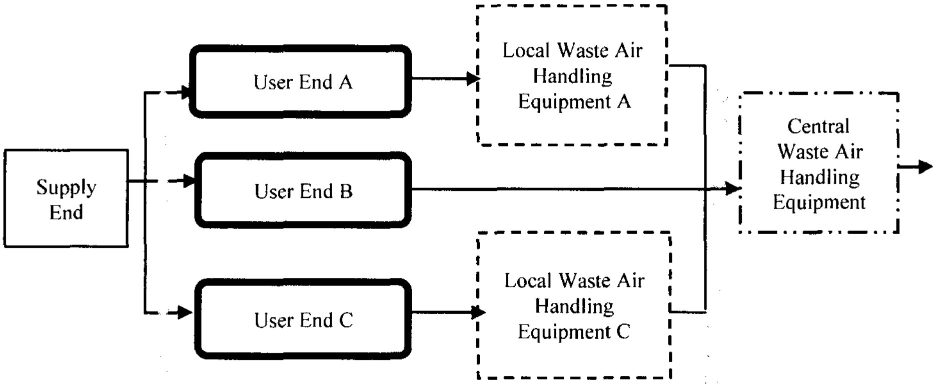

Figure 1. Chemicals Usage Range

2.2 Preliminary Hazard Analysis

The chemical leak hazard from semiconductor machines is assessed using a relative hazard ranking analysis for semiconductor machines and chemical exposure indexes for a hazardous working environment. This method comprehensively considers the fire, explosion, and toxic hazards attributable to chemical leaks and determines the relative hazard rank of various machines. This system establishes the basis for the frequency and depth of subsequent assessments. This method takes into account five factors; substance natural hazard (immediate damage to health or material's inflammable and explosive nature), amount of steam, ventilation system, process-related hazard, and staff/equipment asset exposure. The semiconductor machine relative hazard ranking analysis, as shown in Table 2, can be used as an analytical tool. The procedures are as follows: (1) select a machine with potential fire disaster, explosion, and toxic substance leak; (2) identify the most toxic substance of all of the chemicals used by this machine for the exposure to toxic substances evaluation; (3) assess the hazard rank using every one of the five hazard factors considered by toxic substance exposure index; (4) multiply the hazard rank of the five factors assessed to obtain the toxic substance exposure index; (5) convert the toxic substance exposure index into a toxic substance exposure rank according to Table 3; (6) identify the most explosive substance among the chemicals used by this machine for fire and explosion hazard evaluation; (7) assess the hazard rank using every one of the five hazard factors considered by the fire and explosion hazard index; (8) multiply the hazard rank of the five factors assessed to obtain the fire and explosion hazard index; (9) convert the fire and explosion hazard index into a fire and explosion hazard rank according to Table 4; (10) define the highest toxic substance exposure rank and fire and explosion hazard rank as the machine's relative hazard rank; if both ranks are equal to or greater than 3. The machine's relative hazard rank is determined by adding 1 to the highest rank; and (11) interpret the degree of the machine's hazard based on the machine's relative hazard rank, as shown in Table 5. The method for determining the toxic substance exposure index and the fire and explosion hazard index are illustrated as follows.

2.3 Toxic Substance Exposure Index

(1) Immediate Health Hazard: Immediate health hazard is influenced by two factors, that is, the immediate toxic concentration of the substance and the steam pressure that generates the energy to release the toxic effect and maintain the substance in the air. For this rank, ppm measures the toxin denoted by ERPG-2; evaporation is measured by the steam pressure in the unit of mmHg up to 760mmHg under 25℃ temperature. The immediate health hazard factor is obtained by dividing the ERPG-2 and 760 mmHg product by the steam pressure, as shown in the formula below:

Immediate Health Hazard Factor = ERPG-2 (ppm) x 760(mmHg) / Steam Pressure (mmHg)

ERPG-1: 2 ppm (60 minutes);

ERPG-2: 20 ppm (60 minutes);

ERPG-3: 100 ppm (60 minute).

Following ranges ranks the immediate health hazard factor:

Rank 5: if the immediate health hazard factor falls within 0 ~ 0.99;

Rank 4: if the immediate health hazard factor falls within 1 ~ 9.9;

Rank 3: if the immediate health hazard factor falls within 10 ~ 99;

Rank 2: if the immediate health hazard factor falls within 100 ~ 999;

Rank 1: if the immediate health hazard factor falls within 1,000 ~ 100,000;

Rank 0: if the immediate health hazard factor falls greater than 100,000.

(2) Amount of Steam: Select the maximum amount of substance that may leak or evaporate into the air within 15 minutes in the worst case. Select the possible pressure, temperature, mechanical failure, out-of-control response, pollution, or human error in the worst case, but do not arbitrarily assume that 100% of content will leak or evaporate. The following ranges rank the hazard factor:

Table 2. Relative Hazard Rank Analysis Table of Semiconductor Machines

Factory:	**Appraiser:**	
Module:	Toxic Substances	Inflammable Substances
Machine:	1. Toxic Substance Exposure	2. Fire and Explosion Hazard
1. Immediate Health Hazard (0~5)/Substance Fire and Explosive Nature Hazard (0~4)		
2. Amount of Steam (1~4)		
3. Ventilation System (1~3)		
4. Process Hazard (1~4)		
5. Human/Equipment Asset Exposure (1~3)		
Toxic Substance Exposure Index/Fire and Explosion Hazard Index		
Toxic Substance Exposure Rank (0~4)/Fire and Explosion Hazard Rank (0~4)		
Machine's Relative Hazard Rank (0~5)		
Machine's Degree of Hazard		
Improvement Suggestion/Supplemental Description:		

Rank 4: greater than 10kg;
Rank 3: 1 ~ 10kg;
Rank 2: 100g ~ 999g;
Rank 1: smaller than 100g.

If the substance is liquid and corrosive under normal temperature and pressure, then the amount of steam is equivalent to the maximum amount leaked.

Table 3. The Toxic Substance Exposure Rank

Toxic Substance Exposure Index Range	Toxic Substance Exposure Rank
0 ~ 5	0
6 ~ 15	1
16 ~ 35	2
36 ~ 70	3
> 70	4

Table 4. The Fire and Explosion Hazard Rank

Fire and Explosion Hazard Index Range	Fire and Explosion Hazard Rank
0 ~ 10	0
11 ~ 35	1
36 ~ 60	2
61 ~ 100	3
> 100	4

Table 5. The Machine's Degree of Hazard

Machine's Relative Hazard Rank Range	Degree of Hazard
0 ~ 1	Low
2 ~ 3	Medium
4 ~ 5	High

(3) Ventilation System: The leaked substance diffusion is directly affected by the ventilation system where the substance is located. The hazard factor is ranked in the following ranges:

Rank 2: general indoor ventilation system, for example, chemicals storage room, gas room etc.

Rank 1.5: forced ventilation or convection in air return way, where air is emitted directly from the air return system to the side. In this way, the leaked substance is easily diluted and dispersed.

Rank 1: forced ventilation in FAB, where air is brought directly to the air return system at a lower level by high-rising floor. In this way, the leaked substance is easily diluted and dispersed.

Rank 0: outdoor, where the leaked substance is easily diluted and dispersed.

(4) Manufacturing Process Hazard

A. When the pressure of the system is greater than 10 psig (i.e.1.75 absolute air pressure). This factor is equivalent to 2.

B. If the substance is heat unstable or potentially heat unstable under 100℃, or has a reaction upon contact with general substances such as air, water, or other substances. This factor is equivalent to 2.

C. If the substance is liquid and the machine equipped with a heating function. This factor is equivalent to 2.

If any two of the above factors exist simultaneously, the factor is equivalent to 3. If all of the three factors exist simultaneously, the factor is equivalent to 4. If none of the above factors exist, the factor is equivalent to 1.

(5) Human/Equipment Asset Exposure: Human/equipment asset exposure is used to assess the possibility of human exposure in the neighborhood when the unit or machine under study leaks. The following ranges rank the hazard factor:

Rank 3: Since operations staff, maintenance personnel or other related persons are present around the clock in a Fab, the area where human exposure will most likely occur should be identified.

Rank 2: In the air return area, some personnel work there and the equipment maintenance staff must perform maintenance tasks.

Rank 1: Some routine operations, for example, operational staff must change acid barrels or steel bottles in chemical storage room/gas room.

2.4 Fire and Explosion Hazard Index

(1) Substance Fire and Explosion Hazard: A substance flammability hazard rank has a given value range of 1 ~ 4, where greater value indicates greater hazard. The flammability value can be determined according to Table 6.

(2) Amount of Steam: The same toxic substance exposure index description is used. If the substance fire and explosion hazard involves steam, the hazard is designated as the maximum amount of substance leaked.

(3) Ventilation System: The description is the same as the toxic substance index. If the substance is spontaneously combustible, the hazard point is designated 3.

(4) Manufacturing Process Hazard: The description is the same as the toxic substance index.

(5) Human/Equipment Asset Exposure: The description is the same as the toxic substance index.

Table 6. The Inflammability Value Analysis Table

Inflammability Value	Conditions
4	1. Inflammable air 2. Spontaneous combustible substances 3. Substances with ignition point < 22.8℃ (i.e. 73°F) and boiling point < 37.8℃ (i.e. 100°F)
3	1. Liquid with ignition point < 22.8℃ (i.e. 73°F) and boiling point >=37.8℃ (i.e. 100°F) 2. Liquid with ignition point >= 22.8℃ (i.e. 73°F) and boiling point < 37.8℃ (i.e. 100°F)
2	Liquid of 37.8℃ (i.e. 100°F) < ignition point < 93.4℃ (i.e. 200°F)
1	Liquid with ignition point > 93.4℃ (i.e. 200°F)
0	Not inflammable.

2.5 Detailed Process Safety Evaluation: Hazard and Operability Study (HAZOP)

The hazard and operability study analyzes the possible causes and consequences of the manufacturing process deviating from normal design using deviation guidewords in terms of process parameters such as workflow, pressure and temperature etc. The risk rank for the probability and severity of the possible causes and consequences is derived from the analysis determined according to SEMI S10-1296 [6] (as shown in Table 7, 8, and 9). The probability and severity recognition relies on a systematic, carpet-bombing and pipeline-by-pipeline investigation of anything missed in security protection. Improvement plans are proposed on this basis. The HAZOP techniques essentially employ a series of conferences to examine process designs and procedures. During these conferences, a team of members with different science backgrounds uses designated methods to systematically evaluate the causes of various deviations. The HAZOP team applies a single method to every segment or step at once, and identifies the deviations that have the potential to cause a hazard using a set of established deviation guidewords. This process ensures that all of the deviations related to the process parameters are evaluated. At every segment or step, the team will occasionally consider a large number of deviations (i.e. 10 to 20) and identify their possible causes and consequences. All of these deviations from a specific segment or step are studied before the team moves onto the next segment or step.

Table 7. The SEMI S10-1296 Risk Rank

Risk Evaluation Matrix	**Probability**					
		A	B	C	D	E
Severity	1	1	1	2	3	4
	2	1	1	3	4	4
	3	2	2	4	4	5
	4	2	3	4	5	5

Note: 1. Serious; 2. High; 3. Medium; 4. Low; 5. Slight

Table 8. The SEMI S10-1296 Severity Rank

Severity Category		Human	Equipment/Facility	Leak
1	Serious	Death greater than 1	System or facility loss	Chemical leak causes immediate or sustained damage to environment or public health.
2	High	Permanent loss of functionality	Loss of primary sub-system or damage to facility	Chemical leak causes temporary damage to environment or public health
3	Medium	Medical damage or temporary loss of functionality	Loss of secondary sub-system or damage to facility	Chemical leak requires explanation by accident investigation report to the public.
4	Low	Requires general treatment	Damage to non-important equipment or facility	Chemical leak requires routine clean-up with no need for accident investigation report.

Table 9. SEMI S10-1296 Probability Rank

Probability Category		Expected Frequency of Occurrences
A	Often	More than five times a year
B	Probable	More than once but less than five times a year
C	Possible	More than once every five years but no more than once a year
D	Rare	More than once every ten years but less than once every five years

3. Risk Study and Analysis Results

3.1 Preliminary Hazard Analysis Results

One hundred forty-seven machines in Plant A were evaluated in the preliminary analysis. The machines are ranked by toxic substance exposure, fire and explosion hazard, respectively, on five levels 4, 3, 2, 1, and 0. Data were obtained, for example, from 17 types of machines coded SOG-1 or 2 in the thin film' area. The relative hazard rank analysis results were derived as shown in Table 10. Tables 11 and 12 illustrate the preliminary hazard evaluation results for semiconductor wafer plant A using toxic substance exposure and fire and explosion hazard ranks by summarizing the analysis of 147 machines in five areas. The combined preliminary toxic exposure and fire and explosion hazards are shown. The overall hazard ranking is divided into high, medium and low. The results are explained in Table 13. In the analysis results for Plant A, the etching process showed a toxic exposure rating at Ranks 4 and 3 (1.36% and 15.65%). This was higher than any other manufacturing equipment area. Etching was followed by the Diffusion Department (6.8% and 4.76%). In the fire and explosion analysis, the diffusion department showed the highest percentage (8.84% and 1.36%) at Ranks 4 and 3. In the preliminary hazard analysis results for all machines evaluated at Plant A, 21.77% were defined as high risk. The Diffusion Department showed the highest risk percentage. Based on the accident statistics for semiconductor wafer plant A, over the past 2.5 years, the frequency of accidents related to chemical substances in the etching and cleaning machines was higher than that for any other type of manufacturing equipment. The possible reason is that the Diffusion Department in Plant A is comprised of 1/3 cleaning machines that easily leak and exude peculiar smells.

3.2 Detailed Process Analysis (HAZOP) Results

Preliminary hazard analysis identified 32 machine types in Plant A that were highly hazardous. The machine types specified by the hazardous work site review and inspection according to Article 26 of the Labor Inspection Regulation (the machines that used chemicals such as, , HF, HCL, etc. and determined to be highly hazardous) were added to the detailed process analysis and evaluation list. The detailed process safety evaluation determined that 268 process deviations for 12 types of machines at Plant A were reduced in risk rank. Table 14 shows the risk rank, probability and severity analysis results.

Table 10. Semiconductor Machines' Relative Hazard Rank Analysis Table

Factory: Plant A	**Appraiser:**	**Thin Film/FAC/IS**
Module: Thin Film Area	**Toxic Substance: Ethyl Lactate**	**Inflammable Substance: IPA**
Machine: SOG-1, 2	1. Toxic Substance Exposure	2. Fire and Explosion Hazard
1. Immediate Heath Hazard (0~5)/Hazard of Substance's Fire and Explosion Nature (0~4)	2	3
2. Amount of Steam (1~4)	2	2
3. Ventilation System (1~3)	1	1
4. Process Hazard (1~4)	2	2
5. Human/Equipment Asset Exposure (1~3)	3	3
Toxic Substance Exposure Index/Fire and Explosion Hazard Index	24	36
Toxic Substance Exposure Rank (0~4)/Fire and Explosion Hazard Rank (0~4)	2	2
Machine's Relative Hazard Rank (0~5)	2	
Machine's Degree of Hazard	Medium	
Improvement Suggestion/Supplemental Description:		

Table 11. Semiconductor Wafer Plant A Preliminary Hazard Evaluation Results of Toxic Substance Exposure Rank (Unit: Number / %)

Rank	**4**	**3**	**2**	**1**	**0**	**Overall**
Diffusion	10 / 6.80	7 / 4.76	5 / 3.4	4 / 2.72	3 / 2.04	29 / 19.72
Etching	2 / 1.36	23 / 15.65	8 / 5.44	5 / 3.4	3 / 2.04	41 / 27.89
Developing	0 / 0.00	1 / 0.68	1 / 0.68	4 / 2.72	0 / 0.00	6 / 4.08
Thin Film	1 / 0.68	12 / 8.16	3 / 2.04	0 / 0.00	1 / 0.68	17 / 11.56
Factory Administration	3 / 2.04	7 / 4.76	21 / 14.29	19 / 12.93	4 / 2.72	54 / 36.74
Overall	16 / 10.88	50 / 34.01	38 / 25.85	32 / 21.77	11 / 7.48	147 / 100

3.3 Risk Rank Comparison Before and After SEMI S2-93A Implementation

The machines at Plant A (Hazard and Operability Study, HAZOP) were divided into two groups by manufacturing date; before and after 1993 (the machines were ranked by severity, probability and risk). The distribution results are shown in Table 15, 16, and 17. In the severity distribution, the machines made prior to 1993 showed 9.7% and 38.81% at severity ranks 1 and 2. This was 10% higher than those made after 1993 (9.7% and 28.36%). At probability ranks A and B, the machines made prior to 1993 showed 3.73% versus 0.93% shown by those made after 1993. The machines made prior to and after 1993 showed 15.67% and 14.81% respectively. The severity and probability analysis results found that the machines made prior to 1993 exhibited a higher percentage in terms of both severity and probability than those made after 1993. The implementation of SEMI S2-93A tends to reduce the severity and probability of hazard occurrences. In improving the hazard factors for various machines, the operational or maintenance manuals for manufacturing equipment that used hazardous materials or produced toxic substances described the possible critical failures or errors in detail to protect operators from hazards. Control of flammable substances by avoiding direct contact and potential ignition sources (e.g. heating surface) was instituted. SEMI S2-93A implementation enables evaluation and identification of potential hazards, e.g. toxic and/or flammable substances in the existing operation and maintenance processes as early as at the design or assembly stage. Even though recognized hazards cannot be eliminated, the automatic shut-off safety design prevents injury to operators or equipment loss due to hazard exposure if the equipment goes out of control.

Table 12. Semiconductor Wafer Plant A Preliminary Hazard Evaluation Results of Fire and Explosion Rank (Unit: Number / %)

Rank	**4**	**3**	**2**	**1**	**0**	**Overall**
Diffusion	13 / 8.84	2 / 1.36	5 / 3.40	0 / 0.00	9 / 6.12	29 / 19.72
Etching	1 / 0.68	0 / 0.00	0 / 0.00	6 / 4.08	34 / 23.13	41 / 27.89
Developing	0 / 0.00	0 / 0.00	1 / 0.68	4 / 2.72	1 / 0.68	6 / 4.08
Thin Film	5 / 3.40	0 / 0.00	7 / 4.76	3 / 2.04	2 / 1.36	17 / 11.56
Factory Administration	5 / 3.40	1 / 0.68	4 / 2.72	7 / 4.76	37 / 25.17	54 / 36.73
Overall	24 / 16.32	3 / 2.04	17 / 11.56	20 / 13.6	83 / 56.46	147 / 100

Table 13. Semiconductor Wafer Plant A Preliminary Hazard Evaluation Overall Results (Unit: Number / %)

Rank	**High**	**Medium**	**Low**	**Overall**
Diffusion	16 / 10.88	11 / 7.48	2 / 1.36	29 / 19.73
Etching	3 / 2.04	30 / 20.41	8 / 5.44	41 / 27.89
Developing	0 / 0.00	2 / 1.36	4/ 2.72	6 / 4.08
Thin Film	6 / 4.08	11 / 7.48	0 / 0	17 / 11.56
Factory Administration	7 / 4.76	25 / 17.01	22 / 14.97	54 / 36.73
Overall	32 / 21.77	79 / 53.74	36 /24.49	147 / 100

3.4 Comparison of Actual and Theoretical Accidents

The machines at Plant A were divided by manufacturing date before and after 1993. The number of accidents occurring for the two groups were analyzed and compared to understand if reality agreed with theory. Forty accidents occurred at 1993 equipment made before SEMI S2-93A implementation while 28 accidents occurred at equipment made after SEMI S2-93A implementation in 1993. One hundred seventy-three machines were made prior to 1993 and 195 made after 1993. The average number of accidents per machine, calculated by dividing number of accidents by the number of machines, was 0.23 for machines made before 1993 versus 0.14 for those made after 1993. According to this accident ratio, SEMI S2-93A implementation reduces the risks born by machines. Figure 2 shows that the highest accident occurrence (44%) existed in the Diffusion Department with machines made prior to 1993. The Thin Film Department (43%) consisted of machines made after 1993.

Figure 2: Accident Statistics of All Departments Before and After 1993

Table 14. Those Determined to Fall in Risk Rank at Plant A

Severity	Number	%	Probability	Number	%	Risk Rank	Number	%
1	26	9.70	A	2	0.75	1	0	0.00
2	90	33.58	B	4	1.49	2	0	0.00
3	92	34.33	C	40	14.93	3	29	10.82
4	60	22.39	D	203	75.75	4	182	67.91
			E	19	7.09	5	57	21.27

Table 15. Plant A Detailed Process Evaluation - Severity Evaluation Statistic Results

Rank	Prior to 1993 (%)	After 1993 (%)	Overall (%)
1	9.7	9.70	9.7
2	38.81	28.36	33.58
3	32.09	36.57	34.33
4	19.46	25.37	22.39

Table 16. Plant A Detailed Process Evaluation - Probability Evaluation Statistic Results

Rank	Prior to 1993 (%)	After 1993 (%)	Overall (%)
A	1.49	0.00	0.75
B	2.24	0.93	1.59
C	15.67	14.81	15.21
D	73.88	77.78	75.81
E	6.72	6.48	6.64

Table 17. Plant A Detailed Process Evaluation - Risk Rank Evaluation Statistic Results

Rank	Prior to 1993 (%)	After 1993 (%)	Overall (%)
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	11.19	10.19	10.74
4	70.9	79.63	74.79
5	17.91	10.19	14.46

4. Conclusions and Recommendations

The HAZOP analysis evaluates all of the equipment in the manufacturing process and all operations that occur through pipelines, power supplies, circuits, tower slots. The design, project data preparation, analytical method planning, post-analysis record collection and reports are all analyzed. This is a complicated job task. An important responsibility of HAZOP leaders is to determine how to use previous experience and estimate the implementation time required to schedule effectively without impacting normal operations and accomplish this time- and labor-consuming job within the expected time period. According to the preliminary hazard analysis, 7 high hazard ranked machines made prior 1993 incurred accidents. Six high hazard ranked machines made after 1993 incurred accidents. Hence, the overall accidents analysis showed that machines purchased before and after SEMI S2-93A implementation showed a 16% reduction in accidents. However, based on the overall accident statistical analysis, machines made prior to 1993 incurred 40 accidents, significantly higher than the 28 accidents on machines made after 1993. The highest accident rate existed in the Diffusion Department. The highest accident rate shifts to the Thin Film Department for machines made after 1993. The reason is that Plant A significantly reduced the purchase of diffusion equipment after 1993, thereby reducing the accident rate. Based on the preliminary hazard analysis results, the highest hazard rank for semiconductor wafer Plant A was the Diffusion Department (10.88% and 10.16%). The Diffusion Department (24) is followed by the Thin Film Department (18), Etching Department (13), Developing Department (8) and Factory Administration (5). Therefore, we recommend the largest percentage of safety and hygiene resources be allocated to the Diffusion Department followed by the Thin Film Department, to reduce risk and accidents. Furthermore, the differences in hazard severity between factories must be resolved. A common agreement and system for industrial safety risk evaluation must be shared by the two factories, along with enhanced education and training.

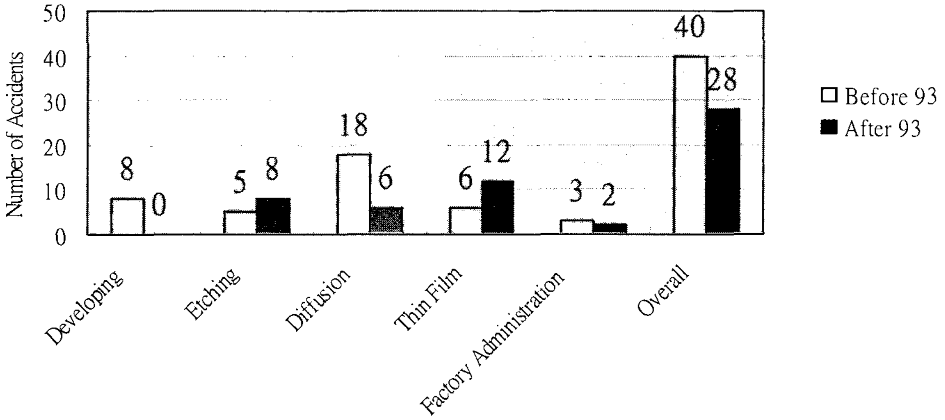

Figure 2. Accident Statistics of All Departments Before and After 1993

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