A Comparison of Wet Manual Cleaning Processes to Carbon Dioxide Cleaning Processes in the Semiconductor Industry

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ABSTRACT

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The purpose of the study was to analyze the risk exposures and costs involved in cleaning parts, equipment, and tooling in the semiconductor industry using wet manual processes and compare carbon dioxide as an alternative cleaning process.

The research focuses on wet manual processes currently used by semiconductor manufacturers to clean parts, tools, and equipment and carbon dioxide cleaning processes as an alternative to these processes.

A current analysis of the chemicals used in the wet manual processes and the risks they pose to an organization compared to the risks associated with carbon dioxide processes.

The research concludes that carbon dioxide blast cleaning processes reduce or eliminate employee health exposures, wastewater discharge, hazardous waste treatment costs, reduced environmental reporting requirements and liability issues, and clean at or better than current wet manual processes.

ACKNOWLEDGEMENT

I would like to thank my parents and my two sisters, Renee and Jessica, for their love and support while pursuing my education.

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CHAPTER 1

STATEMENT OF THE PROBLEM

INTRODUCTION

Cleaning parts, machines and equipment is a function of the production process that focuses on removing contaminants from a surface. These surfaces need to be cleaned to maintain quality, productivity, and overall efficiency of the production process.

The semiconductor industry has traditionally cleaned parts using acids, chlorinated, fluorinated, and other halogenated solvents to remove contaminates because of their stability and ease of drying (SEMARNAP, 1996). Environmental regulations, adverse health effects and costs of disposing of these chemicals has led industries to search for technologies that can reduce or eliminate these issues.

Carbon dioxide blasting processes are an alternative to the traditional processes of cleaning parts, tools, and equipment.

PURPOSE OF THE STUDY

The purpose of the study is to analyze the risk exposures and costs involved in cleaning parts, equipment, and tooling in the semiconductor industry using wet manual processes and compare carbon dioxide as an alternative cleaning process.

GOALS OF THE STUDY

The goals of the study were to:

1. Analyze wet manual cleaning processes and the risks exposures that these processes pose to an organization, specifically health exposures to employees, environmental impacts, facility exposures, and liability issues.
2. Examine using carbon dioxide as an alternative method to cleaning parts that reduce or eliminate the above-mentioned exposures.
3. Provide financial justification for the implementation of an alternative system to clean parts, tools, and equipment used in the manufacturing process.

BACKGROUND & SIGNIFICANCE

Dry cleaning processes are becoming the preferred method for cleaning parts and equipment in the semiconductor industry. The ultimate dream for the semiconductor industry is all dry cleaning processes (Van Zant, 97). The estimated global market for semiconductor equipment parts cleaning, based on 750 fabs worldwide will exceed one billion dollars annually (PRNewswire, 2000). This is a significant cost in the semiconductor manufacturing process. Reasons for utilizing dry cleaning processes include a significant reduction in hazardous waste accumulation and treatment costs, reduced employee health exposures and faster part cleaning times. There is evidence that significant savings can be achieved by the conversion to one of these alternative cleaning systems. Carbon dioxide cleaning processes are examples of these dry process methods.

Solvents and chemicals in use for parts cleaning in the semiconductor industry include methylene chloride, methyl ethylketone (MEK), glycol mixtures, hydrofluoric and sulfuric acids, tolulene, xylene, and alcohols. These chemicals present health, facility, and process quality risks to a semiconductor manufacturer. Dry cleaning processes seek to reduce or eliminate these risks as a tool to minimize losses and increase profitability as part of the semiconductor manufacturing process.

The hidden costs associated with wet cleaning processes include improved employee health and safety, lower maintenance, efficient chemical and water usage, improved productivity, reduced regulatory costs, lower future liability.

LIMITATIONS OF THE STUDY

There is not a significant amount of research published on the implementation of carbon dioxide cleaning processes. The carbon dioxide blast cleaning process and supercritical carbon dioxide cleaning processes are relatively new to the semiconductor industry.

DEFINITION OF TERMS

Dry Cleaning Processes- Processes that do not use water as part of their cleaning medium.

Enthalpy- The sum of the internal energy of a body and the product of its volume multiplied by the pressure.

Glovebox- an enclosure designed to contain the gases and particulates being removed from the object during cleaning.

Lipid- any of various substances that are soluble in nonpolar organic solvents that with protein and carbohydrates constitute the principal structural components of living cells.

Semiconductor fabrication- The process of manufacturing semiconductor devices often referred to as mircoelectronic circuits, integrated circuits, components, microchips, or chips.

Soluble- capable of being loosened or dissolved

Sputum- expectorated matter made up of saliva and often discharges from the respiratory passages.

Sublimation- To pass directly from the solid form to a vapor form

Substrate- Underlying surface of which a layer is formed

Wet cleaning processes- Those aqueous, semi-aqueous, and chemical processes using acids, solvents, surfactants, alkaline cleaners, builders, dispersants, corrosion inhibitors, chelating agents and defoamers to clean parts, tools, and equipment.

Carpal Tunnel Syndrome- An affliction caused by compression of the median nerve in the carpal tunnel. Often associated with tingling, pain, or numbness in the thumb and first three fingers.

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

Included in this chapter is a review of wet manual cleaning systems and two types of carbon dioxide cleaning systems; carbon dioxide blast cleaning and supercritical carbon dioxide cleaning (SCCO2). The review is used to gain an understanding of the technical processes and risks each process pose to an organization.

Cleaning parts, tools and equipment is an essential function of a semiconductor manufacturer. Aqueous, CO2 blast, and supercritical CO2 cleaning processes have advantages in relation to the quality of cleaning, the adverse effects on human health, the environmental impacts, and facility exposures. Ultimately these adverse effects can impact an organizations ability to operate efficiently.

WET MANUAL CLEANING PROCESSES

Wet manual cleaning processes use solvents, acids, and other chemicals to remove contaminants from the substrate of the object to be cleaned. Mechanical agitation such as ultrasonic or scrubbing with an abrasive material to remove the contaminant is often necessary. Monitoring of the chemistry to a specific concentration is sometimes necessary to maintain the cleaning effectiveness of the solution.

Acids, solvents, alkaline cleaners, builders, surfactants, dispersants, corrosion inhibitors, chelating agents and defoamers are some of the following chemical components that can be added to the water to create the cleaning solution. Solvents and acids will be the primary focus of this review due to their toxicity and environmental issues.

Hydrochloric, sulfuric, chromic, carboxylic, and nitric acids are commonly used acids in aqueous cleaning solutions. These acids are effective in the removal of metal oxides and organic metallics.

Organic solvents are used to dissolve and disperse fats, oils, waxes, pigments, varnishes, rubber, and many other contaminants. Organic solvents are classified into chemical groups dependent upon their chemical configuration and the absence or presence of functional groups. Cyclic hydrocarbons (eg. Cyclohexane and turpentine), Esters (eg. ethyl acetate, isopropyl acetate), aromatic hydrocarbons (eg. benzene, tolulene, xylene), alcohols (eg. ethanol, isopropanol), halogenated hydrocarbons (eg. carbon tetrachloride, chloroform), aldehydes (eg. acetylaldehyde, formaldehyde), ethers (eg. diethyl ether, isopropyl ether), and glycols (eg. ethylene glycol, hexylene glycol) (Queensland Health, 1999).

Most solvents aside from chlorinated solvents have the characteristic of a low flash point (<141 degrees Farenheit) giving them the characteristic of flammable. Organic solvents tend to be volatile and evaporate at room temperature and increasingly volatile as the temperature of the solvent solution increases. The lipid solubility of solvents allows the chemical to be absorbed through the skin. The toxicological properties of solvents are dependent upon their chemical grouping, but most have demonstrated adverse effects on the central nervous system, skin system, and the upper and lower respiratory tract. Some organic solvents have been classified as having carcinogenic effects with occupational exposure (Queensland Health, 1999).

The adverse health effects to employees from exposures to solvents include headaches, tiredness, dizziness, unconsciousness, and death. Respiratory effects include irritation to the upper airways, nose, throat, and trachea. Long-term exposure can lead to persistent cough and increased sputum production. Methylene chloride, which is widely used in the semiconductor industry as a solvent, has damaging effects on the heart. A condition known as cardiac sensitation can occur with prolonged exposure to organic solvents. The heart muscle becomes increasingly sensitive to epinephrine; this effects the rhythm of the heartbeat and can lead to sudden death if exposed to high levels of organic solvents (EHGN, 1999).

Organic solvents and acids possess the characteristics that make a substance hazardous waste as classified by the Resource Conservation and Recovery Act of the United States Environmental Protection Agency. The generators of these hazardous wastes are subject to reporting the type and quantity of the chemicals and are responsible cradle to grave for those chemicals (CFR 40). The cradle-to-grave is a significant liability issue for an organization. A company is liable for the damages due to their waste if not managed properly. These types of liabilities pose the risk of depleting an organization of all financial resources. Fairchild Semiconductor was responsible for contamination of a ground well in California in 1975 from the release of acids, cyanide, and organic solvents. The wells were contaminated causing cancer, miscarriage, and birth defects in affected citizens. The company has spent more than fifteen million dollars attempting to clean up the contaminated well (Miller, 1984). The fifteen million dollars does not include any liability damages to affected citizens.

Petroleum distillates, alcohols, and aliphatic hydrocarbons all possess the characteristic of flammability. In a semiconductor facility, the financial loss due to a fire can be very significant. A small fire in a fab can result in property, product, and productivity losses in the millions of dollars (Benson, 2000).

The cost of using organic solvents and other regulated hazardous materials include hidden costs directly related to the use, storage, and disposal of these chemicals. These hidden costs include, but are not limited to spill response equipment, emergency response planning, proper storage facilities, secondary containment, right-to-know training, labeling, waste collection equipment, emission control equipment, sampling and testing, transportation costs, permit preparation and fees, recording and reporting, and hazardous waste disposal costs (PNWPPRC, 99).

The use of halogenated solvents in dip tanks and parts washers are subject to air pollution emissions under the National Emission Standards for Hazardous Air Pollutants (NESHAP) by the Environmental Protection Agency. Methylene chloride, perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, and chloroform are a few of the regulated solvents. These are known or suspected carcinogens. The use of these solvents requires specific job processes to contain and comply with federal regulations.

A finishing step in cleaning with an organic solvent is a water rinse to remove the solvent and contaminant remaining on the surface of the substrate. Semiconductor manufacturing requires the use of ultra pure water to maintain the level of cleanliness necessary for quality product production.

Water from a city water system contains unacceptable amounts of dissolved minerals, particulates, bacteria, organics, dissolved oxygen, and silica (VanZant, 97) The purification costs can be significant. A large fab can use in excess of three million gallons of Ultra Pure Water (UPW) each production day (PPRC, 2000). It requires approximately 1400-1600 gallons of water to make 1000 gallons of UPW. Calculated to get a gross consumption of 4.2 million gallons of raw water usage per day.

Solvent processes account for approximately ten percent of this water consumption per day (PPRC, 2000). Cleaning processes use approximately 420,000 gallons of UPW per day to clean parts. Using the above figures for wet cleaning and treatment costs, 504 dollars per day is spent on water for wet cleaning processes if the price is twelve cents per gallon of city water. This doesn't take into account the energy and filtration equipment required to convert the utility supplied water to Ultra Pure Water and wastewater discharge costs.

The time required to dry a part after the rinsing steps occurs will vary from part to part. Mechanical and Evaporation are two basic types of drying systems. Mechanical systems include air blow off, compressed air knife, vibration, or centrifuge. Mechanical drying removes gross amounts of water, but cannot typically remove trace amounts. Evaporation converts the rinse water to a vapor to dry the part. Examples of these systems include hot forced air, infrared drying, and vacuum chamber drying. Operating costs for these machines include labor, capital cost, energy, and maintenance and costs.

The effects that solvent processes have on humans, the environment, productivity, liability, and compliance costs are leading company's to search for alternative processes which yield the same or better results, yet reduce or eliminate the wastestreams and risks that the wet manual processes present.

CARBON DIOXIDE BLAST CLEANING

Carbon dioxide cleaning processes utilize the physical and chemical properties of carbon dioxide in its various states to remove contaminants from a surface substrate.

Carbon dioxide blast cleaning and supercritical carbon dioxide are two processes that can be used to clean parts, tools and equipment in the semiconductor industry.

Cleaning with carbon dioxide utilizes solid particles of dry ice (snow) striking a surface accompanied by a high-pressure gas to remove the contaminant. This is possible because of the relationship of the solid to gas phase change. Carbon dioxide can move from the solid phase directly to the gas phase without the presence of the liquid phase. (Sherman, Adams 1996). This occurs at the critical point, correct temperature and pressure combination, of the gas.

The carbon dioxide passes through an orifice in the cleaning wand. The expansion of CO2 through an orifice is a constant enthalpy, where the vapor and pressure remains the same without a change in temperature (Sherman, Adams 1996). Liquid or gas phase CO2 is fed into the orifice. With a gas fed source the pressure drops in the orifice until the gas reaches its critical point and a percentage of the gas converts to a solid phase (dry ice particles). When a liquid source enters the orifice, the pressure drops and the solid moves into the gaseous phase. The percentage of solid particles produced varies with the source used. With a gas source, yield is approximately 8% particles and the remainder CO2 gas. When a liquid source is used the yield is approximately 45% dry ice particles (Sherman 97). These yields are dependent on source temperature, orifice design, initial source temperature and pressure.

Carbon Dioxide at normal room temperature and pressure exists as a gas. The carbon dioxide in the liquid or solid phase will return to a gaseous state upon cleaning. There is a generation of particulates when using the CO2 blast process. The contaminant being removed from the substrate will drop on to the floor or the bottom of the cleaning glovebox. Cleaning parts, tools, and equipment in the semiconductor industry usually occurs in a glove box equipped with HEPA filters and recirculating nitrogen to eliminate recontamination while cleaning is being performed (Sherman, 97).

Cleaning with carbon dioxide is similar to sand blasting, metal bead blasting, or soda blasting. A media is accelerated in a pressurized air stream that impacts the surface to be cleaned and removes particles that are not part of the substrate. In CO2 blasting, the medium is solid dry ice particles.

Particles are removed from surfaces by either moving fluid across the contaminant or a momentum transfer between the two surfaces, or a combination of the two processes (Grobe, Sherman, Whitlock 1991) Carbon Dioxide blasting uses a combination of momentum transfer and fluid movement.

Traditional abrasive techniques such as sand or metal bead blasting operate on the principle of a chiseling action when the media strikes the surface. This can damage the substrate surface. CO2 turns into a gas (sublimates) upon striking the surface. The CO2 creates a compression tension wave between the two surfaces, which breaks the adhesive force of the contaminant; it is then carried away by the high velocity gas and compressed air. (Sherman, 97).

Carbon dioxide is a non-toxic, non-hazardous, non-flammable, with no ozone depleting characteristics. The unique physical property of carbon dioxide sublimating directly to a gas from a solid phase results in no liquid wastestream. The only wastestream to be managed is the contaminant removed during the cleaning process. The contaminant is collected in the bottom of the cleaning glovebox with blast cleaning, or the bottom of the separation chamber in SCCO2 cleaning.

The employees performing the cleaning operation have the potential to inhale, ingest or absorb the cleaning solvent. The effects of exposure to these chemicals can lead to respiratory tract damage, cancer, nervous system disorders, and organ damage (Queensland Health, 99). In addition to these, there is the risk for cumulative trauma disorder development from the force and duration required to clean parts (Williams, 1995).

Progress can be made in the environmental impacts through the utilization of carbon dioxide cleaning processes. Rinsing steps of pure de-ionized water following cleaning leads to a reduction in water consumption and wastewater (Rubin, Sivils,). The elimination of solvent usage and subsequent mixtures of waste streams for cleaning leads to a reduction in the amount of hazardous waste that has to be treated. This leads to reduced regulatory reporting requirements.

The CO2 blast process requires the use of clean, dry compressed air. This may require a facility to upgrade their current compressed air system or install a dedicated system for the blast system.

Parts that a semiconductor manufacturer must clean as part of its manufacturing are listed in Table 1. (SEMATECH, 97). It illustrates the feed rates for shaved ice and palletized dry ice, blast pressures, and the time it took to clean each part.

SUPERCRITICAL CARBON DIOXIDE

Supercritical fluids are at a temperature and pressure greater than or equal to the critical temperature and pressure of a fluid. A supercritical fluid has the physical properties of somewhere between a liquid and a gas (Novak, 1993). Figure 1 is a generic pressure- temperature phase diagram that illustrates the composition of a supercritical fluid. The solubility characteristics are controlled by the manipulation of temperature and pressure to achieve the desired solvency power.

Table 1 Experimental Data

Item	Date	Tool	Cleaned	Pellets: Blast Pressure (psig)	Pellets: Pellet Rate (lb/hr)	Shaved Ice: Blast Pressure (psig)	Shaved Ice: Feed Pressure (psig)	Shaved Ice: Ice Rate (lb/hr)	Blast Air Temp (F)	Clean Time (min)
Data from Robotic Delivery System										
1	17-Oct-95		TEOS VALVE			130	56	50		2
2	17-Oct-95	COYOTE	COYOTE PIPE			130	56	50		
3	17-Oct-95	COYOTE	COYOTE PIPE			130	56	50		
4	17-Oct-95		BELLOWS MOSII NITRIDE FURNACE			130	56	50		
5	17-Oct-95	3180	TASI SHIELD			130	56	50		5
6	18-Oct-95	COYOTE	THROTTLE VALVE			130	50	50		5
7	18-Oct-95	SI NITRIDE	AMMONIUM CHLORIDE TRAP			130	50	50		10
8	18-Oct-95	SI NITRIDE	AMMONIUM CHLORIDE TRAP	100	60					5
9	18-Oct-95	3180	3180 TARGET SHIELD			100	50	50		
10	18-Oct-95	BPTEOS	THROTTLE VALVE			100	50	50	180	
11	18-Oct-95	BPTEOS	THROTTLE VALVE			130	50	60	180	
12	18-Oct-95	3180	ALUM SHUTTER	250	100					15
13	19-Oct-95	FURNACE	BLOWER SCREEN	150	50					2
14	19-Oct-95	BPTEOS	THROTTLE VALVE	150	50					2
15	19-Oct-95	8100	ALUMINUM ETCH SHIELD	100	50					
16	19-Oct-95		FURNACE TRAP	100	50					5
17	19-Oct-95	NOVELLUS	SHOWER HEAD	160	80	160	50	60	93	
18	19-Oct-95		WINDOW - HEX TRAY			200	50	60	93	
19	19-Oct-95		BP TEOS THROTTLE VALVE / OSI VALVE	210	40					15
20	25-Oct-95	3180	ALUMINUM SHIELD	210	60	200	50	70		
21	26-Oct-95	3180	TRANSFER PLATE			200	50	70		30
22	27-Oct-95	3180	TRANSFER PLATE			200	50	70		30
23	27-Oct-95	3180	RING - AFTER ETCH	200	50	200	50	40		
24	30-Oct-95		END CAP - HIPOX FURNACE			150	50	40		50
25	30-Oct-95		PRINTED CIRCUIT BOARD			100	50	40		
26	30-Oct-95		PRINTED CIRCUIT BOARD			60	50	40		10
27	30-Oct-95	3180	S/S/RINGS W/CLIPS #5 BARREL HI PRESS			200	50	60		5
28	30-Oct-95		ISOLATION VALVE	200	60					1
29	31-Oct-95	APPLIED 5000	TURBO SCREEN			70	45	22	150	0.5
30	31-Oct-95		POD SHIELD - ECLIPSE SPUTTER - ALUMINUM			250	45	70	150	
31	31-Oct-95	3180	TRANSFER PLATE - 2 SIDES	250	60	250	45	60	150	30
32	2-Nov-95	WHIRLER	PHOTORESIST BOWLS - 3 PARTS - S/S			60	45	28	132	15
33	7-Nov-95		ISOLATION VALVE - A3 FURNACE - MOSV			150	50	30	150	
34	7-Nov-95		POLY SI CARBIDE BOATS - BICII			100	50	30	150	
35	7-Nov-95		TEOS ELBOW (FORELINE)			125	50	20	150	
36	7-Nov-95		NITRIDE ELBOW			125	50	20	150	
37	7-Nov-95		THROTTLE VALVE			70	50	35	150	
38	7-Nov-95		SLOW START			70	50	35	150	
39	7-Nov-95		ECLIPSE SPUTTER WAFER HOLDER			250	50	40	150	
40	27-Nov-95		THROTTLE VALVE - TEOS			160	45	55	180	5
41	1-Dec-95		2 THROTTLE VALVES, 1 ISO VALVE			150	45	70	180	15
42	2-Dec-95		ISO VALVE - TEOS			150	45	70	180	15
43	3-Dec-95		THROTTLE VALVE & ISO VALVE			150	45	70	180	75
44	11-Dec-95		3180 TRANSFER PLATE	200	50				135	30
45	12-Dec-95		3180 TRANSFER PLATE			150	45	45		30
46	19-Dec-95		T4 - VALVES & PIPE			150	45	45	135	2.5
47	19-Dec-95		BPTEOS VALVE ELBOW, THROTTLE			150	45	45	135	1
48	5-Jan-96		3180 XFER PLATE			120	45	50		1
49	9-Jan-96		5000 THROTTLE & TURBO SCREEN - POLY			120	45	50		5
50	10-Jan-96		5000 SLIT VALVE - POLY			120	45	50		1
51	10-Jan-96		3180 XFER PLATE			120	45	50		30
52	17-Jan-96		5000 THROTTLE - POLY			120	45	50		15
53	20-Jan-96		THROTTLE VALVE			160	45	55	180	5
54	20-Jan-96		NECK & THROTTLE VALVE - BPTEOS			150	50	40	ROOM	60
55	21-Jan-96		3 THROTTLE & 3 ISO VALVES - BPTEOS			150	50	40	ROOM	120
56	14-Apr-96		QUARTZ LINER 5000 ETCH			155	35	60	ROOM	10
57	15-Feb-96	X4	NITRIDE END PLATE			150	50	55	ROOM	20
Data from Duck Gun Delivery System										
58	13-Mar-96		ISO VALVE			50	30	45	ROOM	10
59	13-Mar-96		BELLOWS FROM U1 FURNACE			50	30	45	ROOM	5
60	14-Mar-96		THROTTLES - APPLIED 5000 normally 2hrs			50	30	45	ROOM	1
61	14-Mar-96		THROTTLES - APPLIED 5000 normally 2hrs			50	30	45	ROOM	1
62	14-Mar-96		THROTTLES - APPLIED 5000 normally 2hrs			50	30	45	ROOM	1
63	14-Mar-96		THROTTLES - APPLIED 5000 normally 2hrs			50	30	45	ROOM	1
64	14-Mar-96		APPLIED 5000 SCREENS normally junked			50	30	45	ROOM	1
65	15-Mar-96		APPLIED 5000 SCREENS normally junked			50	30	45	ROOM	1
66	16-Mar-96		1 VALVE- 2 TURBO SCREENS			50	30	45	ROOM	
67	18-Mar-96		ISO VALVE -SOFT START			50	30	45	ROOM	20

Figure 1. Generic pressure-temperature phase diagram.

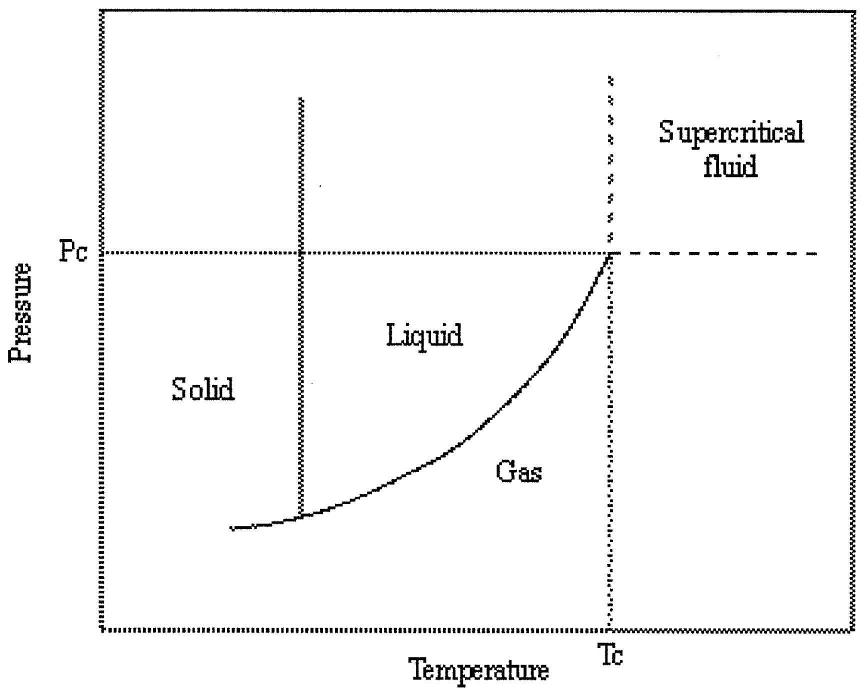

FIGURE 1

The process of utilizing SCCO2 involves a closed loop system to achieve the correct temperature and pressure to make the fluid supercritical. A system consists of a pump, a cleaning vessel, an expansion valve, separator, condenser, and a liquid CO2 storage unit. Figure 2 shows a typical SCCO2 system.

Figure 2. Basic schematic of a supercritical carbon-dioxide cleaning system.

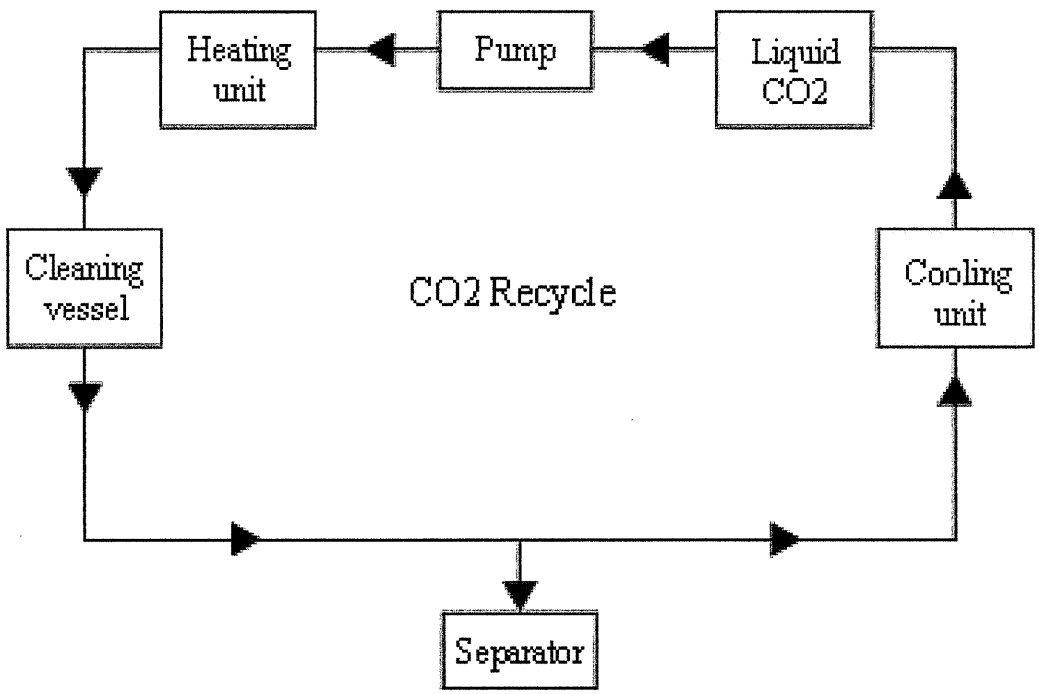

FIGURE 2

The liquid CO2 is transported from a liquid CO2 reservoir to a pump where it is pressurized to a critical temperature. The pressurized CO2 is then sent to a heater where it's heated to a critical temperature, the result after these two processes is the creation of supercritical carbon dioxide. This supercritical fluid is then transported to the cleaning vessel where it is brought into contact with the contaminated part. This is the step in the process where the contaminants are solubolized in the CO2 fluid. The contaminated SCCO2 is then sent to a separation vessel where the CO2 is depressurized back to a gaseous phase. The contaminants that were removed and are contained in the supercritical fluid drop out into the bottom of the separation chamber. The gaseous CO2 exits the separation vessel and is sent to a chiller where it is cooled back to a liquid phase for reuse. The closed loop system eliminates any waste stream other than the contaminant deposited in the bottom of the separation chamber (Davenhall, 2000).

SCCO2 can remove silicon, dielectric and machine oils, plasticizers, monomers, fluorinated oils, lubricants, and organic extractable adhesive residues (Nelson, 1997). It is currently being tested and refined as an alternative to other processes in the manufacture of semiconductor components due to the elimination of waste streams. Some of these processes include thin film deposition, metal etching, photoresist fixer/developer, and as a photoresist-stripping solvent.

Carbon dioxide cleaning processes are a non-aqueous cleaning system. The use of de-ionized water for rinsing the parts and the subsequent drying times are eliminated, increasing productivity.

The cleanliness of the part being cleaned is critical in the semiconductor manufacturing process. Particle removal in the sub-micron range is possible with carbon dioxide cleaning. Applied materials analyzed particles present on an oxide etcher after cleaning by conventional methods and compared those to particles present after cleaning with carbon dioxide. Figure 3 illustrates the results of the comparison. CO2 cleaning is capable of removing extremely small particles (<0.3 micron) (McKinstry, 97).

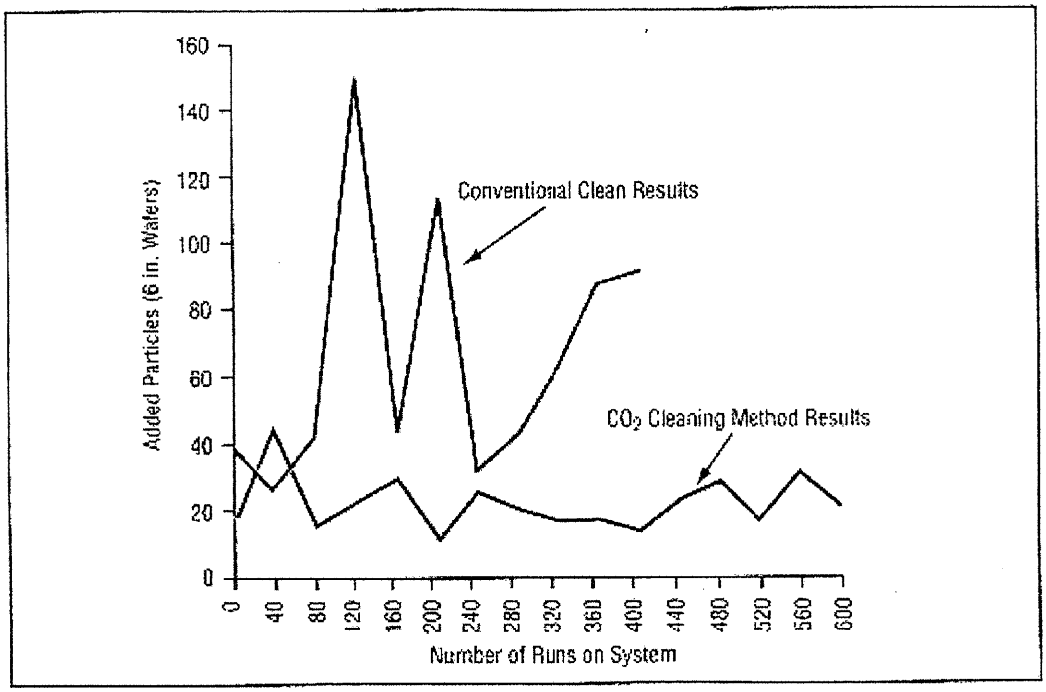

FIGURE 3

The substrate to be cleaned is virtually undamaged by the cleaning process. Unlike abrasive blasting and manual scrubbing methods, CO2 cleans by creating a compression tension wave on the surface of the substrate to remove the contaminant. The CO2 sublimates on impact leaving the surface free from defects.

Frosting and static discharge are some potential problems with CO2 blasting. Frosting is a potential problem with CO2 cleaning systems. Frosting occurs when the temperature of the part drops below the dew point and surrounding water in the atmosphere condenses on the surface. The use of heated plates or radiant heat sources during the cleaning process minimizes frosting. If cleaning is performed in a glove box the atmosphere inside the cleaning glove box can be controlled to eliminate this problem. Static charges are generated by the interaction of the spray and the surface being cleaned. Providing a flow of ionized air to neutralize the charges or grounding the part to the cleaning gun eliminates the buildup of the charge (Williford, 98). The decibel level of CO2 blast cleaning ranges from 85-130 decibels requiring the use of hearing protection or sound attenuated gloveboxes to reduce the level to acceptable levels (CAE Alpheus).

Carbon dioxide cleaning system configurations vary. There are portable units, bench units, automated cleaning systems, blast units contained in sound attenuated cleaning boxes equipped with HEPA filters. Costs can range from 22,000 dollars up to and exceeding 200,000 dollars with the cost of the system and associated equipment. L

Life cycle costs for CO2 cleaning systems are higher for capital costs and significantly lower for operating costs (Weber, 95). Texas Instruments completed a predicative total cost assessment analysis on a SCCO2 system to replace trichloroethylene to clean 150 bearings per year. The results indicate only a 1,400 dollar savings on a 75,000 dollar capital investment. The simple payback was eight years. This would not be justified as an alternative to the solvent process. A high volume of parts cleaning is necessary to justify the implementation of this type of cleaning system (Licis, 1995). The high capital cost of implementing a CO2 system is a deterrent to many companies seeking an alternative method. When calculating return on investment, it's necessary to include the costs currently being incurred by the conventional method that will be eliminated by the new process as well as productivity gains in part cleaning times and reduction or elimination of the hidden costs associated with wet manual cleaning processes (Thomas, 97).

SUMMARY

The process of cleaning parts is a technical process that has an impacts an organizations profitability. There are exposures to employee health, chemical and waste management costs, liability exposures, productivity impacts, water consumption, and associated hidden costs of parts cleaning. Carbon dioxide is an alternative process that enables a company to better manage these exposures as compared to wet manual processes.

CHAPTER 3

METHODOLOGY

The purpose of this chapter is to outline the methods used to develop a comparison of the three processes. To provide an understanding of the three processes used to clean parts and the risks inherent within each process to the affected employee, facility, productivity, and the environment.

The following process was used to gather relevant information pertaining to the purpose of the study and to meet the objectives of the study.

1.0 Research of technical literature to determine:

1.1 Wet manual cleaning processes

1.1.1 Process Characterization

1.1.2 Associated Risks

1.1.2.1 Costs

1.1.2.2 Health exposures

1.1.2.3 Environmental costs

1.1.2.4 Liabilities

1.1.3 Chemistry of cleaning solutions

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1.2.1 Physical properties

1.2.2 Chemical properties

1.3 Carbon dioxide blast processes

1.3.1 Process characterization

1.3.2 Effectiveness of cleaning

1.3.3 Associated risks

1.3.4 Economic impact

1.4 Supercritical carbon dioxide blast processes

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3.0 Case Study Analysis

3.1 Wet/Dry processes

3.2 Hazards

3.3 Costs

3.3.1 Initial

3.3.2 Maintenance

3.3.3 Hidden

4.0 Conclusions

Informal interviews were conducted with several manufacturers of carbon dioxide cleaning equipment. These interviews were used to obtain data concerning system configurations and price of system implementation. The interviews conducted involved process engineers as well as sales personnel from the various organizations.

Case study analyses were conducted to obtain information pertaining to the cost of implementing an alternative cleaning system at a semiconductor manufacturing facility. Case studies were used extensively to determine effectiveness of cleaning and the economic analysis.

CHAPTER 4

THE STUDY

INTRODUCTION

From the review, information was gathered on wet manual, carbon dioxide blast, and supercritical carbon dioxide cleaning processes. The risks and costs associated with each process; health, environmental, liability, maintenance, productivity, water consumption was formatted to provide a means of comparing the processes. Carbon dioxide blast cleaning has been implemented at semiconductor manufacturing facilities as an alternative to wet manual cleaning processes. The following information compares the CO_2 blast cleaning process to the conventional wet manual process.

WET MANUAL PROCESS HAZARDS

The hazards and risks of the wet manual processes include adverse health effects, hazardous waste generation and disposal, environmental compliance, environmental liabilities, respiratory problems, hidden costs associated with hazardous chemicals, water consumption and discharge costs, and cumulative trauma disorders from agitation processes.

CARBON DIOXIDE CHARACTERISTICS

Carbon Dioxide is a dry cleaning process utilizing non-toxic, non-flammable, CO_2 as a cleaning medium. Carbon dioxide sublimates to a gas following the cleaning of the parts, tools, and equipment eliminating the hazardous waste treatment and disposal costs as well as the consumption of Ultra pure water as a rinse.

TABLE 2

Item A. Operating Costs for Cleanblaster		**ANNUAL COSTS**
Power (compressor) - 150hp x 750w/hp x 1kw/1000w x $.06/kw-hr x hr/yr		$58,968
Block Ice - 10 blocks/yr x $.23/# x 50#/block		$5,980
Maintenance Agreement		$3,500
Exhaust (glove box) - $4.00 x 1290cfm x 1 yr		$5,160
	TOTAL ANNUAL OPERATING COSTS	**$73,608**
Item B. Equipment Costs for Cleanblaster		**ANNUAL COSTS***
Dry Ice Tool (purchase) Note - not included in associated costs		$22,200
Installation costs		$7,102
* Assuming Five Year Life	**TOTAL ANNUAL EQUIPMENT COSTS**	**$29,302**
Item C. Associated Savings		**ANNUAL COSTS**
Item 1. Coat Track Assembly		
Manual clean		
Acetone - # gal/yr @ $/gal		$4,992
Disposal costs # gal/yr @ $/gal		$2,600
Exhaust costs @ $4.00 x 775cfm x 1yr		$3,100
Time to clean - 1 hr/set of 3 components		
clean # sets/yr x 1hr/set x labor rate		$31,668
	Manual Clean Cost	$42,360
Dry Ice Method		
Time to clean - 5 min (0.083 hr)/set of 3 components		
# sets/yr x .083hr/set x labor rate	Dry Ice Method Cost	$2,628
	Annual Savings	**$39,732**
Item 2. Throttle Valve Assembly		
Manual clean		
Time to clean - 2 hr/unit x # units/yr x labor rate	Manual Clean Cost	$84,240
Dry Ice Method		
Time to clean - 2 min/unit x # units/yr x labor rate	Dry Ice Method Cost	$1,404
	Annual Savings	**$82,836**
Item 3. Applied 5000 Screens		
Manual clean		
Time to clean - none - unit junked - # units/yr x $/unit	Manual Clean Cost	$22,500
Dry Ice Method		
Time to clean - 2 min/unit x # units/yr x labor rate	Dry Ice Method Cost	$27
	Annual Savings	**$22,473**
Item 4. Throttle Valve		
Manual clean		
Time to clean - 2 hr/unit x# units/yr x labor rate	Manual Clean Cost	$112,320
Dry Ice Method		
Time to clean - 7min/unit x # units/yr x labor rate	Dry Ice Method Cost	$6,552
	Annual Savings	**$105,768**
Item 5. Isolation Valves		
Manual clean		
Time to clean - 2 hr/unit x # units/yr x labor rate	Manual Clean Cost	$112,320
Dry Ice Method		
Time to clean - 7min/unit x # units/yr x labor rate	Dry Ice Method Cost	$6,552
	Annual Savings	**$105,768**
Item 6. Blower Flanges		
Manual clean		
Time to clean - 2 hr/unit x # units/yr x labor rate	Manual Clean Cost	$13,824
Dry Ice Method		
Time to clean - 10 min/unit x # units/yr x labor rate	Dry Ice Method Cost	$1,152
	Annual Savings	**$12,672**
Item D. Net Savings		
Item 7. Sum of Items 1 through 6		
	TOTAL ANNUAL SAVINGS	**$369,249**
Item 8. Total of Items A and B		
	LESS ANNUAL EQUIPMENT AND OPERATING COSTS	**$102,910**
Item 9. Item 8 from Item 7		
	TOTAL ANNUAL NET SAVINGS	**$266,339**