

Environmental Technology Initiative: Chemical-Free Cleaning of Semiconductors by the Radiance Process®

by

Ronald N. Legge
Dan L. Thompson
Diana J. Convey
MOTOROLA

Advanced Process and Characterization Laboratories
Tempe, AZ 85264

Joel D. Peterson
MOTOROLA

Environmental, Safety, and Industrial Hygiene
Tempe, AZ 85264

EPA Reference: **DW97937360-01-0**

Project Officer

Paul M. Randall
Sustainable Technology Division
National Risk Management Research Laboratory
Cincinnati, OH 45268

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

Notice

The U.S. **Environmental Protection** Agency through its **Office** of Research and Development **funded** the research described here under Environmental Technology Initiative Project No. **DW97937360-01-0** to **MOTOROLA**. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency is charged with protecting the Nation's land, sea, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water, and prevention and control of indoor air pollution. The goal of this research is to catalyze development and implementation of innovative **cost-effective** environmental technologies, develop scientific and engineering information needed by EPA to support regulatory and policy decisions, and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as a part of the Laboratory's strategic, long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Preface

Motorola appreciates the opportunity that the Environmental Protection Agency and the Microelectronics Research Laboratory has provided to advance research in the area of dry cleaning in the semiconductor industry. Motorola is firmly committed to reducing waste and preventing pollution and continues to explore new technologies in pursuit of these goals. This evaluation of a laser cleaning technology is consistent with our corporate initiative of “environmental leadership” and has demonstrated the great potential that exists for water, chemical conservation and waste prevention.

The EPA sponsored this particular Environmental Technology Initiative project to build a prototype semiconductor wafer cleaning tool using the Radiance **Process**[®] to evaluate its effectiveness, cost, and pollution prevention potential. The partners in this unique project are the EPA, the Microelectronics Research Laboratory (MRL), a Department of Defense facility in Columbia, Maryland, Motorola’s Advanced Process and Characterization Laboratories of the Phoenix Corporate Research Laboratories in Tempe, Arizona, Radiance Services Company in Bethesda, Maryland, and Neuman **MicroTechnologies**, Inc., in Concord, New Hampshire.

Abstract

The Radiance Process® is a patented dry process for removing contaminants from surfaces. It uses light, usually from a pulsed laser and a gas inert to the surface, to entrain released contaminants. The focus of this effort is to assess the applicability of the Radiance Process® to the semiconductor industry and its pollution prevention potential.

This report discusses the results of experiments conducted to investigate the effectiveness of the Radiance Process® in removing chemical mechanical polishing (CMP) slurries **from** wafers, cleaning flat panel display glass, and removing particles from bare silicon wafers. The results show that post-CMP cleaning using the Radiance Process® can restore bare silicon wafers to near virgin conditions. This can be accomplished without additional wet chemical processing and can potentially eliminate a minimum of two manufacturing tools, thereby reducing the demand for water and chemical waste treatment in a semiconductor manufacturing facility.

For flat panel display material, the Radiance Process® was used to clean vendor-supplied float glass substrates used in fabrication. This resulted in reducing total particle counts in excess of **5000** to below 100. These results were equal to, or, in some cases, better than current wet cleaning processes. Contamination not removed by wet processing was further reduced by using the Radiance Process®. Particle removal from bare silicon wafers was tested in two specific conditions with no statistically significant repeatable removal rates.

“Radiance Process®” is a registered trademark of Cauldron Company.

Table of Contents

Notice	i
Foreword	ii
Preface	iii
Abstract	iv
Table of Contents	v
List of Tables, Figures, and Graphs	vi
Abbreviations and Symbols	vii
Acknowledgments	1
Chapter 1 Introduction	5
Chapter 2 Background	6
Chapter 3 Methods and Materials	12
Chapter 4 Results and Discussion	17
Chapter 5 Conclusion	18
Chapter 6 Recommendations	19
References	20
Appendix A Sample Test Runs	

Lists of Tables, Figures, and Graphs

Tables

1-1	Ultrapure Water Usage	3
4-1	Average Distribution of Particles by Sample Set	15
4-2	TXRF Measurements for Heavy Metal Contamination	16

Figures

1-1	Radianc Process@'	1
1-2	Radianc Process@ Schematic for Cleaning a Flat Surface	2
1-3	Prototype Laser Cleaning Station	2
3-1	Orbotech FPD Glass As-Received Measurements	6
3-2	Orbotech FPD Glass After Laser Clean Results	7
3-3	Silicon 2 Tencor Surfscan 4500 Initial Measurements	9
3-4	Silicon 2 Tencor Surfscan 4500 After Laser Results	10

Graphs

4-1	Post-Laser Clean of FPD Glass	12
4-2	FPD Post-Wet Clean Laser Process	12
4-3	Post-CMP Processing Using a Common Slurry Batch	14
4-4	Post-CMP Processing Using a Dedicated Slurry Batch	14

Abbreviations and Symbols

AOI	angle of incidence
Beam SZ	beam size
Ca	calcium
CFC	chlorofluorocarbon
CFCs	chlorofluorocarbons
Cl	chlorine
CMP	chemical mechanical polishing
c u	copper
DET	detailed
Fe	iron
FLU J/cm^2	fluence joules/cm²
FPD	flat panel display
FPDD	Flat Panel Display Division
HF	hydrofluoric acid
HF:NH₄F	hydrofluoric acid:ammonium fluoride
ID	identification
J/cm²	joules/cm*
MRL	Materials Research Laboratories
mm	millimeter
N₂	nitrogen
Ni	nickel
Nd:YAG	neodymium:yttrium aluminum garnet
np	no polarization
OP	operator
PECVD	plasma enhanced chemical vapor deposition
POL	polarization
REP RATE	repetition rate
RCA	Radio Corporation of America
SCAN PAT	scan pattern
SiO₂	silicon dioxide
SRD	spin rinse dry
Stand Dev	standard deviation
STD	standard
TEOS	tetraethylorthosilicate
Ti	titanium
TXRF	total reflection x-ray fluorescence
UPW	ultra pure water
v o c	volatile organic compound
VOCs	volatile organic compounds
Zn	zinc
Å	angstrom
μm	micrometer

Acknowledgments

Motorola would like to thank Dr. Michael King of the Microelectronics Research Laboratory for his assistance. The Advanced Process and Characterization Laboratories' Chris Freeman and Diana Convey contributed significant time and effort to ensure the timely completion of this project. Neuman **MicroTechnologies** (tool builder) and Radiance Services Company (patent assignees) provided technical support and advice. This project **would** not have been possible without the generous support of the EPA and the Microelectronics Research Laboratory for providing the laser cleaning tool.

Chapter 1 Introduction

Microelectronic device fabrication is heavily dependent on surface preparation. Wafer cleaning processes can contribute significantly to the cost of a device. These costs include equipment, chemicals, engineering, and post-process treatment. Reduction of chemical use and post-use treatment can provide significant dividends to the environment and manufacturing capability. Laser cleaning is a promising new technology that can be used to supplant several conventional wet clean processes.

The Radiance Process[®] is a patented⁽¹⁻⁴⁾, dry process for removing contaminants from surfaces. It uses light (photon flux), usually from a pulsed laser, and a gas inert to the surface, usually nitrogen, to entrain released contaminants as shown in Figure 1- 1. The entrainment of the contaminants prevents redeposition on the surface. The gas can be filtered and reused, or exhausted. The light, either deep ultraviolet from an **excimer** laser or light from a Nd:YAG laser, is used to break the bonds holding the contaminants to the **surface**⁽⁵⁾.

The Radiance Process[®] is tunable to the surface and contaminants to optimize cleaning efficiencies and throughput⁽⁶⁾. It operates at room temperature and pressure and is believed not to cause melting, annealing, and little or undetectable microroughening.

Classic aqueous cleaning methods become problematic for particles smaller than 300 nanometers. Future high technology products require removal of the smallest contaminants.

The Process can remove oxides, metals, fingerprints, and other contaminants from silicon, gallium arsenide, stainless steel and other metals, quartz, glass, ceramics and other industrial plastics making its breadth of application very broad in the aggregate⁽⁶⁾. Figure 1-2 shows a schematic for cleaning a flat surface. Figure 1-3 shows a prototype of a laser cleaning station.

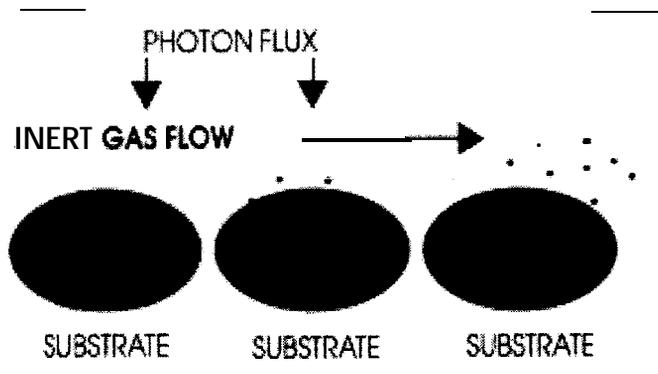


Figure I- 1. Radiance Process[®]

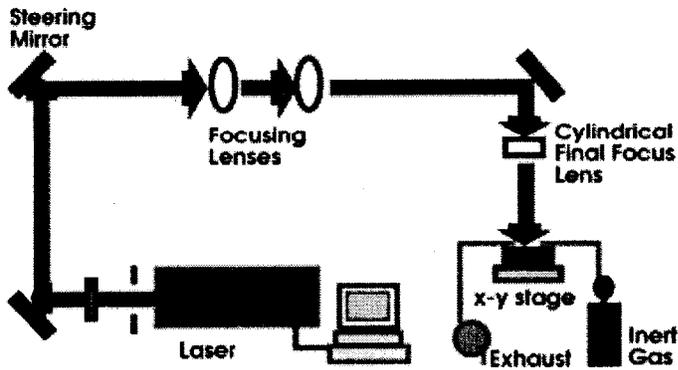


Figure 1-2. Radiance Process[®] schematic for cleaning a flat surface.

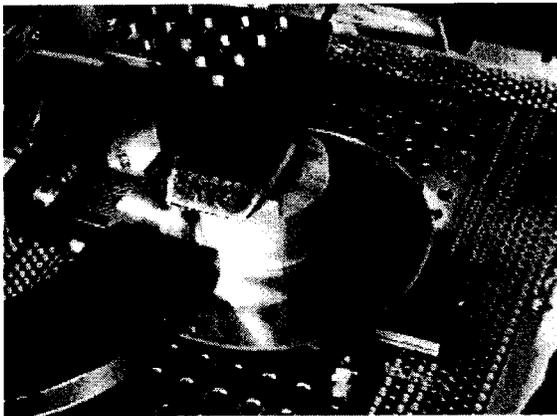


Figure 1-3 Prototype Laser Cleaning Station

Pollution Prevention Potential

Due to the highly competitive and proprietary nature of the semiconductor industry, manufacturers are reluctant to share detailed technical information regarding their processes, including chemical recipes, material consumption, yields, and wastes. Consequently, accurate estimates for the industry as a whole regarding chemical and water consumption are not readily available. Suffice it to say that the industry relies heavily on water and chemicals to achieve the level of cleanliness required to construct sub-micron electrical circuits.

Wet Chemical Process Inputs

There are numerous wet chemical cleaning “recipes” in use across the industry. The most universally employed method is the RCA cleaning process. It was originally developed in the late 1960s and subsequently refined. The process uses mixtures of chemicals to clean surfaces and numerous rinses of ultra pure water (UPW) to transport contaminants away from the wafer. Since this process or a variation is widely used in the industry, the RCA cleaning process can be used as a benchmark to gauge potential opportunities for resource conservation and waste minimization.

Chemical consumption associated with wet cleaning processes can account for one-third of the total chemical costs of fabrication that is estimated to exceed \$700 million world-wide ⁽⁷⁾. The RCA cleaning processes use various concentrated and dilute mixtures of sulfuric acid, hydrogen peroxide, hydrofluoric acid, ammonium fluoride,

ammonium hydroxide, hydrochloric acid, and ultra pure water⁽⁸⁾. One silicon wafer fabrication facility with 6000 wafer starts per week can consume one million pounds of chemicals per year in just this one process.

Estimates of UPW consumption for manufacturing a 200 mm silicon wafer range from 1000 to 2000 gallons per wafer. Factoring in the water required to make UPW (2: 1) and various ancillary processes, many fabrication facilities can use 3 to 5 million gallons of water per day. Data show that the average use of UPW per square inch of silicon has remained constant over the past decade. In 1983 it was 29 gallons per square inch and in 1996 it was 28.4 gallons per square inch (Table 1)⁽⁹⁾. This tracks well with the 1000-2000 gallon /wafer estimate, with the 1996 average usage of 1427 gallons per wafer (29 billion gallons of UPW to produce **980,000,000** square inches of silicon). Without water conservation, projected UPW use in the year 2002 will reach nearly 50 billion gallons per year in the United States alone ⁽¹⁰⁾.

Table 1-1 Ultrapure Water Usage

<u>Year</u>	<u>Gallons per year</u>	<u>Sq. in. of Silicon</u>
1983	6.4 billion	220,000,000
Gap		
1996	28 billion	980,000,000
1997	29 billion	1,020,000,000
1998	32.4 billion	1,142,000,000
1999	37.1 billion	1,307,000,000
2000	42.6 billion	1,500,000,000
2001	45.6 billion	1,600,000,000
2002	49.8 billion	1,755,000,000

Consequently, the potential opportunity for water conservation is very large even if the laser cleaning process is applied to only a portion of the wet chemical cleaning applications. Furthermore, in addition to direct water conservation, the process of purifying water to UPW standards requires substantial inputs of energy, materials and water, and represents an opportunity for waste minimization and cost avoidance.

The cost of producing UPW is typically around \$15 per 1000 gallons. The costs include electrical consumption, chemicals required to maintain the purification equipment and make-up water. A large-scale UPW plant can cost as much as \$20 million. Reducing a fabrication facility's usage of UPW could enable a company to realize substantial savings by installing **and** operating smaller UPW plants. A fabrication facility running at 6000 wafer starts per week, using 1000 to 2000 gallons of UPW per wafer spends \$90,000 to \$180,000 per week or \$5 million to \$10 million per year.

In addition to the direct usage of UPW and the associated costs, UPW production uses approximately two gallons of water to make one gallon of UPW ⁽¹⁰⁾. As a result, between 625 million and 1.25 billion gallons of water could be used, treated, and discharged to support just one fabrication facility. Factoring this into the previous UPW **usage** data results in almost 60 billion gallons of water consumed in 1996 for semiconductor manufacturing in the United States alone. Projecting for the year 2002 raises this number to well over 100 billion gallons consumed annually.

Wet Chemical Process Waste Treatment

Traditional wet chemical cleaning processes result in waste streams that typically require treatment before release. Waste water and exhaust air from these processes contain residuals of the applied chemical. The concentrated chemicals are collected and treated in segregated systems. The management of these solutions as well as dilute process wastes requires a considerable investment in both money and resources and should be incorporated into the assessment of potential pollution prevention opportunities.

Costs and material/energy inputs for industrial waste water treatment systems will vary depending on the specific nature of each operation. The treatment processes typically require addition of chemicals to adjust **pH** and, in some cases, remove fluoride or pollutants subsequent to discharge. Implementation of the laser cleaning process could reduce the size and complexity of treatment systems and the associated costs for installation, operations, and

maintenance. Reducing usage of water and wet cleaning process chemicals would have the direct result of-reducing the mass of water treatment chemicals, perhaps by hundreds of thousands of pounds annually for a typical fabrication facility.

There are substantial costs and material energy inputs associated with exhaust abatement for removal or conversion of pollutants entrained in the process exhaust. These include acids and bases that are removed using wet scrubbers. Volatile organic compounds (**VOCs**) are also removed or converted using carbon adsorption or thermal oxidation. Air emissions are tightly regulated. Limitations imposed through these regulations are an issue with respect to cost of continued operations and viability of expansion plans. Exhaust from the Radiance **Process**® would consist of the nitrogen carrier gas and the particles being removed, which would subsequently be collected using exhaust filtration. Due to the relatively benign nature of the resulting emissions, the process of obtaining a permit to use the process would be relatively simple.

Chapter 2 Background

The tests conducted were separated into three areas of interest: flat panel display glass, silicon wafers, and post-CMP cleaning. The intent was to provide a direct comparison of the Radianc Process™ with an associated wet cleaning process. A discussion of each area is included in the major topics (conclusions, recommendations, etc.) of this report.

Flat Panel Display Glass

Vendor supplied 150mm round soda lime glass substrates for flat panel displays were found to be very high in **particulates** and other contaminants. The standard semiconductor cleaning processes are not applicable to these substrates. Soda-lime float glass would be unusable if exposed to standard HP chemistries. Motorola's Flat Panel Display Division (FPDD) has worked very hard to develop a stringent clean that reduces the incoming contamination level. Typical as-received contamination levels are in excess of 5000 particles (the saturation point of the metrology tool used).

Silicon Wafers

Silicon 1

Silicon wafers are used to make the vast majority of semiconductor devices. Device manufacturing can involve hundreds of steps including numerous cleans using a variety of wet and dry chemicals in large quantities. One of the most common cleans, which is typically used to strip photoresist, exposes the substrates to an **oxygen** plasma generated by an RF source. Unidentified particles are generated by wafers, wafer handling and equipment used for the oxygen plasma cleaning process. These particles can number from 25 to 1500 per **100mm** wafer, and range in size from **0.06µm** to several micrometers in diameter.

Silicon 2

The second silicon wafer set consisted of a **1000Å SiO₂** layer deposited and then stripped in a buffered oxide etch of **HF:NH₄F**. This process resulted in a remaining particle count of ~1000 per wafer ranging in size from **0.06µm** to several micrometers in diameter.

Post-CMP Cleaning

CMP is an inherently "dirty" process. Semiconductor device complexities and resulting topology require the use of CMP to remove or reduce topology for subsequent interconnect metal layers. The process requires the use of silica or alumina particles suspended in a weak base solution that is then applied to a polish table. The wafers are placed on a polishing table with the device side in contact with the slurry and the rotating polish table.

Removal of slurry residues after a CMP process is critical. Slurry residues add to existing surface contaminants and contain a wide range of particle sizes that if left on the surface would result in **low** yield. Manufacturing's task is to reduce the level of contamination to a level that existed before the CMP process. This requires the use of additional equipment like double side brush scrubber tracks. It also requires additional wet clean steps and the use of spin rinse dryers (SRD) to reduce contamination to the lowest practical levels.

Chapter 3 Methods and Materials

Flat Panel Display Glass

As-received 150mm round soda-lime float glass substrates were measured before and after the Radiance Process® using an Orbotech Model LC3050 scanner. The Orbotech program selected for this study measured all particles down to 1.5µm in size within a 106mm X 80mm scanning area. The Orbotech's saturation point is -5000 particles. A data sheet of a typical prescan is shown in Figure 5-1. As can be seen on this figure, once the saturation level is reached scanning stops. The total number of defects it displays is only that which the tool could record prior to saturation. The estimated 5000 particle saturation point was calculated by averaging these displayed values using the 106mm x 80mm scan area.

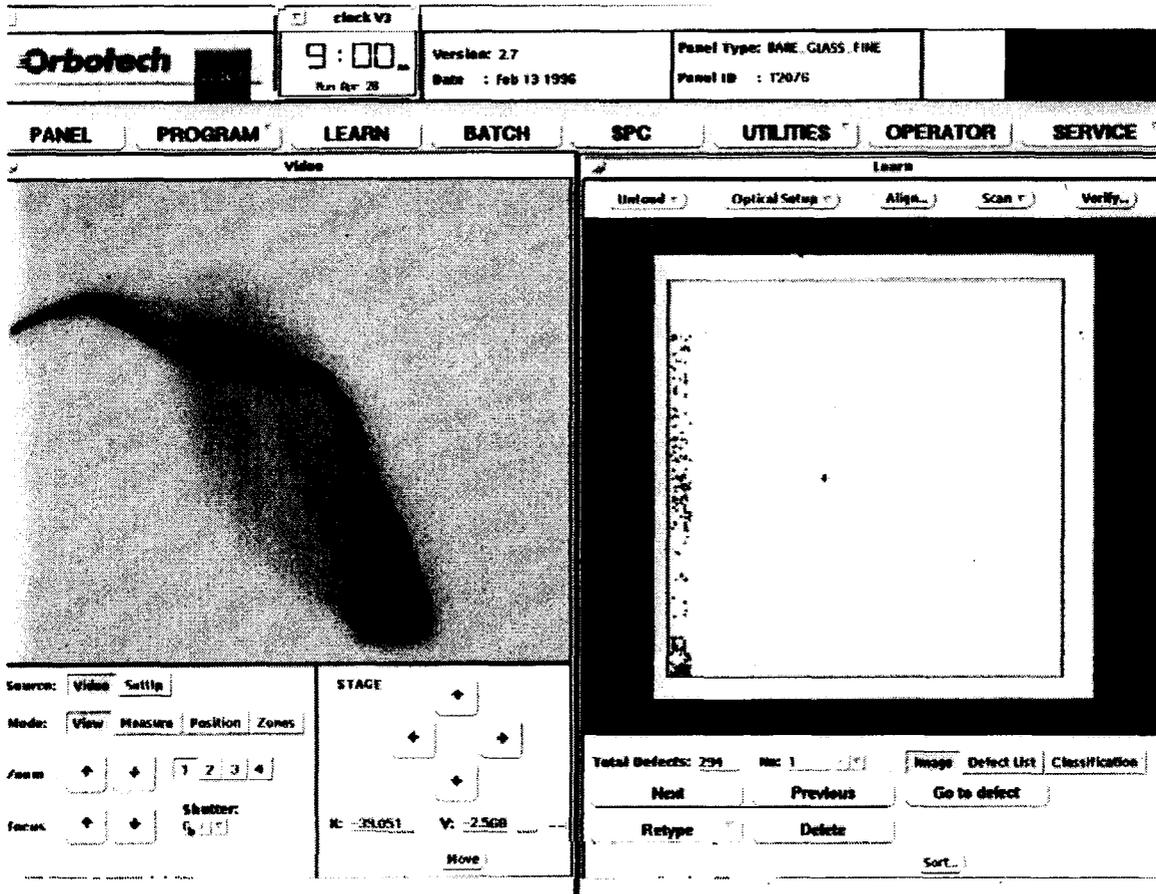


Figure 3-1 Orbotech FPD glass as-received measurements. Orbotech results sheet showing the total particulate count of an as-received 150mm soda lime float glass substrate.

Notice only a thin area on the left indicates particles before saturation occurs. When saturation does occur the tool displays the last count, not the saturation limit. The estimated total particle count at the saturation point is -5000. Also note the image on the left is a magnified view of one of the defects on the right side. Samples were exposed to the Radiance Process® using either the tool's robotics in automatic mode or manually loading the substrate onto the sample chuck. Best results were obtained by using the following parameters:

Polarization	none	Angle of Incidence	90°	Beam Dimensions	22mm x 0.7mm
Repetition Rate	100Hz	# of Pulses	26	N ₂ Flow Rate	40L/min.
Scan Pattern	Standard	Fluence	1J/cm ²		

Figure 3-2 is a typical Orbotech results data sheet indicating the number and position of particles and defects remaining after the FPD glass samples were exposed to the process parameters stated above.

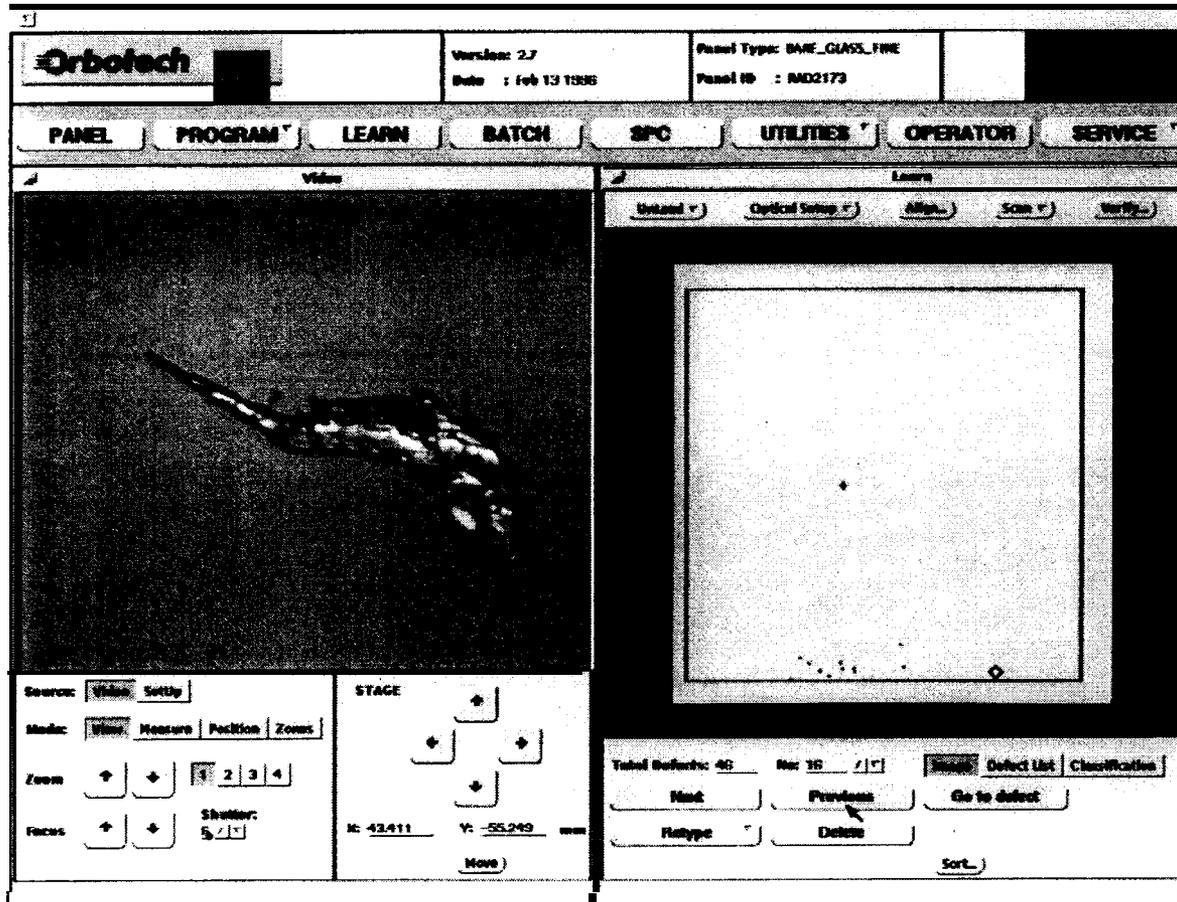


Figure 3-2 Orbotech FPD glass after laser clean results. Typical data sheet showing the number and position of particles and defects after laser clean. The Radiance Process@ has reduced the total particulate count from -5000 to 46. Note that the image on the left is a magnified view of one of the defects highlighted by the diamond on the right side.

Silicon Wafers

Silicon 1

The silicon materials used were boron-doped 100mm wafers. The wafers were coated with 1 μ m thick AZ5214 positive photoresist, patterned, then stripped for 10 minutes in an oxygen plasma generated by an RF source (Branson IPC). These process steps emulated those routinely used in a semiconductor device manufacturing flow. The wafers were scanned on a Tencor Surfscan 4500 particle counting tool. Particles measured from 0.06 μ m to 2.56 μ m within a 4mm edge exclusion region. The wafers were then exposed to the Radiance Process@. Approximately 90 test runs were conducted using a variety of process parameters. The following parameters were used:

Polarization	none, s, or p
Angle of incidence	5°, 10°, or 90°
Repetition Rate	100Hz or 200Hz
# of Pulses	6 - 60

Scan Pattern	standard (laser on over entire wafer including edges) or detailed (laser on only within wafer edges)
Beam Dimensions	22mm x 0.7mm at 90° or 22mm x 2mm at glancing angle
Fluence	250mJ/cm ² - 1.3J/cm ²
N ₂ Flow Rate	40L/min.

The experimentation began using 90°, no polarization and progressed from low fluence settings to highest fluence levels. Wafers were manually loaded on the sample chuck. If no significant change in particle count was observed, the number of pulses was increased. If no significant change in particle count was observed, this progression in fluence and pulse rate was repeated at glancing angles (5° and 10°).

Silicon 2

As-received boron-doped 100mm silicon wafers were deposited with ~1000Å of SiO₂ using a PlasmaTherm 730. The Plasma Therm 730 is a commercial plasma enhanced chemical vapor deposition (PECVD) system. These samples were then exposed to a wet chemical stripping of the oxide in a buffered oxide etch of HF:NH₄F. The wafers were then scanned on a Tencor Surfscan 4500 particle counting tool measuring all particles from 0.06µm to 2.56µm using a 4mm (90°) — 14mm (5°, 10°) edge exclusion region. The results served as a prescan measurement prior to Radiance Process® exposure. Approximately 45 test runs were conducted using a variety of process parameters. The following parameters were used:

Polarization	none, s, or p
Angle of incidence	5°, 10°, or 90°
Repetition Rate	100Hz or 200Hz
# of Pulses	10 - 150
Scan Pattern	standard (laser on over entire wafer including edges) or detailed (laser on only within wafer edges)
Beam Dimensions	22mm x 0.7mm at 90° or 22mm x 2mm at glancing angle
Fluence	88mJ/cm ² - 1.3J/cm ²
N ₂ Flow Rate	40L/min.

Again, the experimental approach was the same as that used in the previous experiment. The study began at 90°, no polarization, and progressed from low fluence settings to highest fluence levels. Wafers were manually loaded on the sample chuck. If no significant change in particle count was observed, the number of pulses was increased. If no significant change in particle count was observed, this progression in fluence and pulse rate was repeated at glancing angles (5° and 10°) with either s or no polarization.

LOW 23 * 1

PARTICLES TOT: 883
PARTICLES/cm²: 22.28
AREA: 13.59mm²

HISTOGRAM:
0.06- 0.31: 228
0.31- 0.56: 126
0.56- 0.81: 109
0.81- 1.06: 115
1.06- 1.31: 99
1.31- 1.56: 68
1.56- 1.81: 44
1.81- 2.06: 39
2.06- 2.31: 26
2.31- UP: 29

MEAN: 0.8670
STD. DEV: 75.37%

HAZE AVG. TOTAL: 2ppm
HAZE REGION: 1%

EXCLUSION: 14
MAX SIZE: 2.56
THRESHOLD: d 0.04
PARTCL: 0.06- 2.56
BIN: 0.01
HAZE: 12- 256

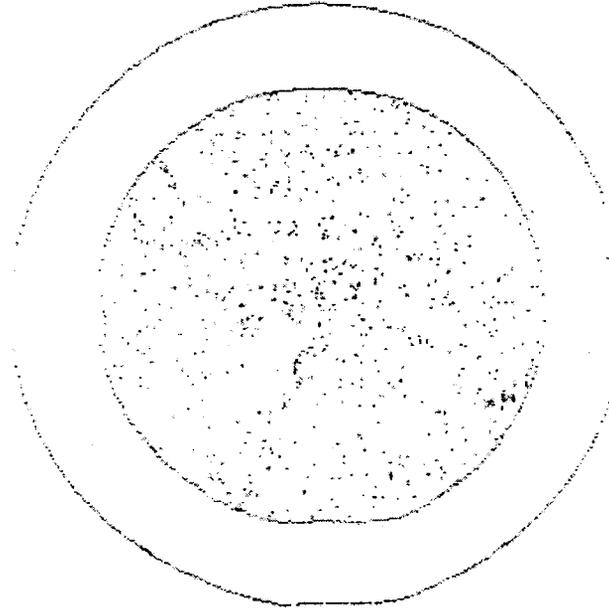


Figure 3-3. Silicon 2 Tencor Surfscan 4500 initial measurements. Tencor Surfscan 4500 measurement of Sample #23 before the Radiance Process®. Included in the data to the left is a listing of all the bin sizes along with the total number of particles measured within that bin size. All particles from 0.06µm to 2.56µm were counted within the scan area using a 14 mm exclusion region. A total of 883 particles is measured.

Figure 3-4 is an example of a measurement taken by the Tencor Surfscan 4500 after the sample was exposed to the Radiance Process®. No significant change in the total particle is detected.

ID# 23 * 1

PARTICLES TOT: 876
PARTICLES/cm²: 22.84
AREA: 14.88mm²

HISTOGRAM:
0.06- 0.31: 272
0.31- 0.56: 130
0.56- 0.81: 85
0.81- 1.06: 100
1.06- 1.31: 98
1.31- 1.56: 64
1.56- 1.81: 48
1.81- 2.06: 33
2.06- 2.31: 23
2.31- UP: 23

MEAN: 0.8083
STD. DEV: 80.56%

HAZE AVG. TOTAL: 2ppm
HAZE REGION: 1%

EXCLUSION: 14
MAX SIZE: 2.56
THRESHOLD: d 0.04
PARTCL: 0.06- 2.56
BIN: 0.01
HAZE: 12- 256

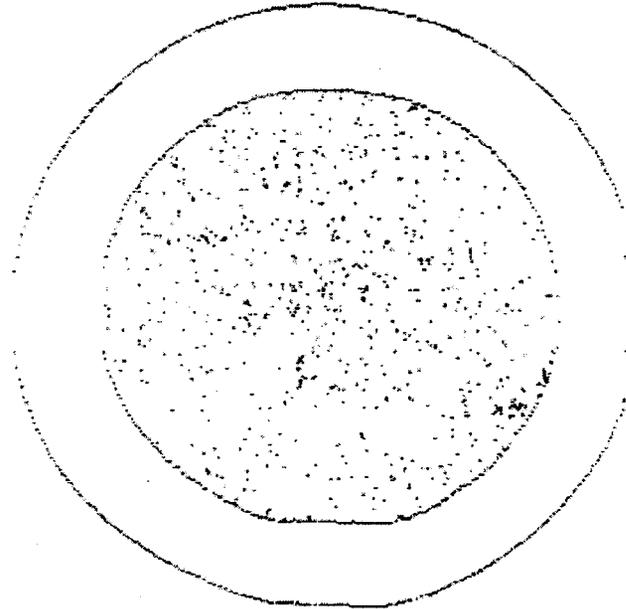


Figure 3-4. Silicon 2 Tencor Surfscan 4500 after clean results. Tencor Surfscan 4500 measurement of Sample #23 after the Radiance Process@. The total particle count of all the listed bins is 876. This indicates no reduction in particle count from the previous prescan measurement.

Post-CMP Cleaning

The first step in this experiment was to establish a baseline for the amount of contamination present immediately after CMP. Silicon wafers that had been processed through CMP were decorated with polish marks. The Tencor Surfscan 4500 labeled this as haze, which severely limited the ability of the instrument to detect smaller particle sizes and levels of contamination. It was important to understand the sizes of all particles on the wafer after cleaning.

Wafer preparation methods were altered to assure that measurements were taken on an undecorated surface. The samples were exposed to the slurry with no mechanical action to avoid polishing marks for a fixed time period to emulate exposure to a CMP process. All samples went through a rinse cycle, followed by a normal scrub track, of 20 seconds brush at the first station followed by a 20 second brush at the second station and a 60 second 2000 RPM spin dry. For those samples that received a chemical clean, all three processes were the same in that all chemical treatments were of 10 minute duration, with manual agitation, followed by a 10 minute D.I. rinse, with a final SRD process.

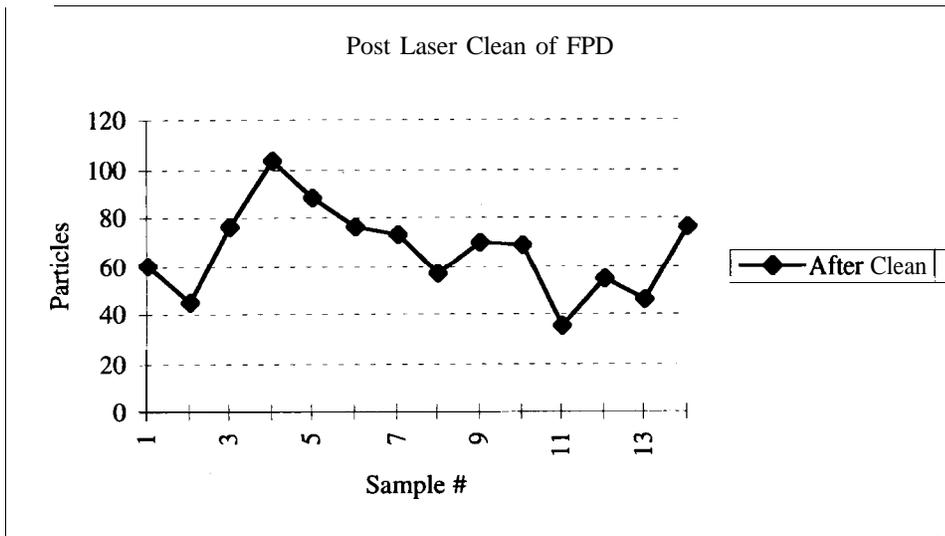
Polarization	none, s, or p
Angle of incidence	90°
Repetition Rate	100Hz or 200Hz
# of Pulses	6 - 60
Scan Pattern	standard (laser on over entire wafer including edges) or detailed (laser on only within wafer edges)
Beam Dimensions	22mm x 0.7mm at 90°
Fluence	250mJ/cm² - 1.3J/cm²
N₂ Flow Rate	10L/min to 40L/min.

The experimentation began using **90°**, no polarization and progressed from low fluence settings to highest fluence levels. Wafers were manually loaded on the sample chuck. If no significant change in particle count was observed, the number of pulses was increased.

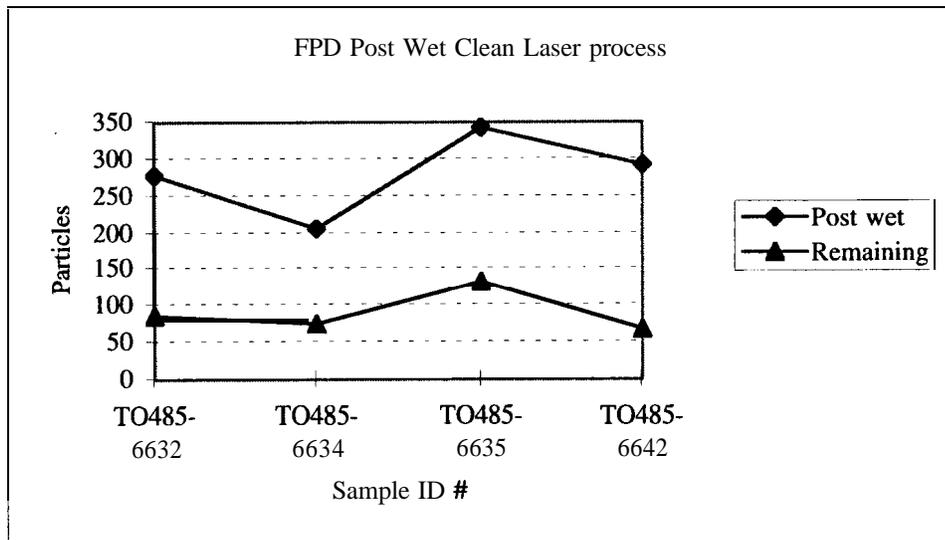
Chapter 4 Results and Discussion

Flat Panel Display Glass

A significant reduction in particles has been observed on 150mm soda-lime float glass substrates after exposure to the Radiance Process®. Total particle counts on these as-received FPD substrates were reduced from an estimated >5000 to <100 counts or lower. Certain imperfections, such as inclusions, which register as **particulates** using the Orbotech scanner, were determined to be non-removable by either the Radiance Process® or the standard wet chemical process.



Graph 4-1 Post-Laser Clean of FPD Glass. The results of as-received FPD material exposed to the Radiance Process® under the described conditions. Initial total particle counts on as-received FPD 150mm soda lime float glass material was in excess of 5000 particles per wafer.



Graph 4-2 FPD Post-Wet Clean Laser Process. Using the Radiance Process® provided an improvement over the wet chemical cleaning. On average the particles were reduced by amounts greater than 50%. The laser process is also beneficial when used as a supplemental clean.

Silicon Wafers

Silicon 1

No statistically significant removal of the particles generated by an oxygen plasma clean exposed to a wide range of Radiance Process™ cleaning conditions was observed. A few experiments did result in a slight reduction in particle count. Attempts to repeat these results using the same Radiance Process™ clean conditions were unsuccessful. It is likely there are different kinds of particles remaining after the oxygen plasma clean or, there could be substrate damage or defects present which cannot be removed by the Radiance Process™. Knowing what these particles are would help a great deal in determining the effectiveness of any cleaning process.

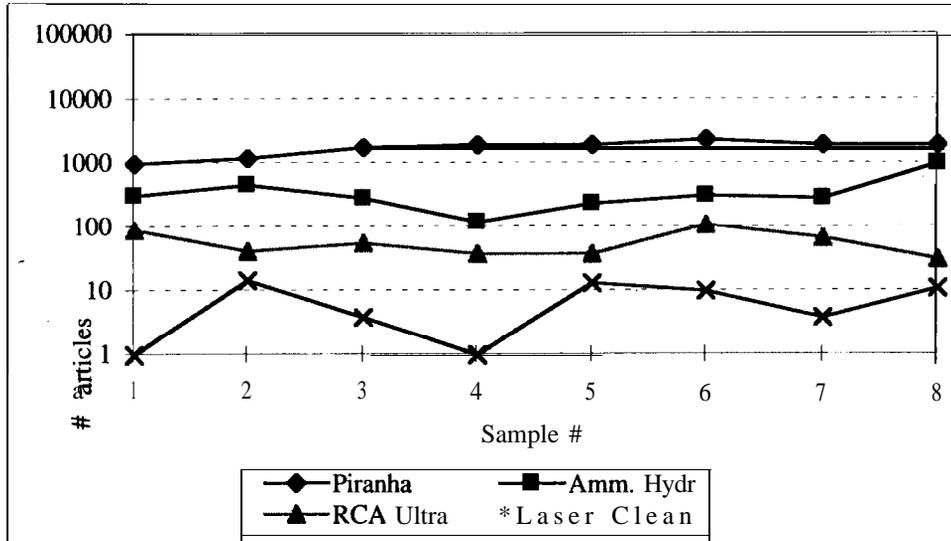
Silicon 2

No significant removal of the particles generated by SiO₂ deposition and subsequent stripping of the oxide in a buffered oxide etch of HF:NH₄F exposed to a wide range of Radiance Process⁰ cleaning conditions was observed. A few experiments did result in a slight reduction in particle count. Attempts to repeat these results using the same Radiance Process™ clean conditions were unsuccessful. There could be substrate damage or defects present which cannot be removed by the Radiance Process™. Knowing what these particles are would help a great deal in determining the effectiveness of any cleaning process.

Post-CMP Cleaning

Four sets of eight wafers each were exposed for 60 seconds in Rodel's® ILD 1300 silicon oxide slurry, followed by a ten minute rinse bath and a scrub track process. Three of the sets were cleaned by a classic wet chemical clean process: one set with Piranha, one set with ammonium hydroxide, and one set with RCA and ultrasonic agitation. The wet chemical cleans were performed by exposing the material to the caustic chemical, with agitation, for a fixed period of time followed by rinse bath treatments and a spin rinse dry (SRD). The fourth wafer set was taken from the scrub track to laser cleaning with no additional wet chemical exposure or SRD processing. Particle measurements were taken after the samples were processed (Graph 4-3).

Method	# Particles	Stand Dev
Piranha	1775	420
Ammonium Hydroxide	387	284
RCA (ultrasonic)	61	29
Laser Clean	7.3	5.3
Initial particles average	<5.0	

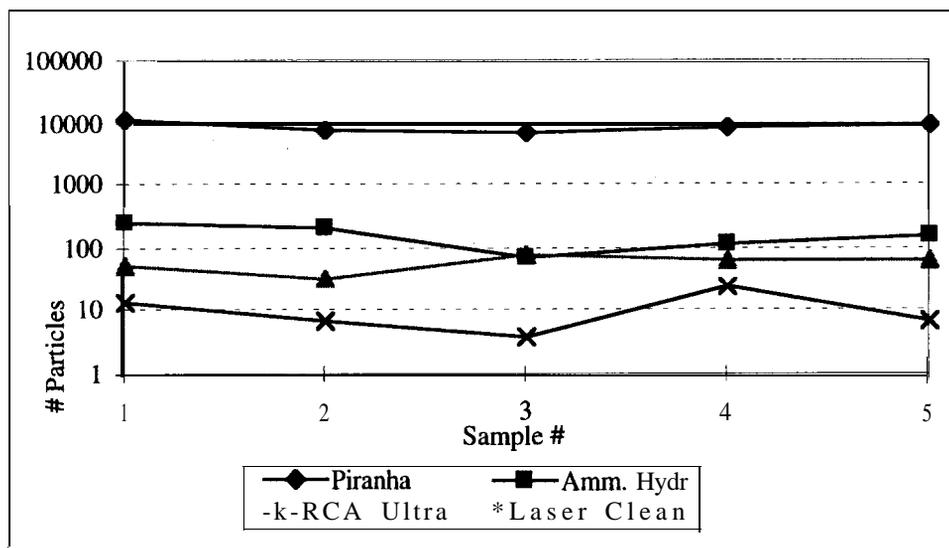


Graph 4-3 Post-CMP processing using a common slurry batch.

The experimental procedures were designed so that each sample set went through the same slurry bath. It was hypothesized that the silica could be depleted resulting in lower levels of contamination. It was not possible to directly confirm the depletion of the silica because of residues causing haze formation.

A second group of experiments was conducted. Each sample set of five wafers was exposed in a dedicated slurry bath. All other conditions remained the same. Particle measurements were taken after the samples were processed (Graph 4-4).

Method	# Particles	Stand Dev
Piranha	8925	1667
Ammonium Hydroxide	164	74
RCA (ultrasonic)	59.6	17.8
Laser Clean	11.6	8.8
Initial particles avg.	<5.0	



Graph 4-4 Post-CMP processing using a dedicated slurry batch.

The distribution of particles within each of the sample sets is displayed below.

Tencor Bins	Piranha	Ammonium Hydroxide	RCA Clean	Laser Clean
0.06-0.3	7922	111	42	7
0.3-0.56	605	24	9	1
0.56-0.81	187	10	5	2
0.81-1.06	88	8	2	1
1.06-1.31	51	5	2	1
1.31-1.56	31	2	1	1
1.56-1.81	19	1	0	0
1.81-2.06	8	1	0	0
2.06-2.31	6	0	0	0
>2.31	9	0	0	0
Total	8926	162	61	13

Table 4- 1 Average Distribution of Particles by Sample Set.

Particle size distribution after Piranha processing:

Eighty-eight per cent of the particles were **0.3µm** and smaller. Of the remaining particles, seven per cent were between **0.3µm** and **0.56µm**. Two per cent were between **0.56µm** and **0.81µm**. One per cent were between **0.81µm** and **1.06µm**. One per cent were between **1.06µm** and **1.31µm**, and less than one per cent were in the bins greater than **1.31µm**.

Particle size distribution after Ammonium Hydroxide processing:

Seventy per cent of the particles were **0.3µm** and smaller. Of the remaining particles, fifteen per cent were between **0.3µm** and **0.56µm**. Six per cent were between **0.56µm** and **0.81µm**. Five per cent were between **0.81µm** and **1.06µm**. Three per cent were between **1.06µm** and **1.31µm**, and less than one per cent were in the bins greater than **1.31µm**.

Particle size distribution after RCA processing:

Seventy per cent of the particles were **0.3µm** and smaller. Of the remaining particles, fifteen per cent were between **0.3µm** and **0.56µm**. Seven per cent were between **0.56µm** and **0.81µm**. Three per cent were between **0.81µm** and **1.06µm**. Three per cent were between **1.06µm** and **1.31µm**. Two per cent were between **1.31µm** and **1.56µm**, and zero particles were in the bins greater than **1.56µm**.

Particle size distribution after Laser processing:

Sixty per cent of the particles were **0.3µm** and smaller. Of the remaining particles, eight per cent were between **0.3µm** and **0.56µm**. Thirteen per cent were between **0.56µm** and **0.81µm**. Five per cent were between **0.81µm** and **1.06µm**. Seven per cent were between **1.06µm** and **1.31µm**. Five per cent were between **1.31µm** and **1.56µm**. Two per cent between **1.56µm** and **1.8µm** and zero particles were in the bins greater than **1.8µm**.

ID	Description	Loc.	Concentration, atoms x 10 ¹⁰ /cm ²							
			S	Cl	Ca	Ti	Fe	Ni	Cu	Zn
CONT	Control Wafer	-18, 18	800	110	200	—	—	—	—	27
		center	800	140	290	—	—	—	—	37
		18,-18	600	130	210	—	—	—	—	22
H1	Ammonium Hydroxide	-18, 18	3500	400	—	—	2	—	6	—
		center	2300	180	—	—	2	2	3	2
		18, -18	2200	170	—	—	—	—	4	—
L1	Laser 1	-18, 18	2300	90	210	—	2	4	—	3
		center	2300	70	260	—	2	—	2	23
		18-18	2100	50	150	—	—	3	—	5
L2	Laser 2†	-18, 18	1900	90	100	—	—	—	57	11
		center	2100	80	210	—	—	—	89	20
		18, -18	2000	80	98	—	—	—	110	18
P1	Piranha 1	-18, 18	3000	130	—	5	—	—	—	—
		center	5100	300	350	—	14	—	—	15
		18, -18	2900	120	12	—	4	7	—	—
R1	RCA 1	-18, 18	2300	100	51	2	2	2	10	—
		center	2200	50	36	—	2	—	7	—
		18,-18	2100	50	52	—	1	3	1	—

Table 4-2 TXRF measurements for heavy metal contamination.

† Copper (Cu) contamination was isolated as coming from N₂ in a stagnant facility copper supply line. The Laser 1 sample does not have copper contamination. The difference between the samples was validated **with** a different test. The validation test consisted of processing a wafer after a 24 hour of non-flow of the N₂ supply line. A second wafer was processed after 60 minutes of N₂ purge time.

TXRF measurements were done on random samples pulled from the first set (common slurry) to look at heavy metal contamination. Each sample had three measurements, one at the center and two 18 mm from the edge, in line with the center.

The control sample was a virgin wafer that came directly from the original packaging. The control sample showed contamination of Chlorine (Cl), Calcium (Ca), and Zinc (Zn). The Piranha-cleaned wafer showed Cl, Ca, Zn, Titanium (Ti), Iron (Fe), and Nickel (Ni) contamination. Ammonium Hydroxide eliminated the Ca contamination, reduced the Zn, contributed no Ti, but did show Fe, Ni, and Cu contamination. The RCA process reduced the Ca, eliminated the Zn; however did show Ti, Fe, Ni, and Cu contamination.

The Laser 1 clean process showed ion contamination for Fe, Ni, Cu, and Zn. It is important to point out that these four samples were also exposed to the oxide polish slurry, which may have contributed to the metallic ion contamination. Sample Laser 2 was a non-processed wafer that was exposed only to the laser clean process. It had slight reductions in Cl, Ca, and Zn as compared to the control sample. The TXRF data indicates that the Laser 1 clean data are comparable to the control wafer that is important to metallic ion contamination control.

Chapter 5 Conclusions

While further work is needed to integrate laser cleaning processes into full scale semiconductor manufacturing, the technology holds great potential for pollution prevention, and more significantly, waste minimization. Successful implementation of this technology could potentially result in large scale conservation of both water and chemicals. Standard wet chemical cleaning can account for up to one third of the total chemical costs of wafer fabrication and is by far the major consumer of water in the industry. The waste from these processes requires costly treatment and control equipment to remove pollutants from waste water and process exhausts subsequent to discharge.

The Radiance Process[®] was successfully used to clean incoming flat panel display material and to clean CMP slurry residues from silicon wafers, in both cases to levels statistically better than typical chemical processes. Not all contaminants were removed from all surfaces. Additional work should be done to define a Radiance Process[®] recipe that might remove more or all of these particles. Reducing contamination of **other** particle types on various material types should be explored and optimized. Several machine designs and metrology challenges to enhance the detection of ultra small particles on surfaces were identified.

Flat Panel Display Glass

The Radiance Process[®] was used to clean vendor-supplied float glass substrates used in fabrication. This resulted in reducing total particle counts from **>5000** to below 100. These results were equal to or, in some cases, slightly better than current wet cleaning processes. Contamination levels that were lowered by wet processes were reduced further by the Radiance Process[®].

Silicon Wafers

Particle removal from bare silicon wafers was tested under two specific conditions with no statistically significant, repeatable removal rates observed. Further investigation with other specific conditions for particle removal on bare silicon wafers is recommended as well as identification of the unremoved particles.

Silicon 1

The particles generated by wafer handling equipment used for an oxygen plasma clean were exposed to a wide range of Radiance cleaning conditions with little or no repeatable statistically significant removal of particles.

Silicon 2

The particles generated by wafer handling equipment for deposition of a **1000Å** thick **SiO₂** film then exposed to a wet chemical strip in a buffered oxide etch of **HF:NH₄F** were exposed to a wide range of Radiance Process[®] cleaning conditions. Little or no repeatable reduction in particle count was observed.

Post-CMP Cleaning

The use of laser processing for post-CMP cleaning is promising. The results show that post-CMP cleaning using the Radiance Process[®] can restore bare silicon wafers to near virgin conditions. This technique reduced the level of contamination without adding additional wet chemical processing. Laser processing thus can be accomplished without additional wet chemical processing, and can potentially eliminate a minimum of two manufacturing tools, thereby reducing the demand for chemicals and associated waste treatment in a semiconductor manufacturing facility.

Chapter 6 Recommendations

Flat Panel Display Glass

Further work using the Radiance Process@' should be done to determine the experimental window in which the same result or better could be obtained. It was observed that varying **fluences**, angles of incidence, or the number of pulses resulted in similar particle removal percentages. Optimizing these parameters could also result in an increased lifetime of the optics and laser gas fills, and a decrease in clean time.

Changing the scan program to allow the laser to remain on during both "up and back" directions would also cut down on the cleaning time significantly. For these studies the laser was turned off during its return travel to begin another cleaning pass.

The estimated cleaning time of -10 minutes per sample could be reduced by simply changing the laser "on" time in the scan program, and/or by increasing the beam size. Reducing the number of pulses might further reduce the cleaning time and produce similar results in particle reduction. It remains unclear whether a slightly lower fluence than $1\text{J}/\text{cm}^2$ might also produce similar particle reductions. A lower fluence level would have the added benefit of increasing the life of the laser optics and fill gas. In addition, newer **excimer** laser technology permits higher power units that may reduce process time.

Silicon Wafers

Silicon 1

All particles (and some pits) are scanned and counted by the Tencor **Surfscan** 4500 particle counting tool. Due to the limitations of this tool, a distinction between these "particles" cannot be made by the instrument. Future work should include analysis that can determine what kinds of particulates remain on **the wafer surface** after an oxygen plasma clean.

Silicon 2

As is stated in the previous experiment, there are limitations to the Tencor **Surfscan** 4500 particle counting tool. No distinction can be made by the tool between particles or pits. Therefore it is difficult to determine the kinds of particulates and defects remaining after the **SiO₂** deposition and subsequent strip. More sophisticated analysis techniques are required to better understand these particulates **and** the feasibility of their removal by any process.

Post-CMP Cleaning

Further investigation into the commercialization of the Radiance Process@ for this application is warranted. Laser processing for post-CMP cleaning is highly effective. The nature of CMP processing within the manufacturing sequence requires additional experimentation. CMP processing is performed on substrates **that** have multi-level patterns, films and **dopants** all in delicately **arranged** structures. The laser process does impart thermal energy into the different materials depending on a material's spectral adsorption characteristics and resulting ablation thresholds ⁽¹¹⁾. Laser processing has been used for annealing of implanted **dopants**, which could occur during a cleaning process ⁽¹²⁾.

Long-Term Study

Further investigation of the fundamental mechanism of the Radiance Process" is recommended. Additional studies cleaning other materials are being discussed with the project participants.

References

U.S. Patents

1. U.S. Patent 5,024,968
2. U.S. Patent 5,099,557
3. U.S. Patent 5,531,857
4. U.S. Patent 5,643,472

Journal

5. C.S. Dulsey, J.H. George, Jr., B. Krauthamer, D.A. Stiger, P.L. Fare, J.M. Calvert "Deep Ultraviolet Photochemistry of Chemisorbed Monolayers: Patterned Co-Planar Molecular Assemblies" *SCIENCE*, Vol 252, p. 551 April 16, 1991

Proceedings

6. Engelsberg, A.C. "Removal of Surface Contaminants Using a Dry Laser-Assisted Process." *Microcontamination 9*, (San Jose, CA, Sept 21-23, 1993), p. 310-319.

Journal

7. Lancaster, M.C. "Ultrapure Water: The Real Cost" *Solid State Technology*, V 39, #9, p. 70
8. W. Kern, D. Poutinen, *RCA Review*, V 31, No. 187. 1970

Personal Communications

9. Sematech, personal communication with B. Duffin and W. Worth, 1/16/98

Journal

10. Roche, T., Peterson, T. "Reducing DI Water Use", *Solid State Technology*, V 39, #12, p. 78
11. Shukov, G., Smith, A. "Micromachining with Excimer Lasers", *Lasers and Optronics*, Sept. 1988

Proceedings

12. Wagner, F.X. et al. "Photo-Luminescence of Pulsed Excimer Laser Annealed Sb-Implanted CdTe," *Applied Surface Science*, Vol. 86. p. 364-367 February 1995.

Appendix A
Sample Test Run Data Sheets

1. Sample Prep - 1000\AA SiO_2 Deposited Then Stripped
in BOE (Buffered Oxide Etch)
2. 0, Plasma Stripped Silicon
3. FPDD 6" (Soda Lime) Glass Plates
4. FPDD 6" (Soda Lime) Glass Plates Lot # TO417

Sample Prep---1000A SiO₂ deposited then stripped in BOE (Buffered Oxide Etch)

DATE	OP	ID	N ₂ /L/MIN	AOI	POL	REP RATE	#PULSES	SCAN PAT	BEAM SZ	FLU J/cm ²	COMMENTS	RESULT
9/3/97	DC	24	40	5	np	100	15	DET	22x1 mm	0.200	approximation of prescan	less 30*
9/3/97	Ix	24	40	5	np	100	15	DET	22x1 mm	0.200	2nd pass	no change
9/3/97	DC	24	40	5	np	100	15	DET	22x1 mm	0.200	3rd pass	less 40*
9/3/97	DC	24	40	5	np	100	30	DET	22x1 mm	0.200	4th pass	no change
9/4/97	DC	23	40	5	np	100	15	DET	22x1 mm	0.200	1st pass	no change
9/4/97	Ix	23	40	5	np	100	15	DET	22x1 mm	0.275	2nd pass	no change
9/4/97	DC	23	40	5	np	100	15	DET	22x1 mm	0.350	3rd pass	no change
9/4/97	Ix	23	40	5	np	100	15	DET	22x1 mm	0.440	4th pass	no change
9/4/97	DC	23	40	5	np	100	15	DET	22x1mm	0.550	5th pass	no change
9/4/97	cc	23	40	5	np	100	15	DET	22x1 mm	0.650	6th pass	no change
9/4/97	DC	23	40	5	np	100	15	DET	22x1 mm	0.750	7th pass	25 more*
9/4/97	DC	22	40	5	np	100	30	DET	22x1 mm	0.650	1st pass	less 50*
9/4/97	DC	22	40	5	np	100	50	DET	22x1mm	0.650	2nd pass	less1 6'
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.088	1st pass	no change
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.095	2nd pass	no change
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.130	3rd pass	less 27'
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.150	4th pass	no change
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.230	5th pass	no change
9/4/97	DC	21	40	5	p	100	15	DET	22x1 mm	0.305	6th pass	no change
9/4/97	Ix	21	40	5	p	100	30	DET	22x1 mm	0.305	7th pass; max fluence	no change
9/4/97	DC	21	40	5	p	100	60	DET	22x1 mm	0.305	8th pass	less47
9/4/97	Ix	21	40	5	p	100	100	DET	22x1 mm	0.305	9th pass	24 more
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.058	1st pass	no change
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.155	2nd pass	no change
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.280	3rd pass	less 36
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.390	4th pass	no change
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.540	5th pass	no change
9/4/97	DC	20	40	5	s	100	15	DET	22x1 mm	0.620	6th pass	no change
9/4/97	DC	20	40	5	s	100	60	DET	22x1 mm	0.620	7th pass; max fluence	no change

O₂ Plasma Stripped Silicon

DATE	OP	ID	N ₂ /L/MIN	AOI	POL	REP RATE	#PULSES	SCAN PAT	BEAM SZ	FLU J/cm ²	c	s
6/23/97	DC	O2/#25	40	90	np	200	6	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#24	40	90	np	200	20	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#23	40	90	np	200	40	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#25b	40	90	np	200	40	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#22	40	90	np	200	25	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#21	40	90	np	200	20	STD	22x0.7mm	0.64		reset flu; dropped to .58
6/23/97	DC	O2/#20	40	90	np	200	30	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#19	40	90	s	200	10	STD	22x0.7mm	0.64		run time error '13' after clean
6/23/97	DC	O2/#17	40	90	s	200	20	STD	22x0.7mm	0.64		
6/23/97	DC	O2/#16	40	90	s	200	20	STD	22x0.7mm	0.40		
6/23/97	DC	O2/#15	40	90	s	200	40	STD	22x0.7mm	0.40		
6/23/97	DC	O2/#16	40	90	np	200	40	STD	22x0.7mm	0.40		run time error '9' during flu adj
6/24/97	DC	dummy	40	90	np	100	6	STD	22x0.7mm	0.50		5 dummies from cassette load
6/24/97	DC	O2/#17	40	90	np	200	40	STD	22x0.7mm	0.40		run time error '9' during flu adj
6/24/97	DC	O2/#17	40	90	np	200	60	STD	22x0.7mm	0.40		
6/24/97	DC	O2/#17	40	10	np	200	20	STD	22x2.5mm	0.30		run time error '13' after abort
6/24/97	DC	O2/#25	40	10	np	200	20	STD	22x2.5mm	0.30		
6/24/97	DC	O2/#18	40	10	np	100	20	STD	22x2.5mm	0.30		
6/26/97	DC	dummy	40	90	np	200	10	STD	22x0.7mm	0.50		3 wafers
6/26/97	DC	O2/#14	40	90	np	200	10	STD	22x0.7mm	0.25		
6/26/97	DC	O2/#13	40	90	np	200	20	STD	22x0.7mm	0.30		
6/26/97	DC	O2/#12	40	90	np	200	10	STD	22x0.7mm	0.25		
6/26/97	DC	O2/#11	40	90	np	200	20	STD	22x0.7mm	0.25		
6/26/97	DC	O2/#10	40	90	np	200	15	STD	22x0.7mm	1.00		beam appeared irregular??
6/26/97	DC	O2/#9	40	90	np	200	10	STD	22x0.7mm	0.30		reset aperture
6/26/97	DC	O2/#9	40	90	np	200	10	STD	22x0.7mm	0.30		adders
6/26/97	DC	O2/#8	40	90	np	200	10	STD	22x0.7mm	0.30		adders
6/26/97	DC	O2/#8	40	90	np	200	10	STD	22x0.7mm	0.30		no change

**FPDD 6" (Soda Lime) Glass
Plates**

DATE	OP	ID	N ₂ /MIN	A	OT	P	O	L	REP	RAT	#PULSES	SCAN	P	A	T	BEAM SZ	FLU J/cm ²	COMMENTS	TOTAL PART
7/9/97	DC	2156	40	10	np	100	20	STD	24x2.2mm	0.30	2 passes	prg fit 200Hz ev oth ps	1422						
7/9/97	DC	2157	40	10	np	100	20	STD	24x2.2mm	0.30	1 pass	907							
7/9/97	DC	2158	40	10	np	100	40	STD	24x2.2mm	0.30	1 pass	805							
7/9/97	DC	2159	40	10	np	100	40	STD	24x2.2mm	0.30	2 passes	116							
7/9/97	DC	2160	40	10	np	100	60	STD	24x2.2mm	0.30	1 pass	110							
7/9/97	DC	2161	40	90	np	100	26	STD	22x0.7mm	1.00	1 pass	61							
7/9/97	DC	2162	40	90	np	100	26	STD	22x0.7mm	1.00	2 passes	45							
7/9/97	DC	2163	40	90	np	100	39	STD	22x0.7mm	1.00	1 pass: cracked	—							
7/9/97	DC	2164	40	90	np	100	39	STD	22x0.7mm	1.00	1 pass: cracked	—							
7/9/97	DC	2165	40	90	np	100	26	STD	22x0.7mm	1.00	3 passes	77							
7/9/97	CC	2166	40	90	np	100	26	STD	22x0.7mm	1.43	1 pass	104							

NOTES:

Best results achieved at 90°, no polarization, 100Hz, 26 pulses, and 1 J/cm².

Same conditions using 3 complete cleans give similar results, but didn't improve or worsen significantly.

Giving it all she had at normal (1.43J/cm²) did not seem to induce any noticeable damage and gave surprisingly good results.

Cleaning at 10°, np, 26 pulses, and 300mJ/cm² also gave good results. But would prefer to run at 90° as this setup is more straight-forward as far as optics and alignment.

It would appear 39 pulses induces too much stress and plate "failure" occurs.

FPDD 6" (Soda Lime) Glass Plates
LOT#T0417
Automatic mode using
robot
Single Pass each sample

DATE	OP	ID	N ₂ L/MIN	AOI	POL	REP RATE	#PULSES	SCAN PAT	BEAM SZ	FLU J/cm ²	COMMENTS	TOTAL PART
8/15/97	DC	2471	40	90	np	100	26	STD	22x0.7mm	1.00	fell off wand hit other plates aft cin	953
8/15/97	DC	2472	40	90	np	100	26	STD	22x0.7mm	1.00		554
8/15/97	DC	2473	40	90	np	100	26	STD	22x0.7mm	1.00		overflow
8/15/97	DC	2474	40	90	np	100	26	STD	22x0.7mm	1.00		1596
8/15/97	DC	2475	40	90	np	100	26	STD	22x0.7mm	1.00		536
8/15/97	DC	2476	40	90	np	100	26	STD	22x0.7mm	1.00		184
8/15/97	DC	2477	40	90	np	100	26	STD	22x0.7mm	1.00	cursor on 2nd # Orbotech print	1396?
8/15/97	DC	2478	40	90	np	100	26	STD	22x0.7mm	1.00		432
8/15/97	DC	2479	40	90	np	100	26	STD	22x0.7mm	1.00		2290
8/15/97	DC	2480	40	90	np	100	26	STD	22x0.7mm	1.00		623
8/15/97	DC	2481	40	90	np	100	26	STD	22x0.7mm	1.00		509
8/15/97	DC	2482	40	90	np	100	26	STD	22x0.7mm	1.00		overflow
8/15/97	DC	2483	40	90	np	100	26	STD	22x0.7mm	1.00		1919
8/15/97	IX	2484	40	90	np	100	26	STD	22x0.7mm	1.00		1727
8/15/97	CC	2485	40	90	np	100	26	STD	22x0.7mm	1.00		469

- * Did robot induce particles?
- Did blow-off gun used prior to RP induce particles?
- Plates are from same vendor as previously run plates