Aspects of Single Wafer Cleans Processing and Tools

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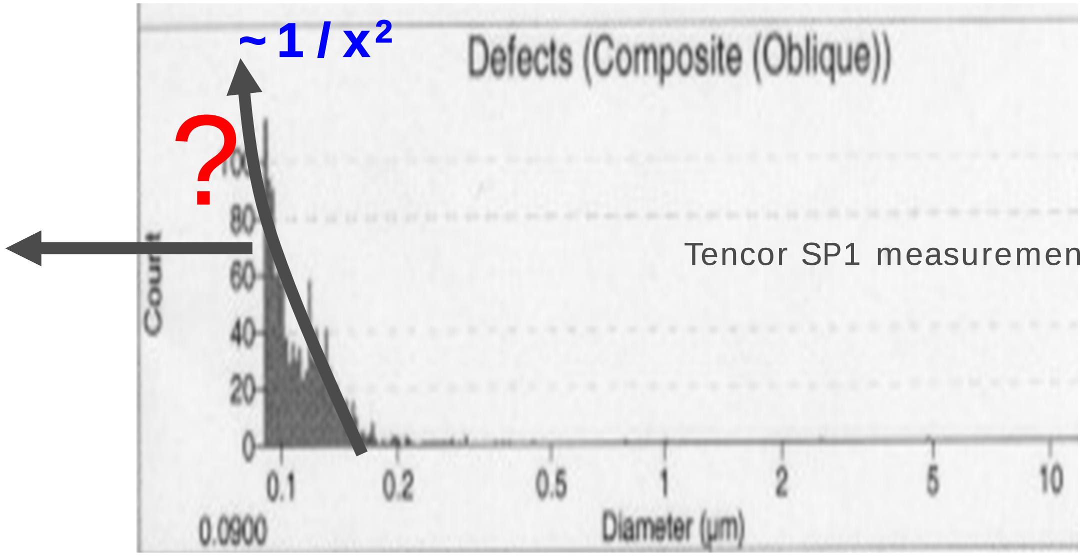
Contents

Particles – Distributions on Wafer



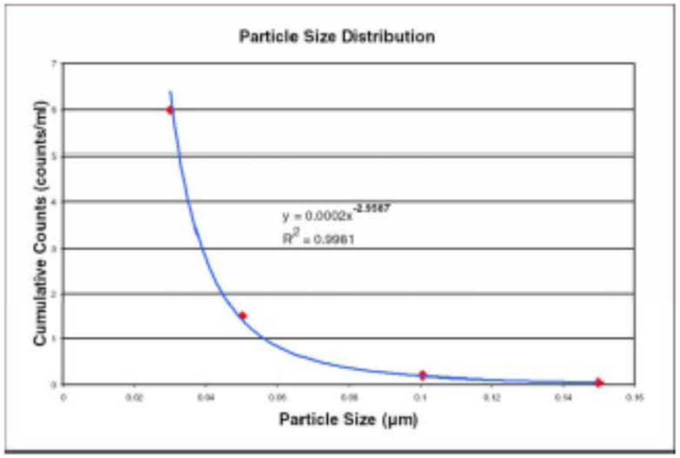
Tencor SP1 measurement >0.09 µm

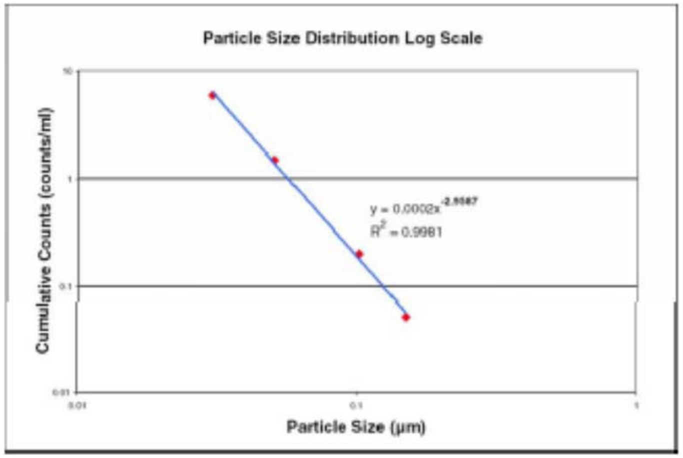
- Typically we measure Particles > 0.09 µm or > 0.06 µm
- Particle Density ~ $1/x^2$
- What about Particles < 0.06 µm?

Particles – Distributions in Liquid

- Typical particle size distributions in liquid systems
  - 1/(particle diameter)^3 is a good "rule of thumb"
- More small particles than large particles
- What happens below 30nm?

Courtesy of PMS





- **In liquid systems: particle density ~ 1/x^3**
- **What about particles < 0.03 μm?**

Particle Density as a Function of Particle Size

- So far Particle Density ~ $1/x^2$ on wafer and $1/x^3$ in liquids

- Can not continue like ~ $1/x^2$ or $1/x^3$ indefinitely

- 80 Particles > 32.5nm would equate to
  84 500 particles >1nm or 338 000 particles > 0.5nm

- This would kill many gates which are 1nm thick.

- Nobody has ever seen a 1nm particle in TEM or SEM

Particles – Distributions in Nature

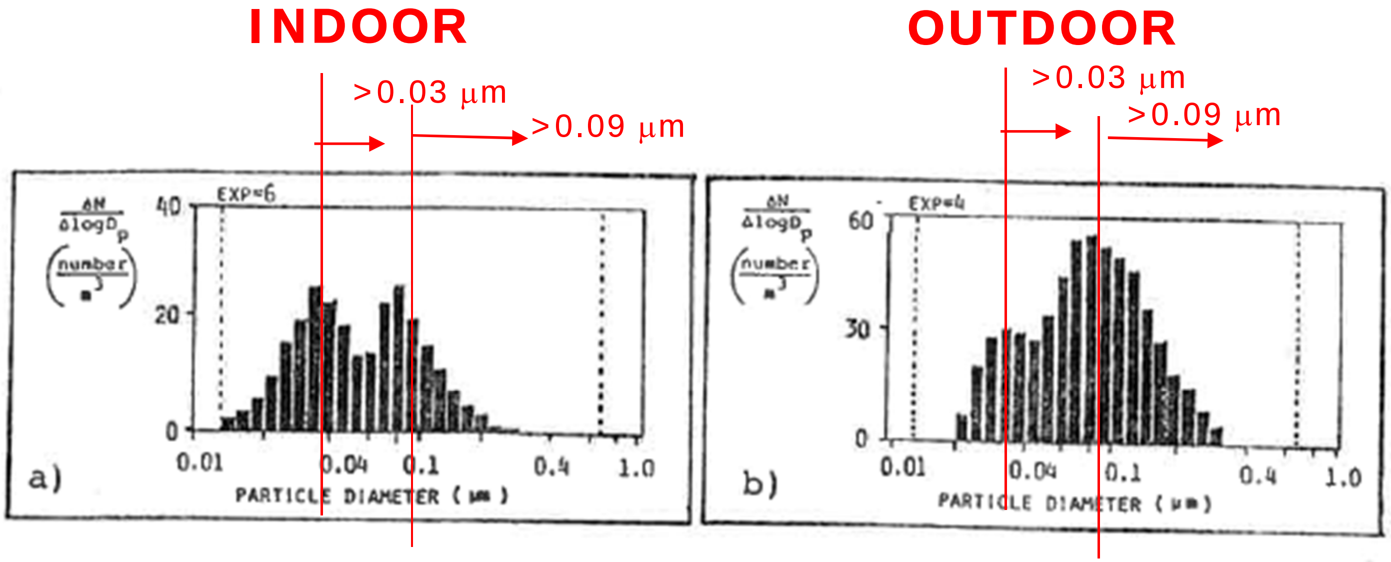


Figure 1. The number concentration size distribution of a) the indoor air (3.3.1988) and b) the outdoor air (24.1.1988).

- **Below 0.06 µm, particle distributions starts to decrease outdoors, indoors below 0.03µm**
- **There are virtually no particles below 0.01 µm**

www.trane.com: EPA studies indicate that indoor levels of many pollutants may be 25 times, and occasionally more than 100 times, higher than outdoor levels. In general, indoor air is four to five times more polluted than outdoor air.

Particles – Sizes in Nature

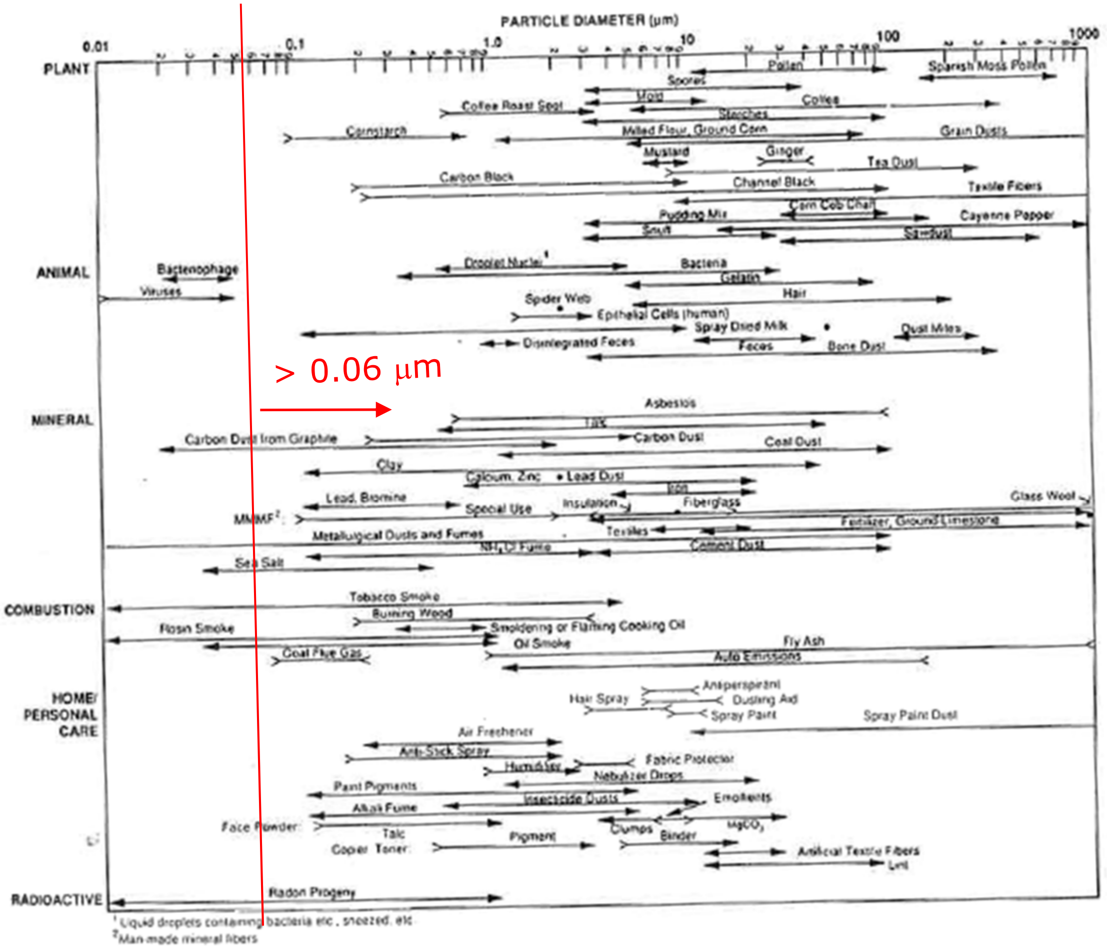


Fig. 5. Sizes of indoor particles.

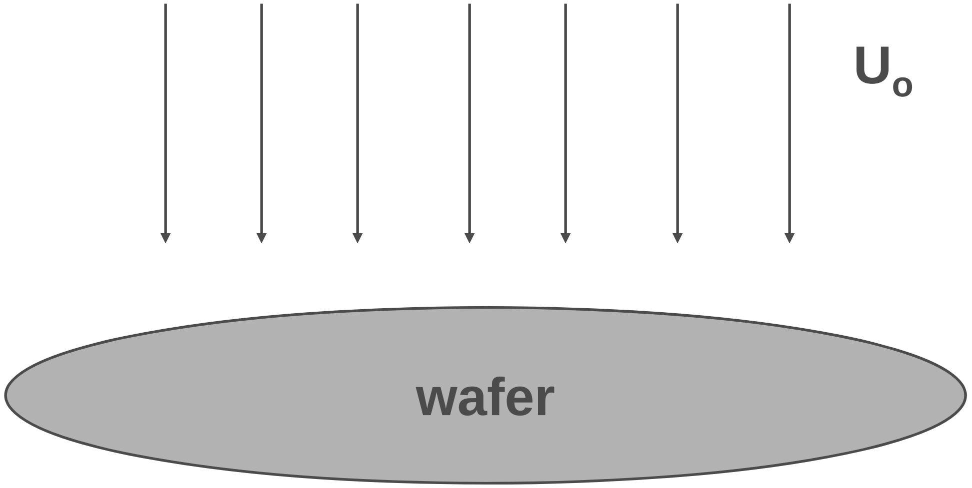
Particles in Gases

- Particle behavior in a gas environment

Geometrical Configuration

Particles behavior in a gaseous environment

A horizontal wafer in a vertical laminar flow



Particle deposition from a gas environment

- Particle deposition velocity V_d or sedimentation velocity V_s:
- $N = c*V_d*t$

N = areal density of particles on a wafer

c = concentration of particles in the gas environment

t = time of exposure to the gas environment

To begin: Only Gravity and Drag Force

V_d or V_s = deposition/sedimentation velocity

(+)

- Gravity

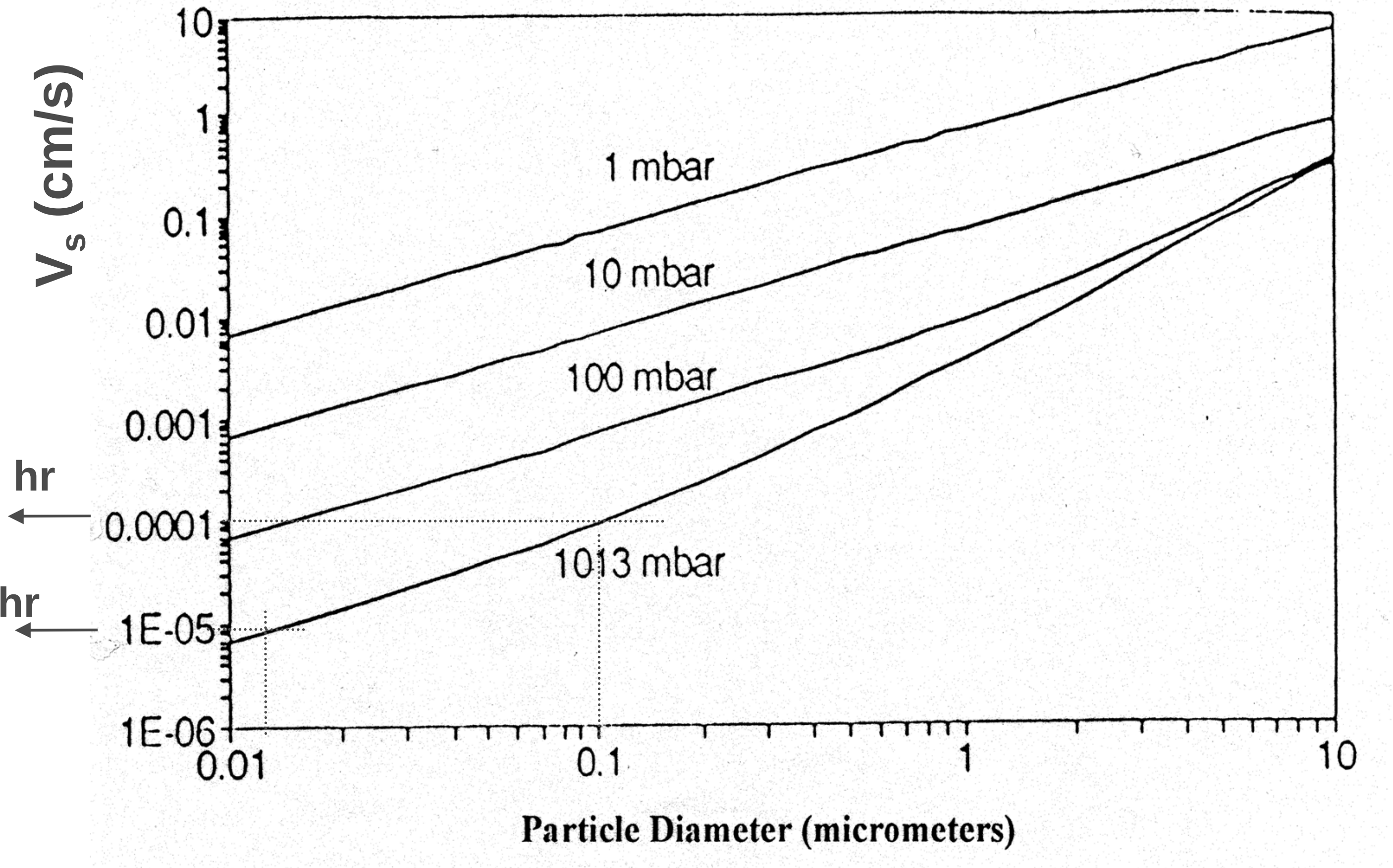
(-)

- Drag Force

SEDIMENTATION

Calculated Sedimentation Deposition Velocity

V_s (cm/s) - Only gravity and drag



1cm/2.8 hr

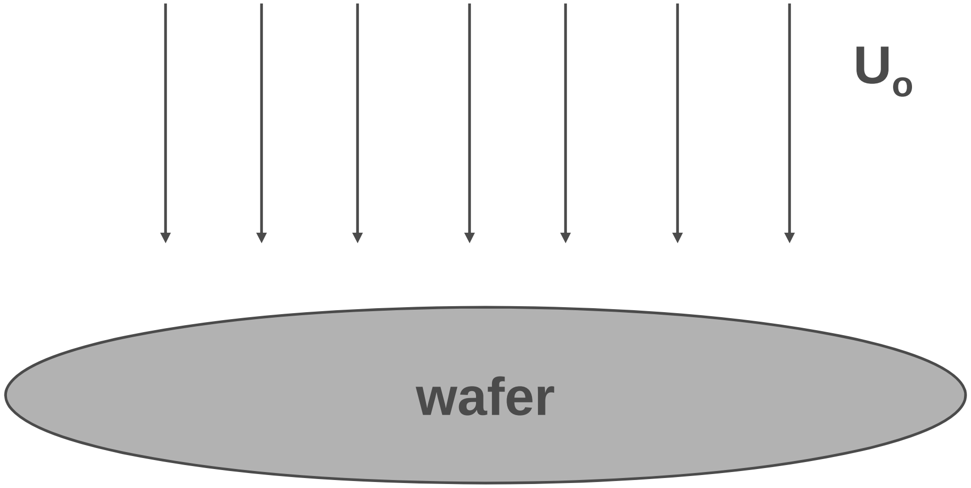
1cm/28 hr

Ref : B. Donovan, Austin, March 25th 1998

Geometrical Configuration

Particles behavior in a gaseous environment

A horizontal wafer in a vertical laminar flow



Next: Diffusion is Added

V_d = deposition velocity

(+)

- Gravity
- Diffusion

(-)

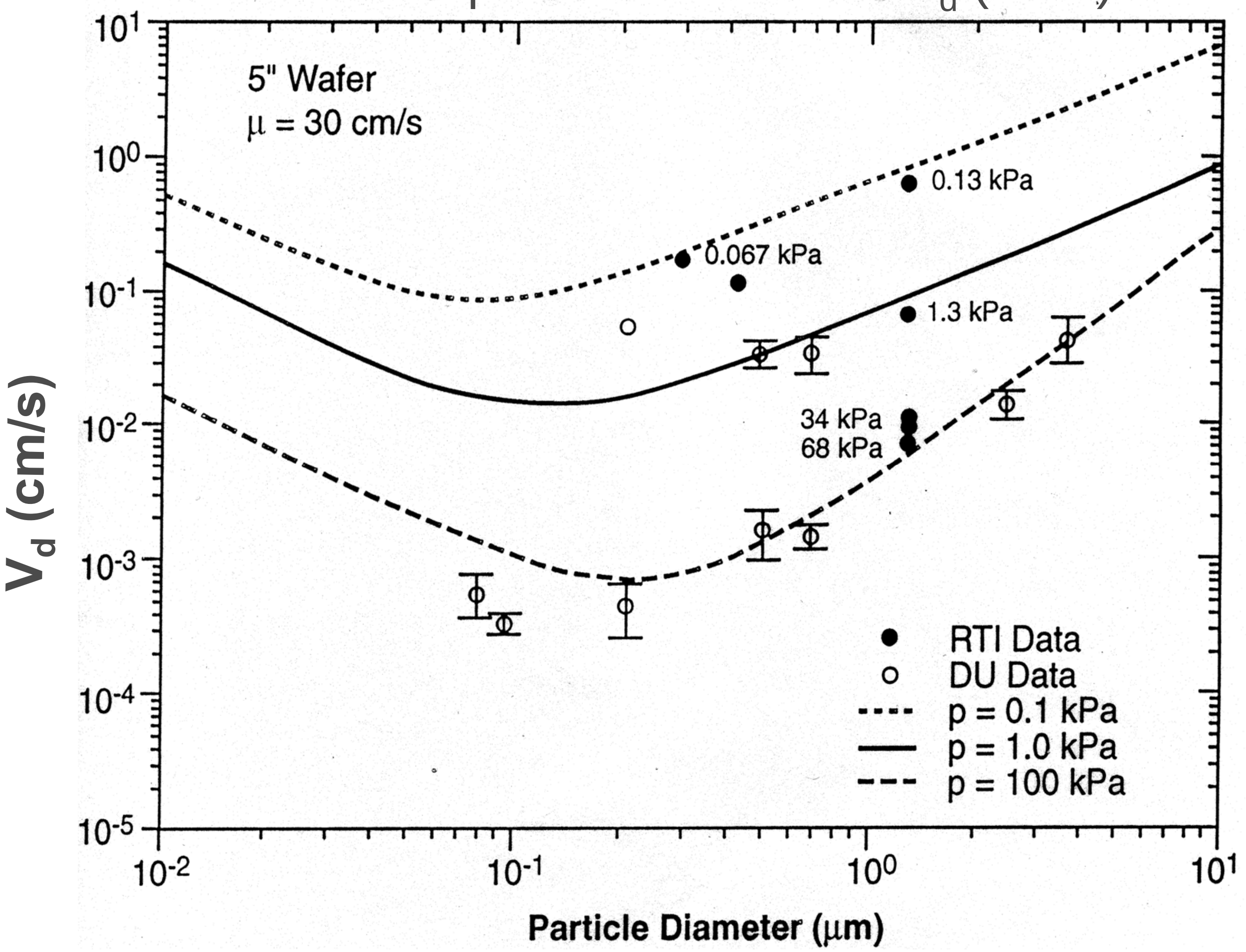
- Drag Force

$$\underbrace{\hspace{10em}}$$

Deposition by sedimentation and diffusion

Deposition Velocity by Gravity and Diffusion Together

With experimental data for V_d (cm/s)



Ref : B. Donovan, Austin, March 25th 1998

Next: Thermophoresis is Added

V_d = deposition velocity

(+)	(-)
Gravity	Drag Force
Diffusion	Thermophoresis

Deposition by sedimentation and diffusion in the presence of a temperature gradient

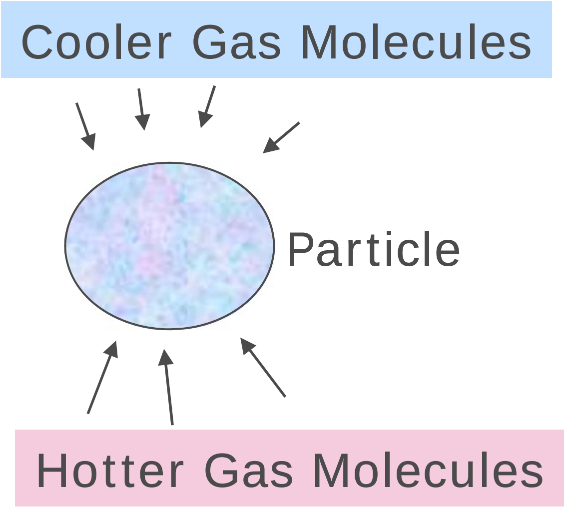
Thermal Shielding

Thermophoresis:

- Creates a repulsive force on an approaching particle attributable to the temperature gradient in the air perpendicular to the heated surface

Repulsive : wafer is warmer than gas environment

Attractive : wafer is cooler than gas environment



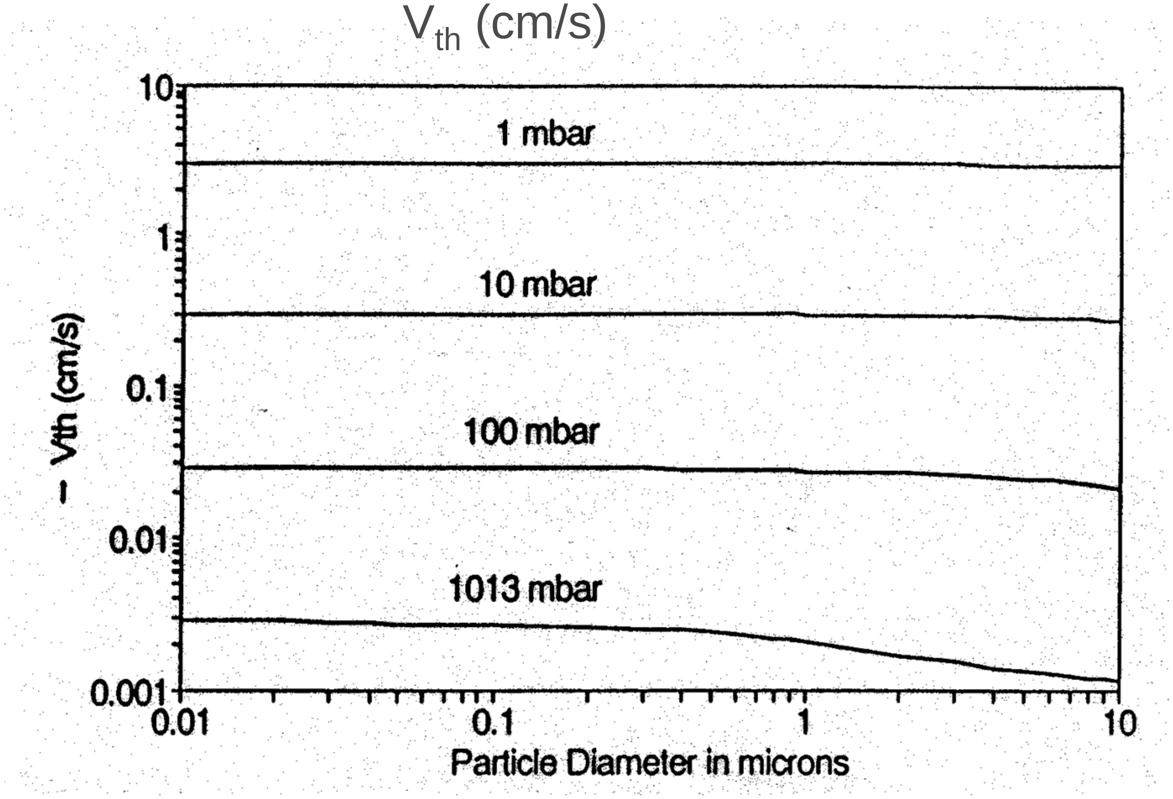
Cooler Gas Molecules

Particle

Hotter Gas Molecules

Deposition Velocity Due to Thermophoresis

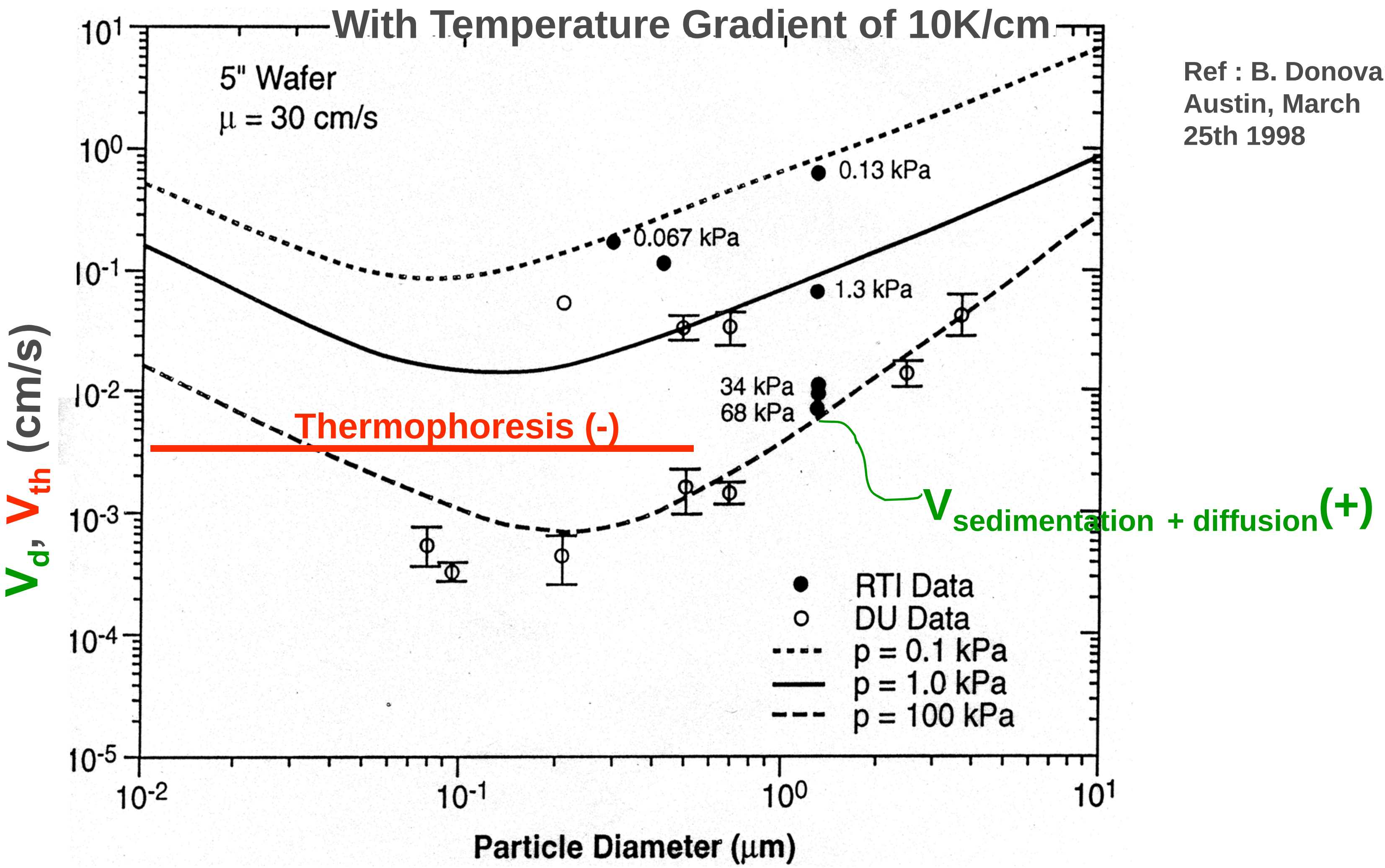
V_{th} (cm/s)



∇T = 10K/cm temperature gradient
V_{th} is not very size dependent
The negative sign means a repulsive force

Ref : B. Donovan, Austin, March 25th 1998

Deposition by Gravity and Diffusion Together with a Temperature Gradient



Ref : B. Donovan, Austin, March 25th 1998

Summary – Gas Phase

- **Particles < 0.1 μm do NOT settle in air (@1atm) for t < 24hr**

- **Particles < 0.1μm follow the air flow perfectly, hence can be carried away with good laminar flow**

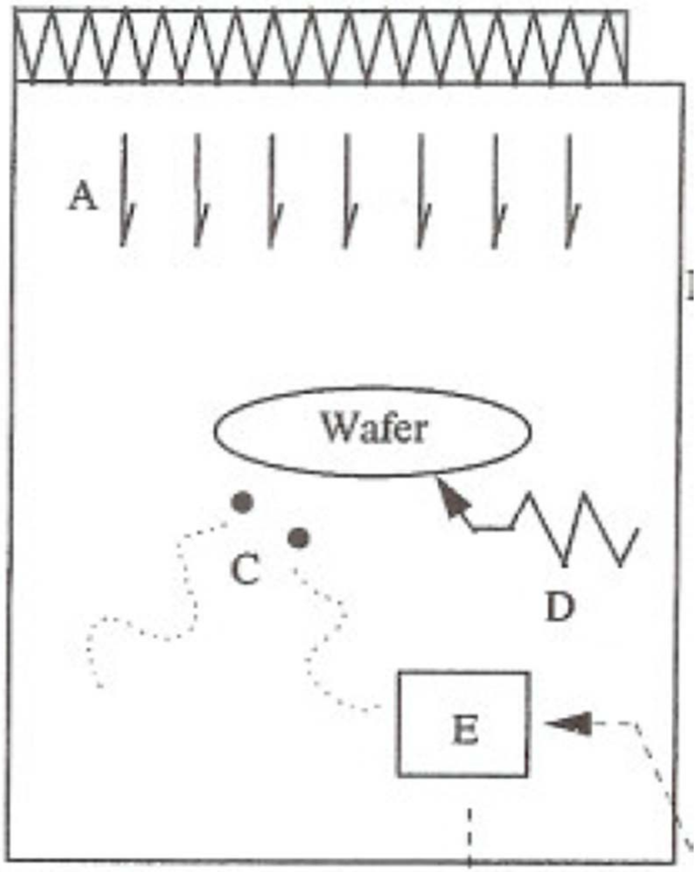
- **If $T_{wafer} = T_{environment} + 10$ °C**
  - **then particles < 0.1 μm do NOT settle even for > 24 hr**

↓

- **Once cleaned, recontamination with particles < 0.1μm is unlikely within practical time limits, with good laminar flow**

Practical Applications of These Theories

- Maintaining laminar flow sweeps the particles, when created by moving parts, through the equipment and prevents stagnation points that can trap particles
- Either open "Flow-Through" design that takes advantage of the vertical laminar downflow already present in cleanrooms (*e.g.* some earlier tools, SEZ) or forced mini-environment (*e.g.* most recent tools)



Application: Particles in a single Wafer Cleaning Tool

- Large, e.g. 6” Exhaust
- Full covered laminar flow with fan to force the air
- Wide open bowl with gradual interfaces
- 250 CFM (Cubic Foot per Minute) clean air flow per 300mm chamber

Isolation of Particle Sources

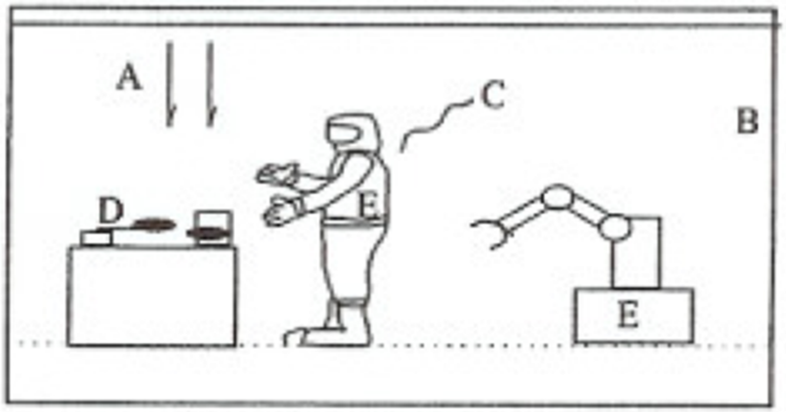
- People were historically the most important source of particles

- Original approach: Isolation of product from contamination, *i.e.* people
  - *e.g.* Wear head, beard, face covers, cleanroom garments, gloves, shoe covers

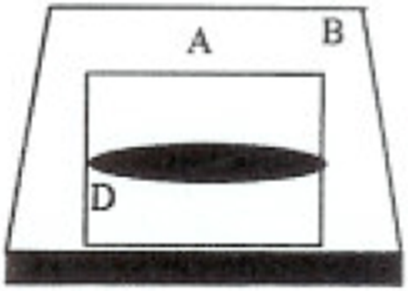
- Newer approach: Isolation of product from contamination, *i.e.* people
  - *e.g.* Added; mini-environments, FOUPs

Examples of Isolation

People Isolation

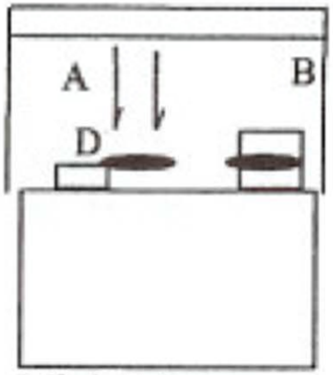


Cleanroom



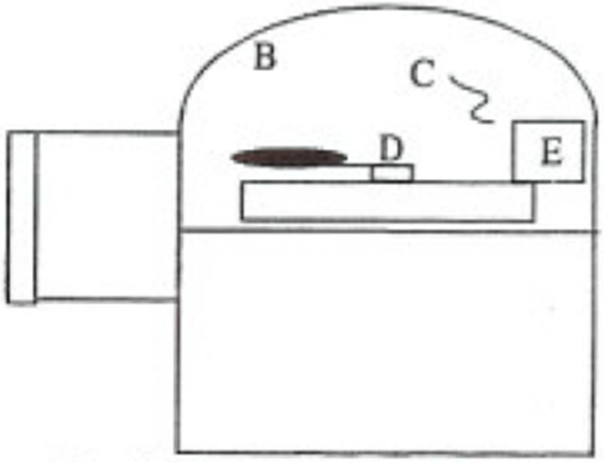
Pod

Atmospheric/ No particles Generated
-> Mini-environment without Laminar Flow



Minienvironment

Atmospheric/particles Generated
-> Mini-environment with Laminar Flow



Low Pressure Process Chamber

Vacuum/particles Generated
-> Mini-environment without Laminar Flow

Entire Cleanroom is Over Pressurized

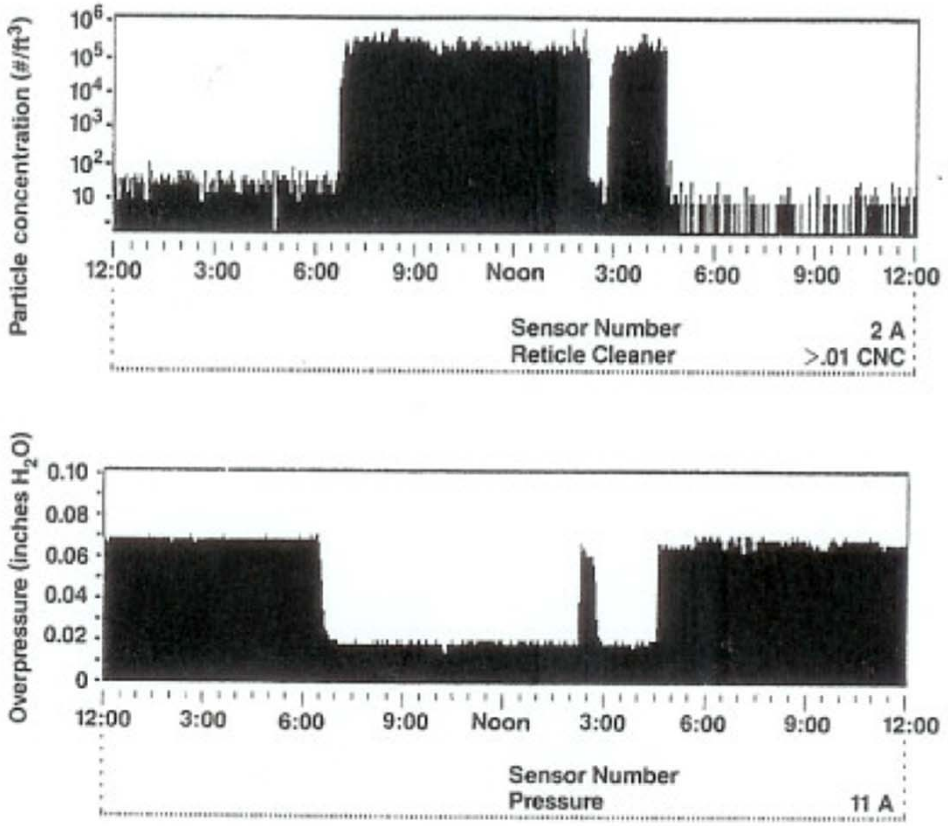
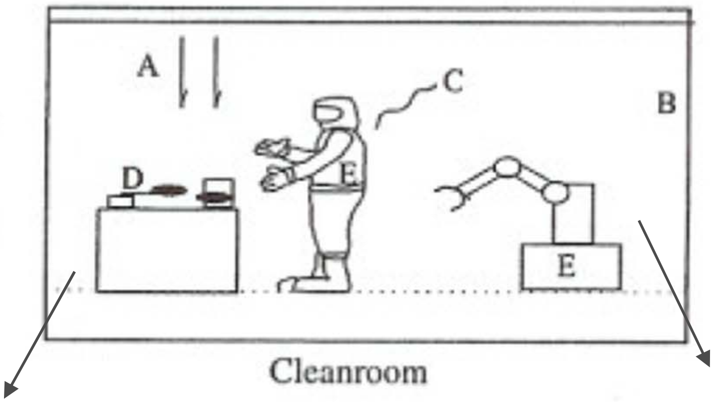


Figure 9 Cleanroom pressurization and particle performance. (From Ref. 13.)



- Dirty air from the outside is disastrous

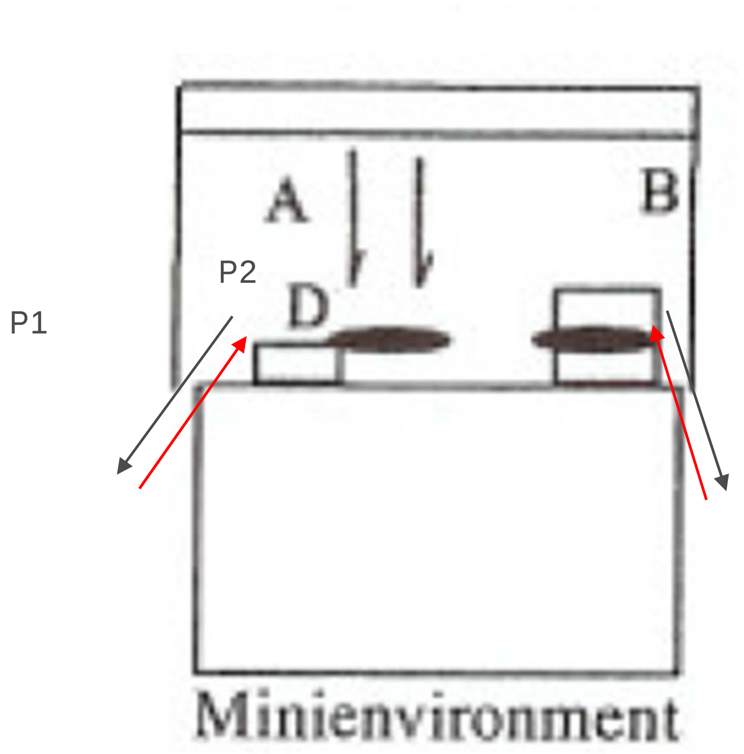
Correlation of particle concentration to over pressurization:
When under pressurized, particle concentration in air increases

Ideal Mini-environment Is Over Pressurized

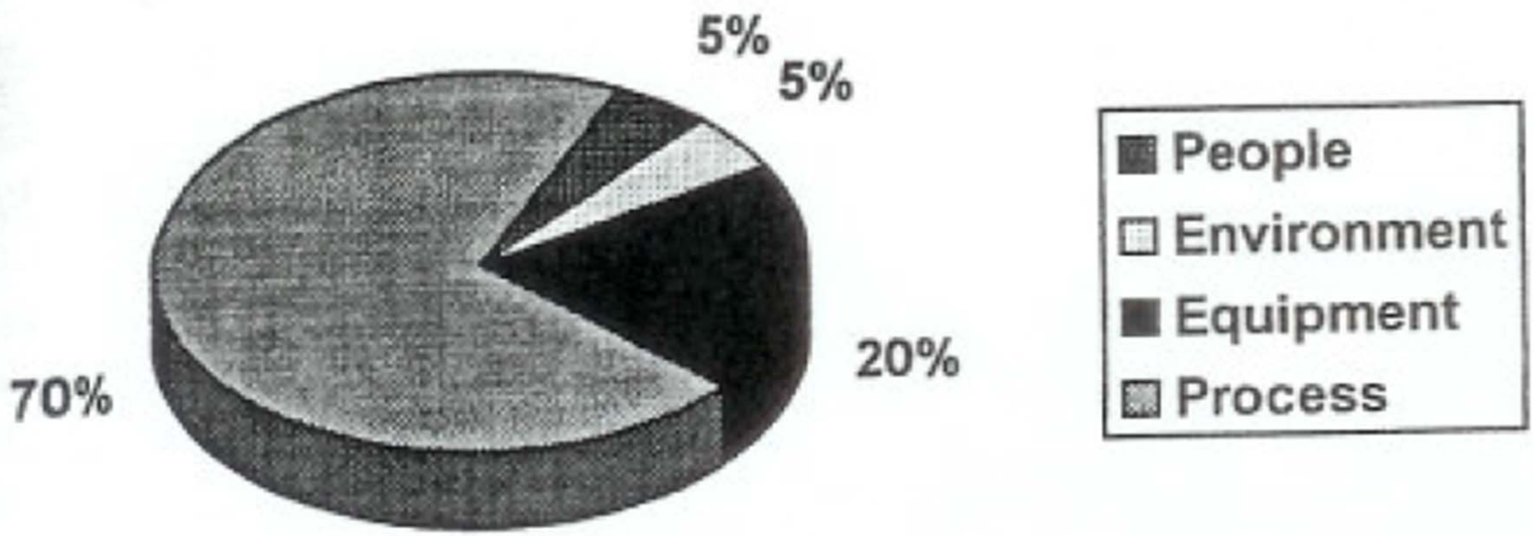
- Flow from inside the mini-environment to the outside by overpressure

- Ideally P1<P2

- However, inside wet chemical tools P1>P2, because of safety



Currently Most of the Particles are from the Process itself

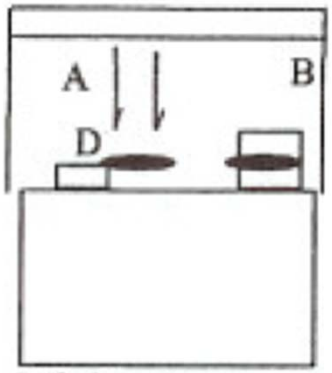


Sources of yield limiting contamination.

- **Typical Example: HF-last**
- **Particles are coming from the wafer itself!**
- **O_2 + Si ⇒ SiO_2 particles**

Remark: Laminar Flow Does Not = Vertical Flow

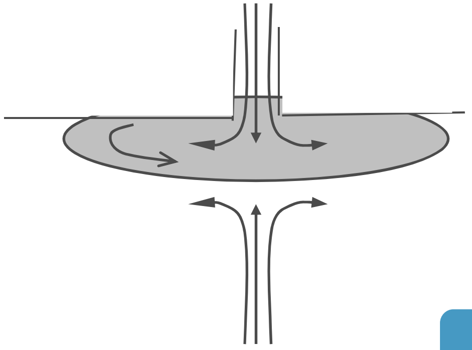
- Traditional:
  - – Laminar Flow = Vertical



Minienvironment

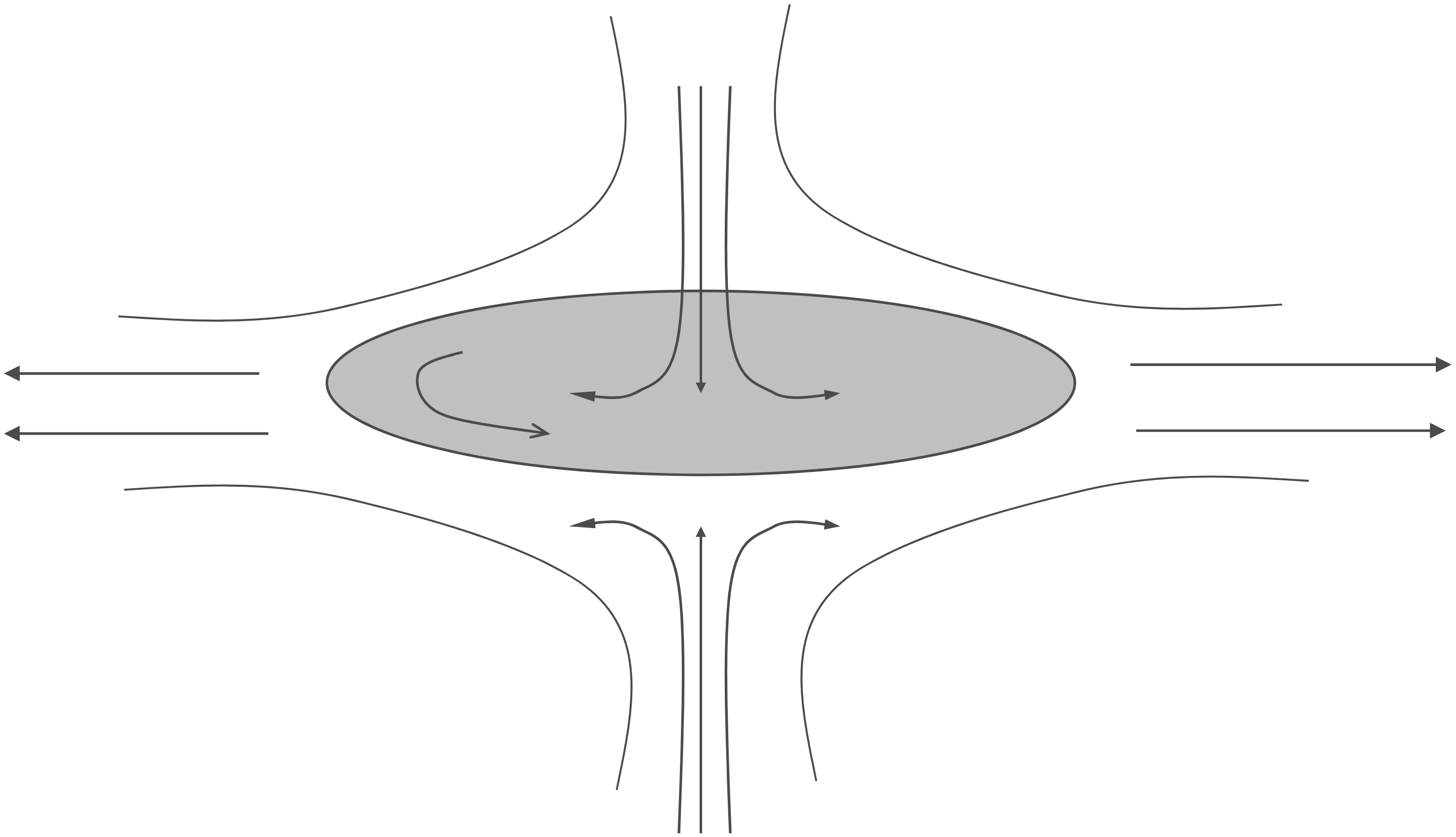
- Laminar flow can also be horizontal

- Laminar flow can be even more complex



Most Ideal Laminar Flow on a Spinning Wafer

- Follow the natural flow lines due to spinning



Next: Electrostatics is Added

V_d = deposition velocity

(+)

- Gravity
- Diffusion
- Electrostatic Attraction

(-)

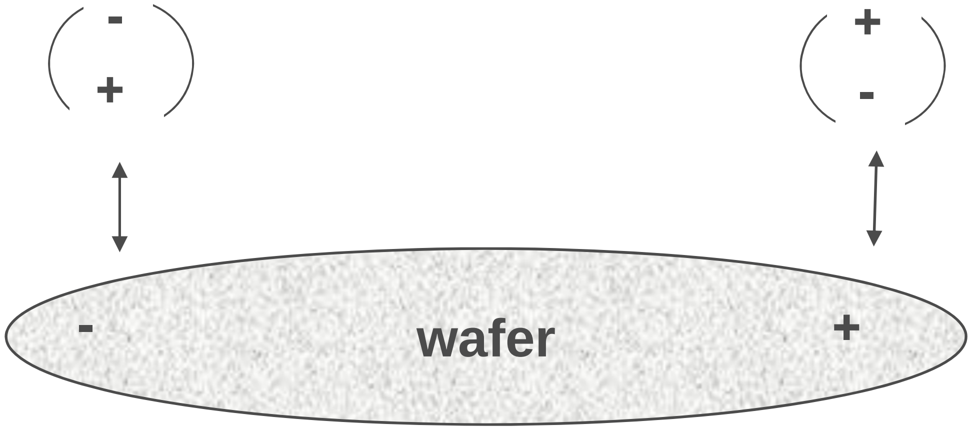
- Drag Force
- Thermophoresis

If the Wafer is Charged, Electrostatic Attraction Will Typically Dominate

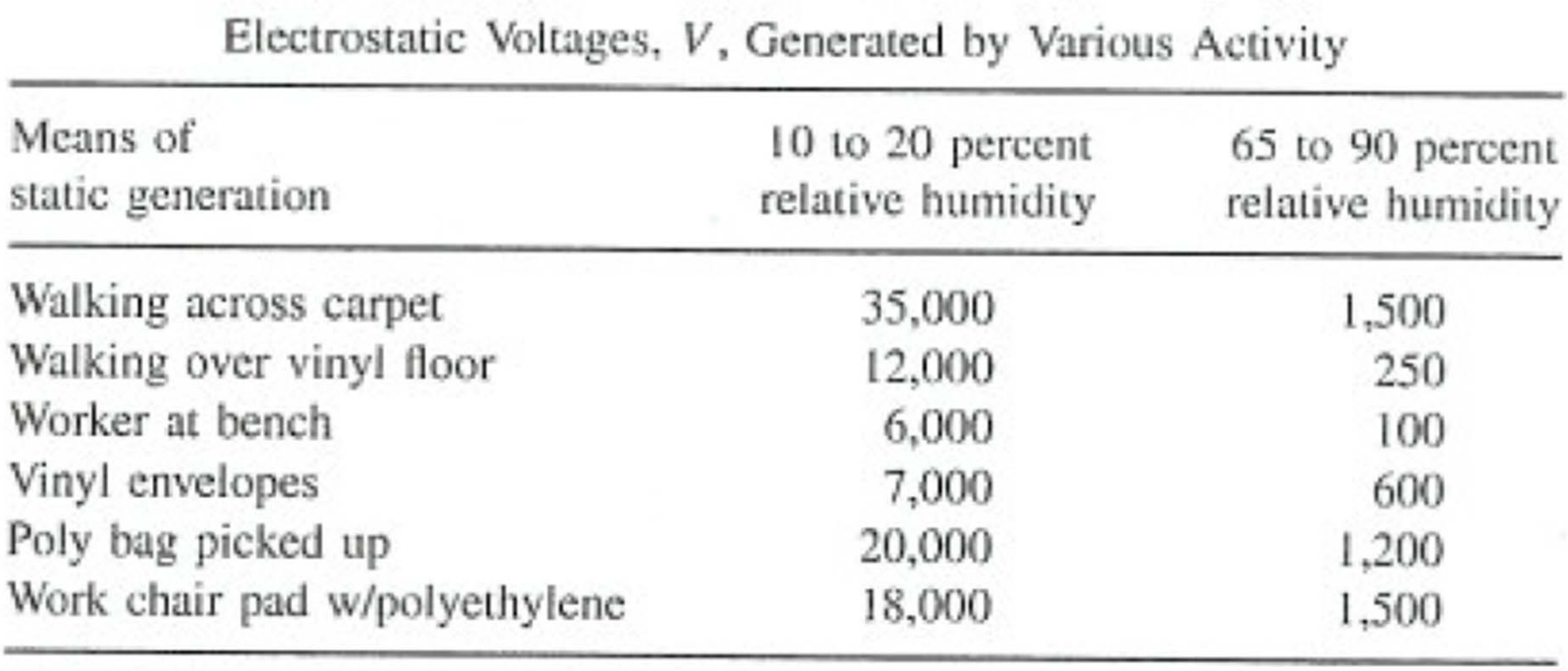
Electrostatic Attraction

- If the particle is neutral and the wafer is charged, force is always attractive, irrespective of the sign of the charge

Charged surfaces always attract particles



Examples of Electrostatic Charge



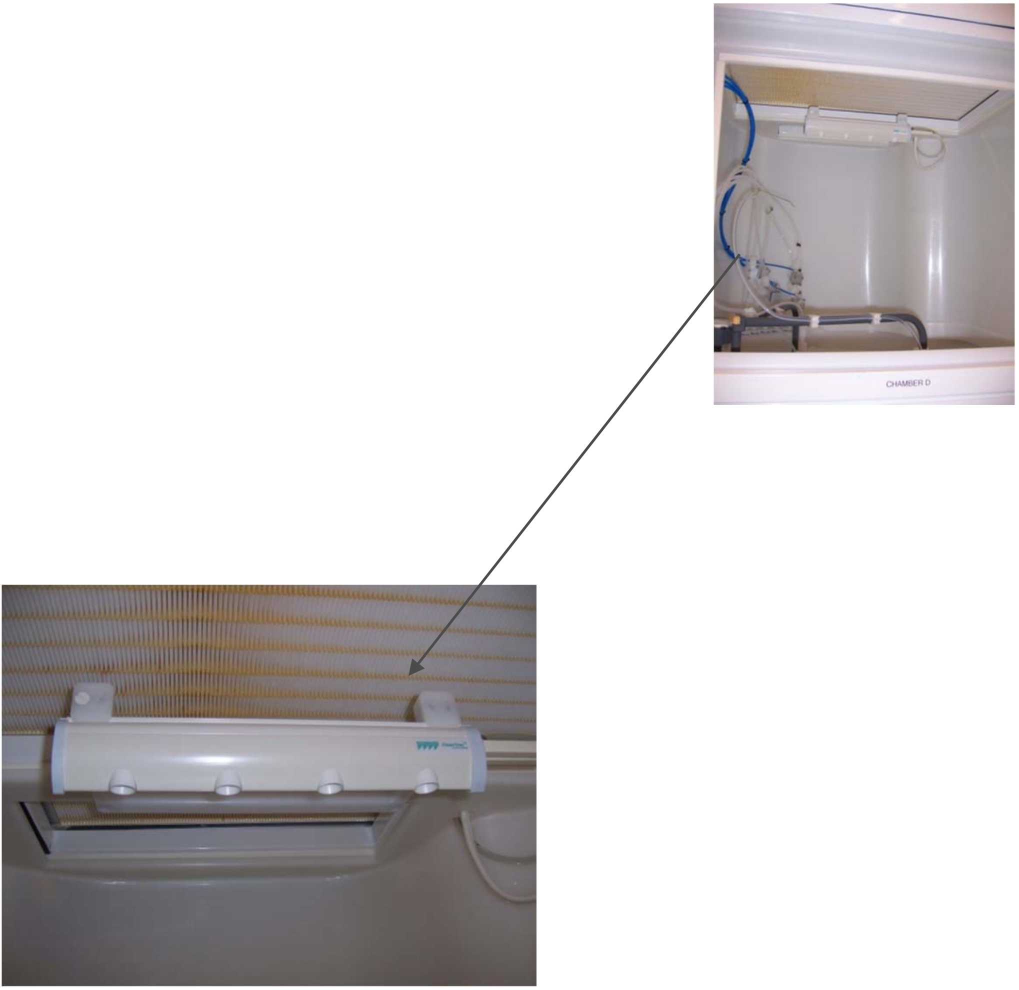
Electrostatic Voltages, *V*, Generated by Various Activity

Means of static generation	10 to 20 percent relative humidity	65 to 90 percent relative humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes	7,000	600
Poly bag picked up	20,000	1,200
Work chair pad w/polyethylene	18,000	1,500

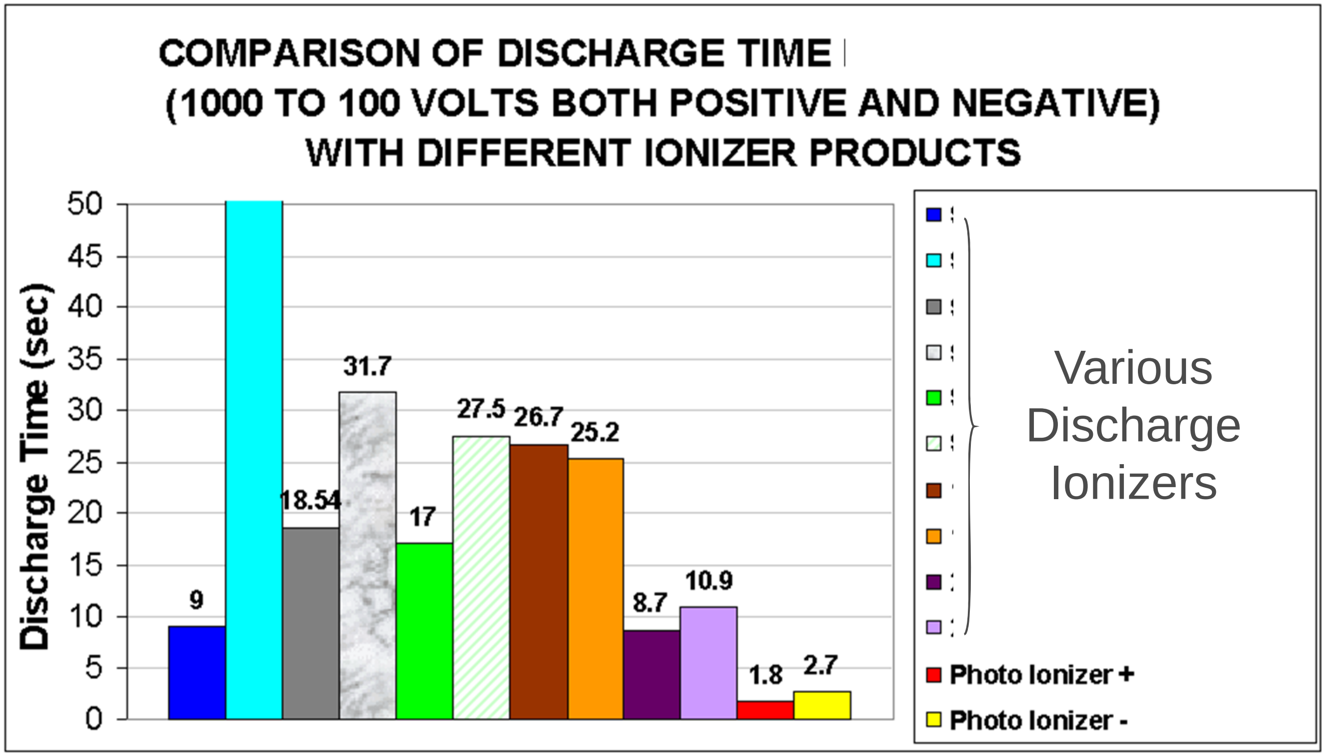
- **Fortunately: High humidity helps in keeping the charge low**
- **Best practice: All conductive surfaces are grounded (typical cleanroom practice)**

Ionizer Bar: To Keep surfaces neutral

- Ionizer is to keep all the surfaces which are non-conductive and not grounded neural, especially Plastics!
- Very useful in a Cleaning Tool where a lot of surfaces are non-conductive
- Not for Keeping the Wafer Neutral!



Ionizer Driven Discharge Times are 20-30s



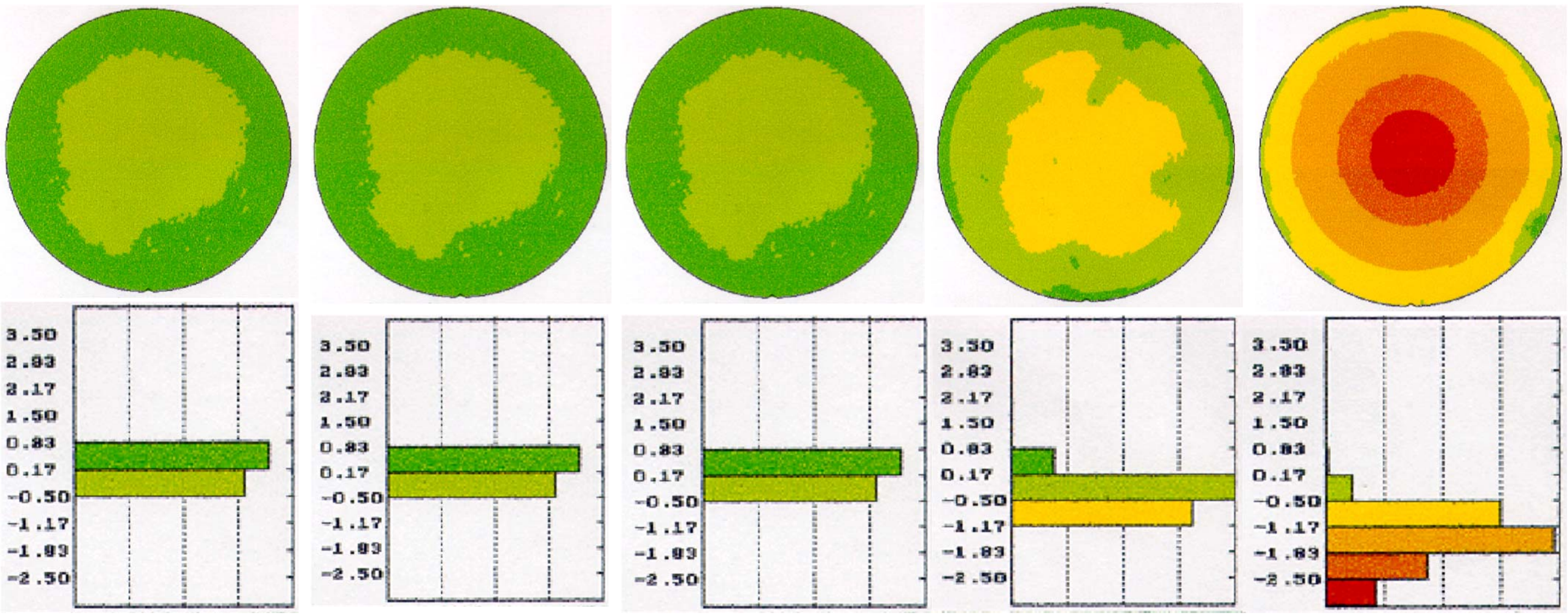
- Discharge times of 20-30s are too long to keep up with a spinning wafer
- Good for discharging plastic parts in the chamber

Photo of accumulation of dirt on a charged plastic part – no ionizer

- Charge is dependent on Material Choice
- HDPE versus PTFE

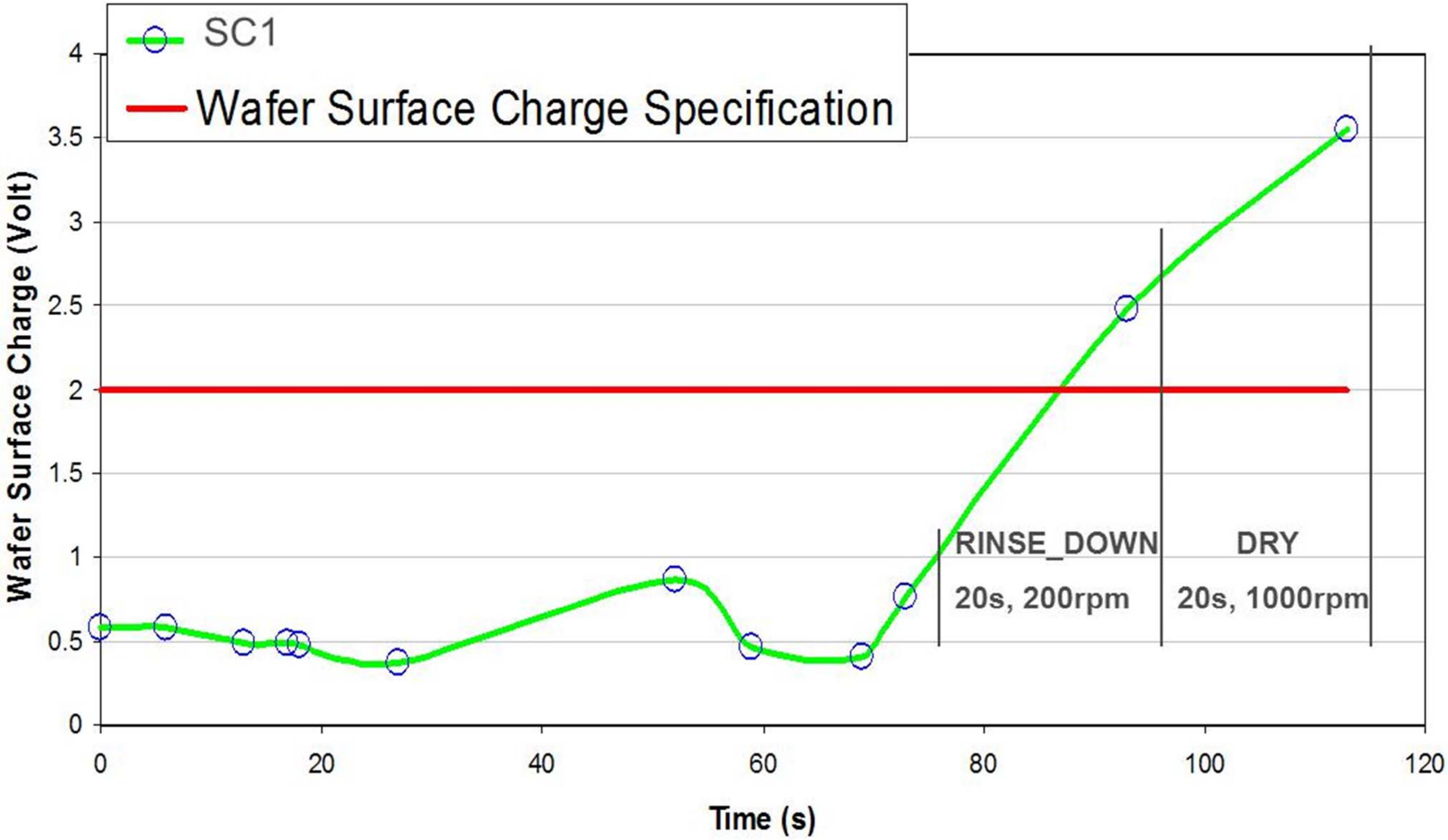
Spin Rate Effect On Wafer Surface Charging

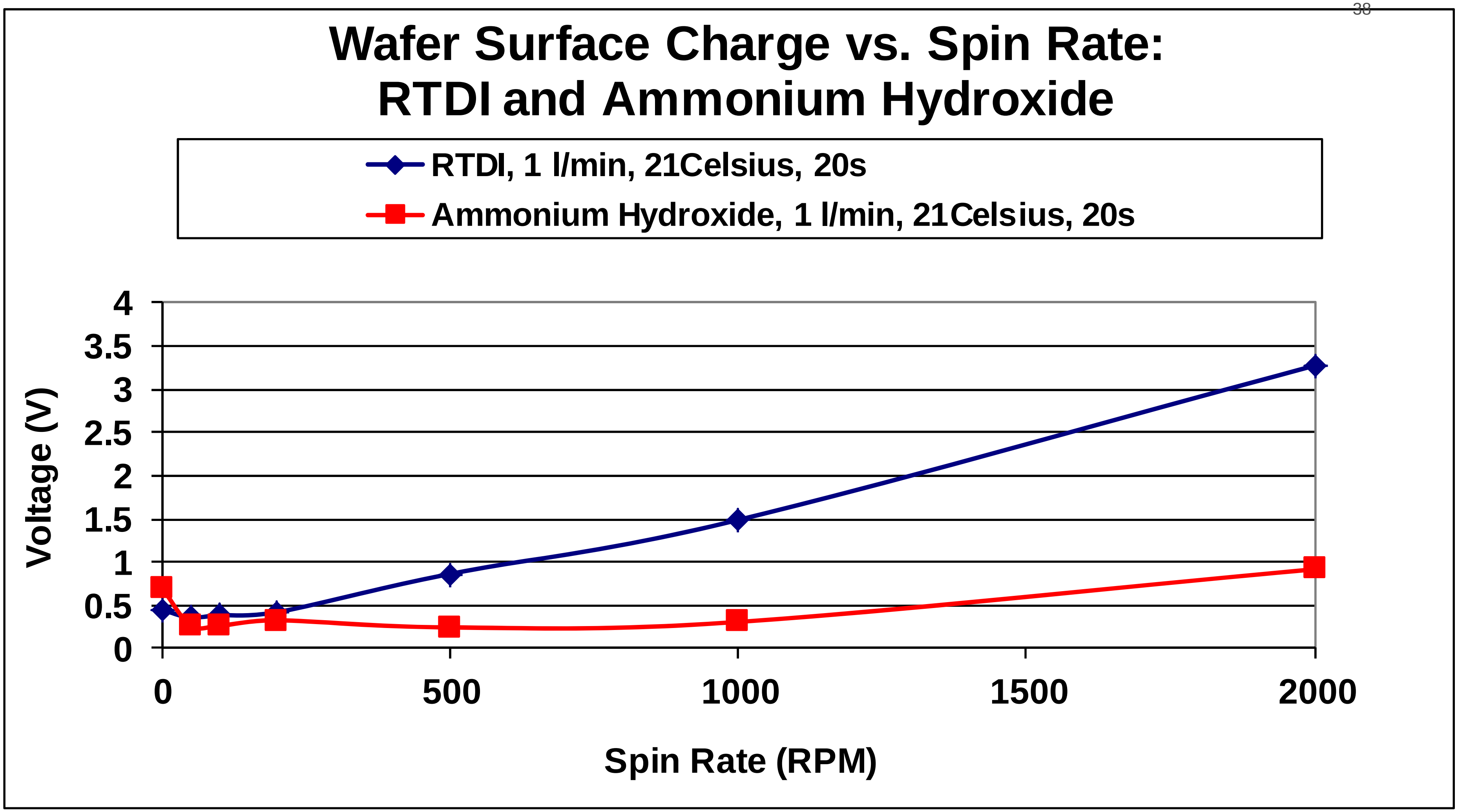
DI (1 l/min, 21°C) for 20s



0rpm	200rpm	500rpm	1000rpm	2000rpm
0.448V	**0.421V**	**0.864V**	**1.487V**	**3.275V**

WAFER SURFACE CHARGE with SC1



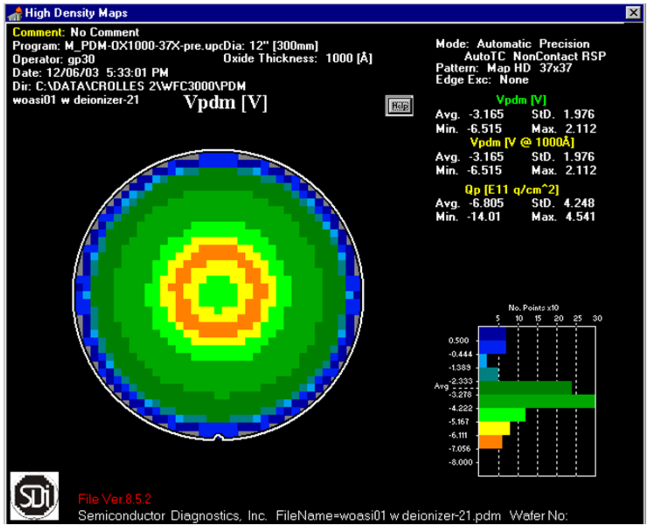


Wafer Surface Charge vs. Spin Rate: RTDI and Ammonium Hydroxide

- Ammonium hydroxide results in a lower wafer surface charge compared to RTDI at the same conditions

Charges are removed very easily

- After Cleaning in Single Wafer:



High Density Maps

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woasi01 w deionizer-21

Vpdm [V]

Mode: Automatic Precision
AutoTC NonContact RSP
Pattern: Map HD 37x37
Edge Exc: None

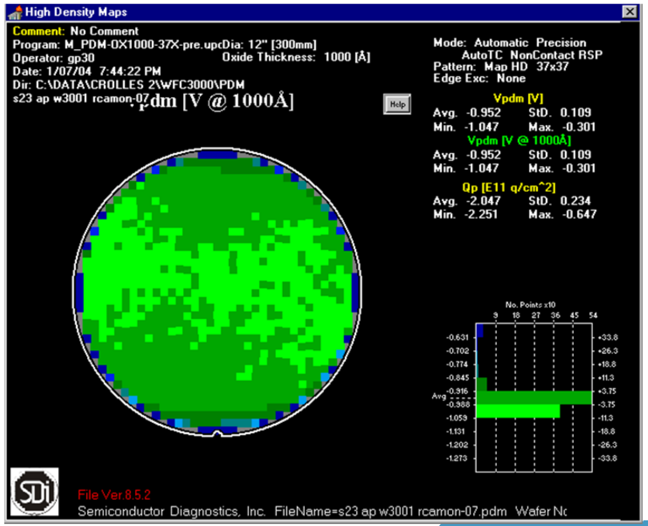
Vpdm [V]
Avg. -3.165 StD. 1.976
Min. -6.515 Max. 2.112

Vpdm [V @ 1000Å]
Avg. -3.165 StD. 1.976
Min. -6.515 Max. 2.112

Qp [E11 q/cm^2]
Avg. -6.805 StD. 4.248
Min. -14.01 Max. 4.541

File Ver.8.5.2
Semiconductor Diagnostics, Inc. FileName=woasi01 w deionizer-21.pdm Wafer No:

- After subsequent Immersion Cleaning in Wet Bench:



High Density Maps

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s23 ap w3001 rcamon-07

Vpdm [V @ 1000Å]

Mode: Automatic Precision
AutoTC NonContact RSP
Pattern: Map HD 37x37
Edge Exc: None

Vpdm [V]
Avg. -0.952 StD. 0.109
Min. -1.047 Max. -0.301

Vpdm [V @ 1000Å]
Avg. -0.952 StD. 0.109
Min. -1.047 Max. -0.301

Qp [E11 q/cm^2]
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File Ver.8.5.2
Semiconductor Diagnostics, Inc. FileName=s23 ap w3001 rcamon-07.pdm Wafer Nc

Wafer Charging on Wafer - summary

- Wafer Charging happens due to spinning with non-conductive liquid
- Wafer Charging can not be prevented with Ionizer
- Wafer Charging can only be prevented with conductive liquid
- Wafer Charge from spinning is easily neutralized in subsequent operations

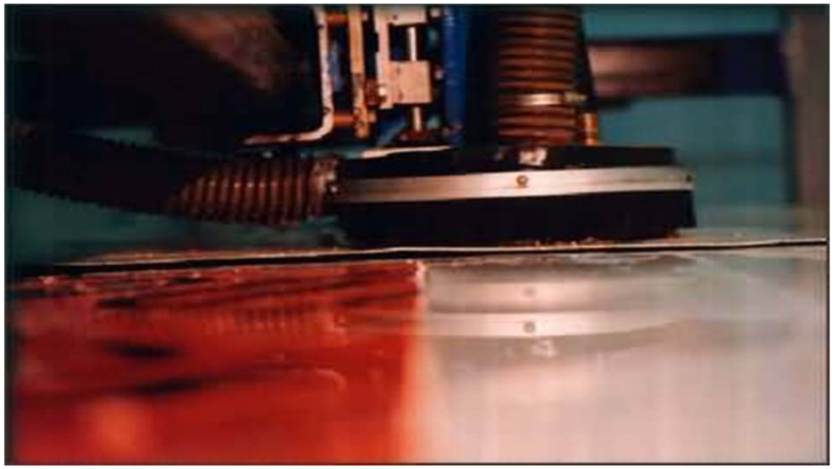
Mechanical Agitation – Non Semiconductor

- Brushes
- Polishing
- Sandblasting
- Megasonics/Ultrasonics
- High Pressure Spray

Mechanical Cleaning is the most common way to remove particles

Brush Scrubbing is Used in Daily Life

Cleaning by Polishing

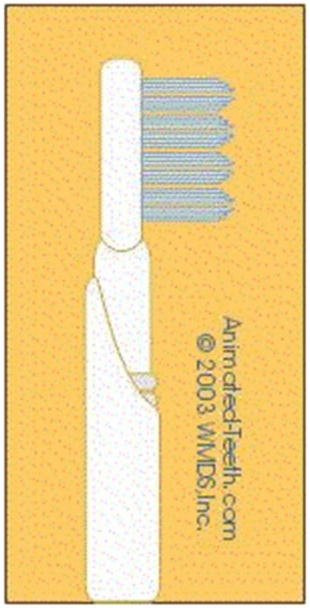


Cleaning by Sandblasting

Open Air

Closed Cabinet

Brush Scrubbing Can Be Combined With Ultra/Mega Sonics



Jewelry Cleaner

Ultrasonic toothbrush

Even Ultrasonics is used in Daily Life for Cleaning

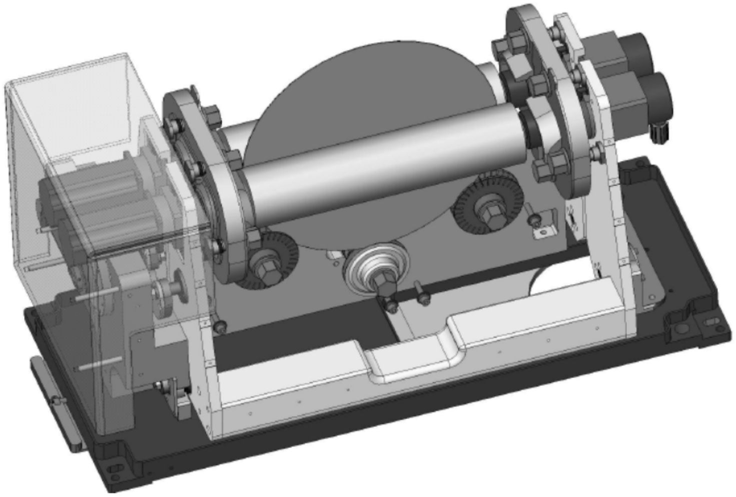
High Pressure Water jet

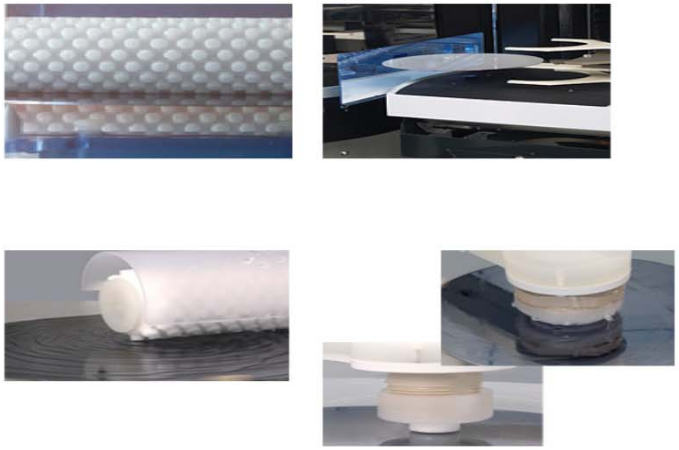
$500, for consumer use

Mechanical Agitation – Semiconductor – Single Wafer

- Brushes
- Polishing
- Sandblasting
- Megasonics/Ultrasonics
- High Pressure Spray
- Others: e.g. Ar ion sputter clean

Brush Cleaning – Single Wafer

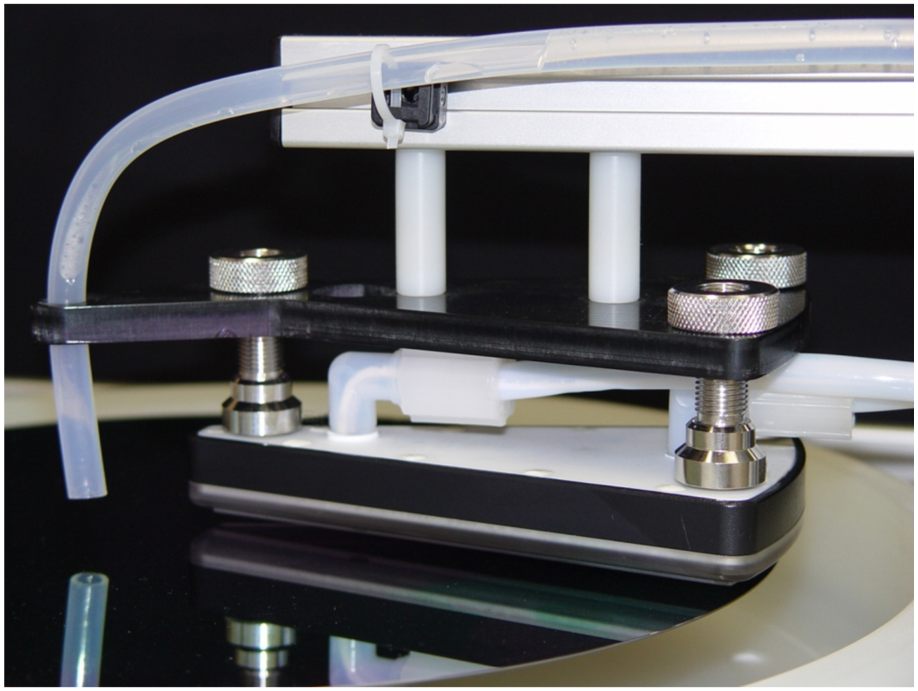




“Sandblasting” with CO_2 pellets

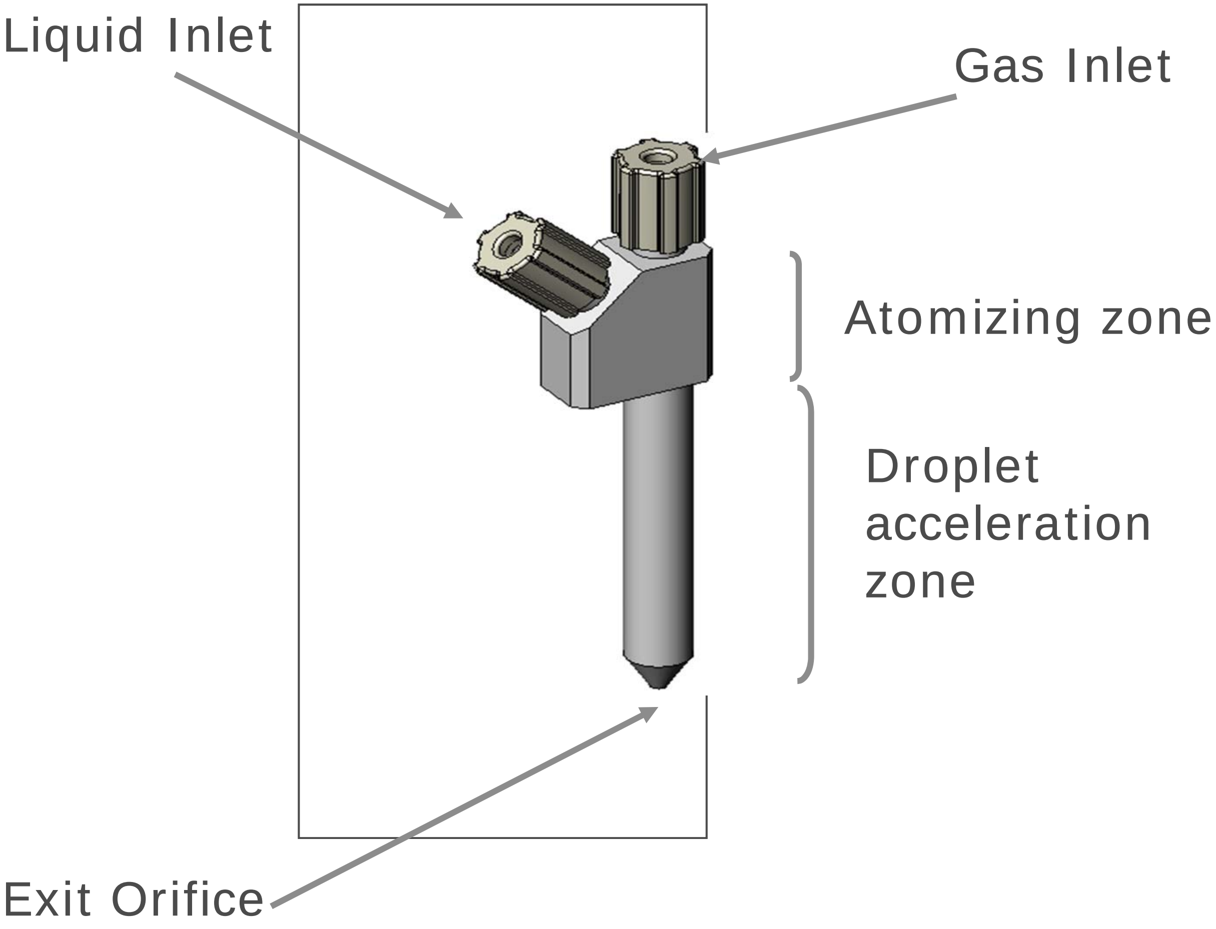
- Ecosnow (part of Linde/Edwards), Livermore, CA

Single Wafer Megasonics Clean



Single Wafer Megasonics

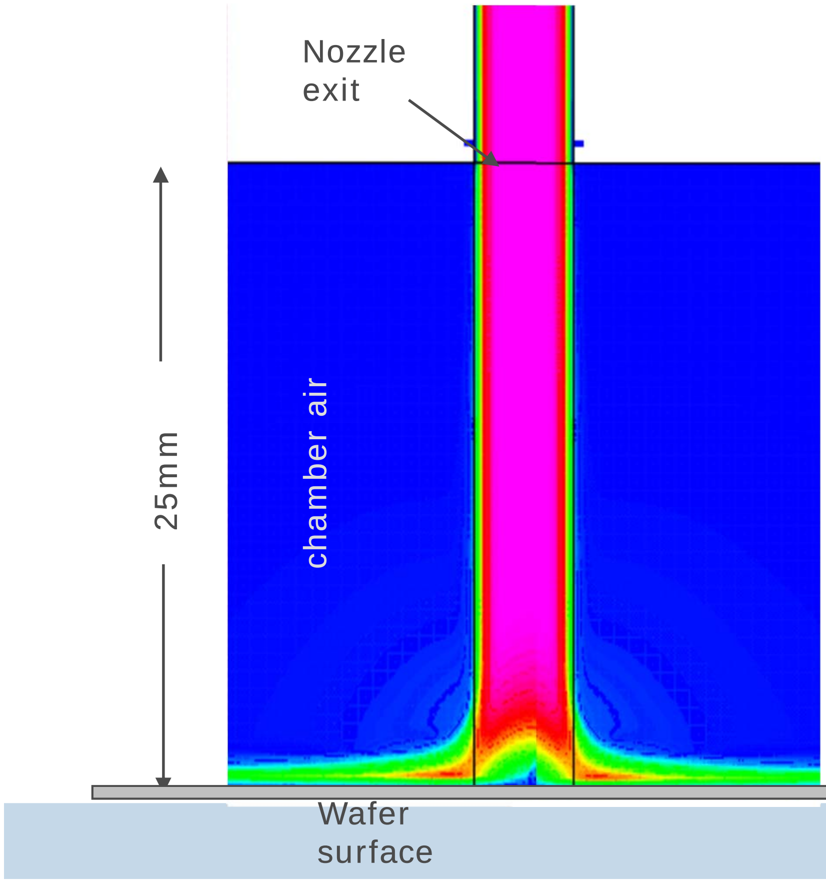
Mixed Fluid Jet - Atomized Spray Nozzle

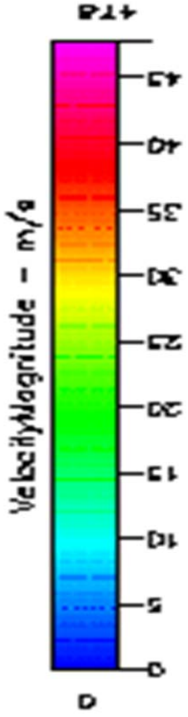


- Micro Droplet Acceleration Technology
- Velocity at ~ 30 to 75 m/sec
- Used for Fine Geometry cleaning alone or in Combination with Chemical Undercut

Gas Velocity Modeling

Gas velocity distribution
At the nozzle exit





- **Not much velocity divergence after nozzle exit**

Any Questions?

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into industries.™