Aspects of Single Wafer Cleans Processing and Tools

Steven Verhaverbeke

Applied Materials, Santa Clara, CA
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- Generalities on particles in a chamber environment – gas phase
- Implications for a single wafer chamber design
- Wafer and environment charging in a single wafer chamber
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Particles – Distributions on Wafer

- Typically we measure Particles > 0.09 \( \mu m \) or > 0.06 \( \mu m \)
- Particle Density \( \sim 1/x^2 \)
- What about Particles < 0.06 \( \mu m \)?

Tencor SP1 measurement >0.09 \( \mu m \)
Particles – Distributions in Liquid

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

- In liquid systems: particle density $\sim 1/x^3$
- What about particles < 0.03 $\mu$m?

Courtesy of PMS
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
Below 0.06 μm, particle distributions start to decrease outdoors, indoors below 0.03 μm

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

$U_o$

wafer
Particle deposition from a gas environment

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

$N$ = 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

\[ V_d \text{ or } V_s = \text{deposition/sedimentation velocity} \]

\[ (+) \]
- Gravity

\[ (-) \]
- Drag Force

SEDIMENTATION
Calculated Sedimentation Deposition Velocity

$V_s$ (cm/s) - Only gravity and drag

Particle Diameter (micrometers)

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

Particles behavior in a gaseous environment

A horizontal wafer in a vertical laminar flow $U_0$

wafer
Next: Diffusion is Added

\[ V_d = \text{deposition velocity} \]

\[ (+) \]
- Gravity
- Diffusion

\[ (-) \]
- Drag Force

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

\[ V_d = \text{deposition velocity} \]

\((+):\)
- Gravity
- Diffusion

\((-):\)
- Drag Force
- 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

![Diagram of Thermophoresis]
Deposition Velocity Due to Thermophoresis

\[ \nabla T = 10 \text{K/cm temperature gradient} \]

\[ V_{th} \] 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

With Temperature Gradient of 10K/cm

5" Wafer
μ = 30 cm/s

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 $T_{\text{wafer}} = T_{\text{environment}} + 10$ °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

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

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

Vacuum/particles Generated -> Mini-environment without Laminar Flow
Entire Cleanroom is Over Pressurized

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

- Typical Example: HF-last
- Particles are coming from the wafer itself!
- $\text{O}_2 + \text{Si} \rightarrow \text{SiO}_2$ particles
Remark: Laminar Flow Does Not = Vertical Flow

- Traditional:
  - Laminar Flow = Vertical

- 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

\[ V_d = \text{deposition velocity} \]

\[ (+) \]
- 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

- 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 neutral, 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: 0.448V
- 200rpm: 0.421V
- 500rpm: 0.864V
- 1000rpm: 1.487V
- 2000rpm: 3.275V
WAFFER SURFACE CHARGE with SC1

- SC1
- Wafer Surface Charge Specification

**RINSE_DOWN**
- 20s, 200rpm

**DRY**
- 20s, 1000rpm
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:

- After subsequent Immersion Cleaning in Wet Bench:
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

Even Ultrasonics is used in Daily Life for Cleaning

Ultrasonic toothbrush

Jewelry Cleaner

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 CO₂ pellets

- Ecosnow (part of Linde/Edwards), Livermore, CA
Single Wafer Megasonics Clean

![Single Wafer Megasonics Clean Image]
Mixed Fluid Jet - Atomized Spray Nozzle

- Liquid Inlet
- Gas Inlet
- Atomizing zone
- Droplet acceleration zone
- Exit Orifice

- 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

- Not much velocity divergence after nozzle exit
Any Questions?