Recovering after Chamber Wet Clean

Sustainability through Controllability

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Plasma – Metrology – Experience

Starting Point: Chamber Recovery after Wet Clean

- Chamber recovery after Wet Clean often requires engineering efforts, increases the consumption of high Global Warming Potential (GWP) gases and of raw material (Wafer, PR,…) and none of what we do is neutral to the environment.

- There are many methods to recover after wet clean but from the tool point of view, two concepts have established:
  1) Suppress as much as possible the interactions between plasma and walls → chamber heating
  2) Accept some controlled interactions and regularly come back to a “known” state → chamber dry clean

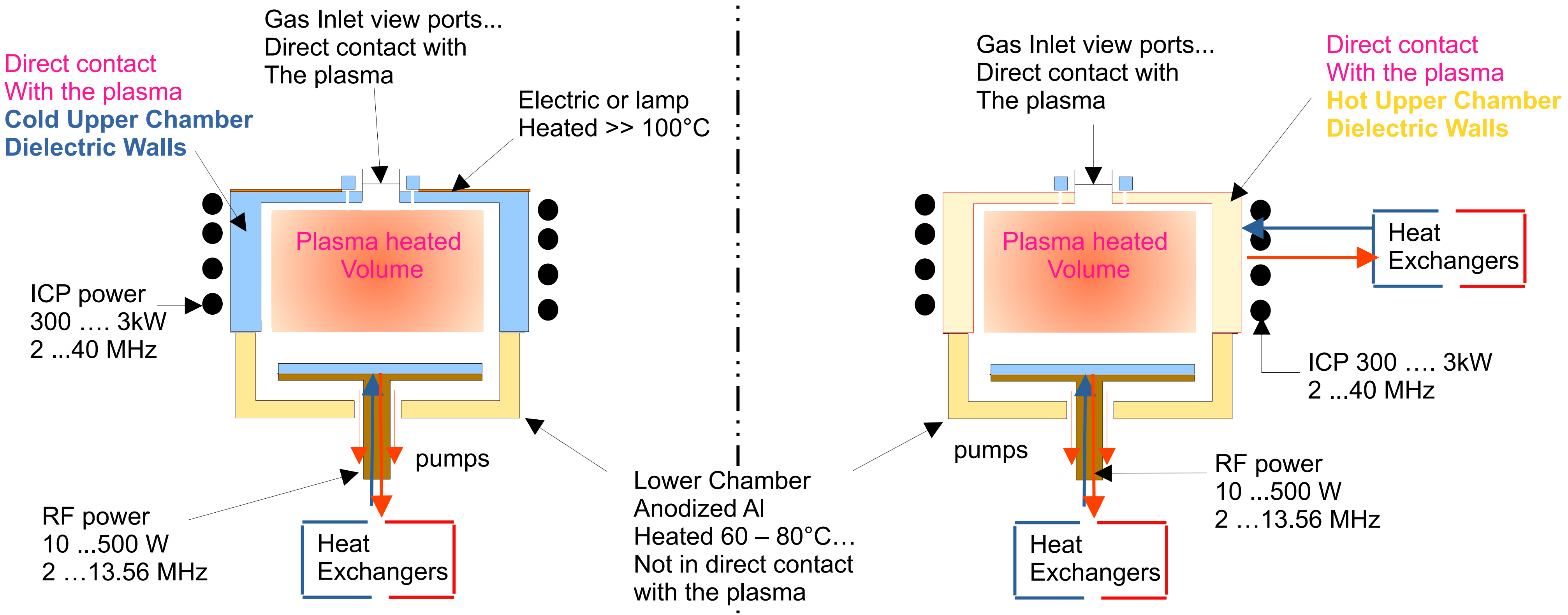
- Interestingly, the “state” to reach, the chamber conditions at which the process is performing as expected, is usually only indirectly known. → Tests on Wafer…

- Is it possible to gain sustainability if the correct control is set?

Case Study of an ICP Reactor used for Etch or CVD

Chamber /w Dry Cleans

Chamber /w Heating



From the Environmental Point of View

- Chamber using Dry Clean:

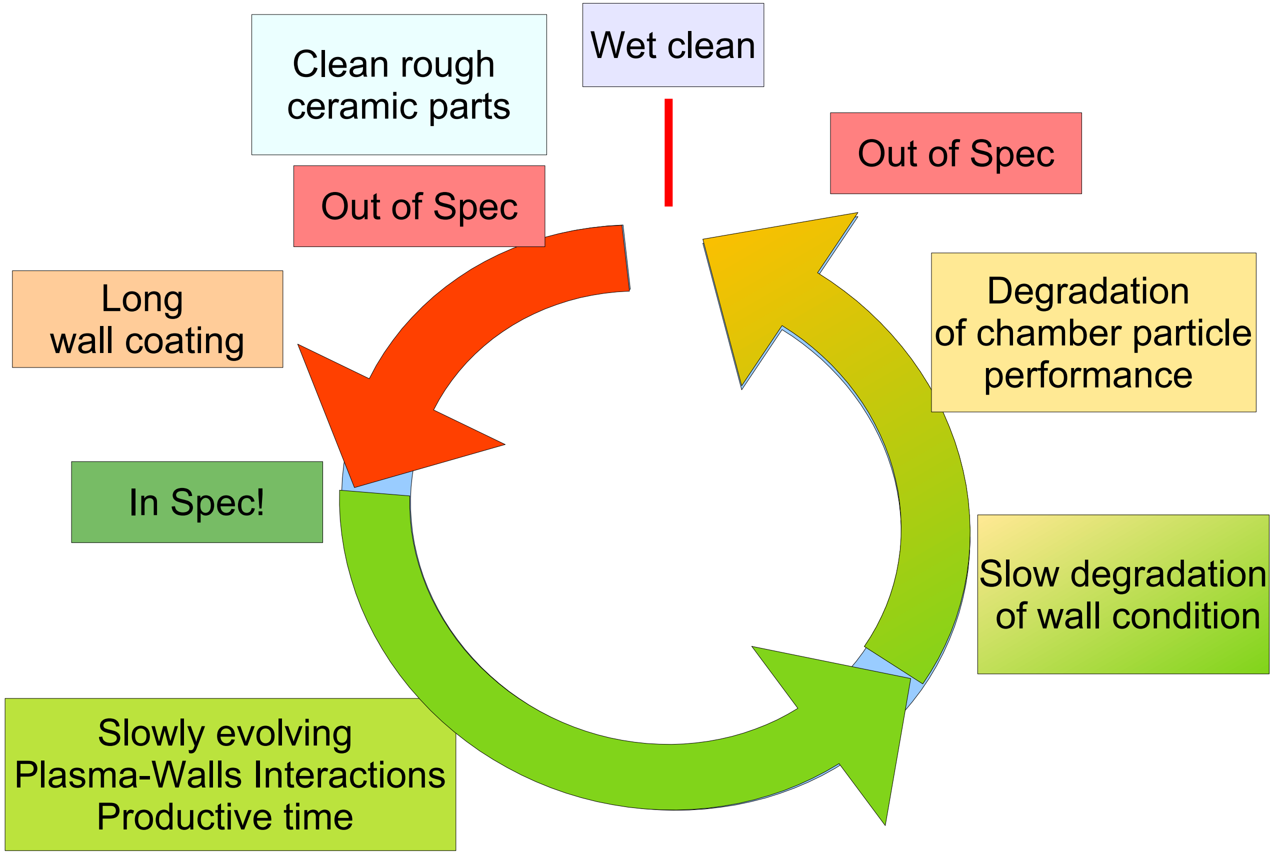
- No upper chamber heating
- Optional Induction plate electrical heating
- Waferless dry clean after x wafer
- Usual dry clean gas: NF_3 (not only)
- Short initial conditioning and re-conditioning later.
- Chamber state “floating” within limits but steady byproducts built-up.
- Process is allowed to drift within limits, request sharp monitoring.

- Chamber using Heating:

- Heating 60 … 80°C...120°C. Hardware/Power
- No dry clean gas
- Slow and tedious initial conditioning
- Chamber state **slowly** evolving as deposit grow up
- Process performance stable, long run

- Usually productive time is limited by particles/contamination released by chamber walls.

Production cycle with Chamber Heating



Advantages

- No additional high GWP Gas (NF_3, SF_6,..) for conditioning
- Conditioning with production recipe / product-close wafers
- Slow drift process
- End of Cycle can be catch with SPC/FDC

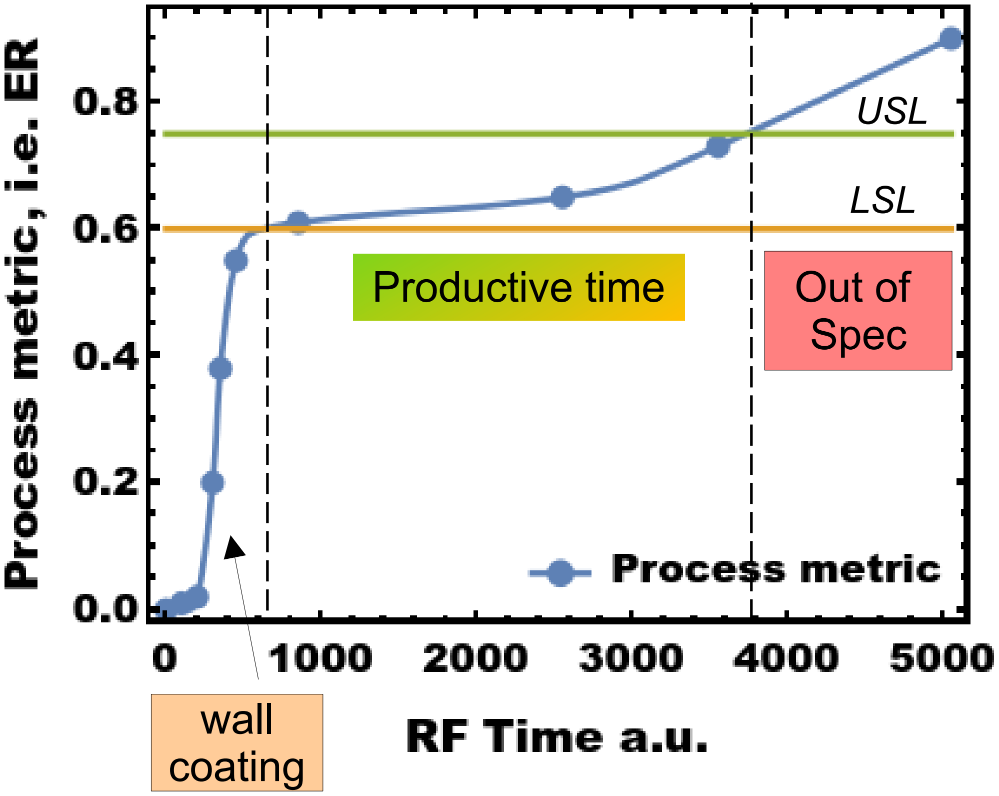
Drawbacks

- Additional energy consumption for heating &
- Additional hardware
- Additional efforts and chemicals to clean ceramic parts.
- Slow initial conditioning

Production cycle with Chamber Heating

- Factors affecting the duration of the stable productive time
  - The surface state of all parts in contact with the plasma
  - The efficiency of the coating process
  - The amount of by products left on the walls by productive wafers
  - Mask + Layer materials
  - Recipe parameters

- Objective is to minimize interactions Plasma-Walls as much as possible



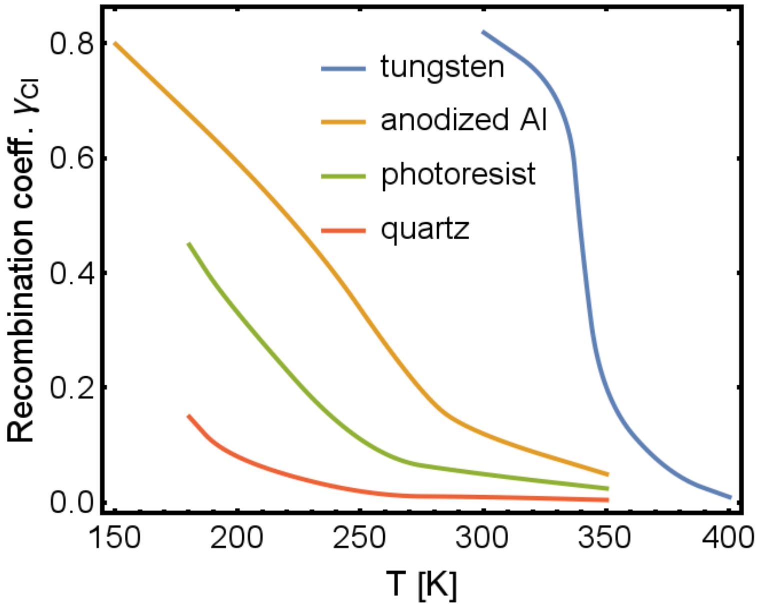
The Recombination Coefficient on Surfaces.

- Recombination flux at the wall (neutrals)

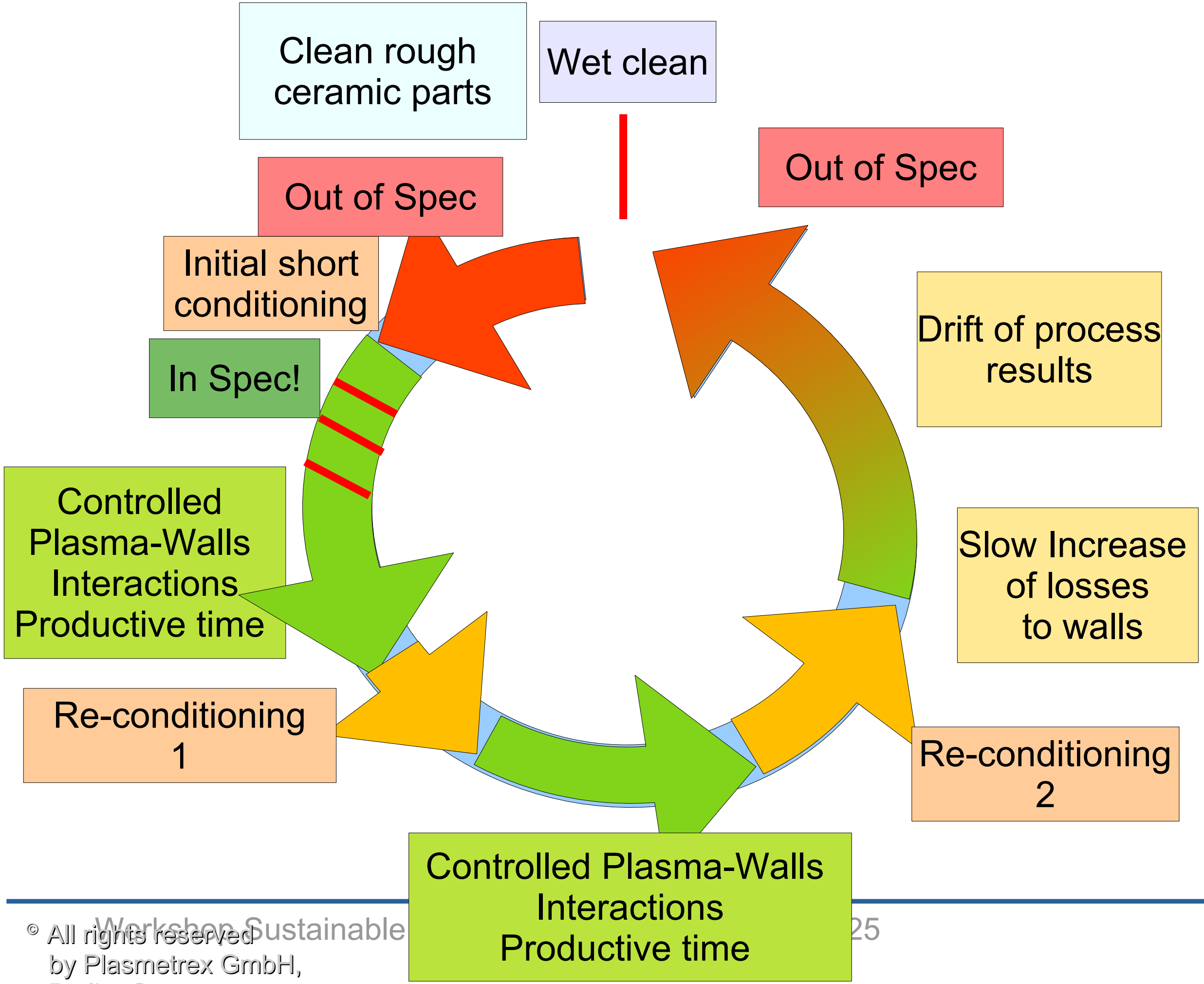
$$\Gamma_w = A_w \cdot \gamma_w \cdot \frac{\langle v \rangle}{2} \frac{y\,p}{2 k_B \vartheta_{gas}} \quad \text{With} \quad \langle v \rangle = \sqrt{\frac{8 k_B T}{\pi m}}$$

- A_w … surface area of the walls
- **γ_w … recombination coefficient (probability) at the wall.**
- $<v>$ ... mean velocity of neutral species
  y ... proportion of reactive fragments in the gas.

- For a given material, the surface temperature dependence of the recombination coefficient take the form of: $\gamma_w(T_w) = A\, e^{-B/T_w}$, where A and B are parameters determined experimentally.



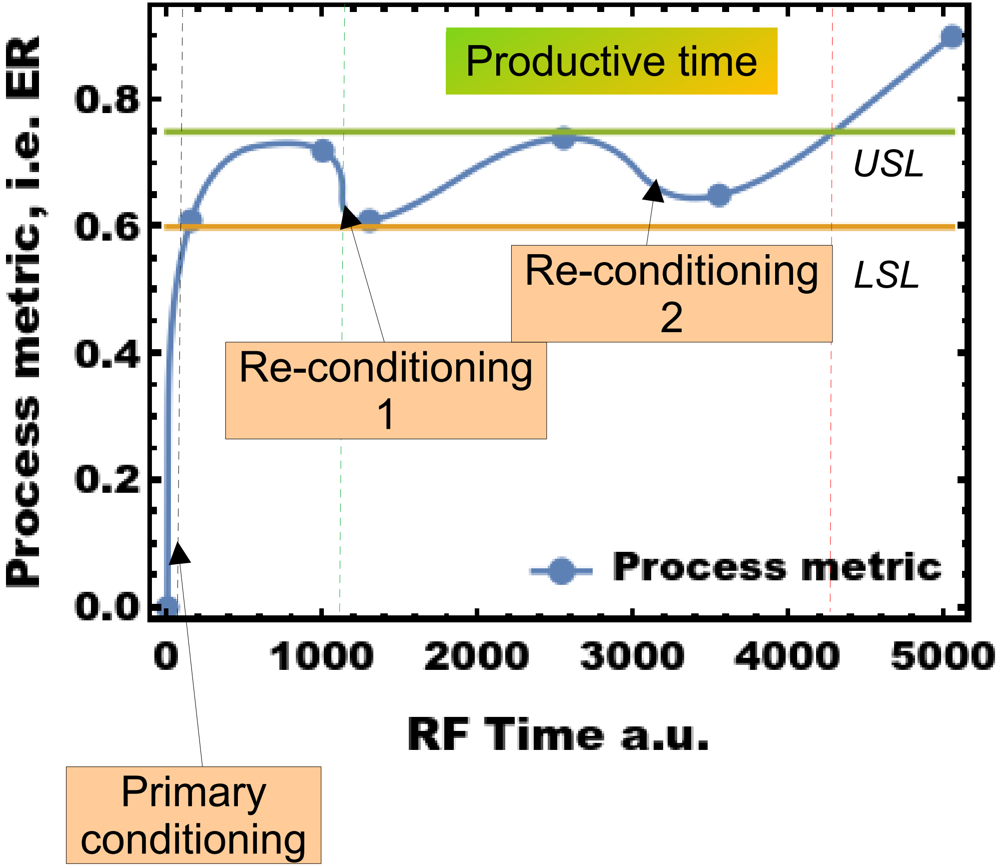
Production cycle with Chamber dry clean



- Advantages
  - No additional energy for heating
  - Productive time rapidly reached
  - Lower efforts to clean ceramic parts
- Drawbacks
  - Additional usage of high GWP process gas
  - More difficult to get the point where the process is really not stable anymore.

Production cycle with Chamber Cleaning

- Process with initial conditioning and dry clean after x Wafers.
  - The primary conditioning is relative short
  - A short re-conditioning happens after x Wafers brings the process back in specs.
  - A second reconditioning will be longer an the process improvement will be smaller
  - Then comes the dilemma:
    - Chamber down?
    - Another re-conditioning?



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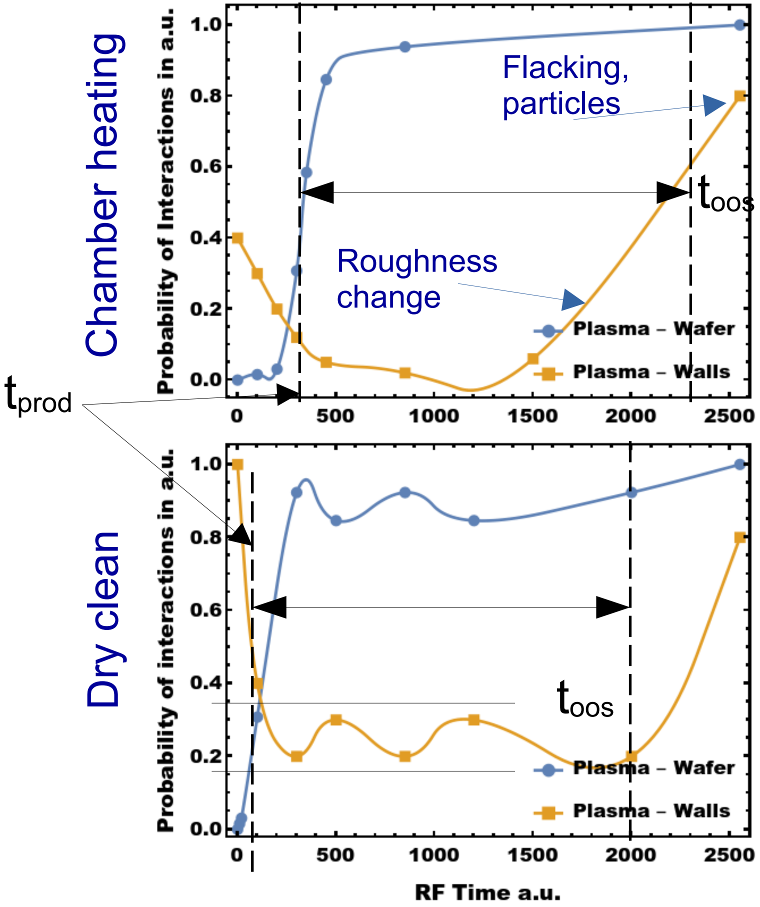
The Key Point: Interactions Plasma – Walls

- **Comments:**
  - t_{prod} is the time at which the interactions between plasma and walls are minimal (or controlled) and stable.
  - t_{oos} is the time at which the chamber will be declared "out of spec".

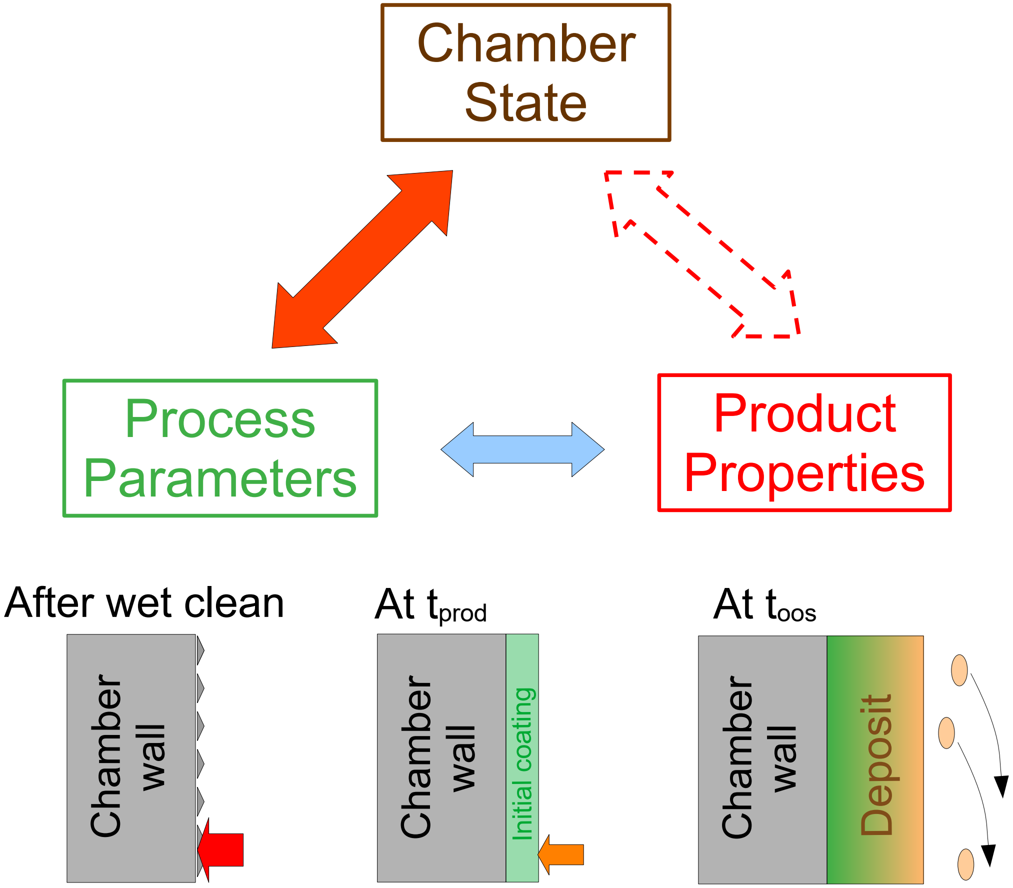
- **Costs saving potentials**
  - $t_{prod} \downarrow$ and $t_{oos} \uparrow$

- **Two questions rise immediately**
  - What **parameter/metric** do I use to quantify the **probability of Interactions Plasma – Walls?**
  - **How do I define "state"** where my process can be run within specifications?



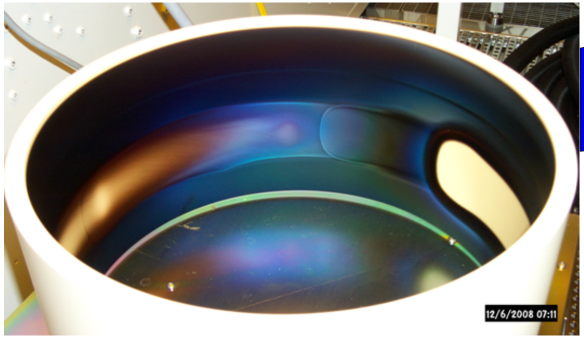
Process and Equipment Interaction: Defining the “normal” State

- During a wet clean, clean ceramic parts are inserted others are washed with solvents. Rough clean walls are not atomically clean and will interact strongly with the active species from the plasma.
- Adsorption and desorption will take place, as well as chemical reactions like etching and deposition until a thin stable layer covers the full surface. This layer behaves “quasi-neutral” against the plasma.
- ***The 'normal' state is the state in which the process was developed!***
- The goal of conditioning is to bring the chamber in the state at which the process was developed.
- Without any chamber monitoring with adequate sensors, It is very tricky to find a good and cheap solution for the conditioning.



What is influencing the Plasma?

Manufacturing cycle



- **Influencing the Plasma:**
- Chemical activity of chamber walls
  - Adsorption and desorption
  - Recombination of neutrals and ions

- Secondary electron emission
  - Depends on the wall material
  - Plasma density close to wall → uniformity

- Gas flow change due to roughness
  - Primarily for high gas flow
  - Gas distribution in the chamber
  - Loading effects → uniformity

- Gas temperature
  - Heat flow
    plasma → gas → chamber wall / liner
  - Affect all of the above

- **What is the adequate parameter???**

Monitoring the Chamber State after Wet Clean

- The key parameter for a plasma is the density of neutrals n_n which is controlled by the pressure p, by the gas temperature T_{gas} and by the gas flow (MFC).

- In the case of interactions Plasma-Walls there are additional flows:
  - a) coming from the walls
  - b) going to the walls

-

Pressure Control

MFC

$$n_n = \frac{P_{gas}}{T_{gas}} = \left[\frac{q_{pV}(T_0)}{T_0} + I_p^{walls} \right] \cdot \frac{1}{S_{eff}}$$

walls

- When the density is increasing, electrons find more collision partners (inversely when decreasing), the collision rate changes linearly with n_n.

Kept constant

$$\nu_e = \bar{v}_e \boxed{n_{gas}} \sigma_{e,gas} = \bar{v}_e \sigma_{e,gas} \frac{p}{T_{gas}}$$

Collision rate

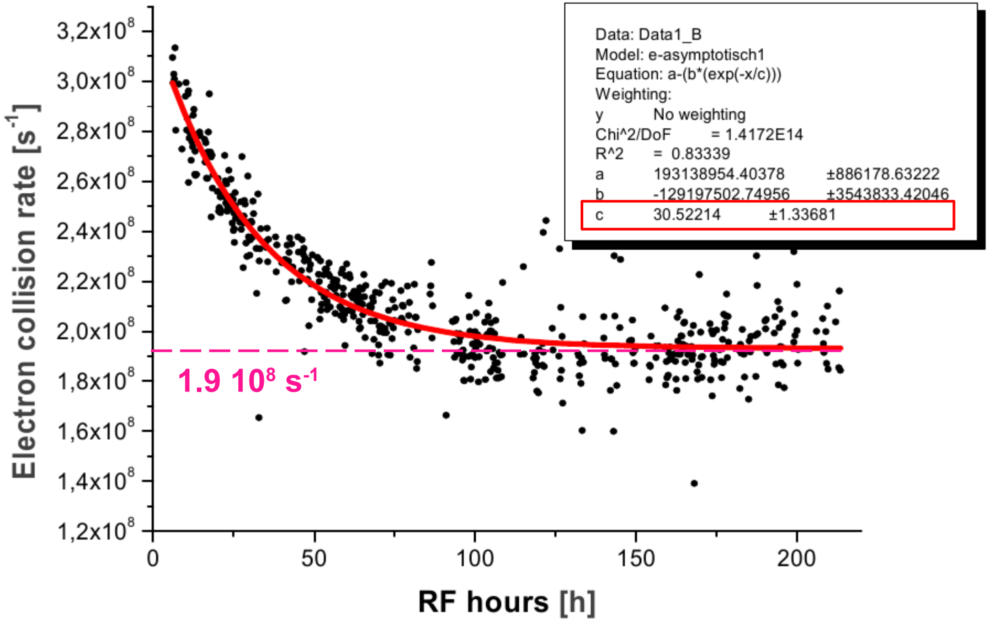
Thermal velocity of electrons

- Gas Heating Mechanisms:
  - Heavy particle collisions
    - Fast ions → neutral in boundary sheath
  - Electron → neutral collisions
    - In the hot skin layer
- **<u>But :</u>** $T_{gas} \neq T_{wall}$

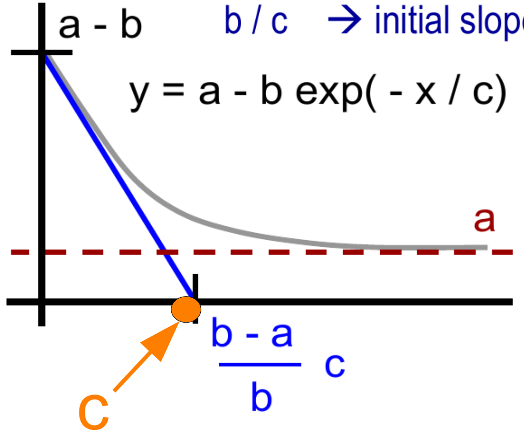
Monitoring the Chamber State after Wet Clean

- Deep trench etch with hardmask and Cl/HBr chemistry, AMAT HART™. Chamber walls are heated to 80°C.
- The electron collision rate vs RF hours gives a good indication on the strength of the interactions between plasma and walls.

Electron collision rate vs. RF hours



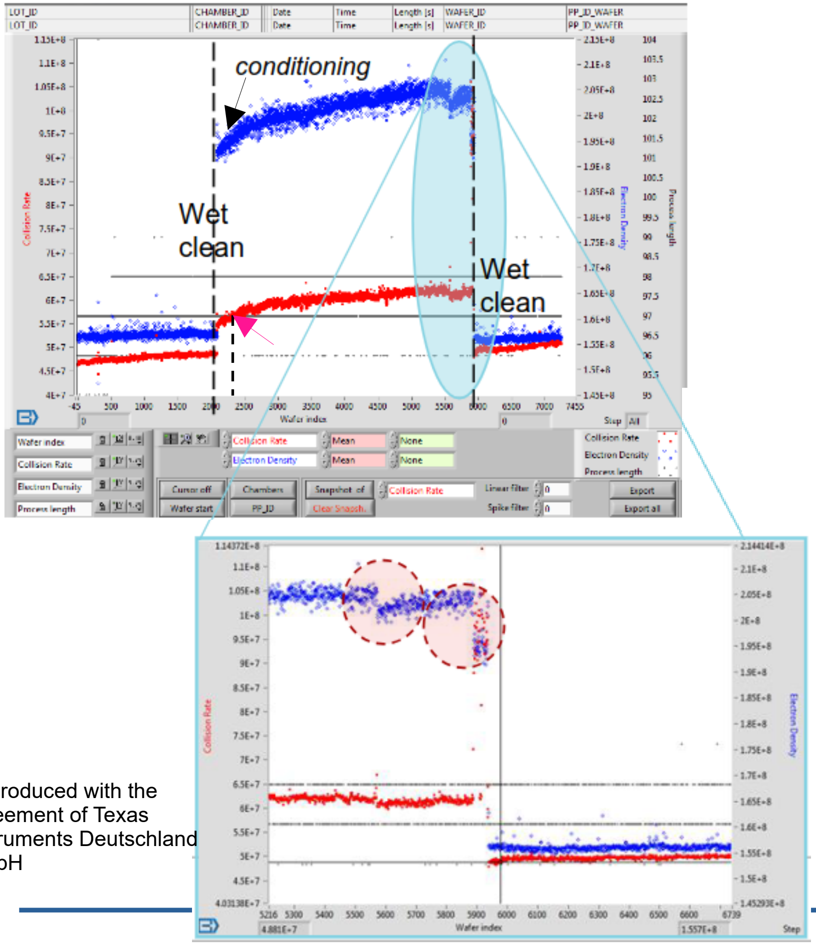
a - b → initial value
a → final value
b / c → initial slope



I_p^{wall} is decreasing. Ground Level would be reached after 30 RFh.

R. Wolf, S. Barth: 5thEuropean AEC/APC Dresden, 2004.

Monitoring the Chamber State after Wet Clean



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- Deep trench etch AMAT DPS DT^{TM} chamber. Chamber walls heated to 80°C.
- Trends of Collision Rate and Electron Density during a production cycle (between wet cleans)
- Conditioning effort ~ 300 Wafers. Productive time ~ 3700 Wafers.
- n_n *is* increasing with RFh → less absorption from the walls.
- The slow drift within the production cycle is visible on both Collision Rate and Electron Density.

Rupert Wagner, Heiko Richter, Ertzoument Chasanoglou, Michael Klick
14th European Advanced Process Control and Manufacturing Conference (APCM) Rome, Italy - April 7-9, 2014

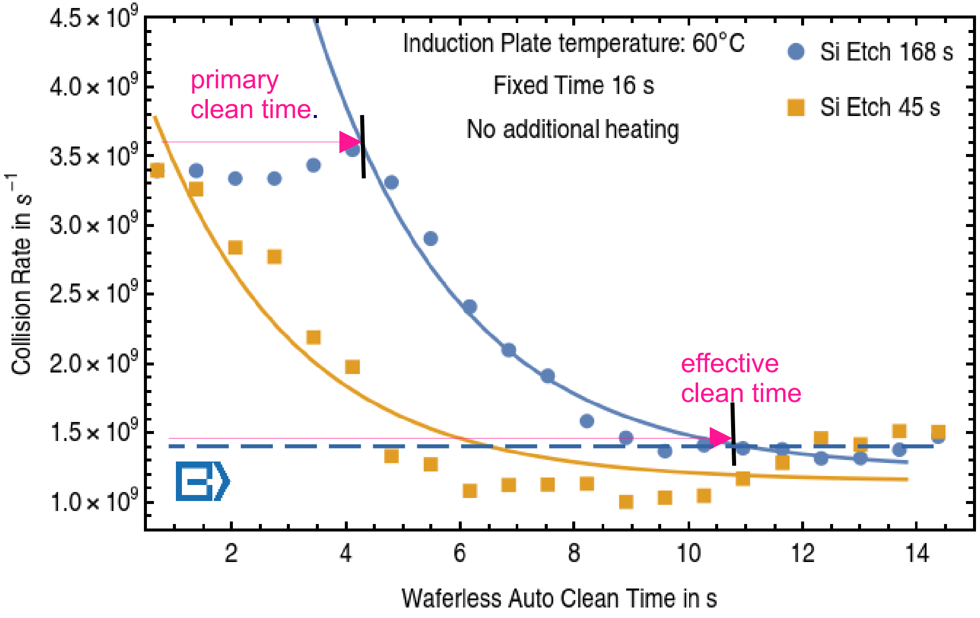
Collision Rate vs. Quartz Plate Temperature at LAM 2300 Kiyo

- The collision rate during Waferless Auto Clean (WAC) after Si Etch 168 s, (blue dots) and after Si Etch 45 s (orange dots).

- Long Si Etch: ν is constant during 4.5 s. No change in the gas phase → Desorption from the walls is constant. The deposited layer is etched away at constant ER. Primary clean time.

- After 4.5 s, the collision rate can be fitted with an exponential function. Extracted decay constants are fairly identical at a value of 2.5 s for both processes. The gas phase is changing → Desorption from the walls is decreasing rapidly.

- After 11 s WAC process (6 s respectively), the collision rate levels off and stabilizes around 1.5 10^9 s^{-1}. Chamber walls are at ground state



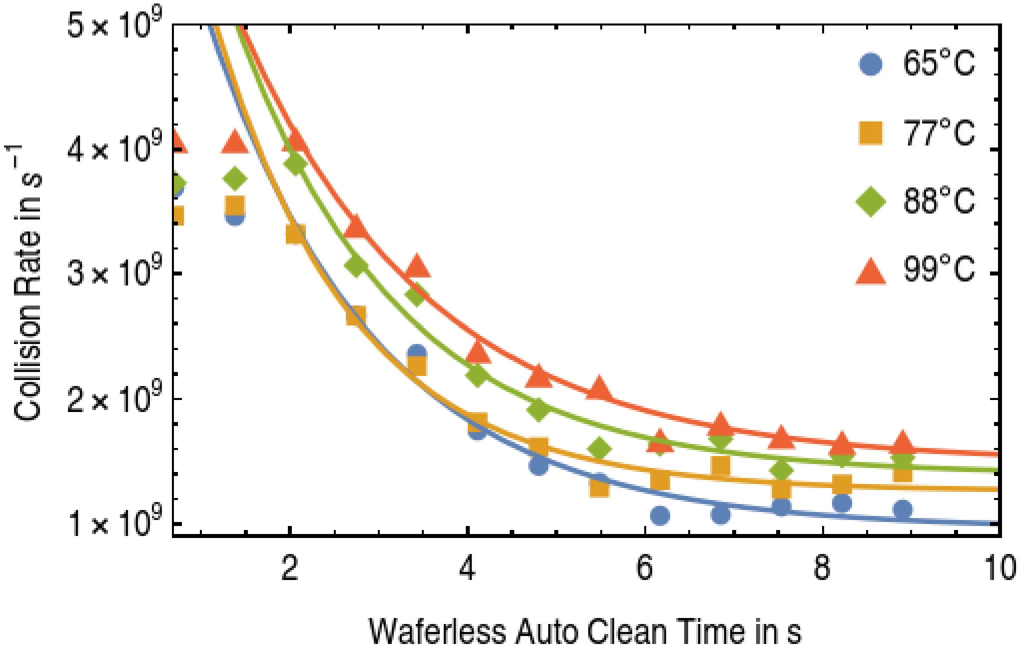
$$n_n = \frac{P_{gas}}{T_{gas}} = \left[\frac{q_{pV}(T_0)}{T_0} + I_p^{walls}\right] \cdot \frac{1}{S_{eff}}$$

Influence of the Top Chamber Window Temperature on the STI Etch Process, D. Shamiryan, E. Danilkin, S. Tinck, M. Klick, A. Milenin, M.R. Baklanov, T.W. Boullart, ECS Transcations, 27 (1) 731 - 736 (2010)

Collision Rate vs. Quartz Plate Temperature at LAM 2300 Kiyo

- The diagram shows the collision rate measured during the Waferless Auto Clean (WAC process) after 4 wafers processed with short Si Etch at different **quartz plate temperature between 65°C and 99°C. No Chamber Wall heating.**

- The primary clean time depends on the temperature of the windows. Higher temperature → longer primary clean time.
  - Less deposition on the window means more deposition on the walls.
- As previously, a decay is observed after the primary clean time. The decay rate depends on the temperature
  - "High Temp → slow decay, the effective clean time is harder to reach!"



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Conclusions

- How to reach the desired chamber state is strongly bounded to the tool type and to the initial state in which a recipe is developed.

- In both cases, chamber heating or dry clean, recovering after Wet Clean is a matter of monitoring the interactions between Walls and Plasma to achieve an accurate real time control of the chamber state.

- A parameter that is closed to the plasma <u>is necessary</u> . We have demonstrated that the electron collision rate provides a good metric for a reliable monitoring.

- With this metric, strategies (process, hardware, …,) can be developed to minimized the time required to reach the steady state and increase the productive time and thus make a step towards sustainability.

- Our analysis show that heating partially (i.e. only Window) is not necessarily leading to saving high GWP gas as deposits grow thicker on the cold parts of the chamber and thus the chamber is more difficult to clean off.
- Heating the walls works if the all the walls in contact with the plasma are heated at the same temperature.

Thank you for your attention!

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