The application of plasma parameters for process control: Multiple plasma regimes

Michael Klick

ASI Advanced Semiconductor Instruments GmbH
Rudower Chaussee 30
D - 12489 Berlin, Germany
Michael.Klick@asinst.com

Contents

- Motivation
- Multiple plasma regimes
- Process pressure variation
- Secondary plasmas
- Conclusions

Background

- Shrinking of the CD down to the range below 100 nm results - particular for memory manufacturing - in a significant reduction of the process window. In conjunction with 300 mm processing, the development and optimisation becomes more and more tricky and requires a real-time process characterisation.
- Owing the complex nature of the etching or deposition plasmas and the impact of many pre-processes, the relation between product and plasma parameters is difficult to analyze and much more difficult to utilize. Beyond the matching of process chambers by plasma or process parameters, this requires either
  - a stable correlation between the process result (product parameters, etch rates ...) to be established usually for each product separately,
  - a simple process model or at least some basic understanding of physics and chemistry behind.

The need of process understanding and control

Pre-process *faults detection as hard mask issues*

Fast ***conditioning*** *after PM and dry clean, early detection of product mix issues*

Early ***chamber fault*** *detection as corrosion and arcing*

Fast ***chamber matching and process transfer and development***

Critical Dimensions, yield

Test & conditioning wafer usage

Up-time, maintenance spare parts & manpower

Main target

- Often processes are found to switch between different discharge regimes providing unexpected process results. This becomes more important through the upcoming usage of more complex chamber setup's as two plasma excitations as ICP or two 'capacitive' frequencies.
- The understanding of the underlying mechanisms becomes more and more important for routine production control as well as for process and tool development.

Multiple plasma regimes

- Pressure variation in critical ranges

→ Switching between different physical energy transfer mechanism to electrons

- Impact to the energy transfer regime by secondary plasmas and/or particles.

→ RF power loss for 'main' discharge

- Additional enhancing: Variation of RF power input:
  - In case of two excitation mechanisms as ICP or high/low frequency excitation → Changed ratio of effective power dissipated in the plasma.
  - Different matchbox positions, in particular in the case mentioned above caused by power dissipation interaction.

→ Best Indicator: **Electron collision rate**

Process pressure variation

- The process pressure affects mainly:
  - The plasma chemistry (direct impact not considered here)
  - Ion energy distribution (by collisions not considered here)
  - Electron heating mechanisms - ohmic ↔ stochastic heating

  → Indicator: Electron collision rate

→ Large impact on process physics and chemistry.

→ Electron collision as electronic core parameter can be used as indicator.

Process pressure and electron collision rate

Pressure /
gas temperature
= density of neutrals

Relative concentration of species i
(partial pressure ratio)

Cross section x
thermal velocity
~ const.

$$\nu_{eff} \approx \nu_{stoch} + \frac{p}{kT_n} \sum \frac{p_i}{p} \cdot \sigma\left(v_e^{-1}\right) \cdot v_e$$

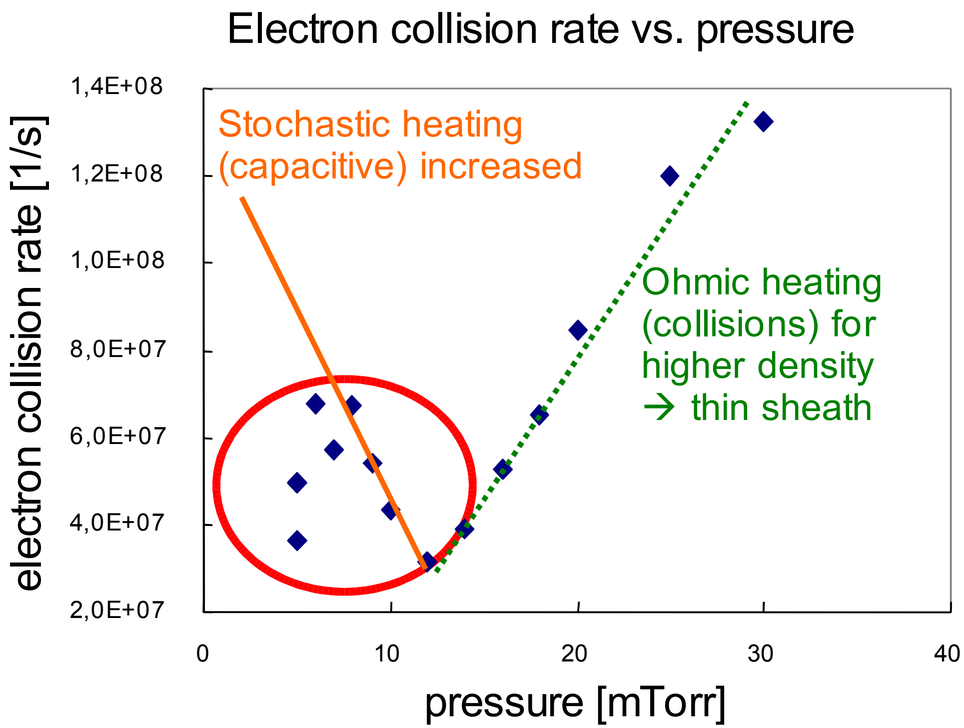
Stochastic heating,
dominating for low pressure,
< 10 Pa = 75 mTorr,
depending mainly on the
electron energy distribution.

Mean thermal velocity of electrons

Momentum transfer,
dependent on gas mixture, pressure,
and gas temperature directly

No magnetic field (B = 0) and capacitive coupling.
Stochastic heating is a collisionless electron heating mechanism at the interface between plasma bulk and sheath.

Collision rate depending on pressure: Lam® TCP® 9400 (poly-Si etch)

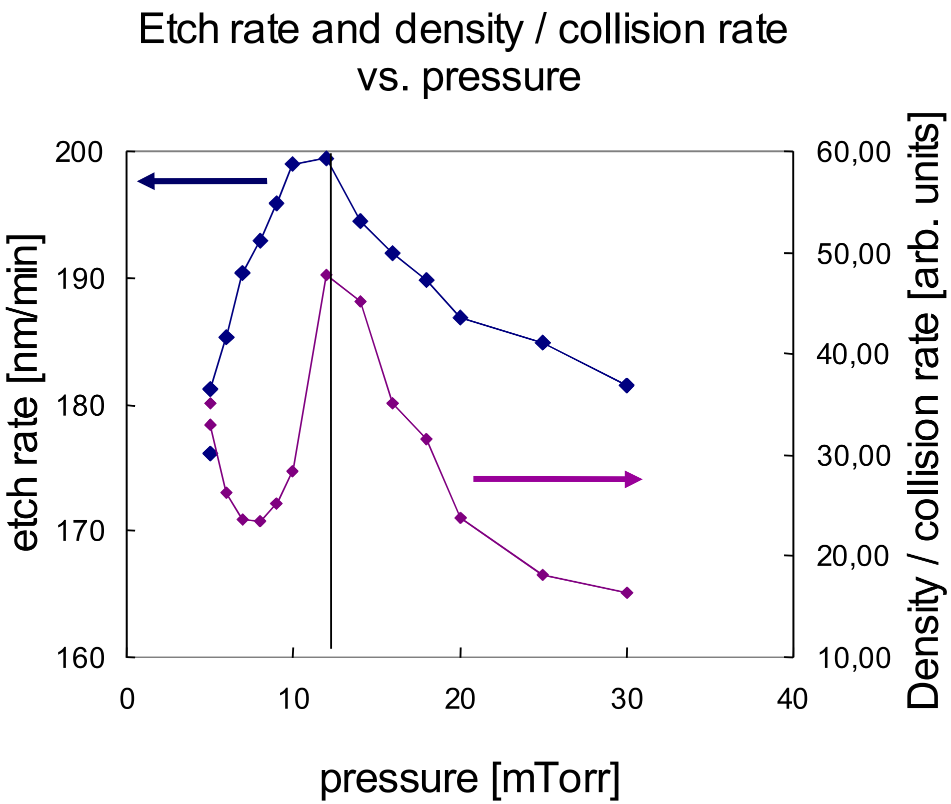


- TCP power = 300 W.
- Pressure variation: collision rate shows nonlinear behavior.
- Distinction of domination by ohmic heating / stochastic heating possible (= different modi of power conversion into plasma).

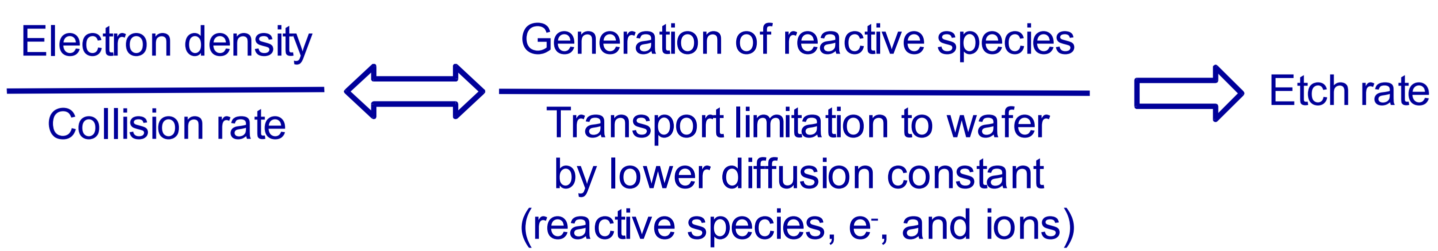
Potential process instability, basic understanding is needed for process development!

C. Steuer, 2nd SEERS Workshop, Dresden, Germany, 2000.

Lam® TCP® 9400 (poly-Si etch): Etch rate and plasma parameters depending on pressure



- Plasma parameter: electron density / collision rate.
- Correlation between in-situ and in-line measurements
  - etch rate (blue)
  - quotient electron collision rate over density (purple)



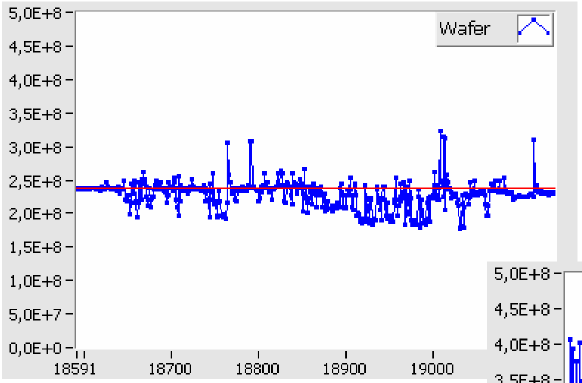
C. Steuer, 2nd SEERS Workshop, Dresden, Germany, 2000.

Secondary plasmas

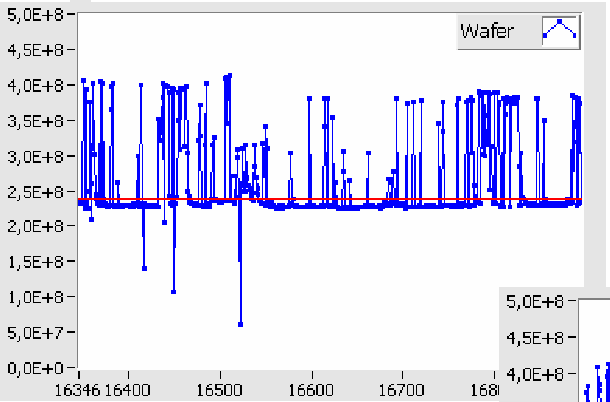
- A secondary plasma is an additional discharge disturbs the process by:
  - Additional power consumption leads to short time RF miss-matching and direct RF power loss.
  - Particle generation
  - Impact on chemistry
- Root causes:
  - Chamber design, e.g., insufficient RF grounding
  - Chamber coating erosion
  - Additional DC current in insulating (anodized) RF chamber
  - Heavy contamination of chamber wall by byproducts

The electron collision rate – Indicating secondary plasmas

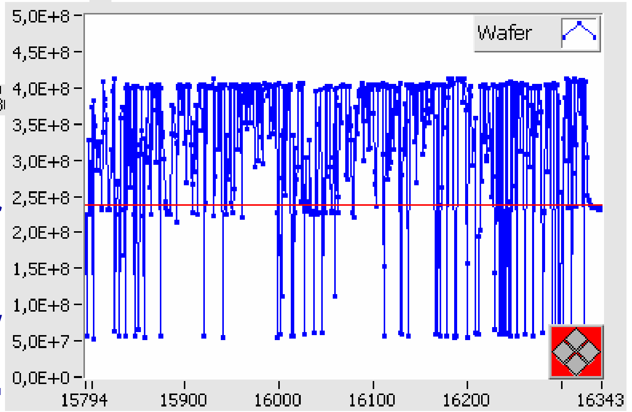
- Depending on chamber hardware faults, different signatures of the electron collision rate (wafer means) were found.



Slight variation around key level at second etch step.
Verified root cause: Erosion of chamber spare parts.



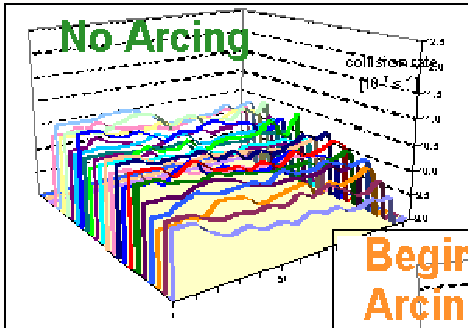
Variation between upper and key level.
Verified root cause: Erosion at screws.



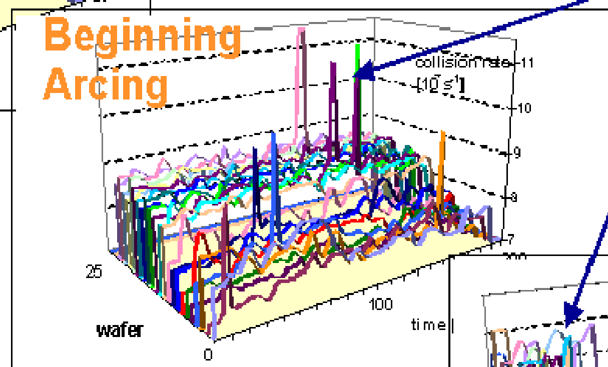
Strong variations between upper and low level.
Verified root cause: Heavy arcing at location pins.

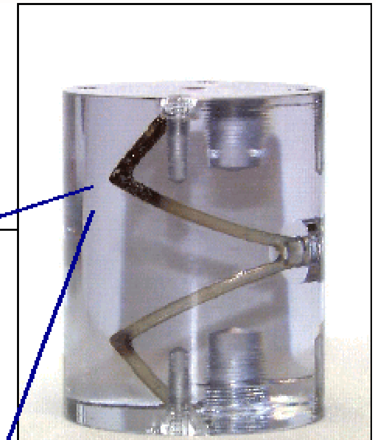
L. Eichhorn et. Al., 5th European AEC/APC Conference, Dresden, Germany, 2004.

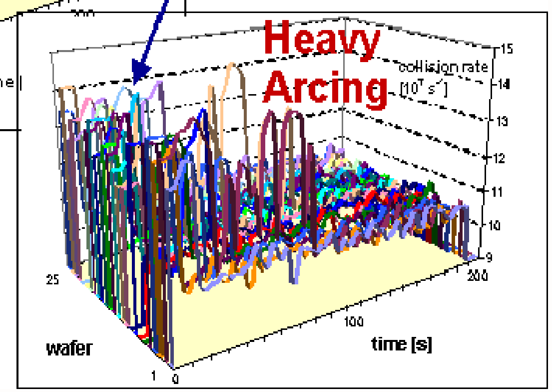
Secondary plasma in helium feed-through at MxP+™



Contactetchat AMAT MxP+







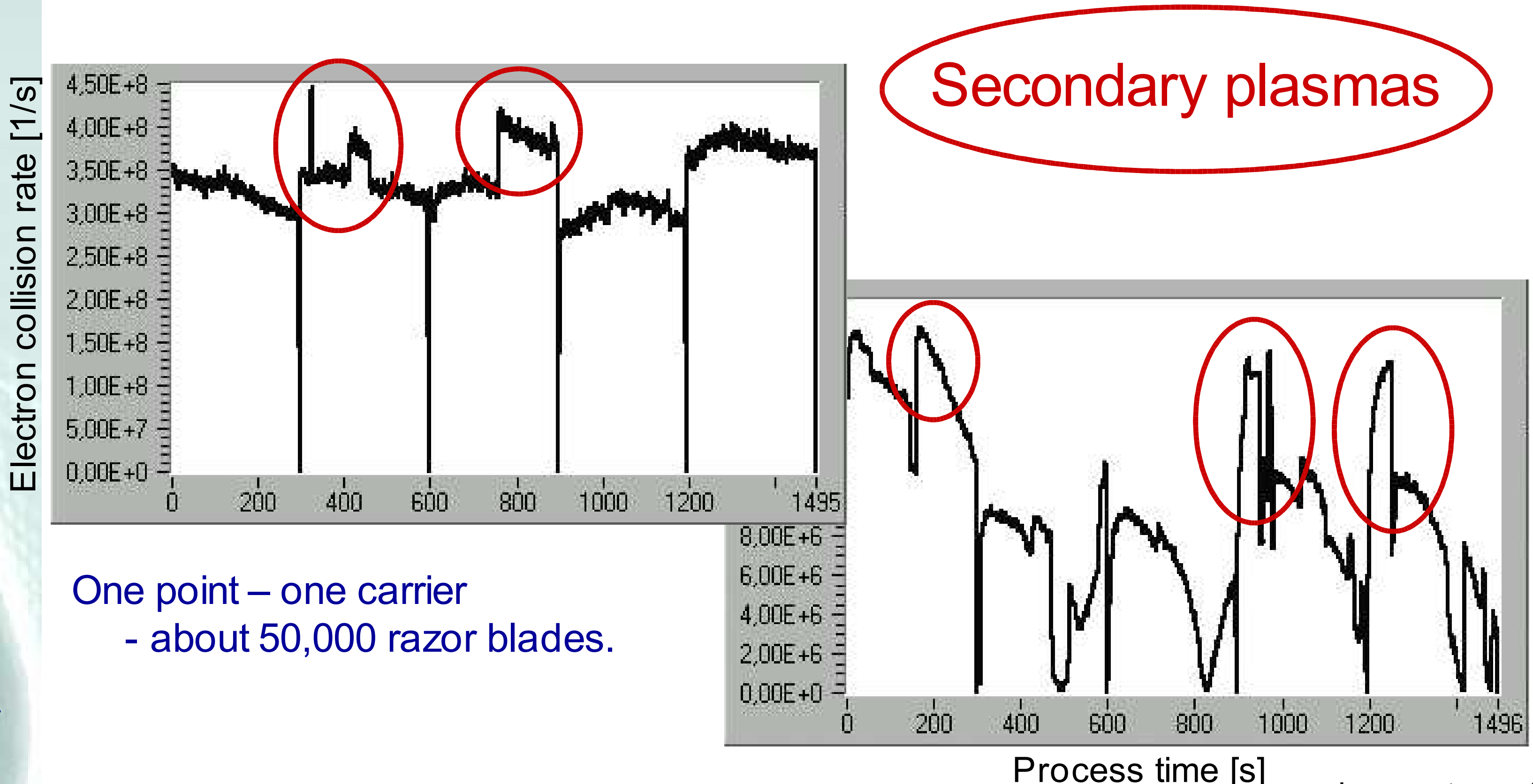
Process instability was caused by parasitic plasma inside He feed-through. Indicator: Electron collision rate.

→ Secondary plasma affects the plasma process!

A. Steinbach, et. al., SEMATECH AEC/APC Symposium XI, Vail, USA, 1999.

Secondary plasma in sputter clean process for PVD

- Inert gas used for cleaning process leads to layers at chamber wall and RF feedthrough → **Secondary plasmas**
- Electron collision rate used as indicator for secondary plasmas

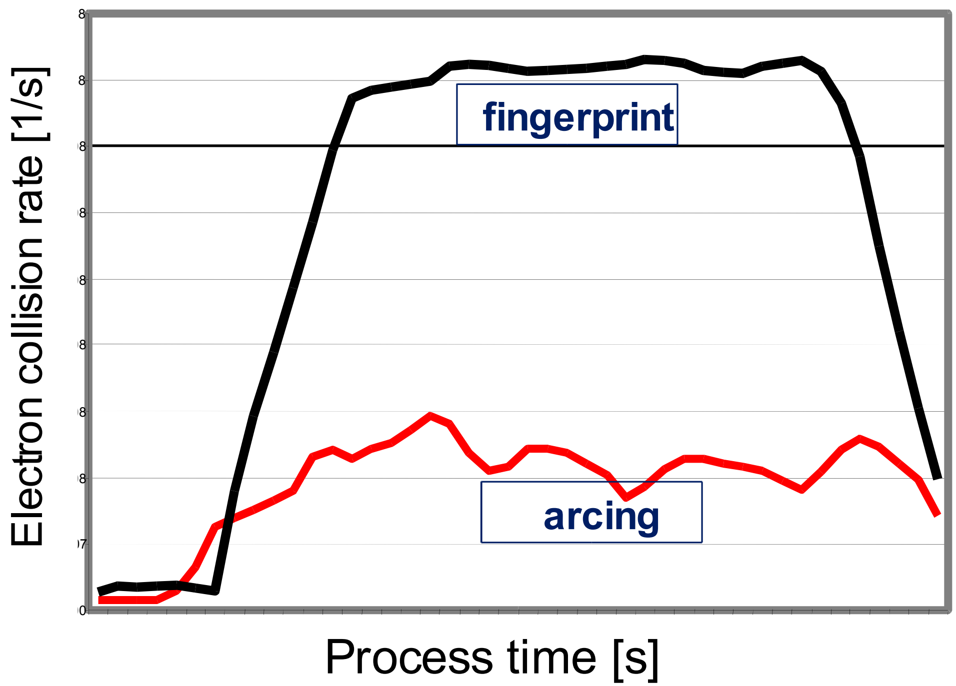


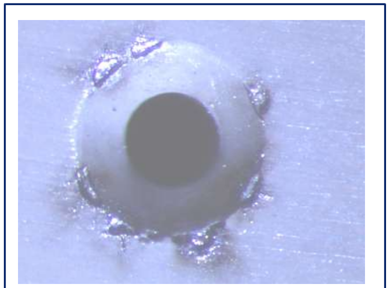
One point – one carrier
- about 50,000 razor blades.

by courtesy of

P. Krenzlin, 1th European AEC/APC Conference, Dresden, Germany, 2000.

Secondary plasma through arcing at gas distribution in AMAT eMxP+™




Arcing traces at gas distribution

- Recipe:
  Step 1
  25mtorr / 215W / 30G/ 50 sccm O_2
  Step 2
  25mtorr / 215W / 0G/ 50 sccm O_2

Arcing at the GDP (shower head) at brand new tool. Detected first at one chamber, the other ones were saved.

Reason: Additional DC current from ESC!

V. Tegeder, SEMATECH AEC/APC Symposium XII, Lake Tahoe, USA, 2000.

Conclusions

- Variations of recipe parameters can change the dominating discharge (plasma) mechanisms dramatically.

→ Most critical: Process pressure – affects both chemistry and physics strongly.

- Secondary plasmas and arcing are the main reasons for the unexpected and undesired 'switching' to different discharges states.

→ Beyond the influence onto the product this results in erosion of chamber parts and reduces chamber parts lifetime.

- Both effects require a sensitive process monitoring.

→ Owing to the direct connection to the underlying plasma physical mechanisms, the electron collision rate is the best indicator.