A Reduced Model for Etch Rate Prediction Based on Plasma Parameters

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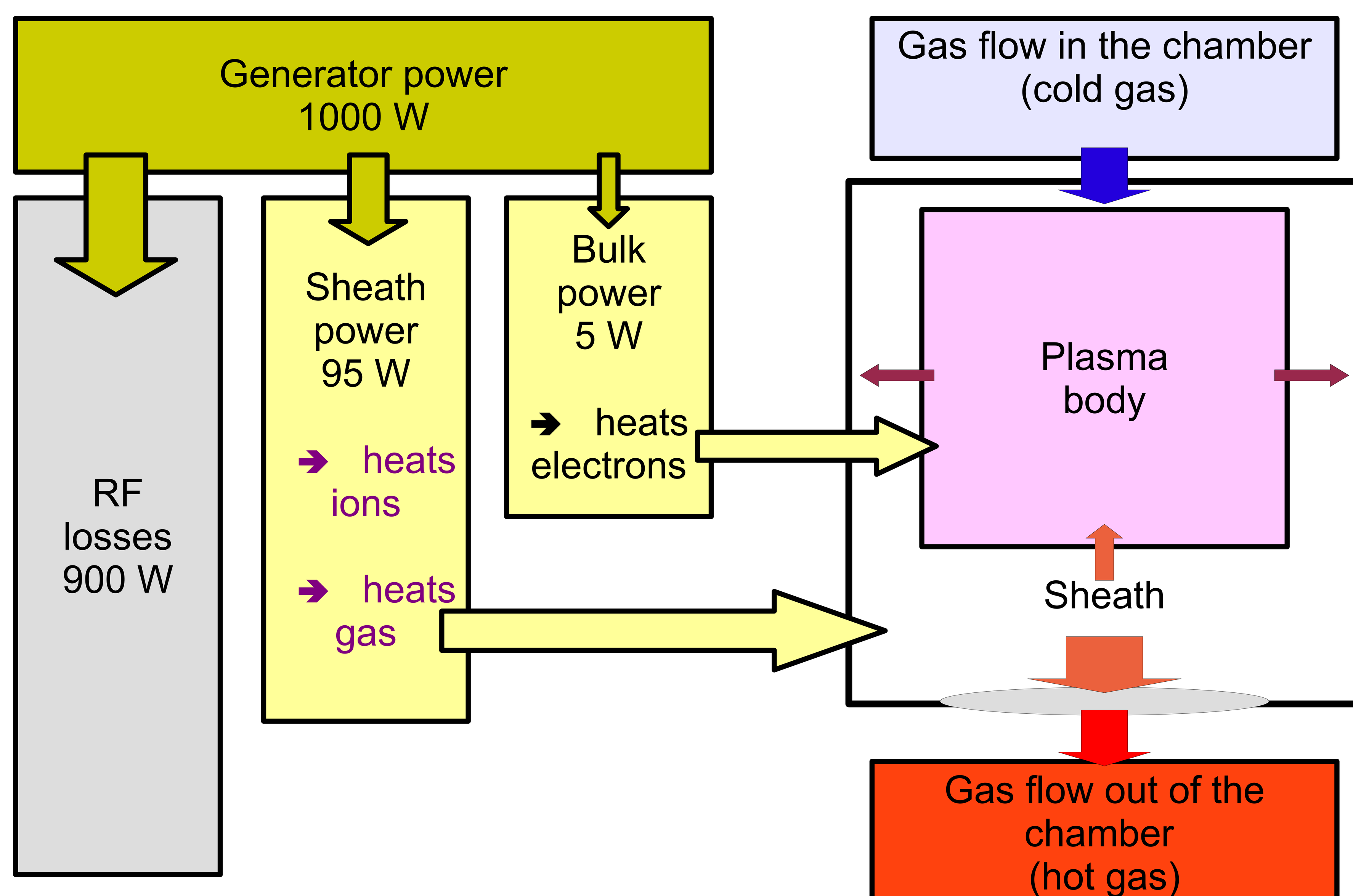
Motivation

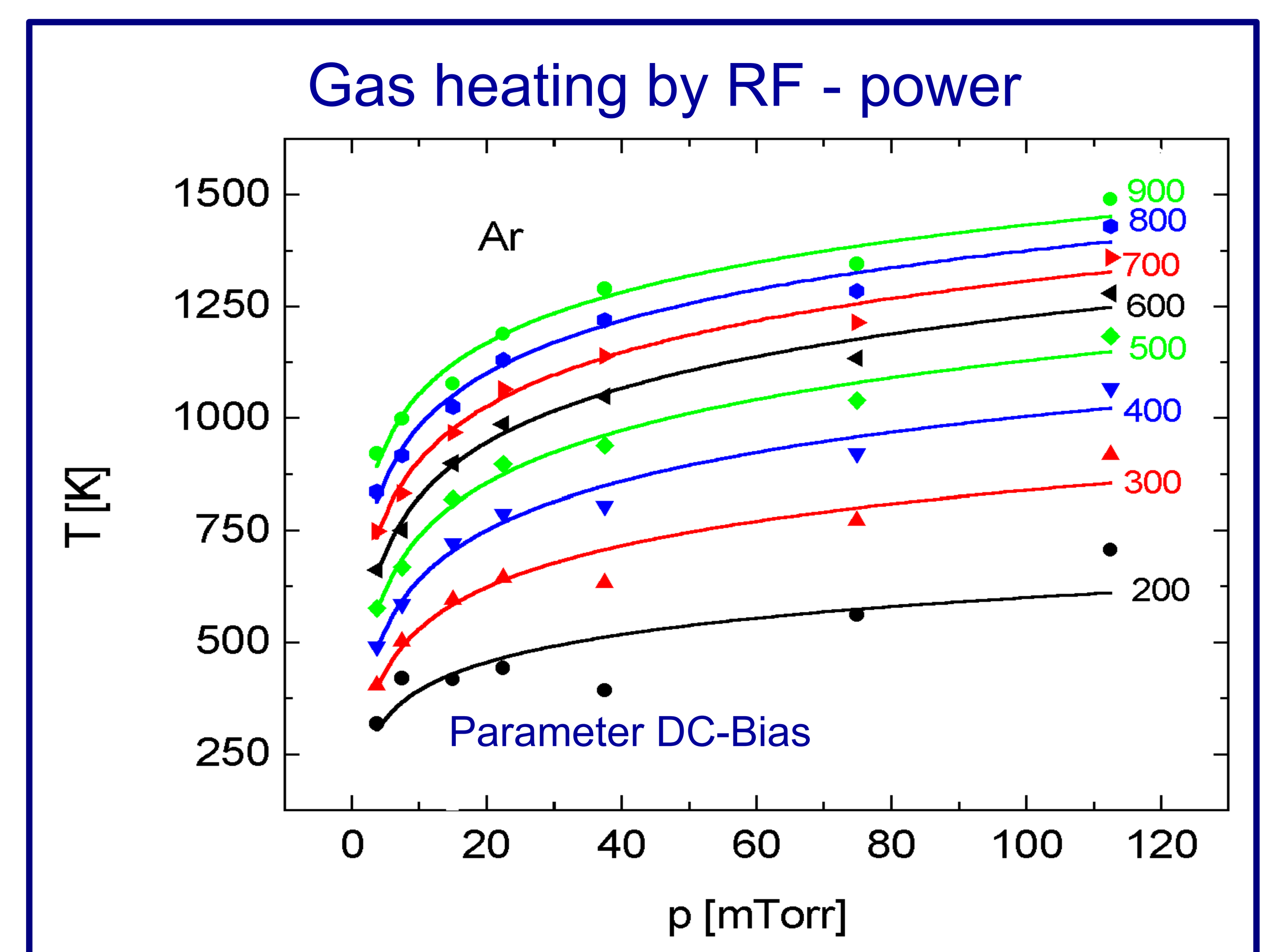
- The trend to larger wafer and smaller device size leads to higher costs of one wafer. Together with rising demands on quality and reliability, a paradigm change in quality management is inescapable.
- The lot-level control are going to replace by the wafer-level control.
- A simple transition from sample-based control, that means 100% wafer inspection, would cause remarkable costs.
- The only solution for wafer-level control is virtual metrology.

Multivariate model

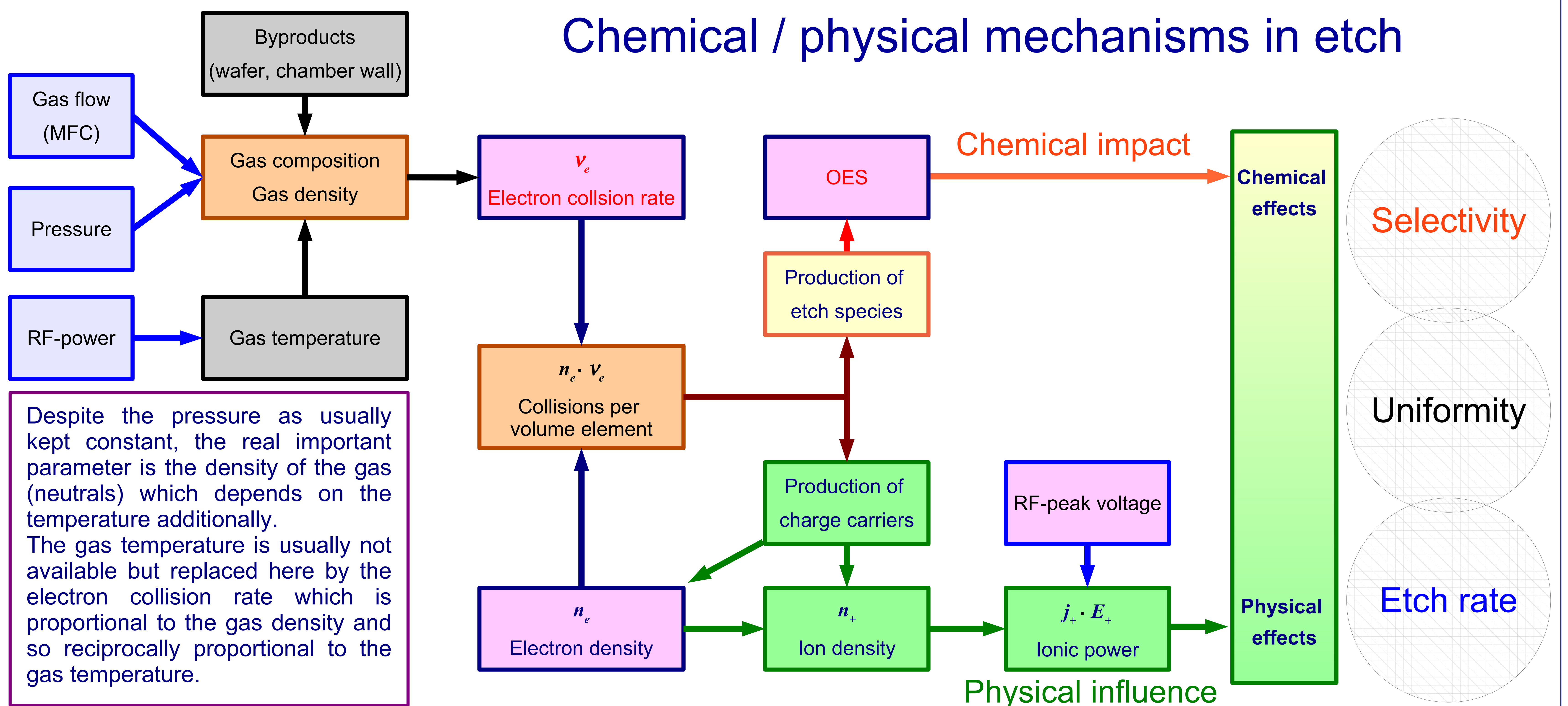
- The prediction of etch rate, CD's, and other wafer parameters by means of process models is the basic idea of a virtual metrology.
- This requires
  - ⇨ a chemical and physical model and
  - ⇨ reasonable information about plasma process to estimate the model parameters.
- A complete plasma process model is unrealistic - in particular due to the large amount of mechanisms. For the plasma process under consideration, the dominating scaling parameters must be found .

Power balances in plasma and gas heating





The electrical field in the sheath accelerates the ions. The ions collide with neutrals in the sheath and transfer energy to the neutrals. The gas in the chamber is heated.

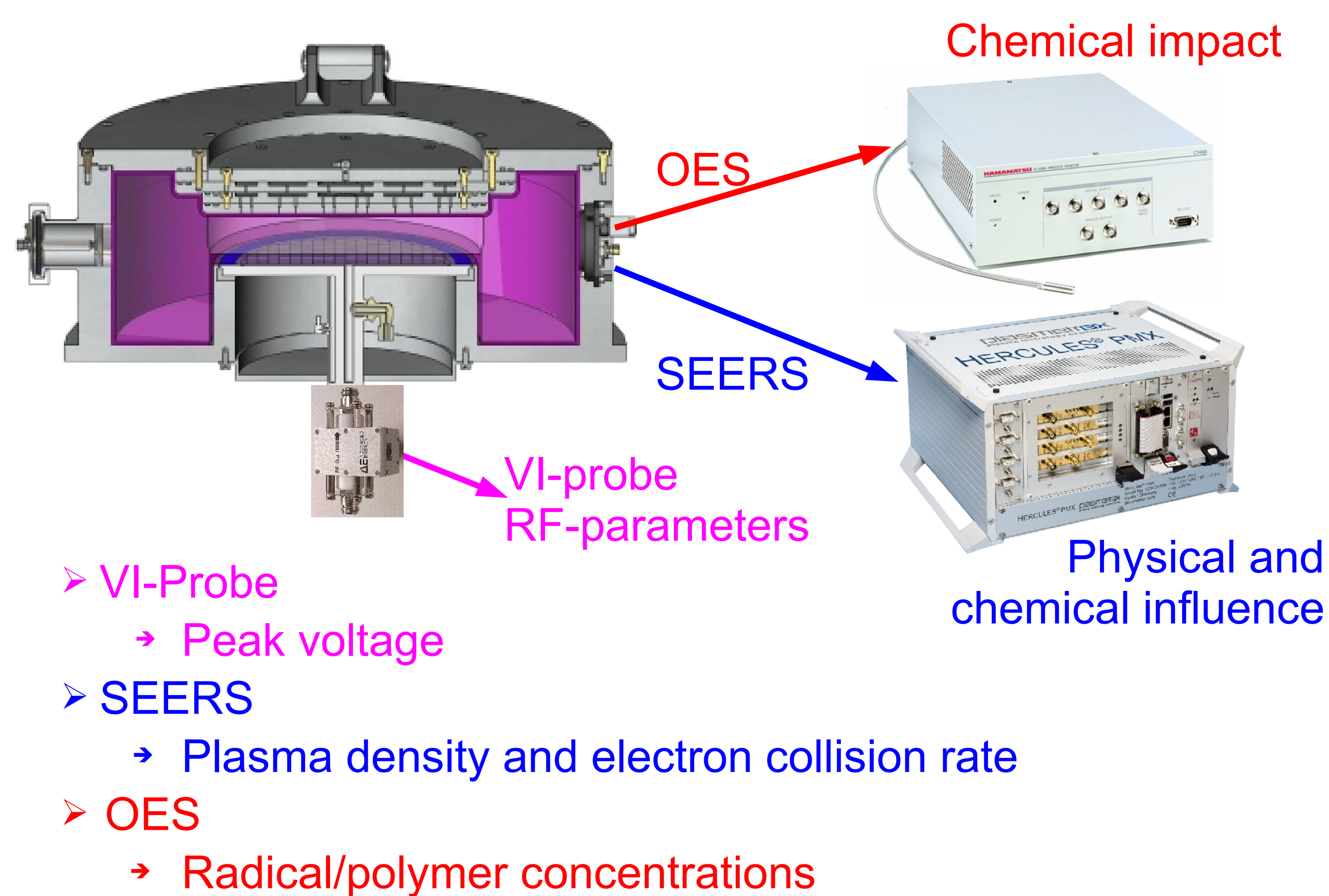


Despite the pressure as usually kept constant, the real important parameter is the density of the gas (neutrals) which depends on the temperature additionally.
The gas temperature is usually not available but replaced here by the electron collision rate which is proportional to the gas density and so reciprocally proportional to the gas temperature.

Selection of key parameters

- The most important issue for the development of a chemical / physical model is the identification and determination of key parameters.
- The tool parameters such as RF forward/reflected power, gas flow rate, pressure, and ESC temperatures reflect only the tool properties, not the real process.
- For the process description with a chemical / physical model, real process parameters are indispensable:
  - Plasma density
  - Electron collision rate and electron energy distribution
  - RF-parameters (RF-power, Peak voltage)
  - Radical/polymer concentrations
- Complementary methods deliver necessary process parameters:
  - Plasma density and electron collision rate by SEERS
  - RF-parameters by VI-probe
  - Indicator of radical/polymer concentrations and electron energy distribution by OES

Complementary process parameters



- VI-Probe
  - Peak voltage
- SEERS
  - Plasma density and electron collision rate
- OES
  - Radical/polymer concentrations

Multivariate model

- An example shows how a simple model can be build using a gas density and the RF-power:

$$R_{chemical} = A*(gas\,density)*(rf\ power) = A*\frac{pressure}{(gas\,temperature)}*(rf\ power)$$

- The gas temperature is usually not available but the electron collision rate is reciprocally proportional to the gas temperature (Russ Benson, Micron, AEC/APC 2007) so that we

$$R_{chemical} = A*(collision\,rate)*(rf\ power)$$

where temperature based effects as the well known first wafer effect are already included. This should be completed by relative, optical intensity of the leading etch species (e.g, CF_2) by

$$R_{chemical} = A*(collision\,rate)*(intensity\,optical)*(rf\ power)$$

- Beside the chemical processes, the physical impact on the wafer is important. The ion current depends mainly on the ion density which usually equals the electron density. So we get a simple scaling law for the physical processes at the wafer surface

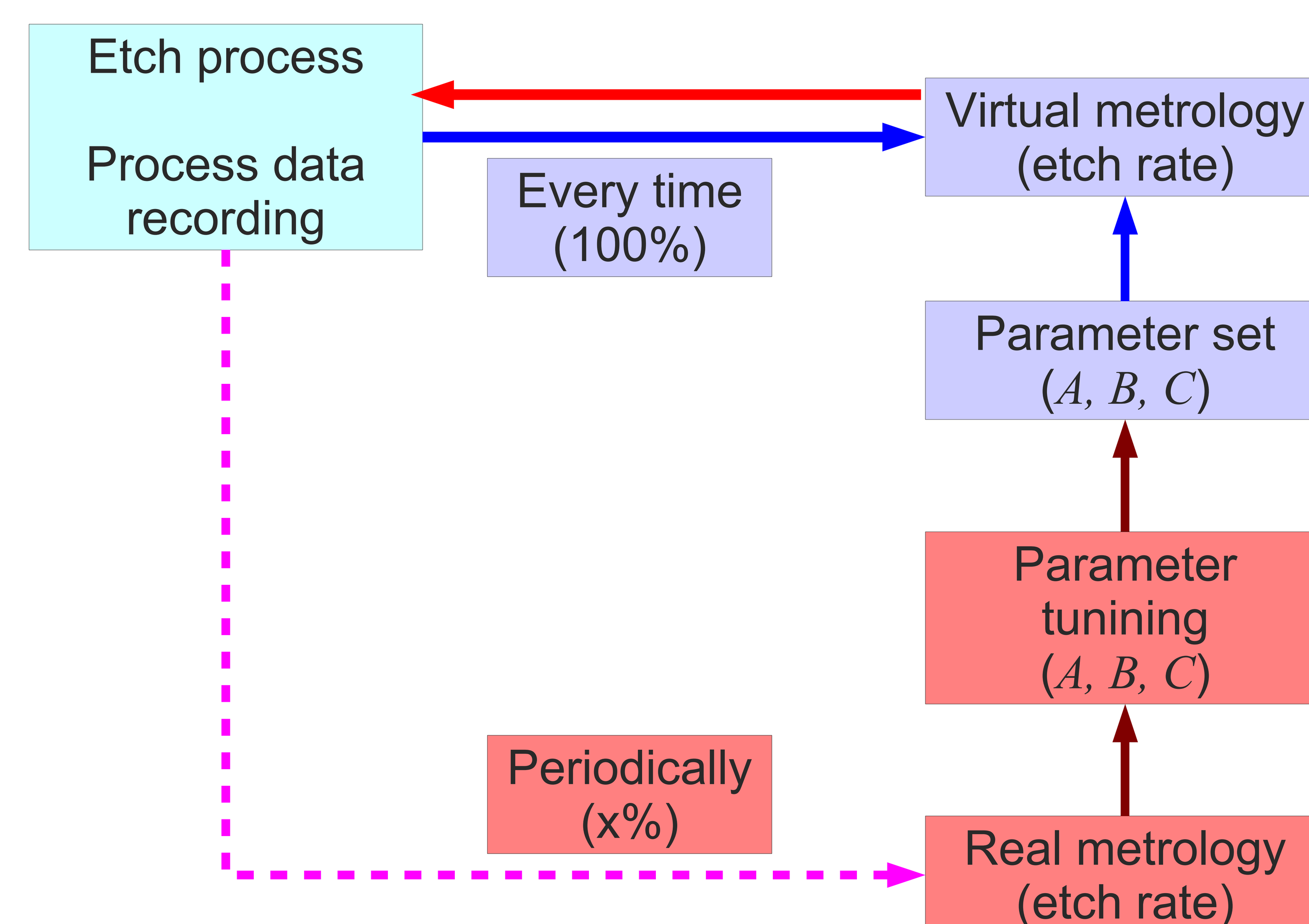
$$R_{physical} = B*(electron\,density)*(peak\,voltage)$$

- The final effective rate, e.g., an etch rate, is given by

$$R = R_{chemical} + R_{physical} + C*R_{chemical}R_{physical}$$

- The coefficients A, B, and C are determined empirically. The prediction can be improved by using additional derivatives of the excitation $R_{chemical}$ and $R_{physical}$ in the working point - defined by the recipe. This simple model does not consider all variables. The precision of prediction can be degraded later if the properties of the etch chamber are changed (e.g., wet clean). To maintain the prediction precision an adaptive model tuning is necessary.

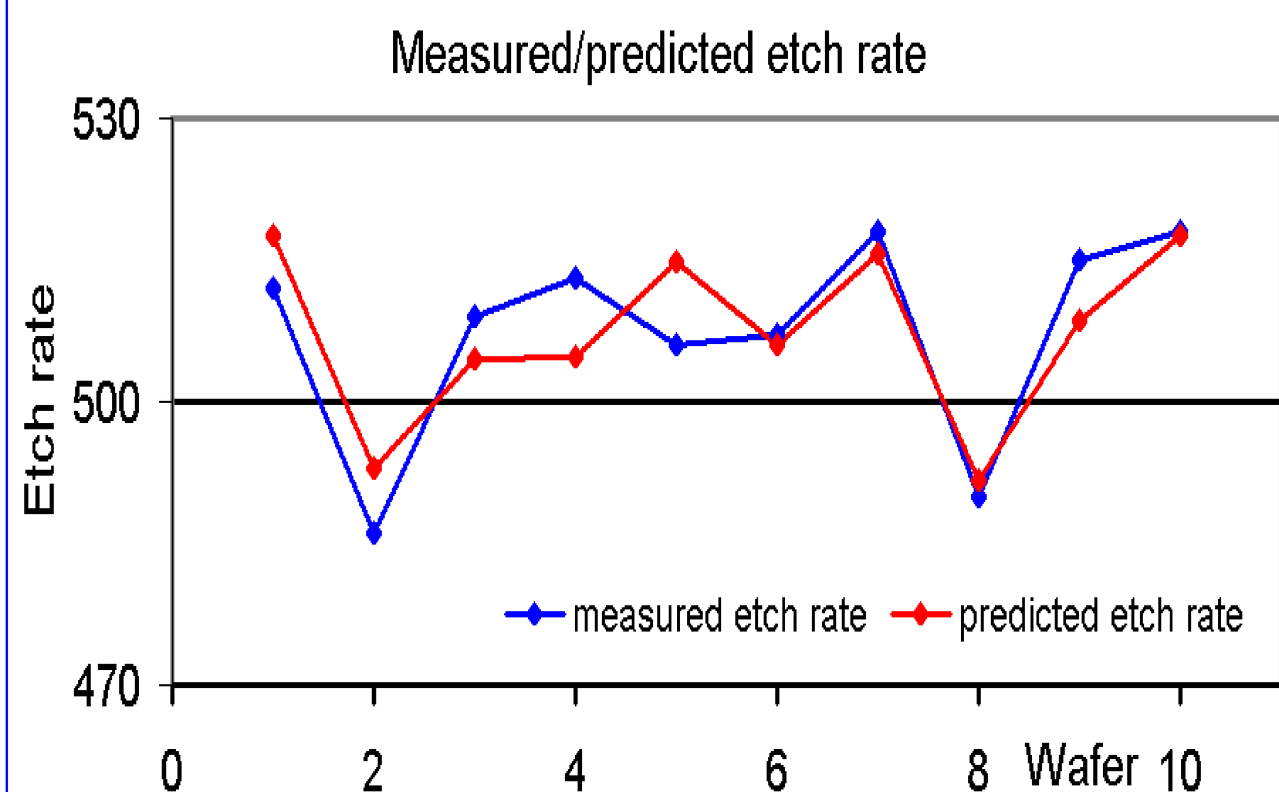
Parameter tuning considers chamber aging

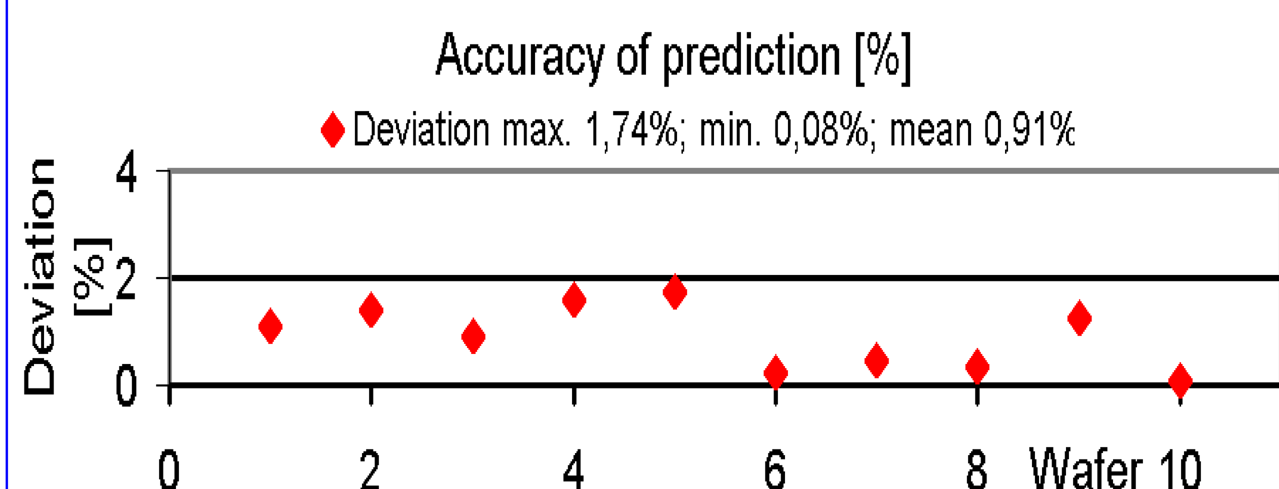


Chamber aging:

- Films at chamber wall (chemistry)
- Erosion of chamber parts
- Films on the optical port (smaller intensity of spectral lines)
- Variable RF-power losses (contacts, ...)
- E-chuck aging (leakage current)
- MFC's
- .....

Etch rate prediction via plasma density for oxide etch[1)]





- This prediction model is based on strong influence of the ion flux in case of oxide etch.
- Thus the plasma density was the dominating parameter for the prediction of the etch rate.
- The second parameter RF peak voltage was nearly constant.
- The deviation between the real and predicted etch rate is smaller than 2 %.

[1)] D. Föh, Micronas, unpublished.

Summary

- The prediction of etch rates for plasma processes can reduce the effort of expensive in-situ metrology.
- The dominating process mechanisms must be known to build the right process model.
- The interaction of chemical and physical mechanisms requires usually nonlinear and multivariate models.
- In some cases univariate model are sufficient (in some oxide etch processes dominates physical etching). Model tuning is indispensable at least for the long term usage.