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 inescapably.

- The lot-level controls have to be replaced by the wafer-level controls.

- A simple transition from sample-based control to complete, that means 100% percent wafer inspection, would cause remarkable costs.
Multivariate Model

- So the prediction of 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 large amount mechanisms. For the plasma process under consideration, the dominating scaling parameters must be found as indicated in the following schemes.
The most important issue for the development of a chemical / physical model is the 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

- Using 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
Multivariate Model – Chemical Impact

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

$$R_{chemical} = A \cdot \left( \text{gas density} \right) \cdot \left( \text{rf power} \right) = A \cdot \frac{\text{pressure}}{\text{gastemperature}} \cdot \left( \text{rf power} \right)$$

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 get

$$R_{chemical} = A \cdot \left( \text{collision rate} \right) \cdot \left( \text{rf power} \right)$$

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

$$R_{chemical} = A \cdot \left( \text{collision rate} \right) \cdot \left( \text{intensity optical} \right) \cdot \left( \text{rf power} \right)$$
Multivariate Model for Etch Rate Prediction

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

\[ R_{\text{physical}} = B \times (\text{electron density}) \times (\text{peak voltage}) \]

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

\[ R = R_{\text{chemical}} + R_{\text{physical}} + C \times R_{\text{chemical}} \times R_{\text{physical}} \]

- The coefficients \( A \), \( B \), and \( C \) are determined empirically.

- The prediction can be improved by using additional derivatives of the excitation \( R_{\text{chemical}} \) and \( R_{\text{physical}} \) in the working point - defined by the recipe.

- This simple model does not consider all actuating variables. Therefore 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

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.
- .....
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 must be taken into account and requires usually nonlinear and multivariate models.

- In some cases univariate models are sufficient (some oxide etch processes).

- Model tuning is indispensable at least for the long term usage.