Virtual Metrology using Advanced Plasma Sensor and Multivariate Model for Etch Rate Prediction

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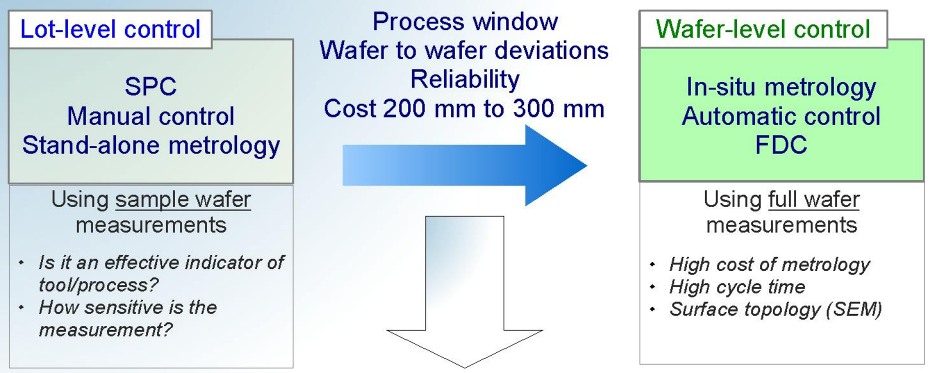
Motivation

- 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 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.

In-situ Plasma Monitoring and Virtual Metrology

Paradigm change in quality management



Lot-level control

SPC
Manual control
Stand-alone metrology

Using sample wafer measurements

- *Is it an effective indicator of tool/process?*
- *How sensitive is the measurement?*

Process window
Wafer to wafer deviations
Reliability
Cost 200 mm to 300 mm

Wafer-level control

In-situ metrology
Automatic control
FDC

Using full wafer measurements

- *High cost of metrology*
- *High cycle time*
- *Surface topology (SEM)*

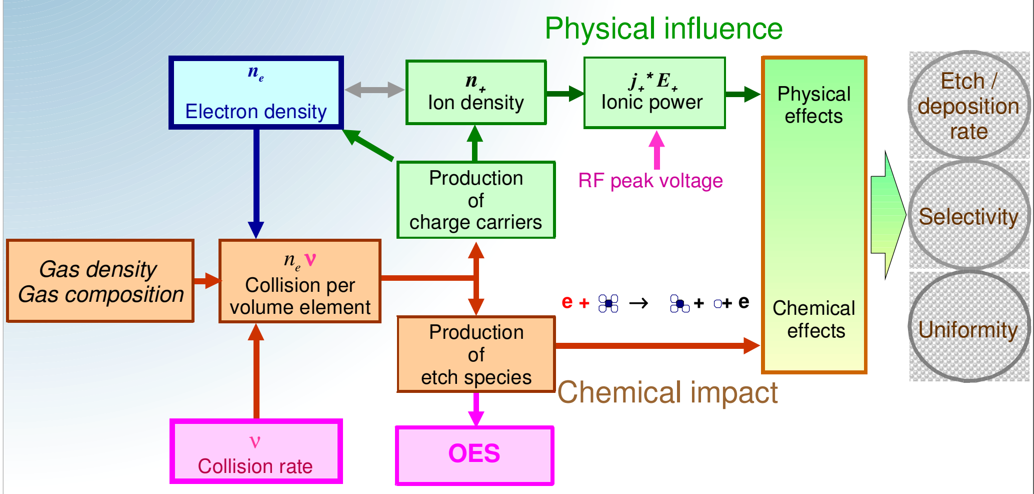
Plasma monitoring & Virtual metrology

Yoon-Jae Kim, K. H. Baek, Y. J. Kim, Samsung Electronics Co., Ltd.,
8th European AEC/APC Conference, Dresden Germany, 18 - 20 April 2007

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.

Chemical / physical Impact on Etch/Deposition



Physical influence

n_e
Electron density

n_+
Ion density

$j_+ * E_+$
Ionic power

Physical effects

Etch / deposition rate

Production of charge carriers

RF peak voltage

Selectivity

Gas density
Gas composition

$n_e \nu$
Collision per volume element

e + → + + e

Chemical effects

Uniformity

Production of etch species

Chemical impact

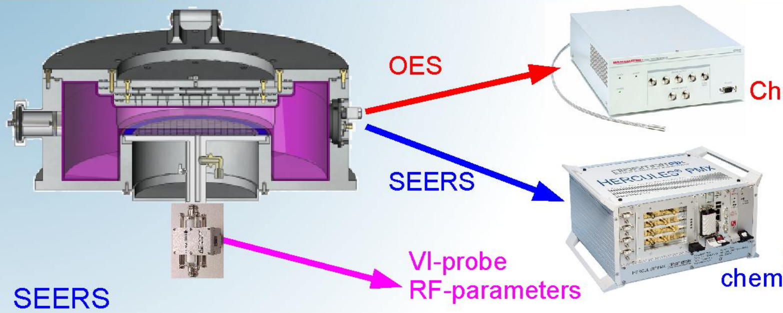
ν
Collision rate

OES

Selection of Key Parameters

- 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

Complementary Process Parameters



OES

SEERS

VI-probe
RF-parameters

Chemical impact

Physical and
chemical influence

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

Using complementary methods, we can determine the key process parameters.

Multivariate Model – Chemical Impact

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

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

- 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 get

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

- 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

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

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

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

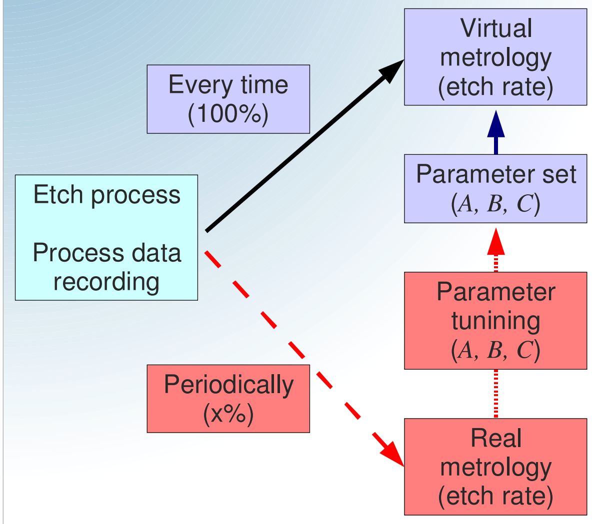
- The final effective rate, e.g., an etch rate, is given by

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

- 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 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

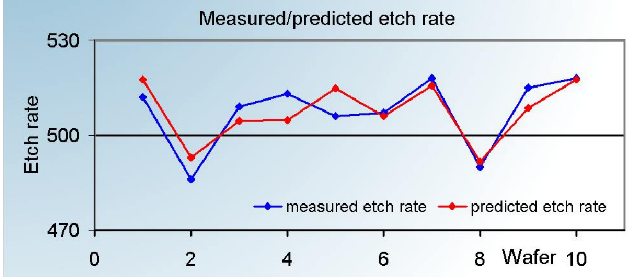
Parameter tuning considers chamber aging.

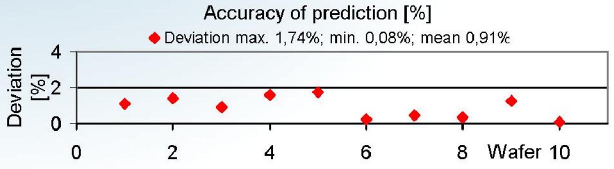


Chamber aging:

- 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.
- .....

Etch Rate Prediction via Plasma Density for Oxide Etch


Measured/predicted etch rate


Accuracy of prediction [%]

- 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 %.

* 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 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.