Process Stability in Photo Mask Manufacturing

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plasmetrex
plasma metrology experience

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Motivation

- Photo mask manufacturing shows some particularities - due to the small throughput and high product mix but immense value added. So knowledge of processes and plasma are mandatory for successful manufacturing.

- For the manufacture of masks, the following applies:
  - Very high demands on process stability.
  - Each mask is unique, resulting in process mix and constant adaptation of processes.
  - So the production is very expensive and each mask counts.

Process Control

- Important parameters for mask manufacturing:
  - etch rate
  - uniformity

- Both depend strongly on the plasma discharge in particular on the mode in which an inductively coupled plasma runs – E- or H- mode. E- and H-mode changes lead to an etch rate variation and different ion energy impact on the etched substrate.

- usually no tool parameter clearly indicating changes of the plasma mode (due to large RF losses in matchbox and coil)

Approach – Process Characterization by Plasma Parameters

- Inductively coupled plasma can be in different modes:
  - E-mode: The power input in the plasma is capacitive!
    ICP plasma ignite in the E mode.
  - H-mode: The power input in the plasma is mainly inductive, a small part of energy coupling is capacitive.
    ICP plasma can not ignite in H mode!

- Find suitable process and/or plasma parameters to detect E- and H-mode reliably. In terms of a sufficient process characterization, the usage of tools parameters was shown to be insufficient. Therefore the SEERS* method was used additionally.

*SELF EXCITED ELECTRON PLASMA RESONANCE SPECTROSCOPY

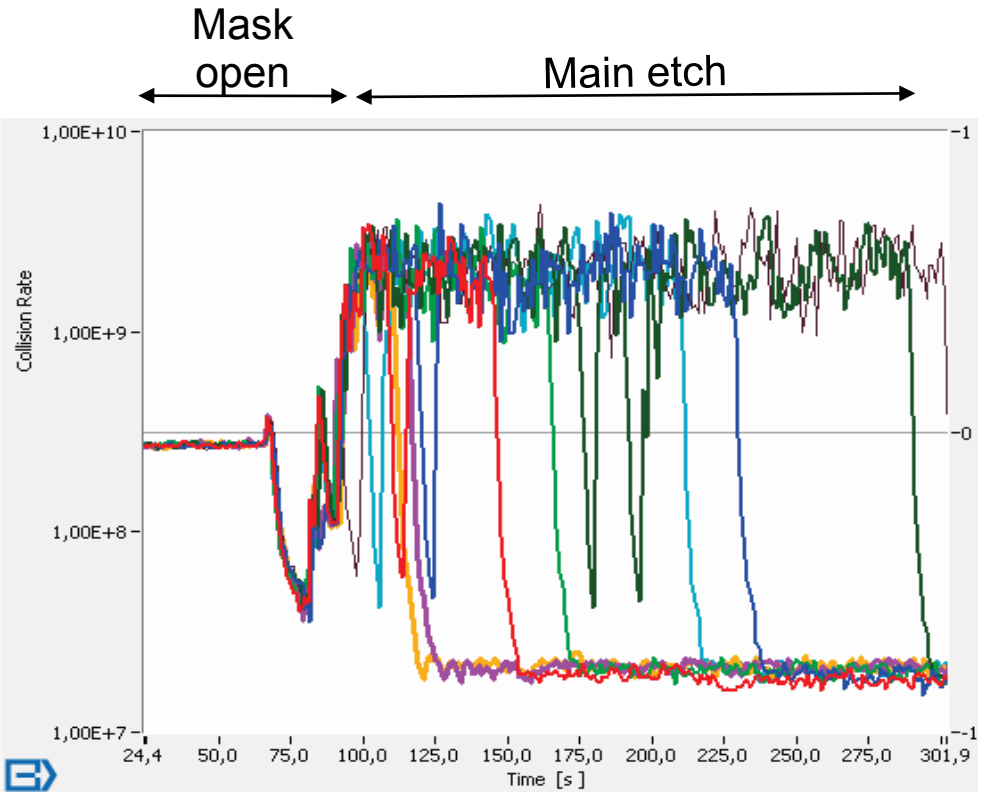
Root Causes for Process Deviations

- Process deviations can be readily classified regarding their root causes:

  1. Changes of spare part properties (permittivity of insulators...).
  2. Impact of substrate surface, chamber conditioning or other plasma-relevant properties.
  3. RF power loss variation can result in a change of running plasma mode.

- The investigation of etch processes were done at an ICP etcher driven by 13.56 MHz at source (coil) and lower electrode (bias).

Known Interactions between E-H-mode and Plasma Chemistry

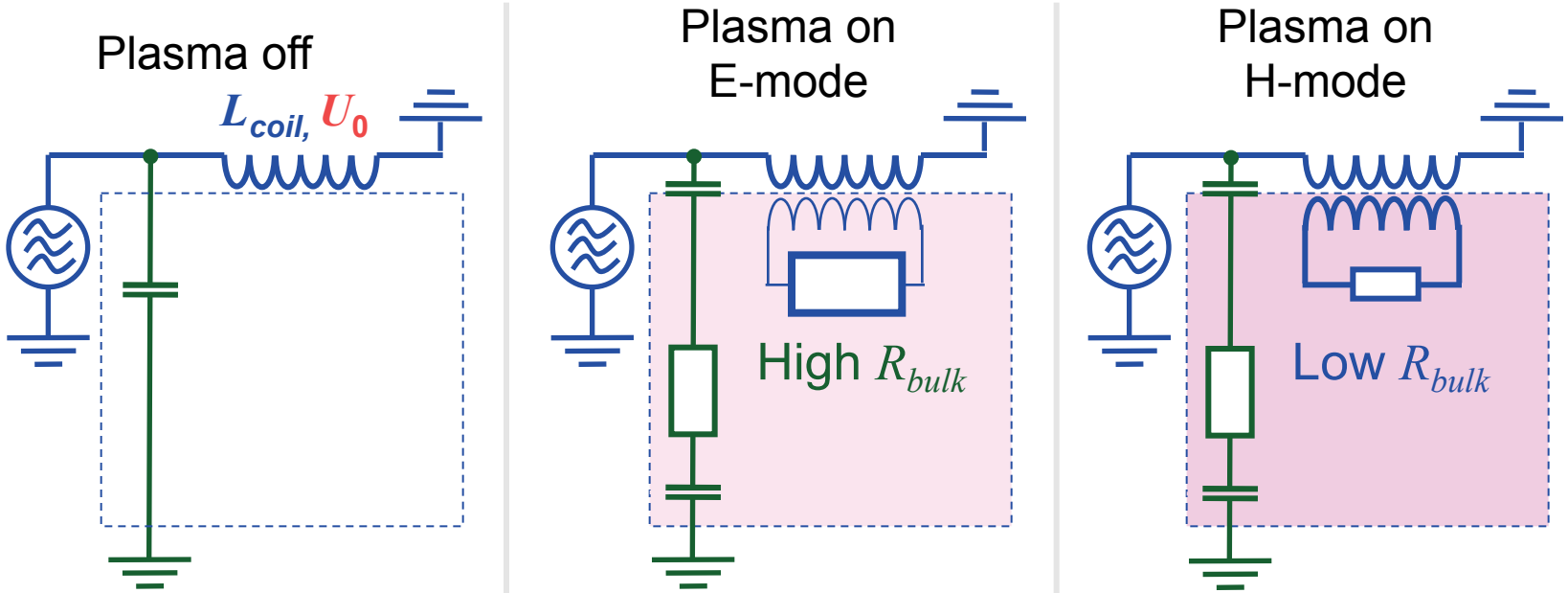


- The electron collision rate shows the impact of plasma chemistry (from F to Cl) on plasma physics.
- Instabilities are caused by switching from an inductive (H-)mode to unstable capacitive (E-)mode.
- The stable level depends on chamber state and recipe.

E-H-mode Transition and its Detection in SF_6 Plasma during Silicon Trench Etch,
E. Chasanoglou, Texas Instruments, Freising, Germany, 13th European APCM Conference , April, 2013 Dresden, Germany

ICP - Plasma Ignition and Transfer from E- to H- Mode

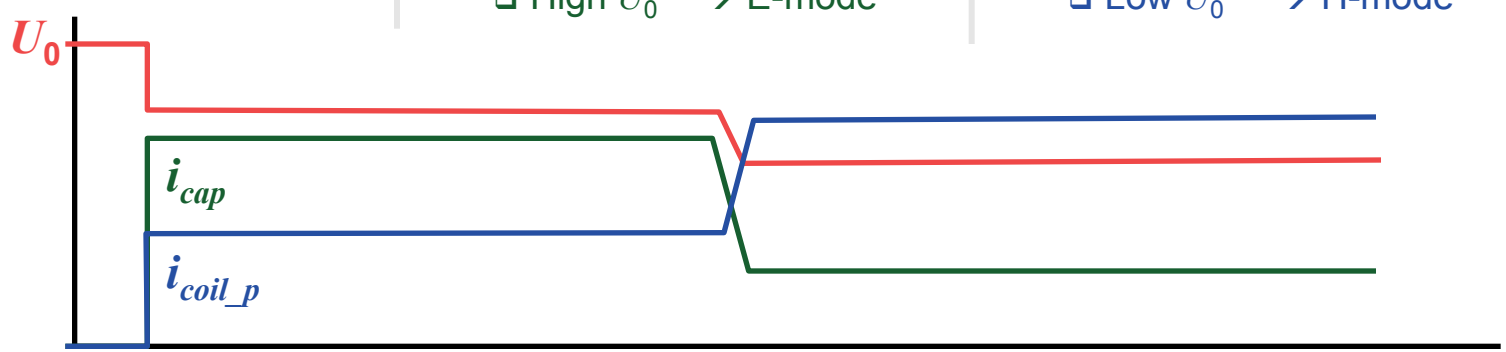
Plasmatrex' Plasma School
Fundamental Course



RF Switch on:
- High U_0

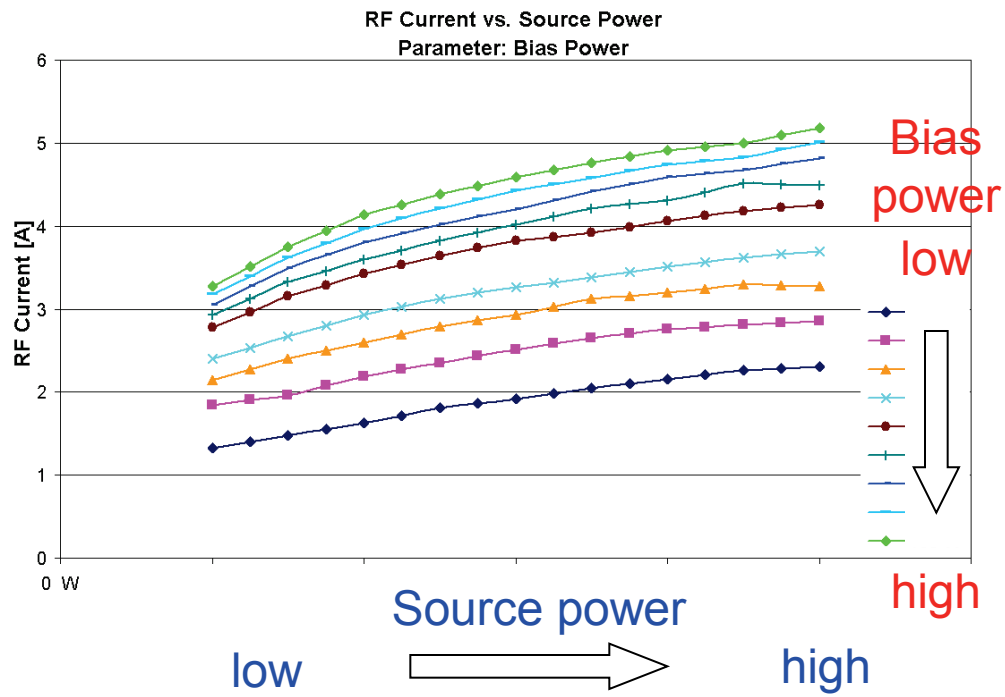
Low RF power:
- High R_{bulk} → Low i_{coil_s}
- High U_0 → E-mode

High RF power:
- Low R_{bulk} → High i_{coil_s}
- Low U_0 → H-mode



Source Power Variation, Parameter: Bias-power

- RF current on chamber wall shows clear dependencies.
- current increases with source power and with bias power.
- Higher source power increases plasma density.

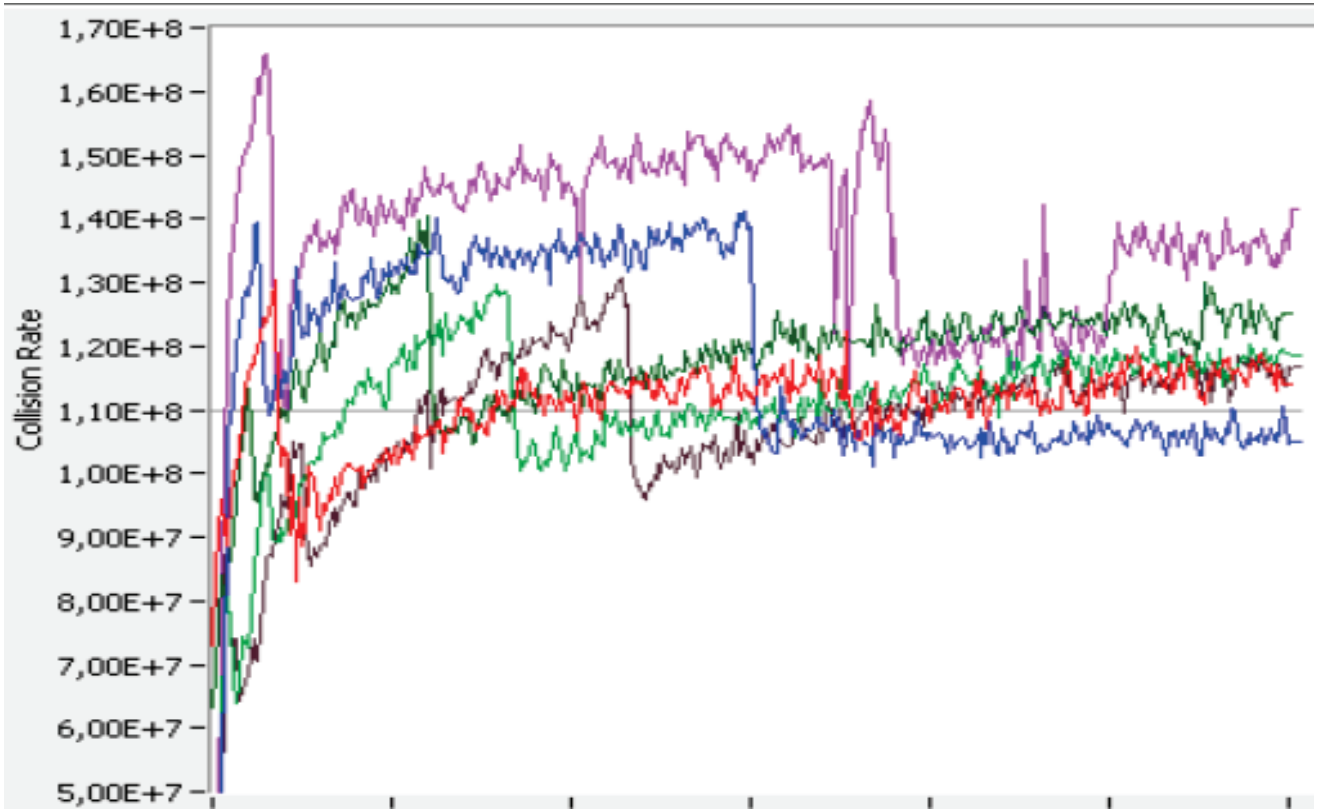


- RF current mainly defined by bias power
- Influence of the source power low

  (due to the small capacitive part of the power input at the coil)

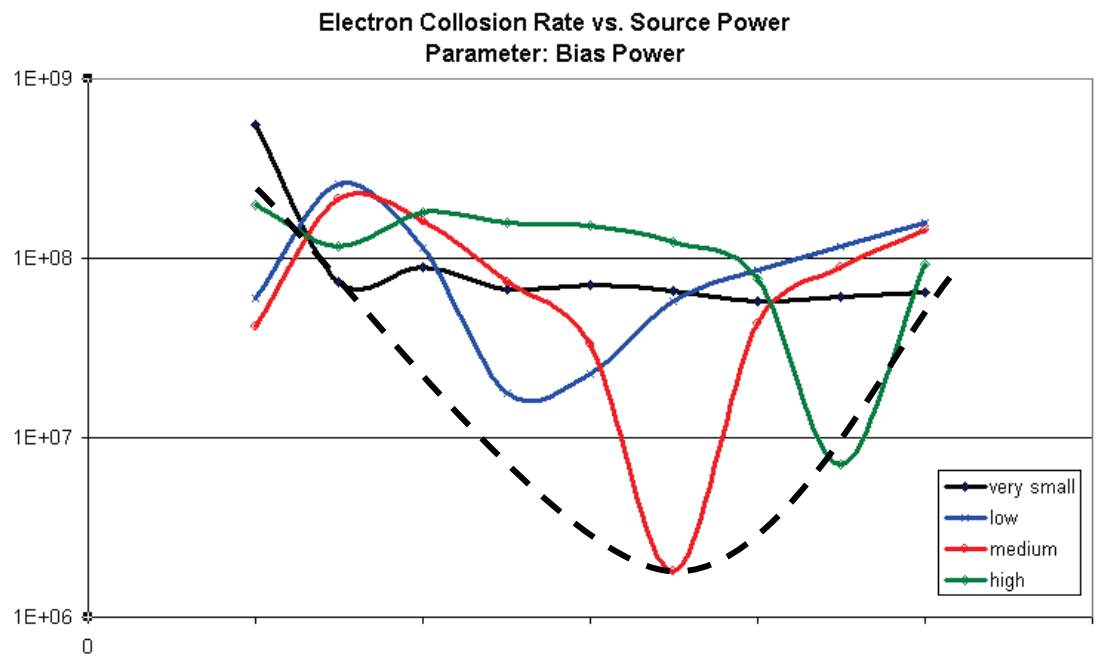
Experimental Procedure and Description

- Pretests for typical recipe to find process or plasma parameters with visible parameter changes
- plasma parameters (mainly electron collision rate) vary up to 30 % during the etch



Results and Conclusions

- Pronounced minima of electron collision rate indicating H-mode



- position of H-mode depends on other parameters e.g. bias power, gas density (and therefore from the pressure and gas temperature).

Source power

low → high

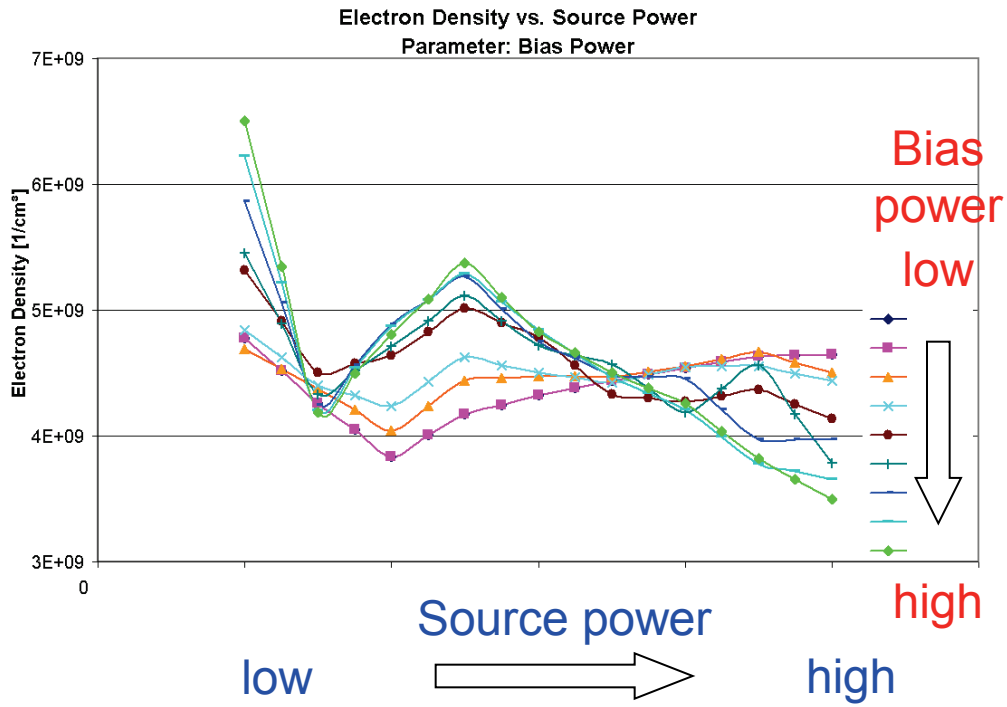
- etch process in H-mode
  → high etch rate→ favorable

- BUT: small process window only at minimum
  →potentially unstable →stringent process supervision required

Electron Density in electro-negative Plasma

- Due to the well pronounced electro-negative plasma the number of electrons can be by a factor of ten less than the number of negative ions!

- Changes in the ratio of electrons and negative ions depend mainly on the source power, and the plasma mode respectively, and change the process properties significantly.



Conclusion

- E-H-mode switching domain monitored through a wide part of the parameter window
  - relative quick and cost efficient experiment
  - map with distinct E-mode and H-mode dominance.
  - improved process window and stability prediction reducing in consequence remarkably the development time and costs.

- The E-H-mode transition not detectable by tool parameters, only plasma parameters contain information on plasma mode.

- The influence of the plasma mode at the process result is significant!

Literature

- M. W. Kiehlbauch and D. B. Graves: Effect of neutral transport on etch product lifecycle, J. Vac. Sci. Technol. A, Vol. 21, No. 1, Jan/Feb 2003

- Marakhtanov et al., J. Vac. Sci. Technol. A, **21**, 1849 (2003).

- E-H-mode Transition and its Detection in SF_6 Plasma during Silicon Trench Etch, E. Chasanoglou, Texas Instruments, Freising, Germany, 13th European APCM Conference , April, 2013 Dresden, Germany