Process Stability in Photo Mask Manufacturing

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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 SF₆ 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

Plasma off

\[ L_{\text{coil}}, U_0 \]

RF Switch on:
- High \( U_0 \)

Plasma on

E-mode

High \( R_{\text{bulk}} \)

Low RF power:
- High \( R_{\text{bulk}} \) \( \rightarrow \) Low \( i_{\text{coil,s}} \)
- High \( U_0 \) \( \rightarrow \) E-mode

H-mode

Low \( R_{\text{bulk}} \)

High RF power:
- Low \( R_{\text{bulk}} \) \( \rightarrow \) High \( i_{\text{coil,s}} \)
- Low \( U_0 \) \( \rightarrow \) H-mode

Plasmatrex' Plasma School

Fundamental Course

\[ U_0 \]

\[ i_{\text{cap}} \]

\[ i_{\text{coil,p}} \]
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).

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

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


- E-H-mode Transition and its Detection in SF₆ Plasma during Silicon Trench Etch, E. Chasanoglou, Texas Instruments, Freising, Germany, 13th European APCM Conference, April, 2013 Dresden, Germany