Online-CD and -excursion monitoring in deep trench Si RIE etching using optical emission spectroscopy for future R2R applications

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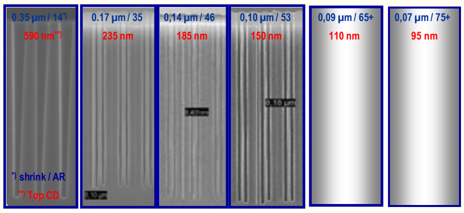
Introduction – Process and Motivation

- IFX DRAM technology with **trench cell** capacitor concept (DT = deep trench)
- Si etch with **high aspect ratio** (AR = trench depth / Top CD) and **fragile sidewall passivation** (HBr-NF3-O2 chemistry)
- current shrink roadmap requires additional online sensoring for **excursion monitoring** and future ***online* CD controlling**

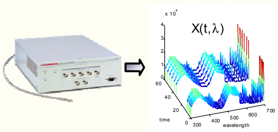


In future: tiny DT process window - adjustment of etch recipe on **intra-wafer** and **intra-step level**!

How can the DT etch process be controlled in ***real-time***? By **optical emission spectroscopy** (OES) :

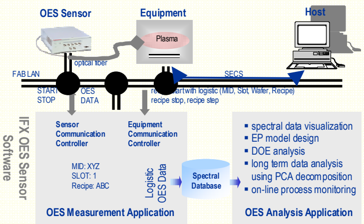
Setup – Sensor and Application Software

Features of Hamamatsu MPM



- wide spectral range: 200-950 nm
- real-time 1024-channel operation
- pre-calibrated and maintenance free
- scientific-grade sensor (excellent sensitivity, unlimited lifetime)
- internal data processing capability (script handling, ...)
- easy LAN connection
- I/O ports for tool connection

Features of Hamamatsu MPM



- spectral data visualization
- EP model design
- DOE analysis
- long term data analysis using PCA decomposition
- on-line process monitoring

Process & Sensor

Spectral Data Analysis
→ *analysis of reference plasma*

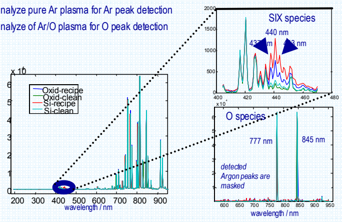
- **complex plasma interactions** and a huge amount of optical emission lines require a assignment of observed **spectral peaks** to the applied **chemistry**
- most of observed **spectral lines** were characterized based on experimental recipe variations respective the **applies gas flows** HBr / NF3 / Ar / O / SiF4 chemistries at **oxide wafer** and **Si wafer**

important detected spectral lines

- Oxygen: **778, 845 nm**
- Nitrogen: 316, 337, 358 nm
  and area between 575 – 607 nm and 632 – 677 nm (mixed with F)
- Fluorine: 686, 690, 704, 713, 720, 731 ,740, 775.6, 780.7 nm;
- SiX: 336 , **437, 440 , 443nm**

example

1. analyze pure Ar plasma for Ar peak detection
2. analyze of Ar/O plasma for O peak detection

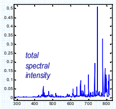


Spectral Data Analysis
→ *long-term process+clean monitoring*

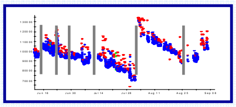
- main objective of OES data analysis is the extraction of the most important spectral information by assessment of spectral changes in full spectral data
- Principle Component Analysis (PCA) is a suitable method for dimension reduction for highly correlated OES data
- in context of long term spectral data analysis the PCA is used to extract most significant spectral changes, described by the calculated spectral pattern

- moreover the calculated spectral pattern allow a chemical interpretation of plasma interactions
- long term DT etch analysis distinguishes two different task:
  (1) step accurate analysis of the clean processes between DT processes
  (2) step accurate analysis of the DT etch process

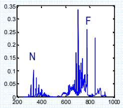
First spectral PCA pattern of DT etch process



→ scores belonging to the first component distinguishes different wetclean cycles



First spectral PCA pattern of DT clean process



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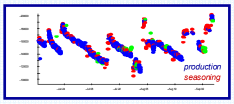
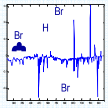
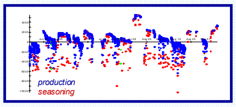


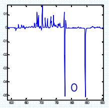
Second spectral PCA pattern of DT etch process



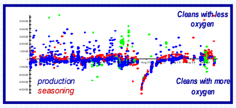
→ scores belonging to the second component show that the camber conditioning is sufficient



Second spectral PCA pattern of DT clean process



→ scores belonging to the second componen distinguishes Cleans with different oxygen concentration depends on chamber wall polymerization



Analysis & Results

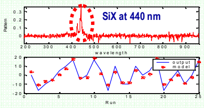
Custom-designed experiments
→ *CD modelling*

- variation of gas mixture in PHMO and DTMO pre-processes in order to change the CD Target for DT Process

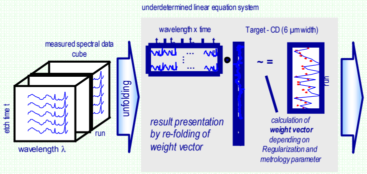
Expected CD **Wafer No.**

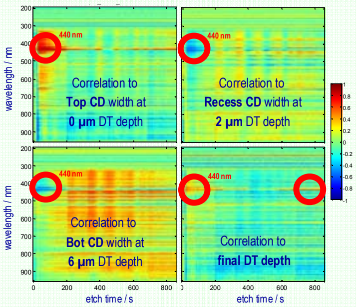
Split	CD Target	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Wafer
B	-17		X										X								X						2, 12, 20
C	-10			X											X	X								X			3, 14, 15, 23
D	-5				X				X													X					4, 8, 21
A	+/- 0	X								X								X							X		1, 9, 17, 24
E	+5					X						X							X				X				5, 11, 18, 22
F	+10						X							X			X										6, 13, 16
G	+17							X			X									X						X	7, 10, 19, 25

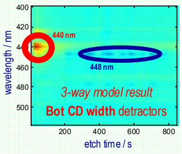
Linear modeling with mean spectra show that the **SiX concentration** at 440 nm **correlate with** the **CD** Target



- **3-Way modelling** based on regularization techniques allow the **search** for **dependencies** in the whole spectral data cube



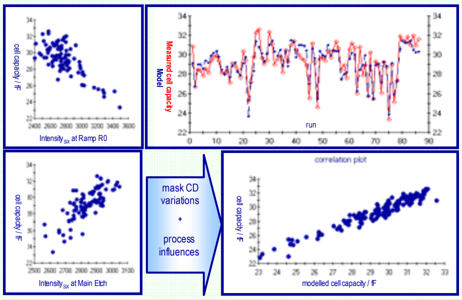




- Final DT **Top CD** width is defined by **SiX concentration** within the first etch steps (ramp step R0).
- Final DT **Recess** CD width correlates **inversely** to the **SiX concentration** at R0.
- Final DT **Bottom CD** width correlates inversely to the **SiX concentration** at R0 and directly **to Br* variations** after **change** of main etch **steps.**

Long-term correlation of OES run-keynumbers with capacity measurements of the final trench cells

- approximately 190 keynumbers from OES system for DT etch process and DT clean were feed back to the IFX APC-FDC system
- correlation analysis and modelling between inline + electrical parameter (CD, defect density data, trench cell capacity, yields, ...) and the calculated OES run-keynumbers



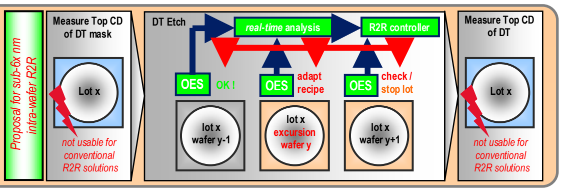
*** ***Known*** ***

SiX as wafer's main **reaction product** during DT structuring and **cell capacity** as result of etched **DT volume**

*** ***New*** ***

SiX concentration can be used ***real-time*** by OES to **model** the final electrical measured trench **cell capacity**

- characterization of spectrally **unknown etch processes:** structuring into **(1)** element analysis by **reference plasma's**, **(2)** running custom-designed **experiments**, **(3)** long-term **mass analysis** of productive data and finally **(4)** feeding forward OES data into the fab database for **correlating spectral process data to inline + electrical data** (prerequisite: full OES sensor integration!)
- SiX-based OES model can be used to **extrapolate the evolution** of the subsequent **DT structuring process** in a very early stage of DT etch (i.e. during the ramp steps) and **correct** – if needed – the etch recipe to **match** the requested final **dimensions** (by changing the etch times and/or the sidewall passivation (NF_3-to-O_2 ratio)



Conclusion & Outlook

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