Economical benefits
by new plasma tool concepts and AEC/APC

Session :

Equipment and Process Fault Detection

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Outlook

- The up-coming challenges
- Tool selection
- Cost analysis - Increase of profit by reducing the tool's costs
  - Average semiconductor tool OEE
  - OEE - efficiency for producing 'good' wafers
  - Cost per 'good' wafer
  - Relation between OEE and CoO
- Demands and conclusions for future chambers
- How to meet the demands on future chambers
- Trends of new tool generation
- Summary and conclusion
- References

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The up-coming challenges

Increased wafer size

Decreased CD (below 100 nm)

New products

Increased demand of process stability (smaller process window, process mix, ...)

Fab-wide APC platform with reasonable costs

Smart ex- and in-situ sensors

APC control as FDC, R2R, ...

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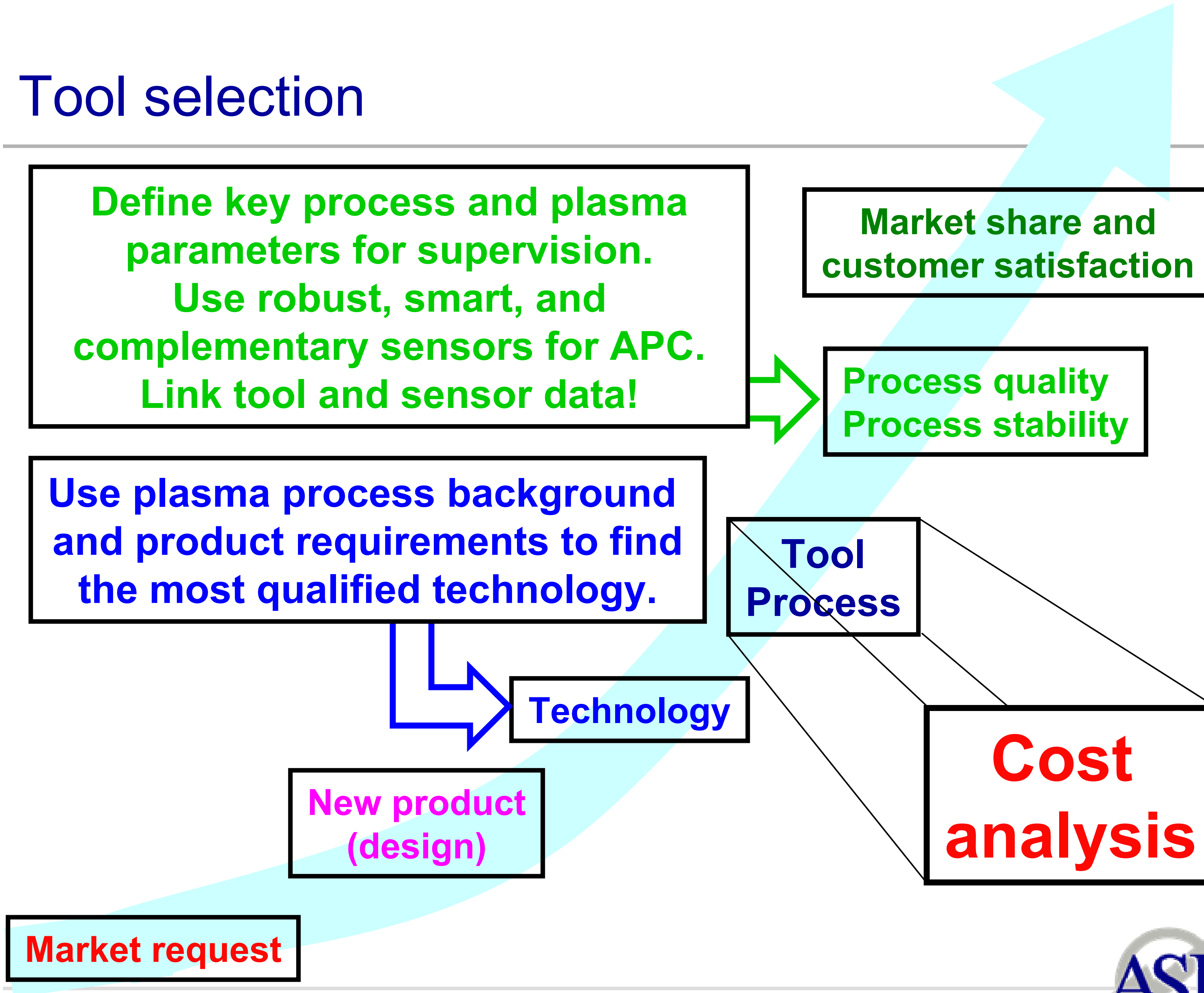
Tool selection



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Cost analysis - Increase the profit by reducing the tool's costs

- OEE: Overall Equipment Effectiveness (efficiency)
  - Part of time used producing good wafers.

$$OEE = \frac{\text{process time for 'good' wafers}}{\text{total time}} = \frac{UPT \bullet U}{LT}$$

UPT - Uptime
U - Utilization (process time for 'good' wafers /UPT)
LT – Lifetime

- CoO: Cost of Ownership
  - Addresses economic and productive performance of a fabrication tool by estimating total life-cycle cost of a specific semiconductor process step.
  - SEMI E35: full cost of embedding, operating, and decommissioning.

Detailed, more comprehensive definition → Semi E79

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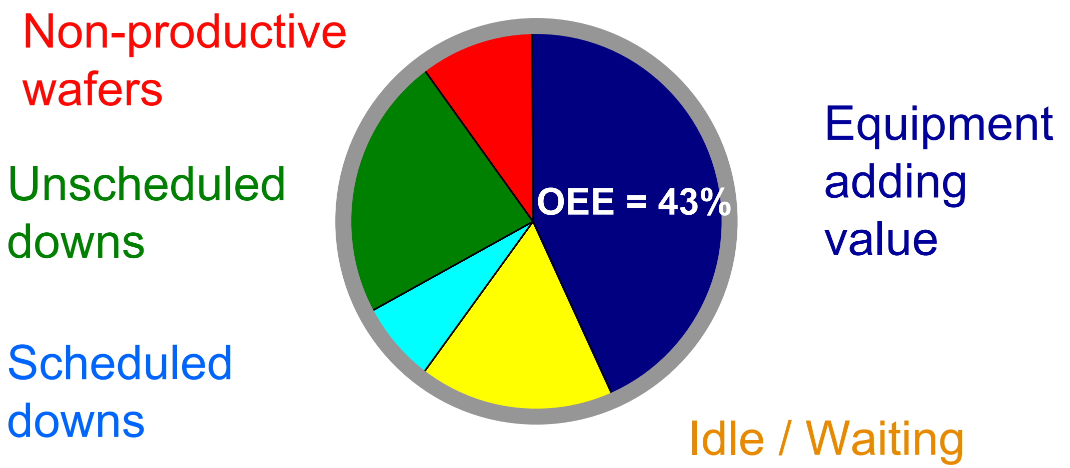
Average semiconductor tool OEE

- The average OEE of semiconductor tools shows the resources for increasing the effectiveness. For improvement:
  - Decrease number of non-productive wafer by, e.g., optimization of conditioning procedure or use dynamic conditioning.
  - Decrease scheduled downs by life time monitoring.
  - Decrease idle/waiting time by improvement of production management.
  - Use robust and smart sensors for process and chamber characterization to avoid unscheduled downs.



[ISMT2002], other references [SOME1999], [USAM 2002], [SEMI E34, E79]

Cost per 'good' wafer

- The cost per ‘good’ wafer is determined by fixed costs, recurring costs, and costs of yield loss as well as life time, through put, and utilization.
- Operation and maintenance improvement have a big potential for CoO increasing.

$$\mathrm{CoO} = \frac{\text{total cost during life time}}{\text{total number of 'good' product wafers}}$$

$$\mathrm{CoO} = \frac{CF + CR + CY}{LT \cdot TPR \cdot U \cdot Y}$$

CoO	Cost of Ownership
CF	Fixed Cost (invest + discarding)
CR	Recurring Cost (operating + maintenance)
CY	Cost of Yield loss (pre-processing)
TPR	ThroughPutRate (pre-processing)
Y	Yield

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Relation between OEE and CoO

$$CoO = \frac{CF + CR + CY}{OEE} \cdot \frac{EPT}{LT}$$

- EPT- Effective Process Time
  - Including dry clean and wafer handling.
- CoO decreases with increasing OEE.
- OEE is influenced by the number of conditioning and test wafers, MTBC, ….
  - Example of benefit potential: Increasing of OEE (2%) and MTBC (25%) as well as decreased scheduled PM time (1%) were reached by APC with an additional plasma process sensor [PETIT] .
- EPT is dominated by process, handling, and clean time.

[PETIT]

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Demands and conclusions for future chambers

OEE ↗

Utilization — Dry clean (waferless), **conditioning and test wafer usage.** Reduce: MTTR, MTBF, MTBC.

CR ↘

Maintenance effort
Spare parts, personnel — New coatings, service friendly.

EPT ↘

Effective process time
High rate etching — High/medium plasma density. High gas flow and/or low pressure.

Life time (LT) ↗

Shrinking — Low pressure.
Process flexibility
Maximum uniformity
Low damaging
'Adjustable' profile

Control of: Ion energy, peak voltage.
Plasma density.
Process gas density (temperature).
Chemistry.

CY (Yield Loss) ↘

Controllability
Uniformity, Tool faults — Process time well above time constant of tool and maximum two excitations. Robust, smart sensors.

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How to meet the demands on future chambers?

- High/medium density
  Low pressure
  Control of plasma density
  ⇒ High capacitive or inductive coupled excitation frequencies 40 – 100 MHz

  Gas density and chemistry
  ⇒ Gas density or gas temperature control

- Control of ion energy
  ⇒ Additional low frequency 2 – 13,56 MHz (VCI mode …)

- Robust, smart and complementary sensor system
  ⇒ Optical sensor → end point
  Electrical sensor → RF circuit
  Plasma sensor → plasma
  Link of sensor and tool data

- Avoid process drift
  Low damaging
  'Adjustable' profile uniformity
  ⇒ Maximum two excitation frequencies
  B-field only for confinement

- Process understanding
  ⇒ Well skilled employees

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Trends of new tool generation – Two frequency excitation and low pressure

Aim	→ Realization	→ Consequence
High plasma density	Inductive coupled RF or capacitive RF > 40 MHz	Increased plasma density but thinner plasma sheath due to decreased Debye length [PLSCH]. RF power dissipated by electrons in the plasma bulk increases, ionic power decreases → low ion energy. Nota bene! RF > 80 MHz is difficult to handle RF connectors, cable, feed through
Suitable ion energy	Add second excitation frequency 2 – 27 MHz (depends on process)	Low excitation frequency increases plasma sheath thickness and hence the ion energy. Ion energy is controllable separately. Nota Bene! Both discharge frequencies are coupled by plasma – mutual influence! [PLSCH]
Change etch mechanism	Low process pressure	Two etch modes Low pressure mode where free mean path of ions is larger than plasma sheath → no collisions, → higher diffusion coefficient. High density plasma & low pressure → no loading effects. [PLSCH] High pressure mode where free mean path of ions is smaller than plasma sheath → collisions.

[PLSCH]

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Summary and conclusion

- The major scope of this paper is to show the connections between economic values and tool configuration and in particular process design (plasma process physics).
- The approach of etch processes and the understanding of principle fundamentals of plasma physics are very important for the right tool application to reach the expected benefits and economical parameters.
- For AEC/APC smart complementary sensor systems are necessary to meet future challenges in the semiconductor industry.
- Well skilled employees become more and more an economical factor!
- Preparation for data coupling of tool data and additional sensor data as well as peak voltage measurement for APC have to be integrated parts of future tools.

References

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