

APC (Advanced Process Control), Current Status and Issues

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for Process Control**
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1. Background



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Factory Needs

The factory is driven by the following **cost & productivity** needs irrespective of technology nodes:

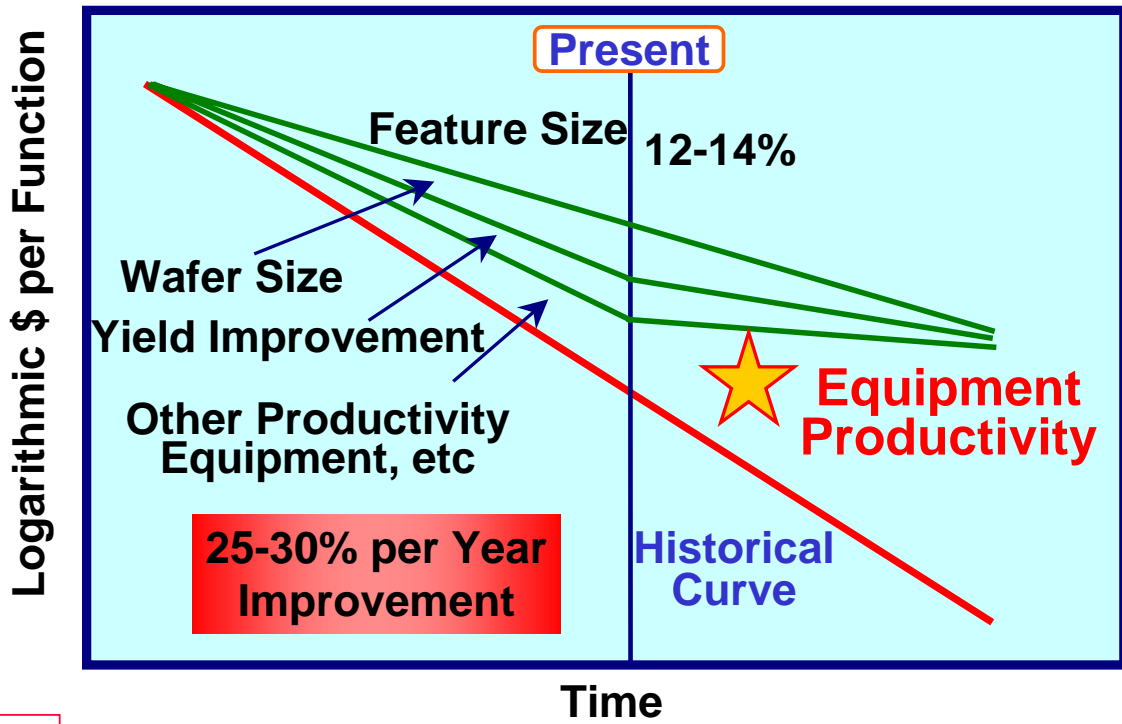
- ① Reduce factory **capital and operating costs per function**
- ② **Improve factory optimization for different business models** (high-volume/high-product mix and high-volume/low-product mix)
- ③ Increase factory life via **extendibility, flexibility, and scalability**
- ④ **Increase equipment reliability and availability**
- ⑤ **Reduce ramp time** for both new and retrofit factories

From ITRS'99



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Tactics for Improving Productivity



2. Motivation



Overall Equipment Effectiveness of High Density Plasma Etcher (SiO₂)

Increasing and Unsolved Items
(8%+11%+21%= 40%)

Working 70%					Out of Working 25%		
Seasoning 8%	Wafer Process 51%		Plasma Cleaning 11%	Waiting 5%	Quality Control 21%		Trouble 4%
	Etching Process 38%	Wafer Trans. etc. 13%			Eq. QC 9%	Prtcl tst-run 12%	



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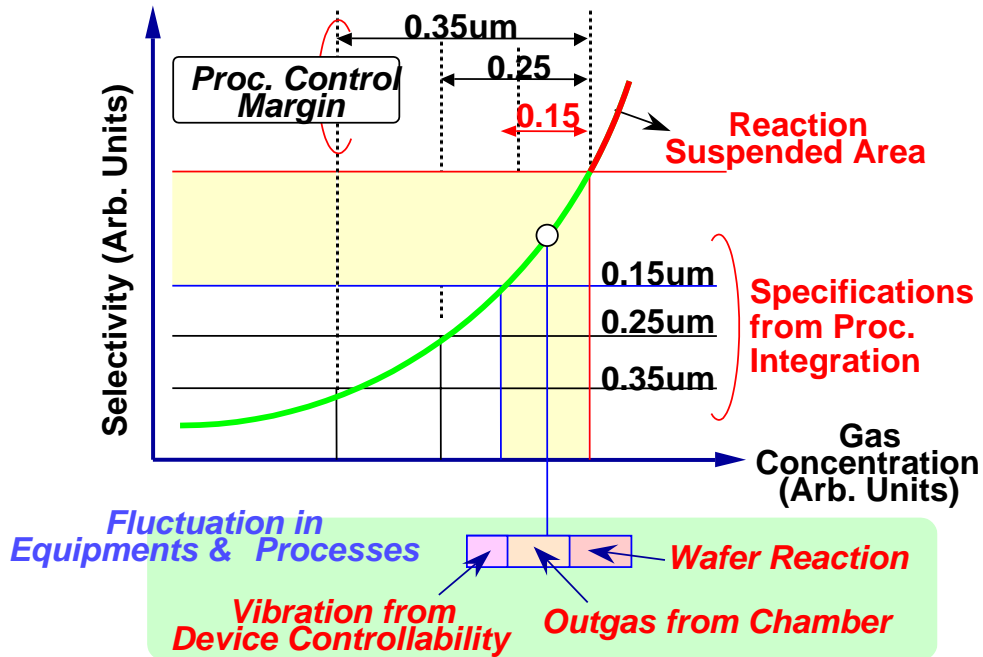
Problems of Plasma Process Equipment for Deep Sub-micron Devices Fabrication

1. Steep Rises of Equipment Cost for Safety, Installation, Maintenance, and Operation
2. Low OEE (Overhead Equipment Effectiveness)
 - 1) Low Reliability and Stability (Yield Loss)
 - 2) Increasing Needs for long QC Operations
 - 3) Individual Differences among the same Equipments
3. Lack of Ability to keep up with the next Generation Processes
 - 1) Insufficient Process Controllability
 - 2) Difficulties in Modifies or Functional Additions



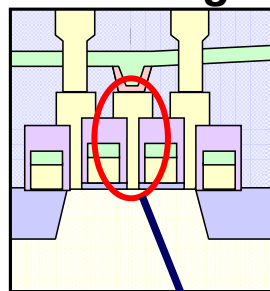
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Difficulty in Deep Submicron Process

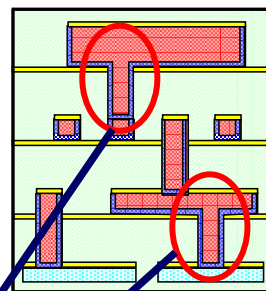


New Insulator Plasma Etching

Self Align



Dual Damascene



Rapid Change of Exposed Area and High Selectivity

Change of Reaction Products from Wafer (O₂, N₂) is a few sccm.
This Change influences Plasma Decomposition and Etching Selectivity.

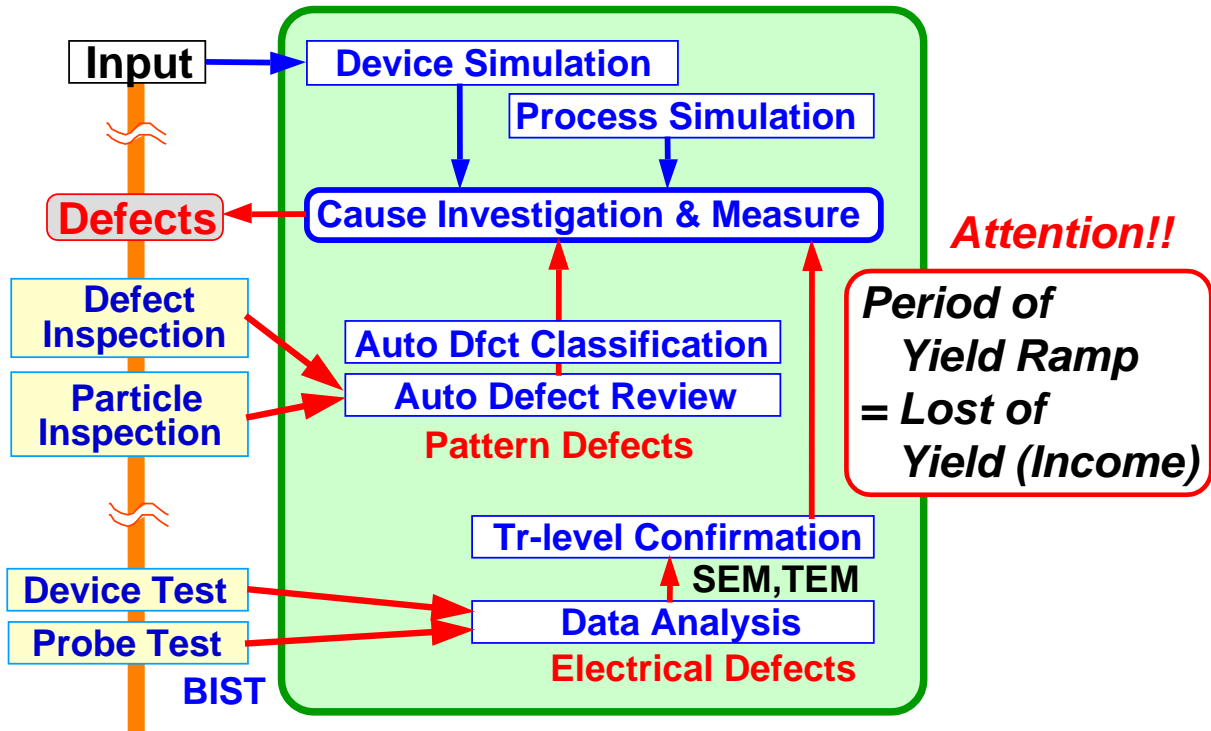
High Margin Process

In-Situ Process Control System
(Intelligent Machine)

- Applicable Process Condition is pin-point. (difficult)
- To develop high Margin Process is very difficult .



Yield Management



The Needs for Short Period Problem Solving

Loss per Incident (Arb. Units)

- Functional Probing Test : 100%
- Parametric Test : 99%
- Short Cycle Electrical QC Test : 20%
- **In-Line Inspection & Feedback : 5%**
- **In-Situ Process Control : 0.01%**

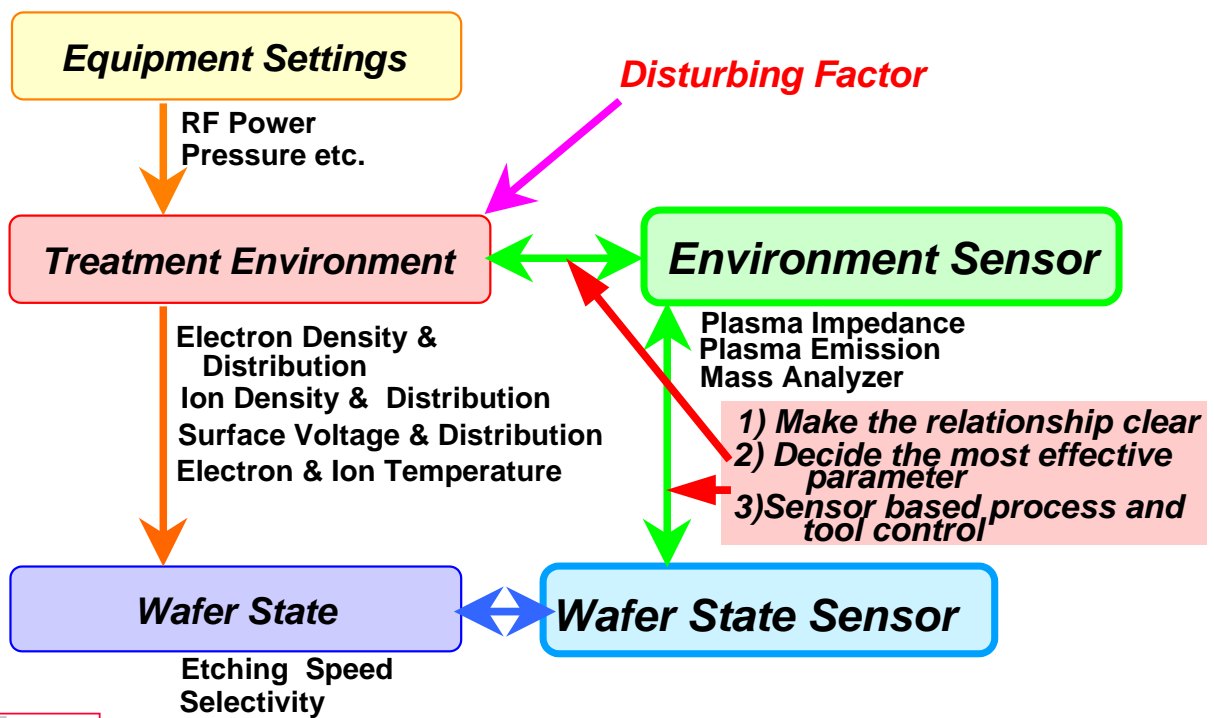
$$COO = \frac{CF + CR + CY}{L \times TPT \times Y \times U}$$



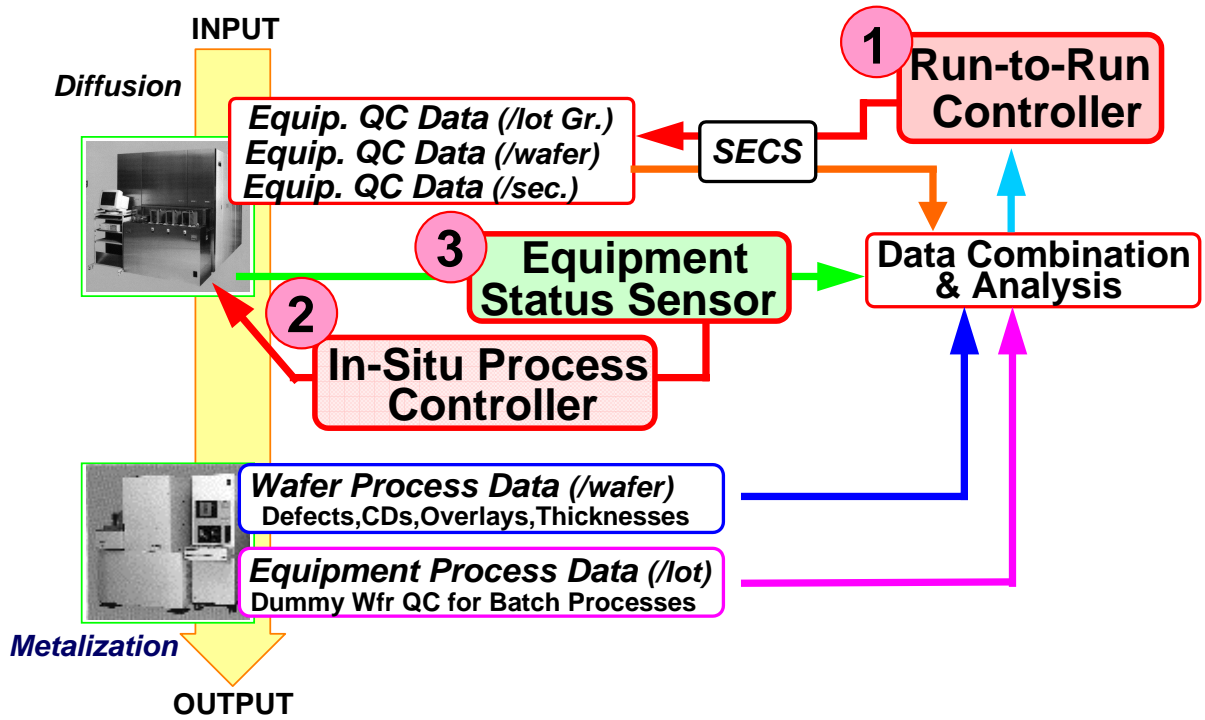
3. Process Control and Current Issues



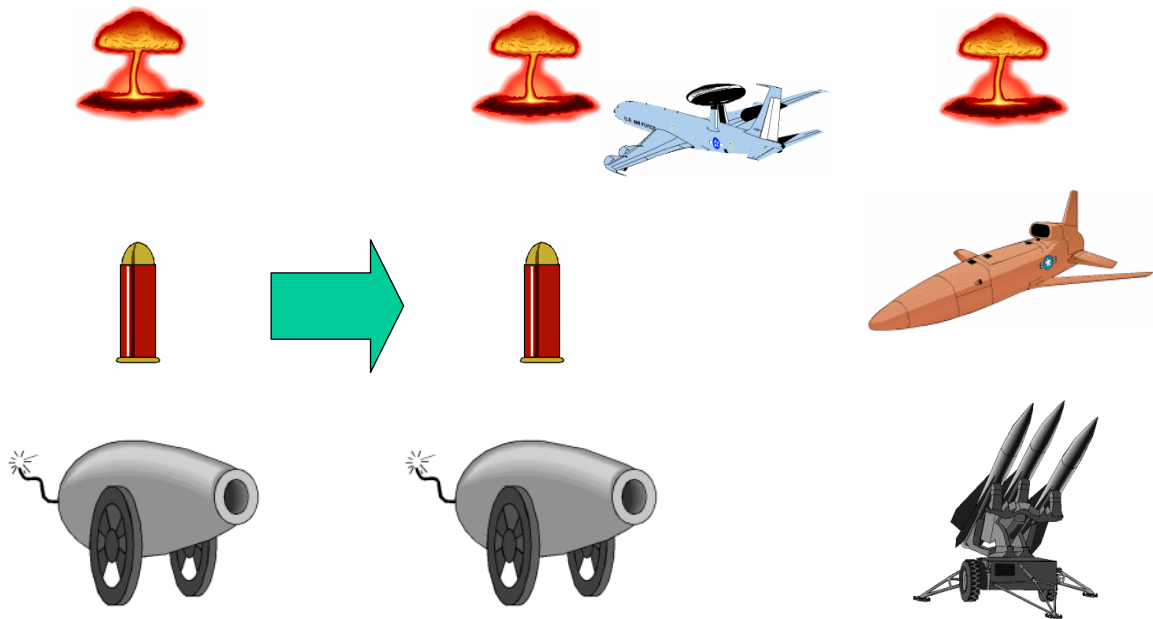
Treatment Environment and Wafer State



Outline of APC



What is APC in short



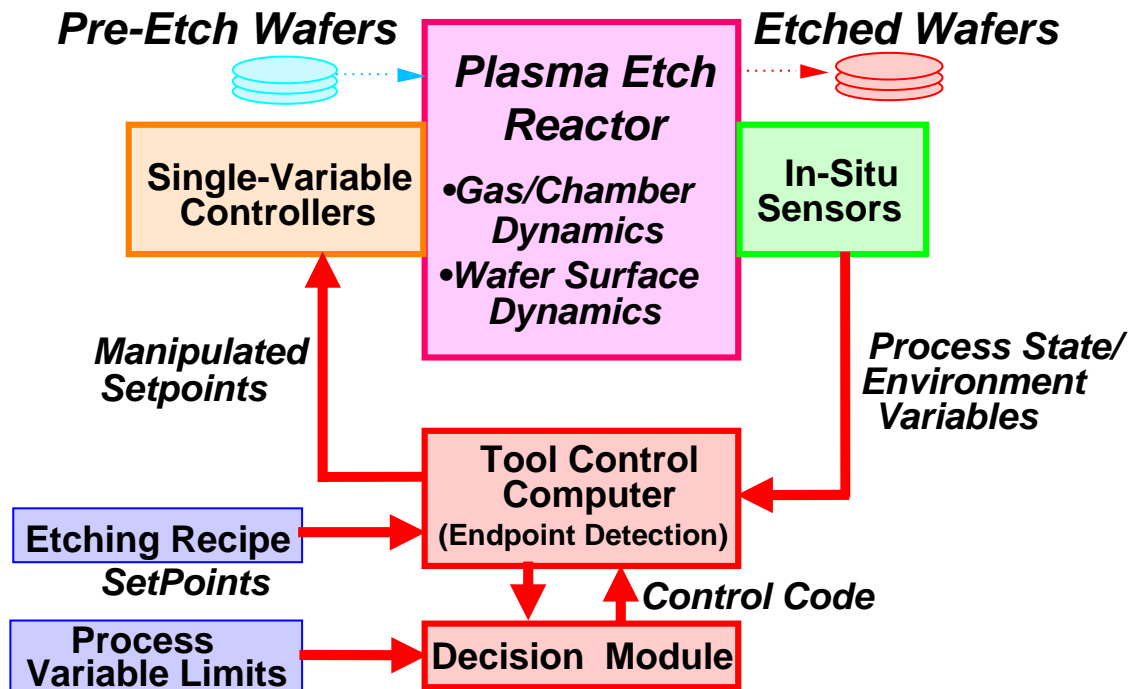
Without APC

With R to R APC

With In-Situ APC



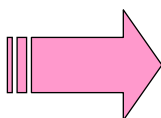
Advanced In-Situ Process Control



Indispensable Items for APC

1. Control System
 - 1) Decision module
 - 2) Control Algorithm (MIMO)
 - 3) Process Model
2. Add-on Environmental Sensors

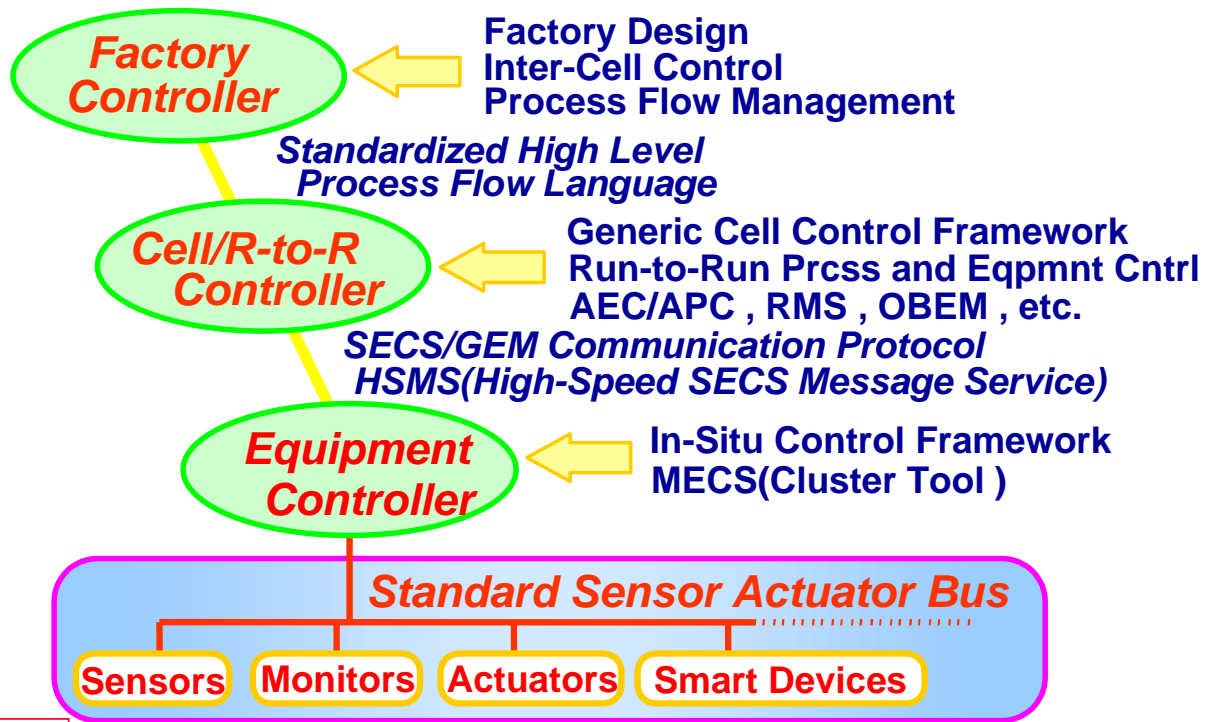
--Real time, Connection Network, Plug & Play--
3. Delay-free Actuators
4. Realization for Equipments on the market



Complex Four-level Value Chain
Sensor Suppliers, Data Integrators,
Equipment Venders and End Users



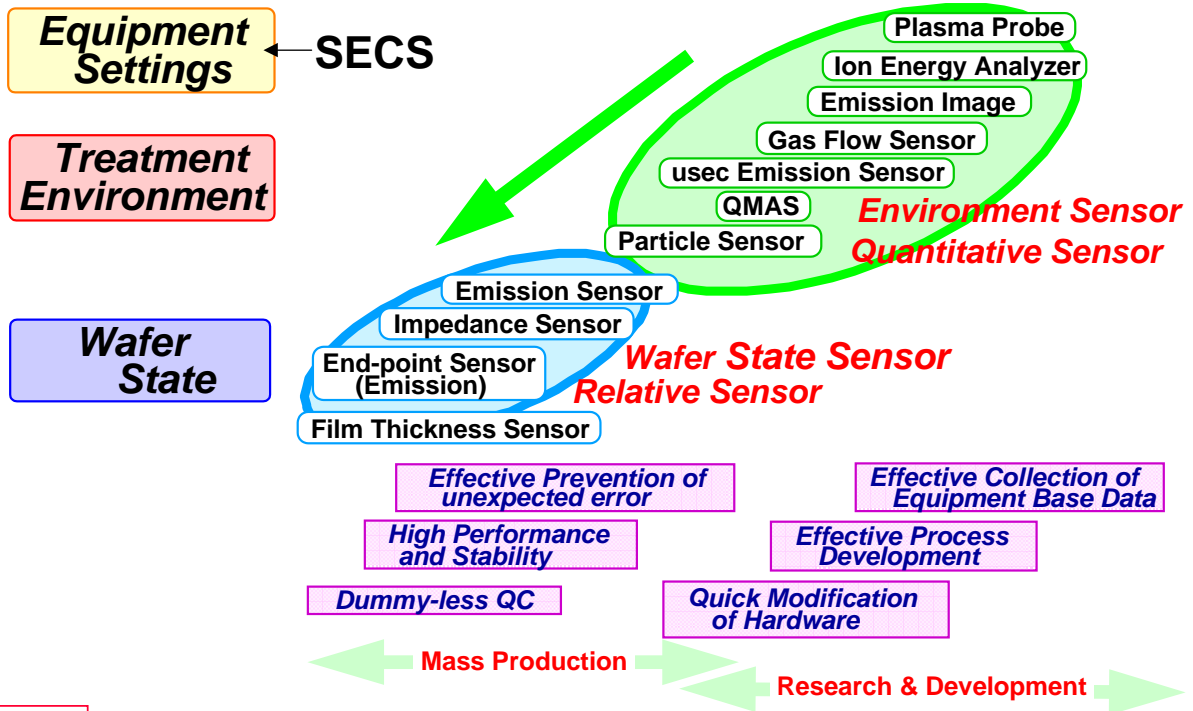
SAB Technology in Semiconductor Manufacturing



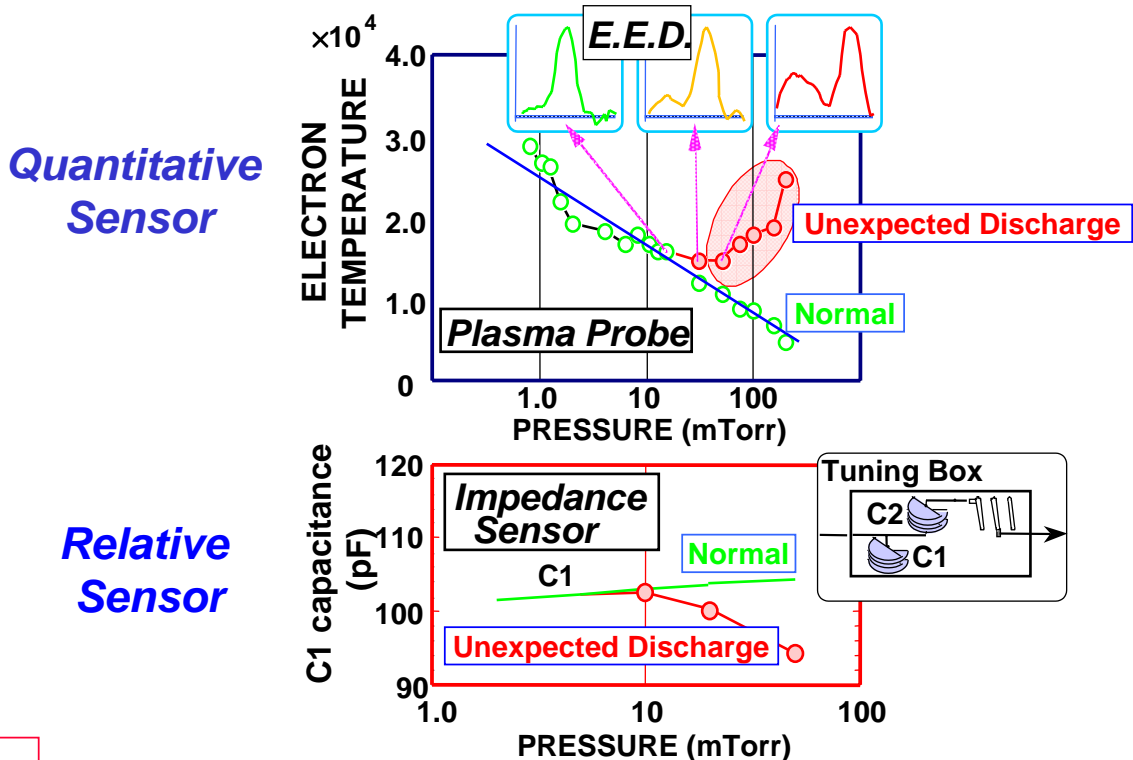
4. Sensors and Actuators for Process Control



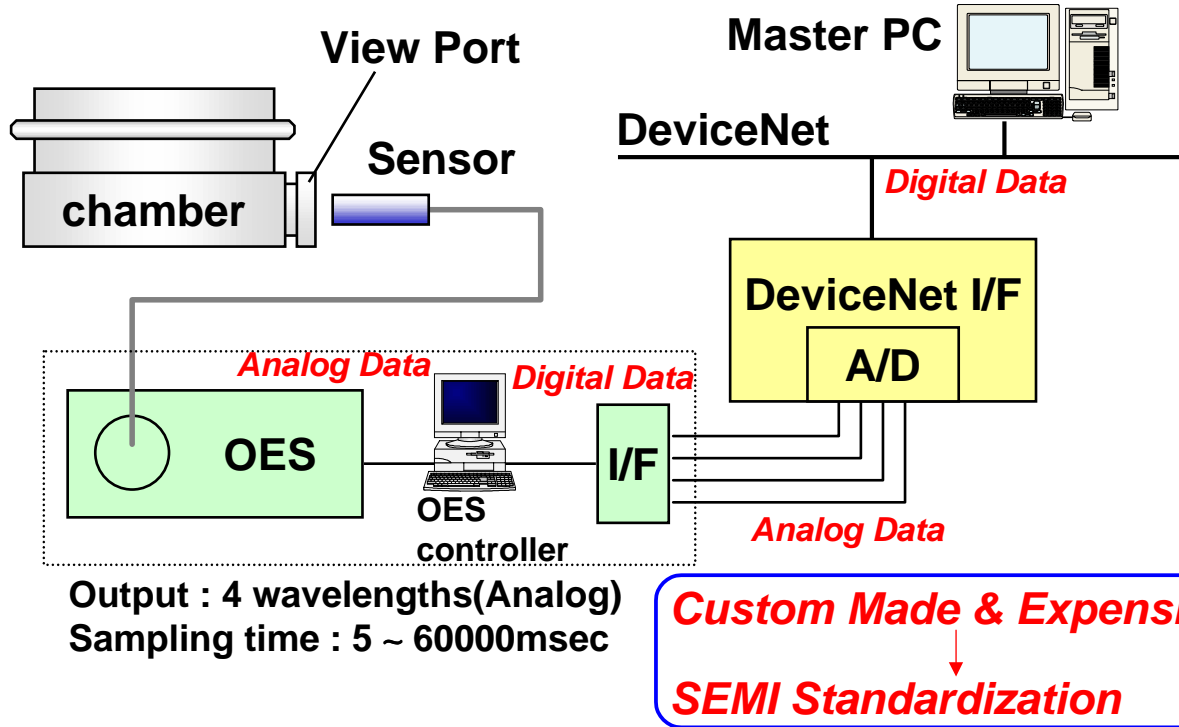
Classification of Sensors based on Application



Detection of Unexpected Discharge



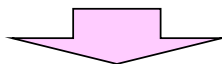
Issues for Interface of OES



Response of Actuator/Sensor

Under the present conditions:

		Quick Response
Actuator	RF	OK
	Gas	NG
Sensor	OES	OK
	QMS	NG
	RF Monitor	OK

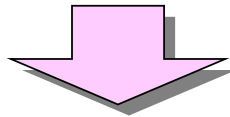


- The problem that we have to consider is how to reduce these time delay.



The Problem of QMS Sensor Delay

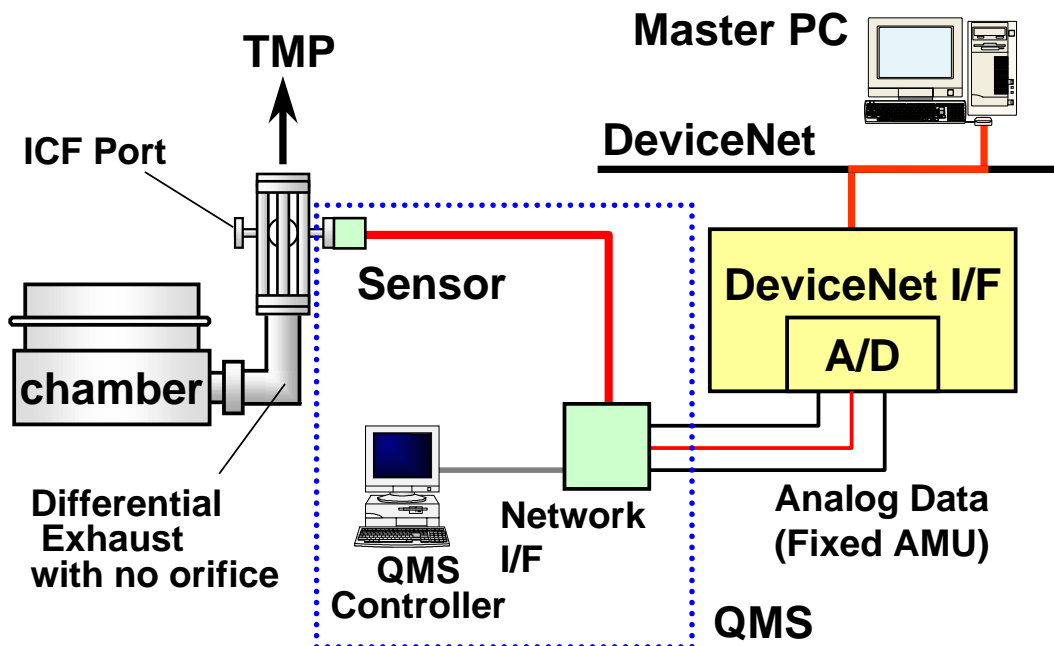
- Using Differential Exhaust
The change of monitoring data with time depends on time constant of analyzing chamber.
- The scanning time of AMU is **more than 20s.**



- Using QMS operated up to **high pressure** without differential exhaust.
- **Scanning Fixed AMU.**

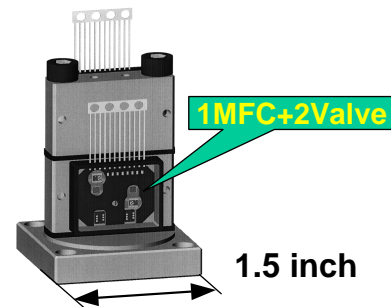


Real Time Sensor of QMS



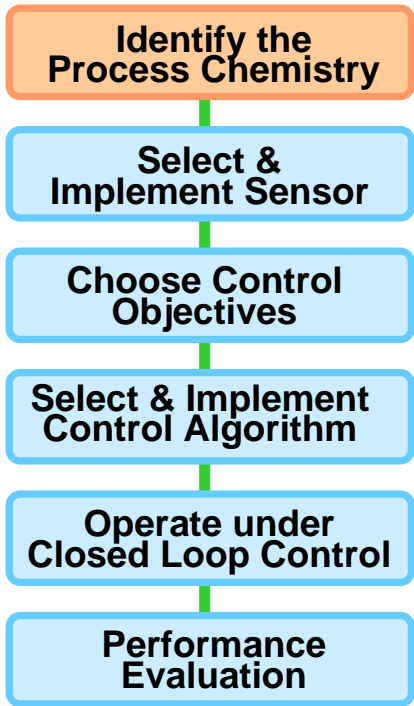
The Time Delay of Gas Transfer

- The Volume and the Conductance of the gas unit decide the time delay of gas transfer.
- To reduce the time delay of gas transfer, it is necessary to use the shorter pipe.
- The Compact Surface-Mount Gas Unit can be located near the reaction chamber and allows compact piping.

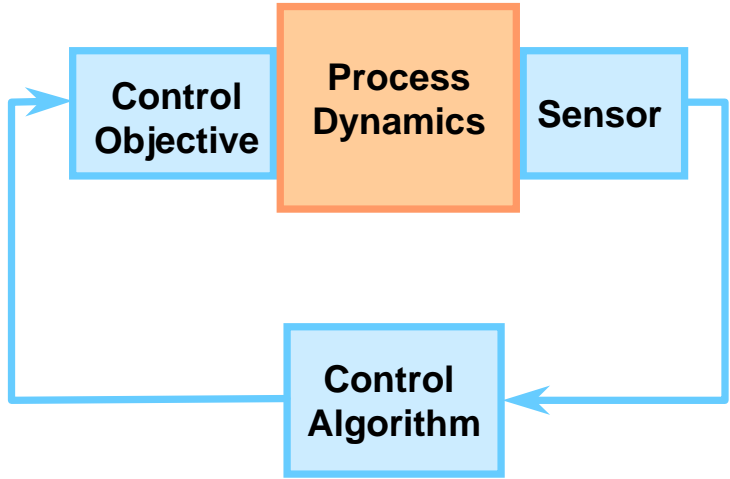


5. In-Situ APC System

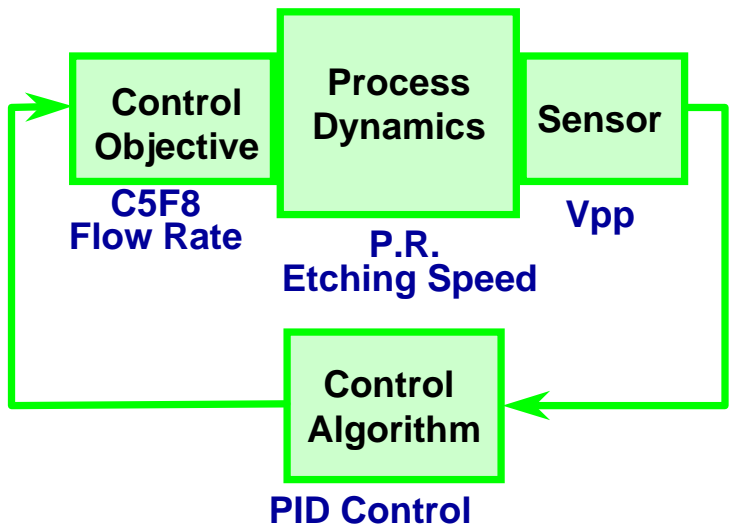
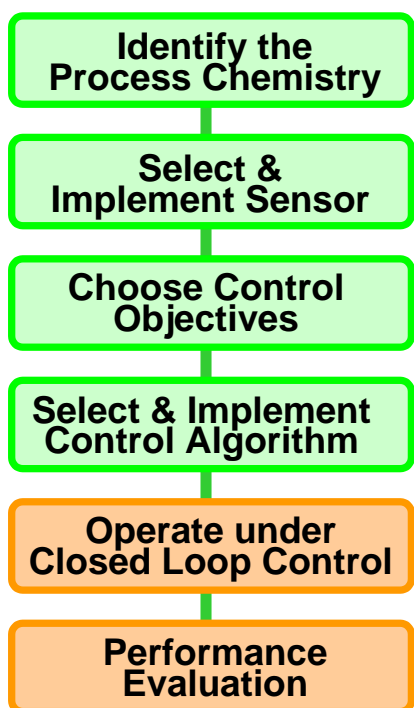




Design Procedure for In-Situ APC



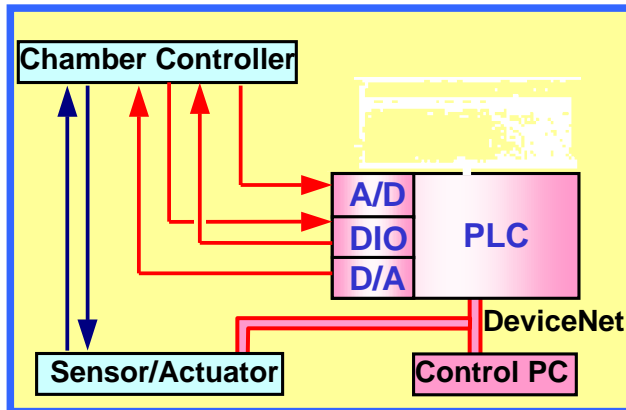
Performance of Process Control



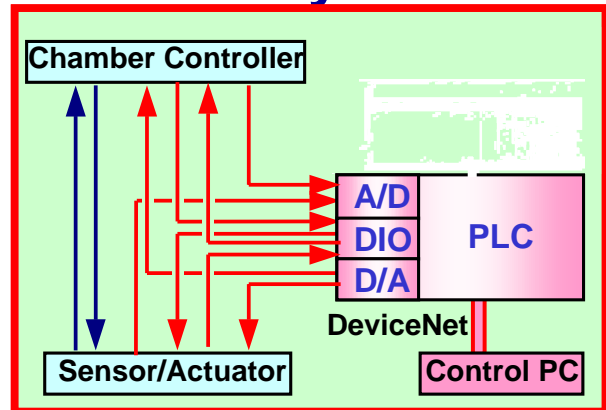
Variation of P.R. Etching Speed
 $\pm 9\% \rightarrow \pm 4\%$



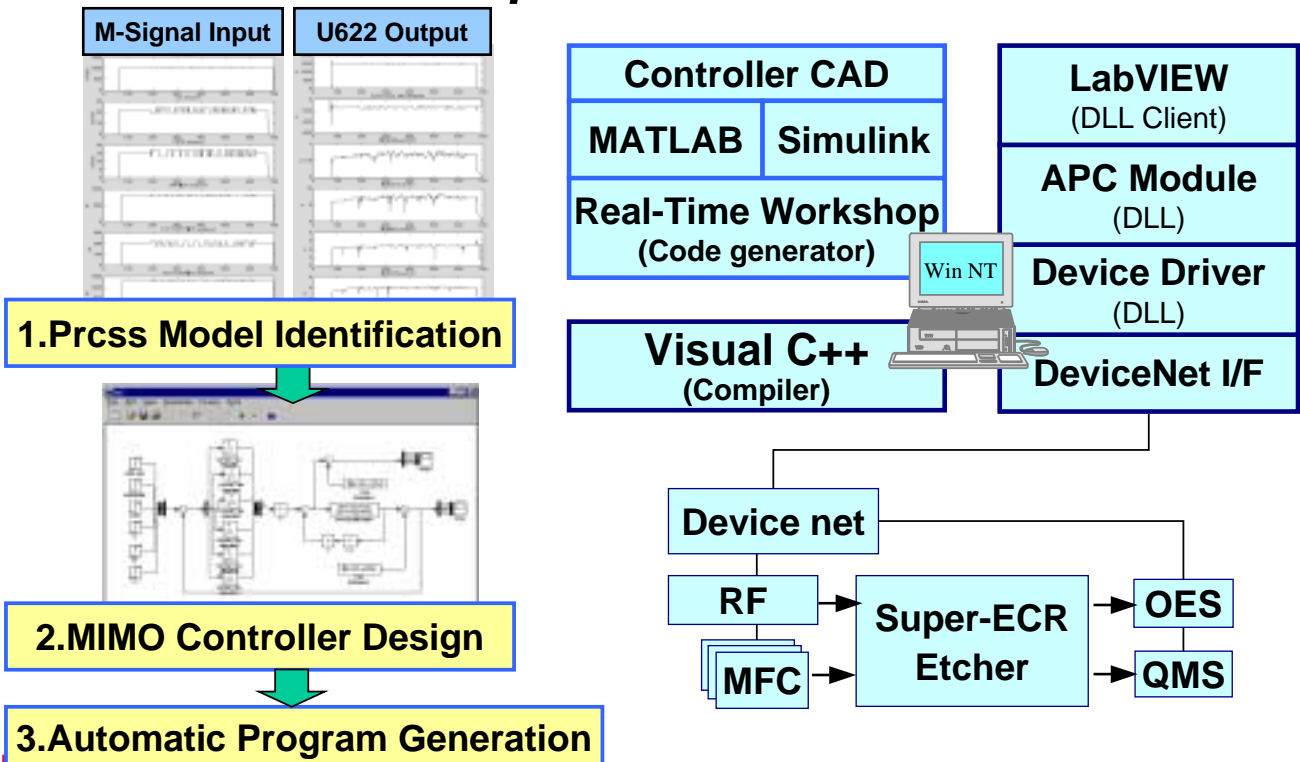
TEST Equipment for APC Demonstration



the Equipment (U622) on the Market with APC System



On-Site Development of In-Situ Controller



6. Current Status of APC

from IMA “NIST ATP Program Overview”

1) Characterizing Variability Tasks

2) Reducing Variability Tasks

3) System Integration Tasks

4) Economic Benefits at IC Manufacturers



Characterizing Variability Tasks *(from IMA “NIST ATP Program Overview”)*

1.1 Analyzing Variability in the Patterning Process

Variance components and sources

1.2 Lithography Cluster Tool Variation

CD error budget model for 0.18mm

1.3 Equipmnt and Behavioral Modeling of Plasma Etching

Virtual Plasma Equipment Model (VPEM) and
behavioral models

1.4 Data Mining of Multivariate Time Series in Snsr Data

1.5 Insitu Spectral Reflectometry for Process Monitoring

1.6 Insitu Scatterometry for Deep-UV Process Control

**1.7 In-line CD Metrology via Elctrcl Linewidth
Measurement**



Reducing Variability Tasks

2.1 Intelligent Control of the Lithography Cluster

Implement resist thickness, PEB, and exposure dose control

2.2 Small-spot RFTIR for R2R Deep UV Process Control

Develop with On-line Technologies and incorporate in R2R control loop

2.3 R2R Control of Lithography Using High-speed Simulation

2.4 Diode-laser Sensors or Real-time Control

2.5 FTIR Downstream Gas Analysis for Plasma Etchers

2.6 Model-based Control of Plasma Etching

2.7 Real-time Monitoring and Control of Plasma Etching

2.8 Feed-forward Recipe Adjustment for CD Control



System Integration Tasks

3.1 Factory Automation & Process Control Infrastructure

Network, computers, database, and control platforms
APC Framework

3.2 Equipment Integration

Equipment interfaces to APC FW
Wafer level tracking capability
Existing sensor and tool state information

3.3 Sensor and Metrology Integration

Off-line metrology tools
In-line sensors and metrology (FTIR, reflectometer, diode laser)
Metrology database for real-time sensor signals

3.4 Data Analysis & Control Integration

R2R and FDC algorithms
Data analysis methods



Economic Benefits at Other IC Manufacturers (1)

(from IMA “NIST ATP Program Overview”)

IBM: Fault Detection/Classification Project

**IBM invested \$2 million in APC and saved
\$20 million**

**Improved time-to-market 50%, reduced
unscheduled downtime by 20%, and
tripled the time between preventative
maintenance**



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Economic Benefits at Other IC Manufacturers (2)

AMD: Gate CD Control project

**Reduced gate CD standard deviation by 48%
using feedback lot-to-lot BARC etch time
adjustments**

Motorola: Active CD Control (ACDC) Project

**Increased revenue \$2 million / week / 1K
starts by adjusting exposure dose lot-to-
lot (67% Cpk increase)**



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7. Conclusion



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For the near future Semiconductor production APC is dispensable. This Technology has been studied for 10 years and is nearly at the step of application.

- (1) APC is able to reduce the period of yield ramp and lost of yield.**
- (2) APC needs flexible control system, add-on quick response sensors and delay free actuators.**
- (3) Using feedback controller, variation of Si etching speed is reduced from $\pm 9\%$ to $\pm 4\%$.**
- (4) Several NA IC manufacturers could get economic benefits by using APC.**



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