GaN on Si Manufacturing Excellency in CMOS Foundry Fab

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Agenda

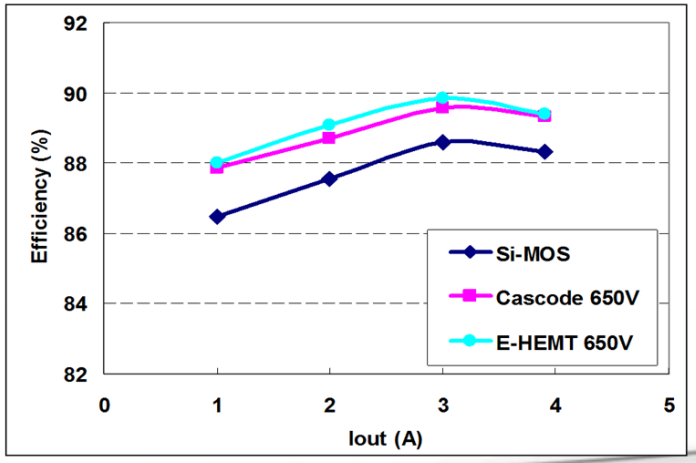
1. GaN Device Offering
2. GaN Production
3. GaN MoCVD Manufacturability
4. Yield Improvement
5. Summary

GaN device offering

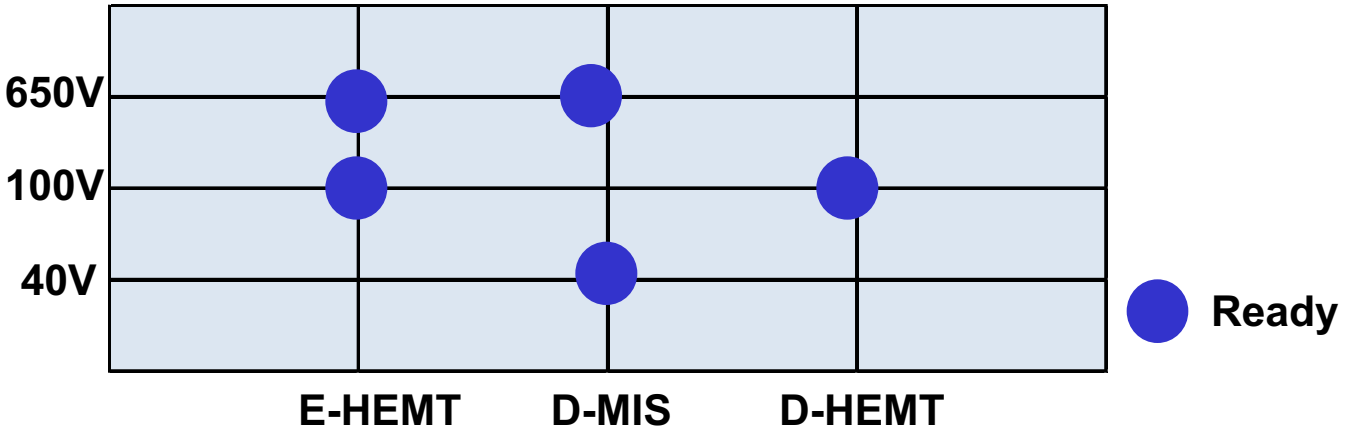
- **GaN superiority**

Physical Properties	(Si)	(SiC)	(GaN)
Bandgap (eV)	1.11	3.2	3.4
Thermal Cond. (W/cm·K)	1.5	3.5	1.5
Breakdown E-field (MV/cm)	0.3	2.5	2.5~3
Saturation velocity ($\times 10^7$cm/s)	1.0	2.0	2.5
e Mobility ($cm^2/V{\cdot}s$)	1300	300-900	2000
Heterojunction	Si/Ge	No	AlGaN/ GaN

- **Good efficiency on system operation**



GaN device offering



Technology	Function	Application
650V E-HEMT	AC-DC, DC-AC	Adaptor, Motor controller, PV inverter
650V D-MIS	AC-DC, DC-AC	Adaptor, Motor controller, PV inverter
100V E-HEMT	DC-DC	IBC, Server, Notebook
100V D-HEMT	RF-PA	WiFi, Base station
40V D-MIS	RF-switch	WiFi, Base station

- **GaN production since 2015**
- **Engaged 15 customers/ 53 NTO**
- **>90% of GaN common tools are shared with CMOS manufacturing**

GaN device offering

- **Passed MIL-STD750/JEDEC standard reliability qualification**
  - **MIL-STD750 requirement for HTRB and HTGB**
  - **JEDEC requirement for PCT, T/C, HTS, and THB**

Item	Stress Condition	Pass/Fail criteria	Sample Size	Merit Number	Result
HTRB (High Temperature Reverse Bias) or SSRB (Steady-State Reverse Bias)	150C, Vds=520V 168 hrs (1 lot to 1000 hrs)	Idlin deg.<30%, Ioff<1E-9A/um @520V, Vt shift: -0.75V~+1V	77ea per lot, total 3 lots	1 fail/77ea per lot 2 fails/231ea (3 lots)	Pass (0 fail/231ea)
HTGB (High Temperature Gate Bias) or SSGB (Steady-State Gate Bias)	150C, Vgs=6V 168 hrs (1 lot to 1000 hrs)				Pass (0 fail/231ea)
PCT (Pressure Cooker Test) or AC (Autoclave)	121C/100% RH 96 hrs				Pass (0 fail/231ea)
T/C (Temperature Cycling)	-65C~150C 500 cycles				Pass (0 fail/231ea)
HTS (High Temperature Stress)	150C 1000 hrs				Pass (0 fail/231ea)
THB (Thermal Huminity Bias)	85C, 85% RH, Vds=100V 1000 hrs				Pass (0 fail/231ea)

* Device width=120k um; package type: TO220

Production in tsmc

Total Clean Room Space (m^2)
C/R area: 9,800 m^2

Technology Capability
0.45um/0.5um/0.6um/0.8um/1.0um
/1.2um/2.0um/3.0um

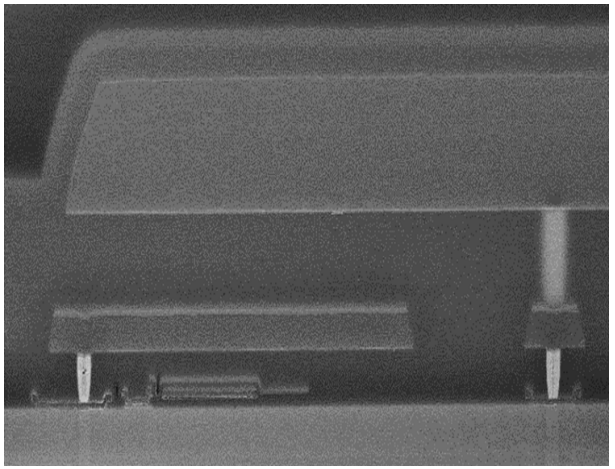
Lithography
i-line stepper, DUV stepper

6" Fab Key Milestones

• 3.0um/1.2um/1.0um production	1990
• 0.8um production	1992
• 0.6um production	1994
• 0.5um/0.45um production	1995
• 1.0/0.6/0.5um HV production	2001
• 0.6um BCD production	2006
• 1.0/0.5um MEMS production	2007
• GaN R&D	2011
• GaN production	2015

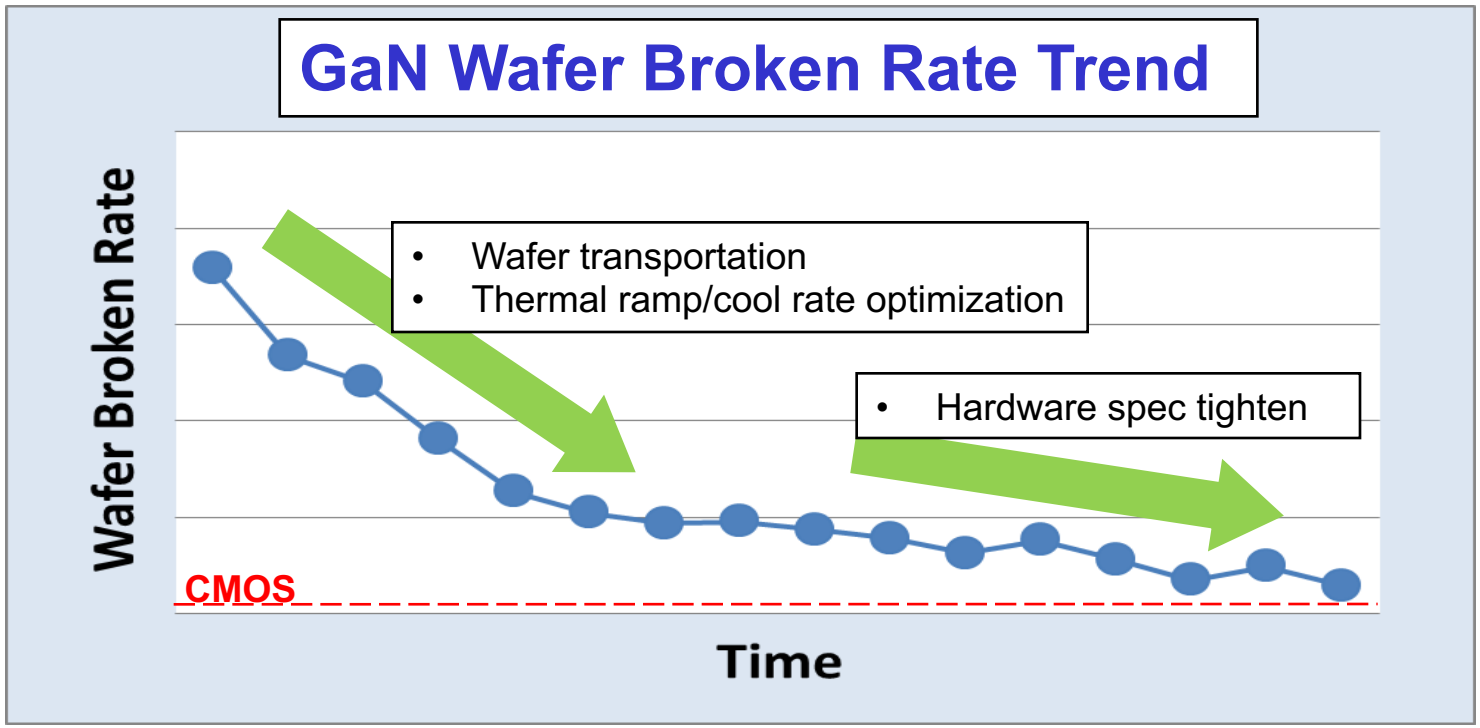
Production Challenges

- Complex epitaxy GaN deposition
- Warpage/Fragile wafer handling
- 1.5X thick substrate
- Ultra thick metal
- CMOS compatible metallization
- Contamination control



GaN Production

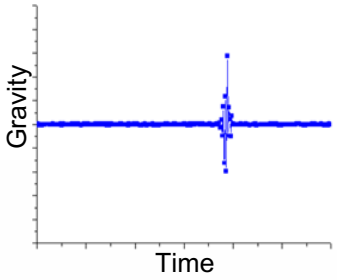
- **Minimize vibration during transportation and process**



Vibration sensor

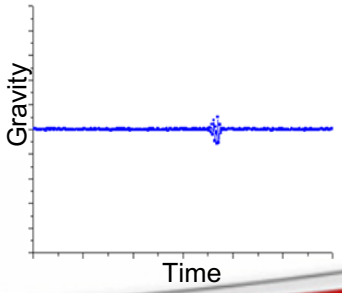
- **Wireless**
- **Real time monitor**

before action



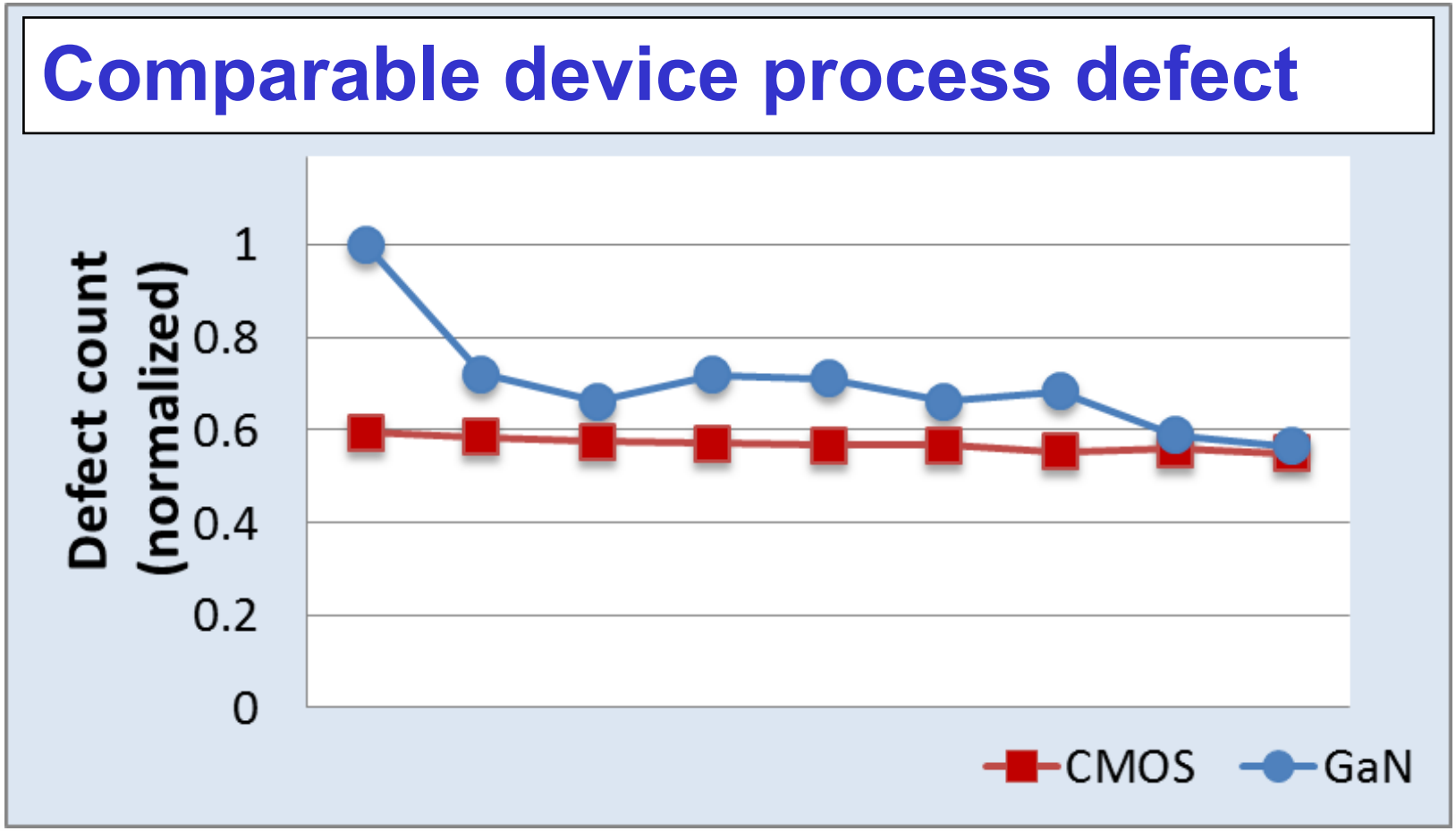
Action

after action



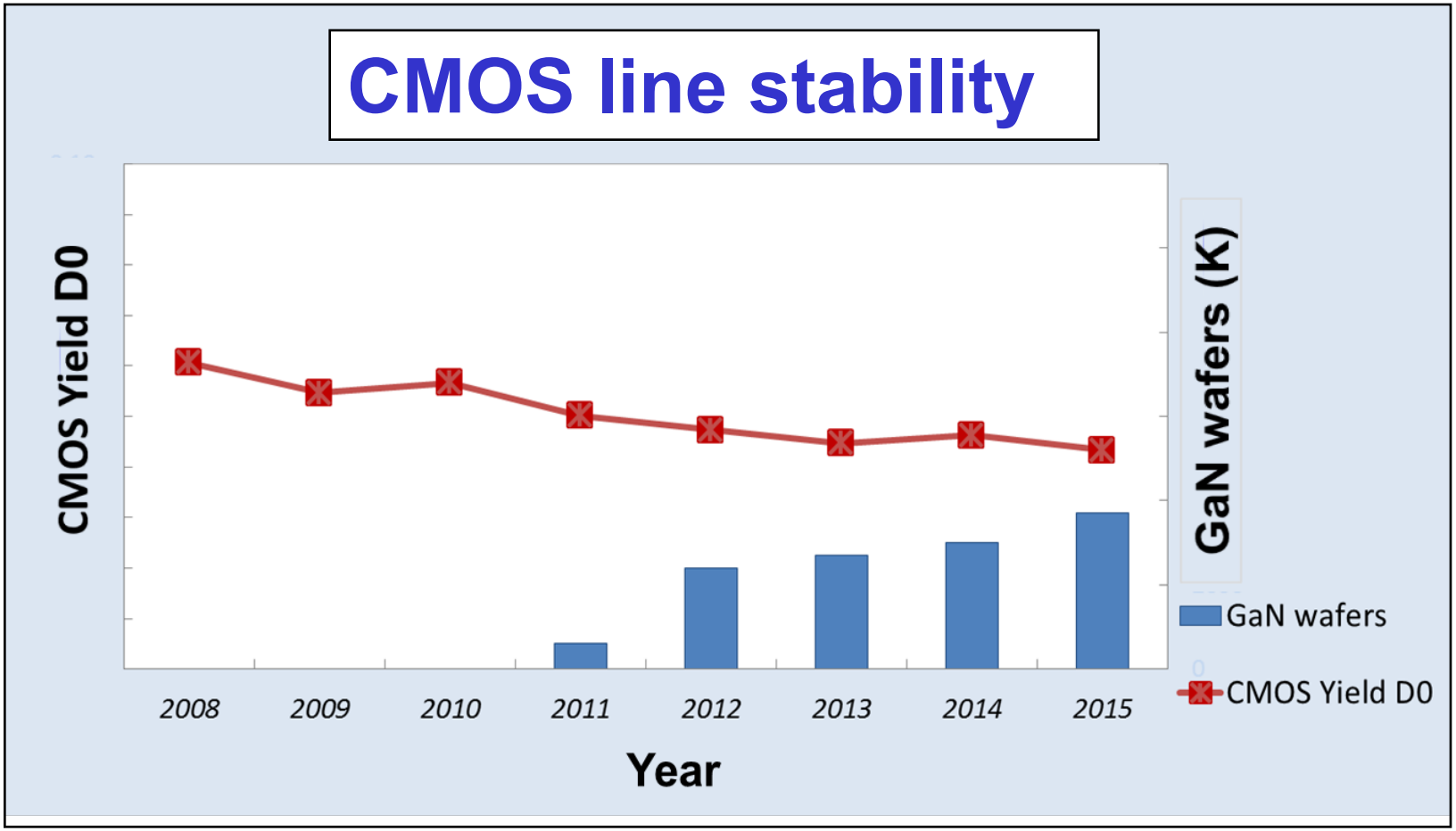
GaN Production

- >90% common tools with CMOS



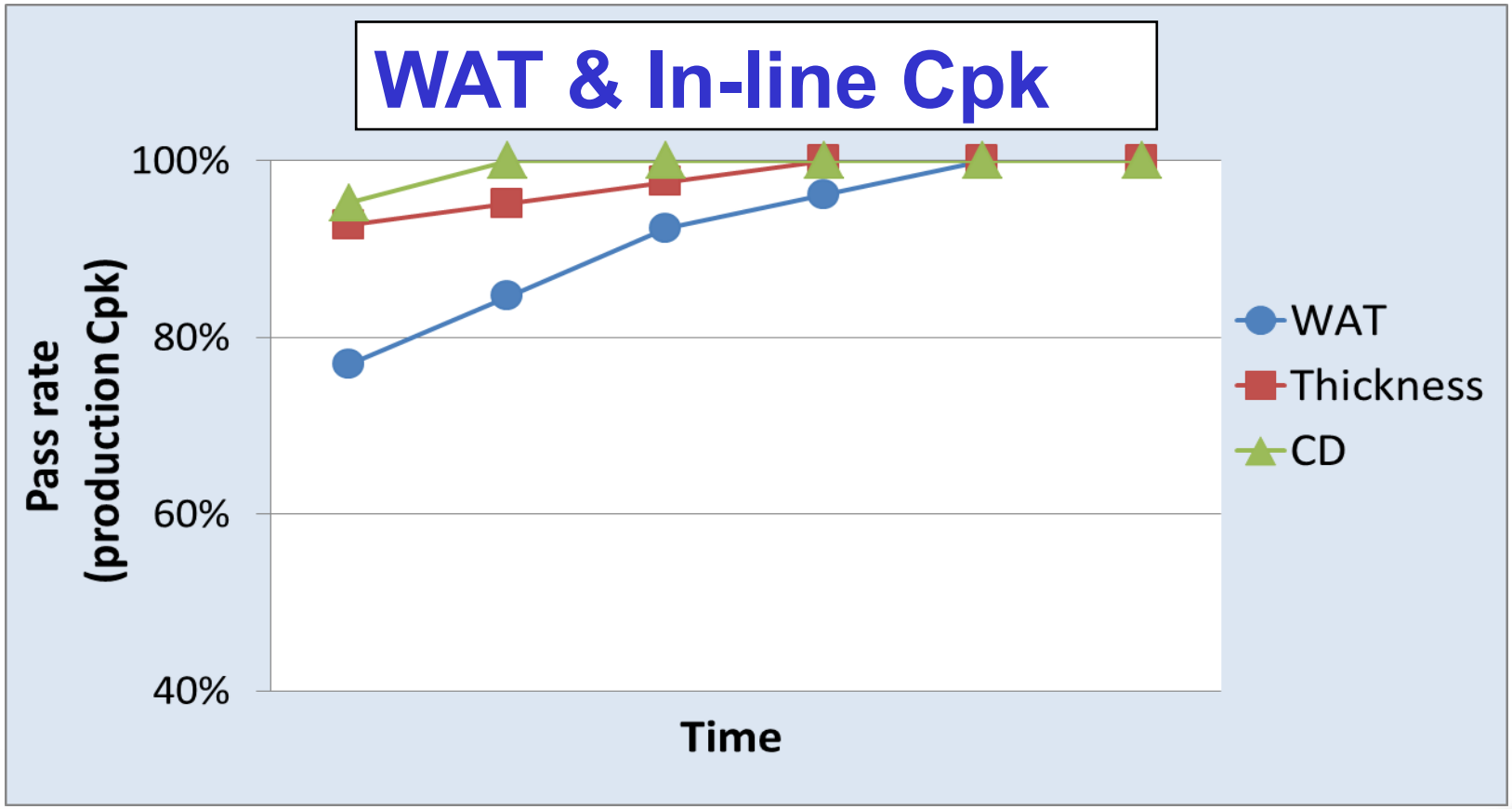
GaN Production

- GaN didn't contaminate CMOS process



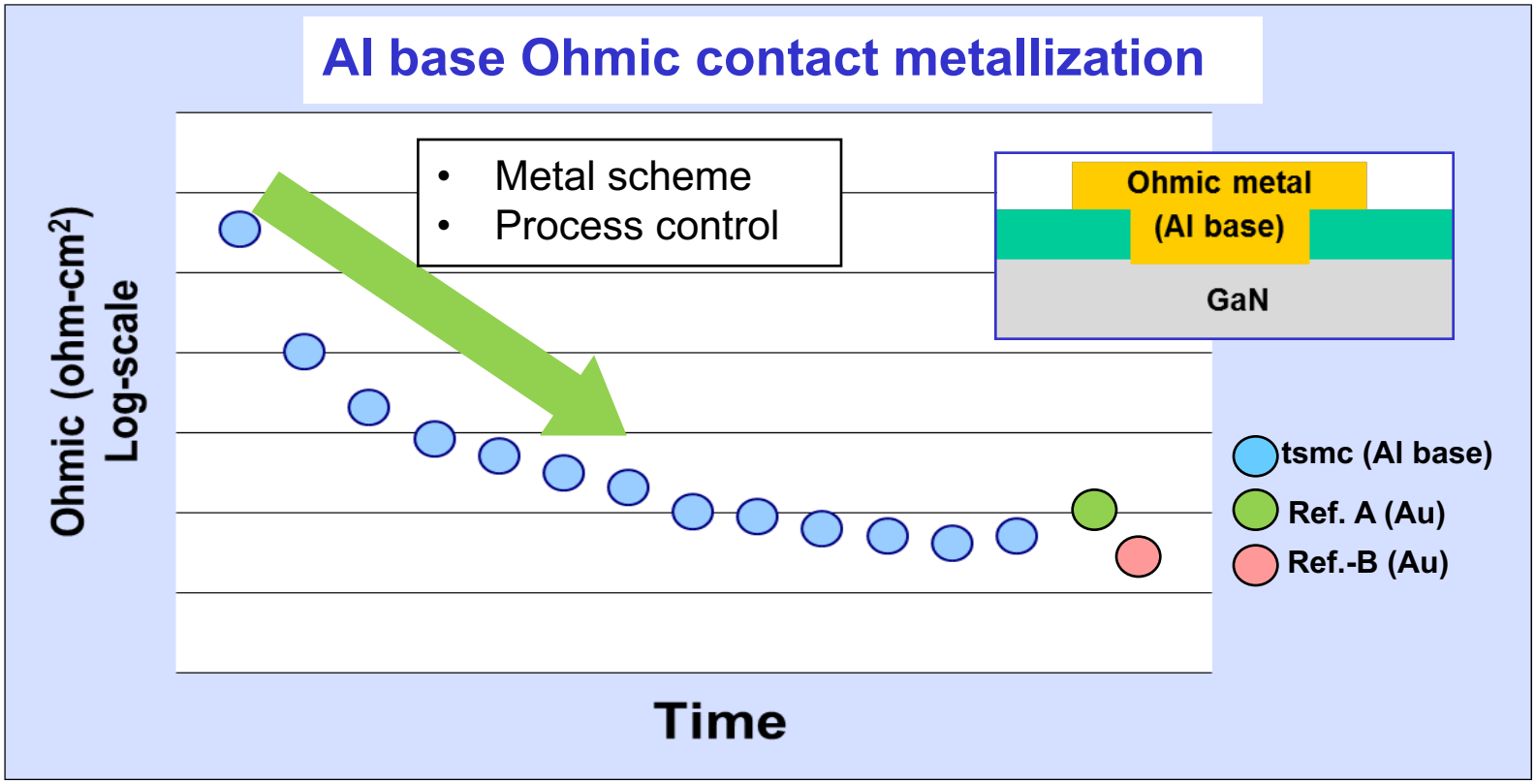
GaN Production

- 100% of WAT & In-line items passed production Cpk criteria (Cpk > 1.33)



GaN Production

- **Comparable contact Rc with Au based metallization**

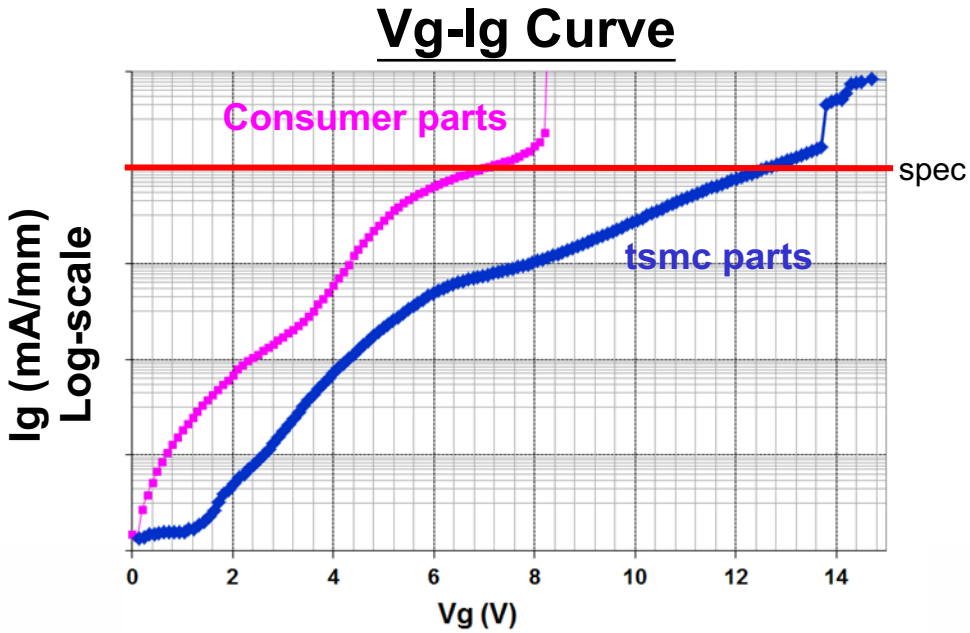


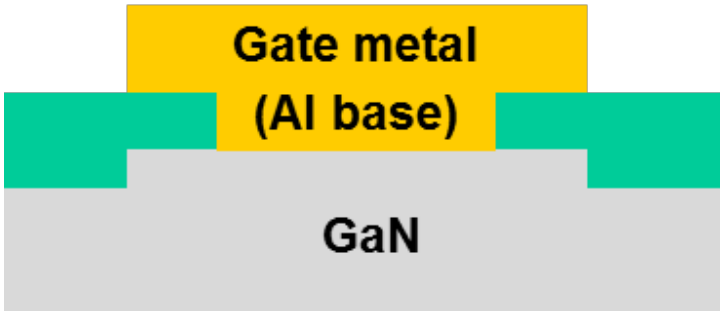
Ref.-A: Low-resistance and high-reflectance Ni/Ag/Ru/Ni/Au ohmic contact on p-type GaN, APPLIED PHYSICS LETTERS VOLUME 85, NUMBER 19 8 NOVEMBER 2004

Ref.-B: Electrical, thermal, and microstructural characteristics of Ti/Al/Ti/Au multilayer Ohmic contacts to n-type GaN J. Appl. Phys. 93, 1087 (2003)

Production in tsmc

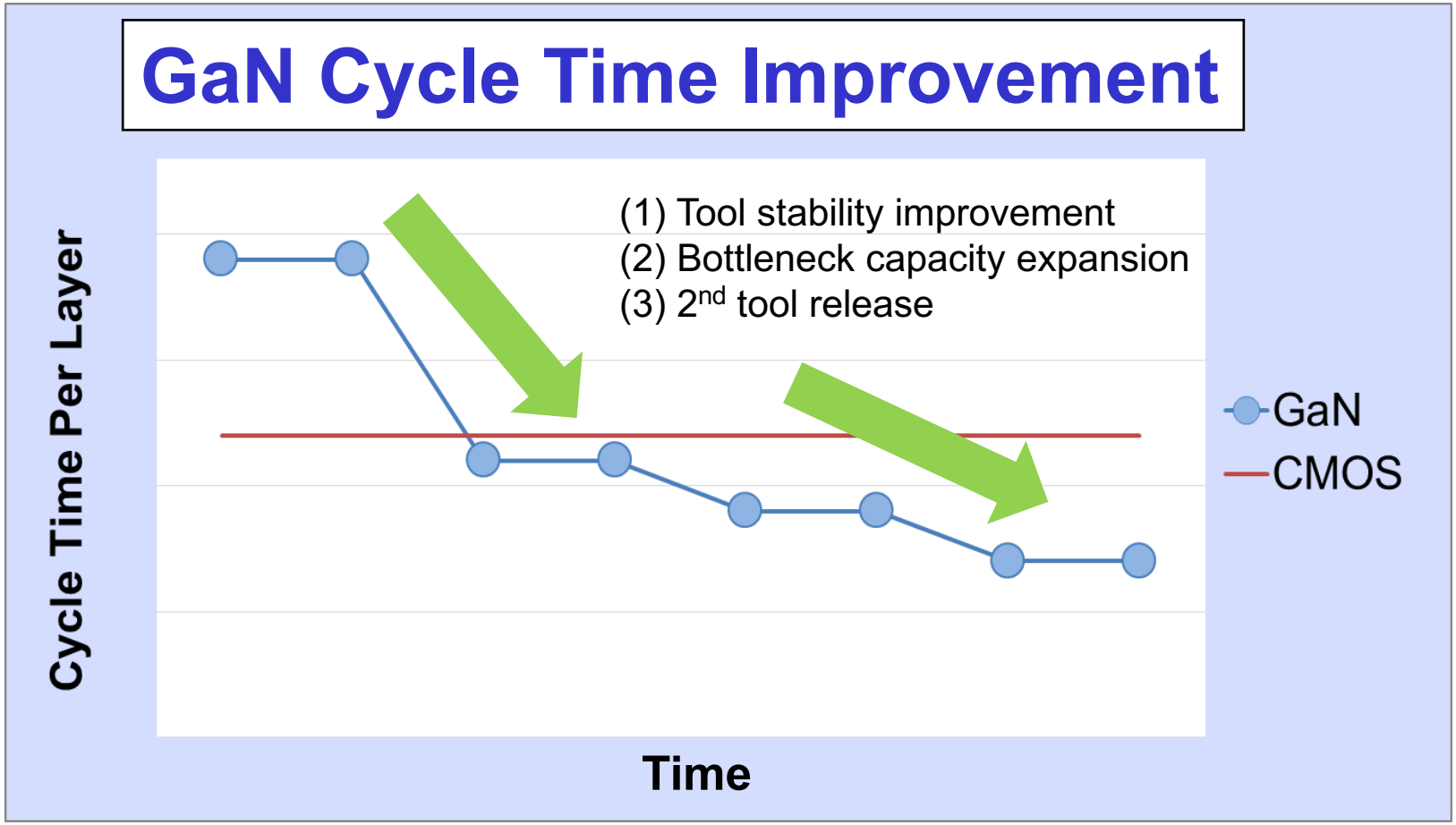
- **Al based gate metallization with low gate leakage and wider Vg operation range.**
  - **Interface control**
  - **Electrical field optimization**
- **Offer Vg=7V operation (2016/Q4)**





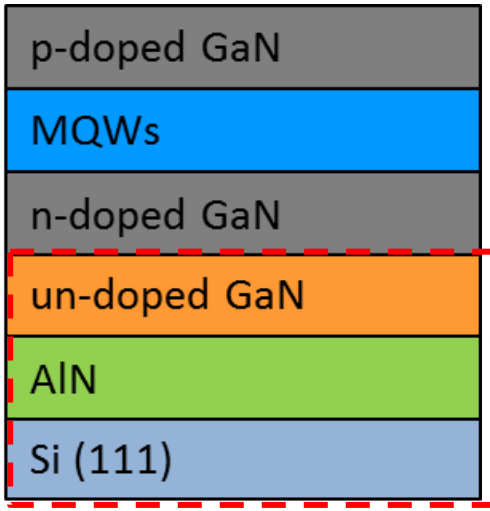
GaN Production

- **Excellent Cycle Time**

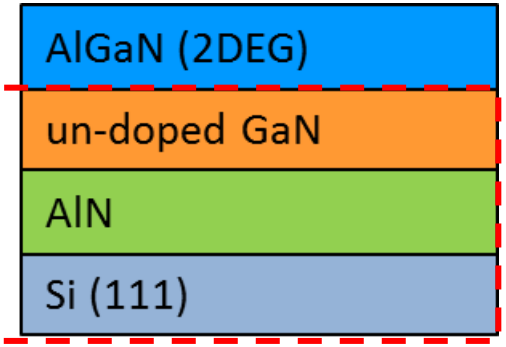


GaN MoCVD Production

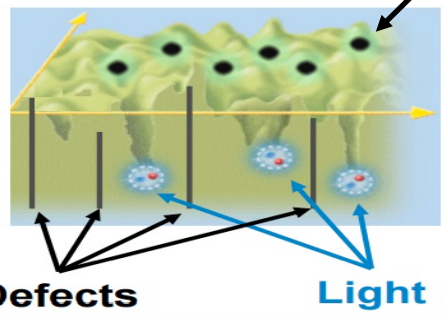
LED



Power Device



Similar scheme w/i different challenges/requirements



Issue:

1. Quantum efficiency
2. Light extraction

Challenges:

1. **Particle**
2. **Wafer bow**
3. **Dislocation density**

GaN MoCVD Production

- **Hardware modification**
  - Automation handling
  - H/W weakness & tighten spec
- **Software optimization**
  - Big data interactive correlation
  - Heating system control
- **Key components specification**
  - Pumping system design
  - Consumable parts quality control
- **Recipe optimization**
  - Critical layers optimization
  - Stress control

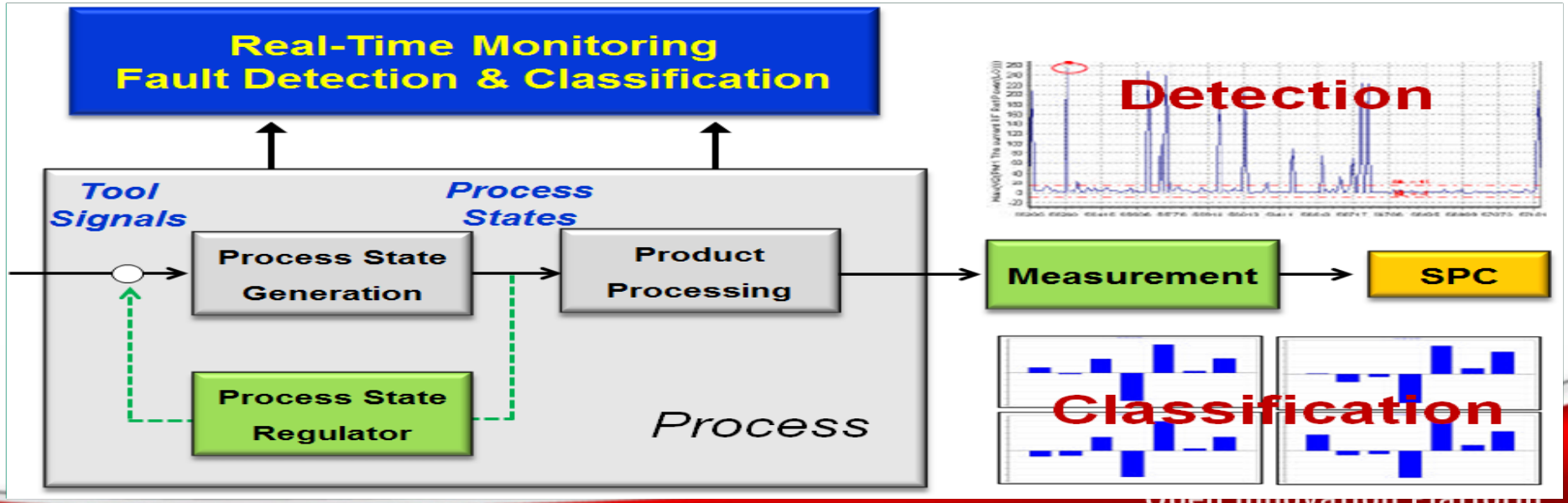
GaN MoCVD Production

Characterization Technique

- **Non-destructive**
  - Crystal quality: HR X-ray diffraction
  - Wafer bow: In-situ monitor curvature, Ex-situ optical measurement
  - Surface inspection: Candela optical metrology
- **Destructive**
  - AFM: Surface morphology
  - SIMS: Profile of composition, impurity concentration
  - TEM: Interface quality, dislocation density

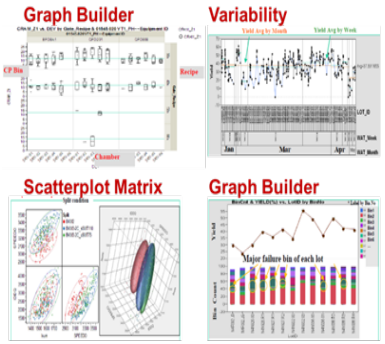
Fault Detection and Classification

- **The analysis of process data taken during a process run to determine:**
  - If the process is running normally or not (i.e. is a fault detected)
  - The classification of faults for their source or cause
- **Prevent excursion events by early detecting and warning**
- **Fault classification enables automatic fault identification**



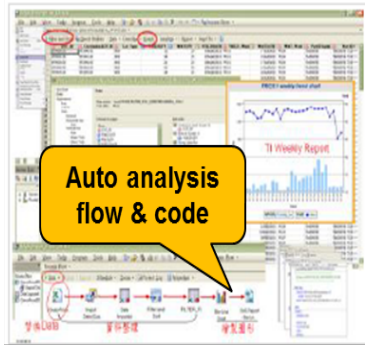
iEDA (Interactive Engineering Data Analysis)

- SAS/graphic statistical software
- Easy access, URD & IT skills not required
  > 90% reporting time saving

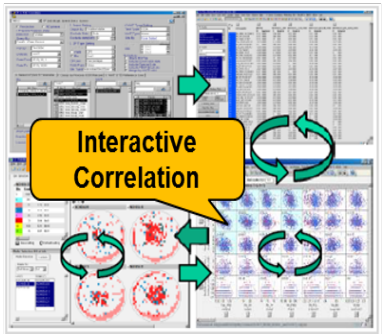


Statistical Analysis

DIY Auto-Report

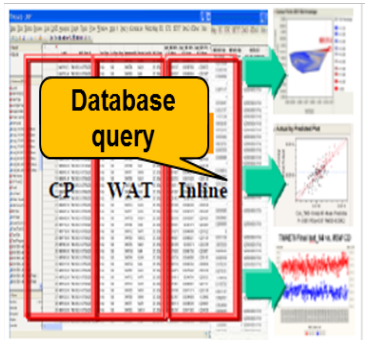


iEDA



Interactive Correlation (w/i wafer map)

All-in-One Data Query

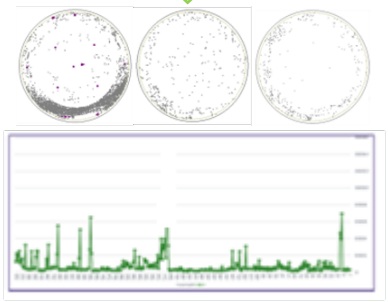


- Wafer map correlation
  > Days to hours CP yield analysis
- Data access
  > 10X data access speed

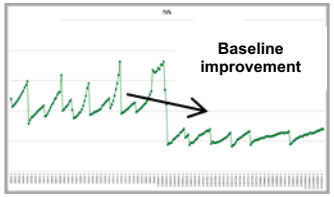
Particle Control

Particle control with FDC and iEDA system

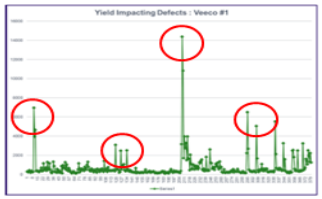
Step1: Wafer handling



Step2: Chamber Condition control

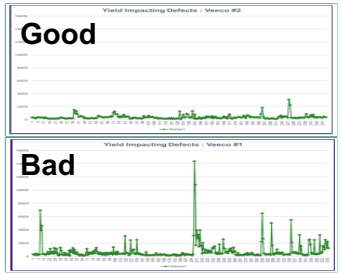


Step3: Particle excursion detection

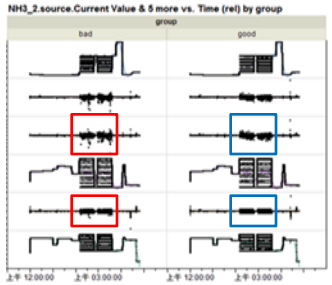


✓ SPC excursion

Step4: Good –to-bad lot comparison



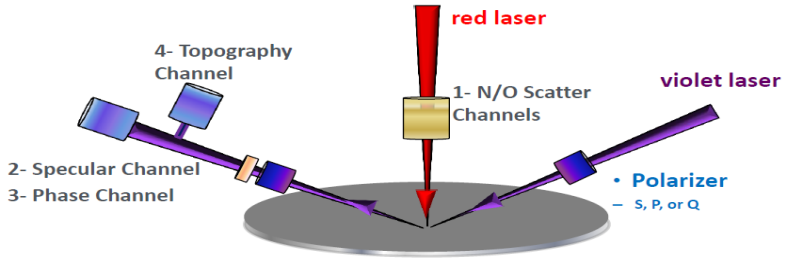
Step5: H/W excursion detection



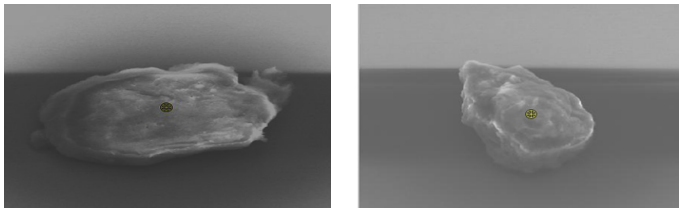
✓ FDC correlation

Particle define

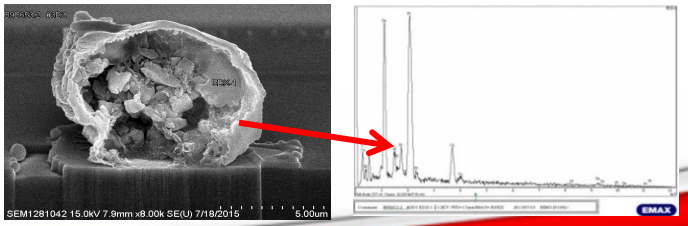
Candela (Distribution)



SEM (Type)

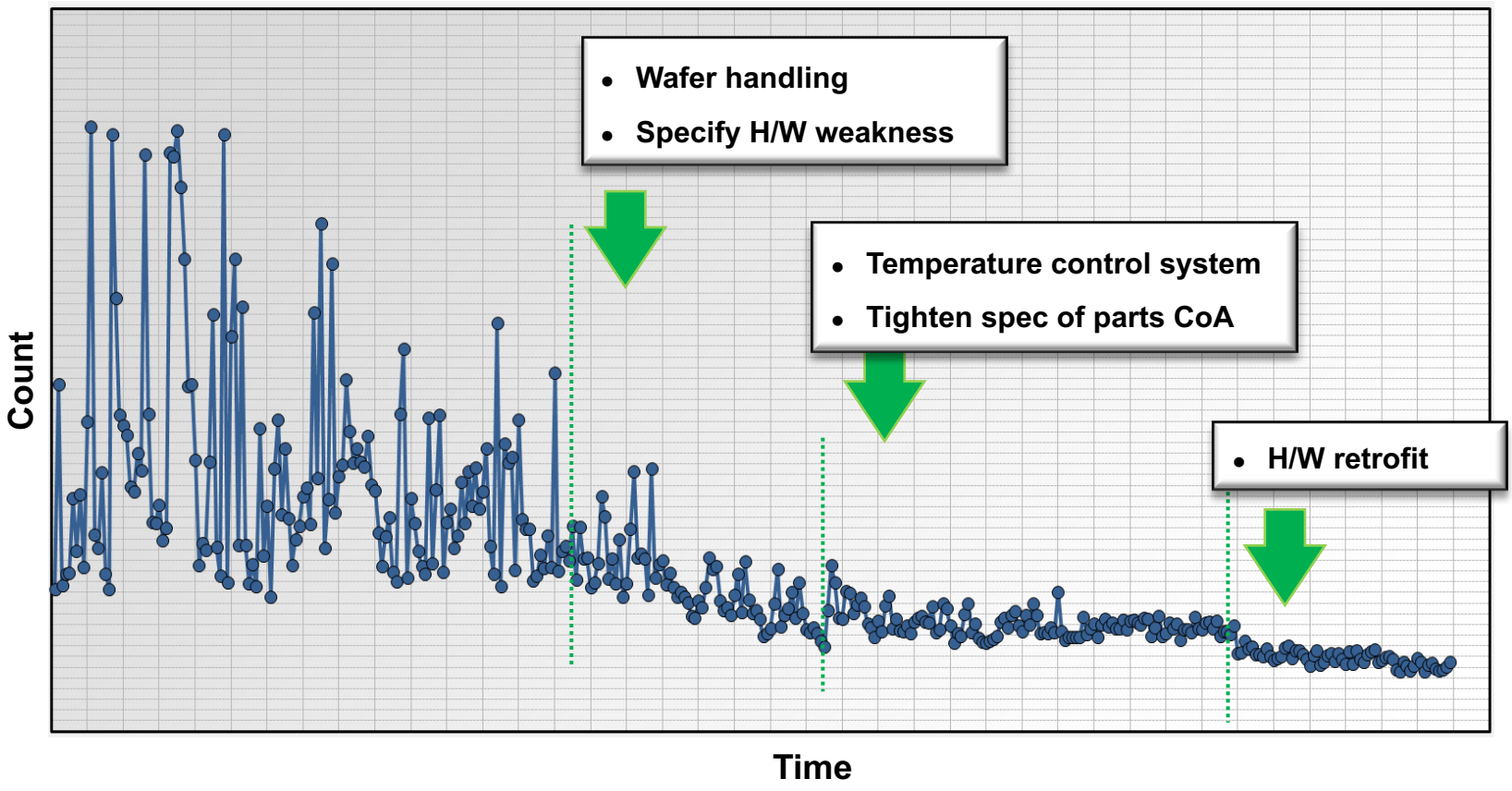


PFA analysis



Particle Control

- Particle trend chart



Wafer Bow Control

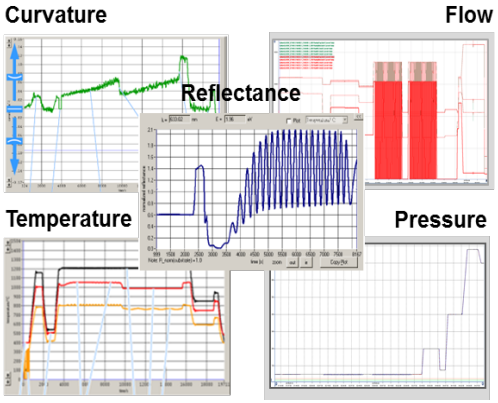
- **Bow control with FDC and iEDA system**

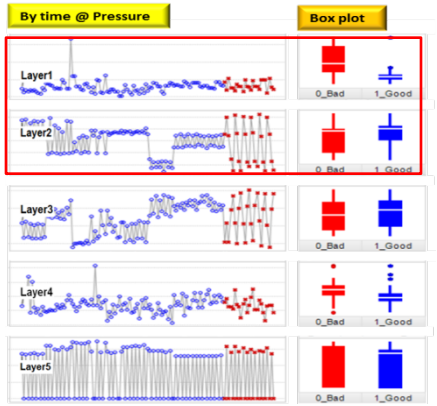
Step1:
FDC & SPC empowered by in-situ metrology

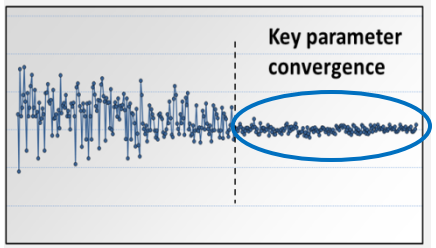
Step2:
Good –to-bad lot comparison

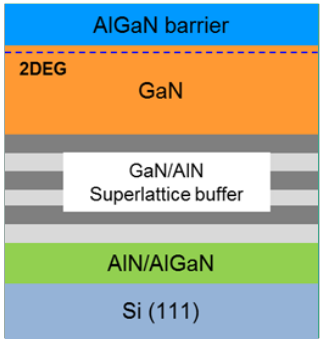
Step3:
Tighten key parameters control

Step4:
Recipe structure optimization

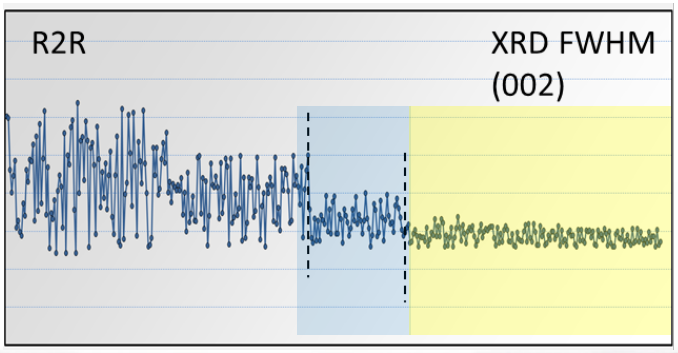


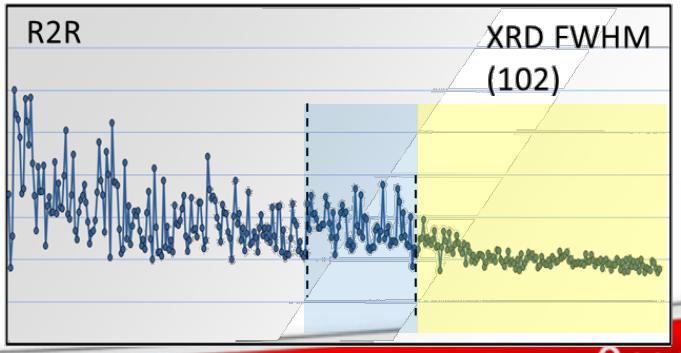






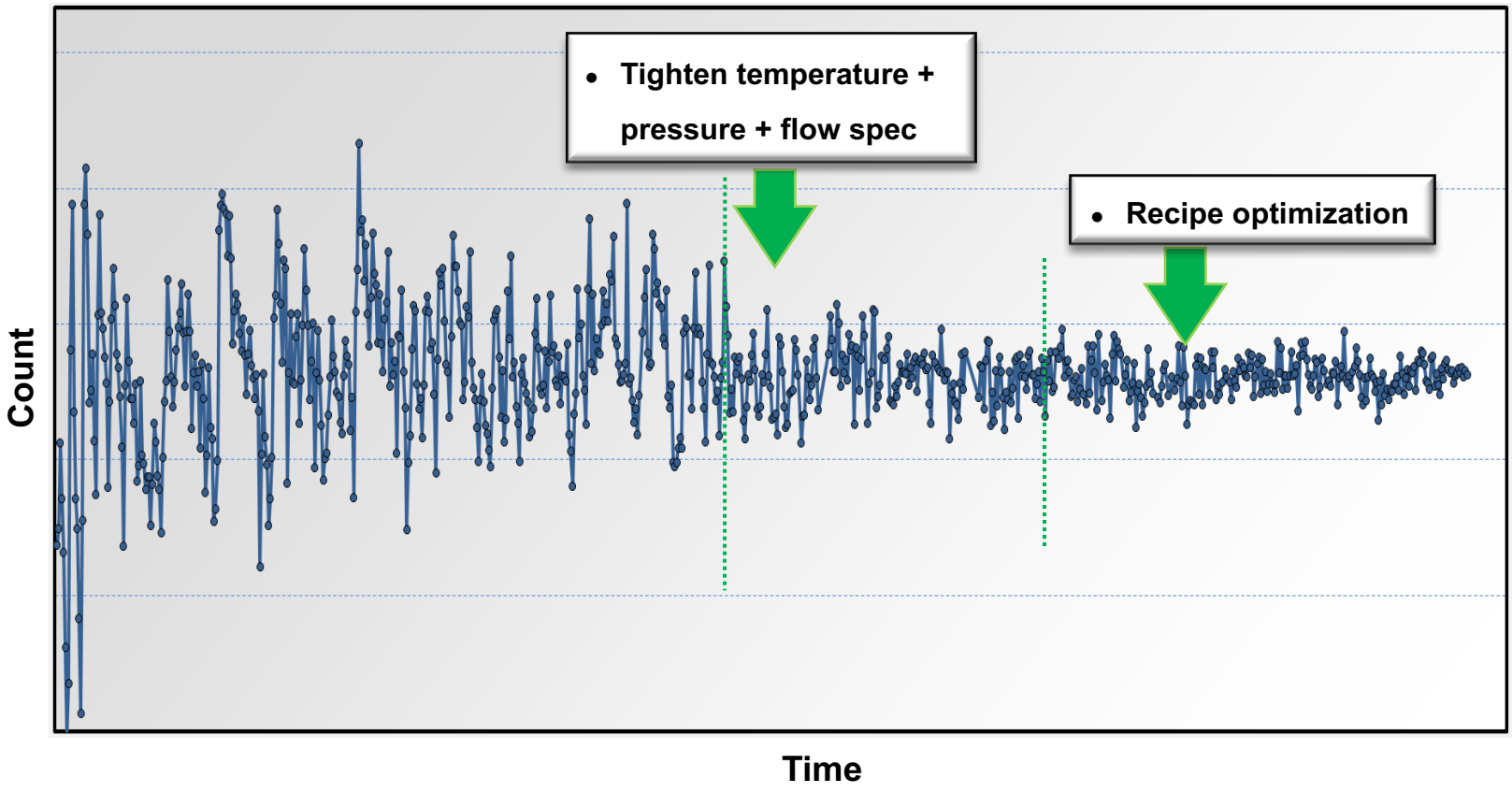
✓ **Critical layer optimization**





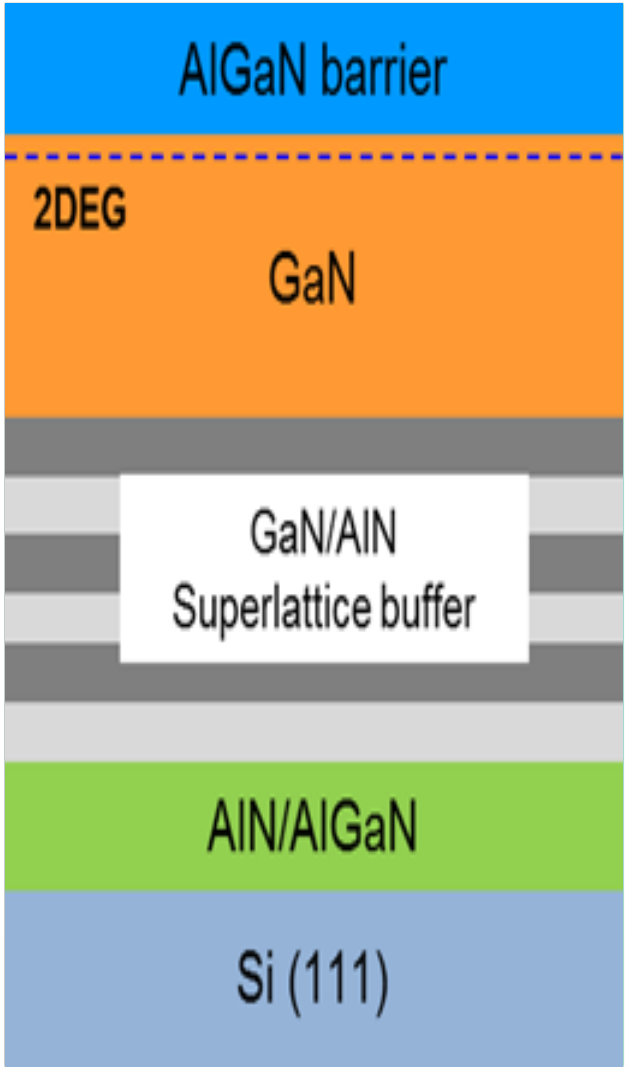
Wafer bow Control

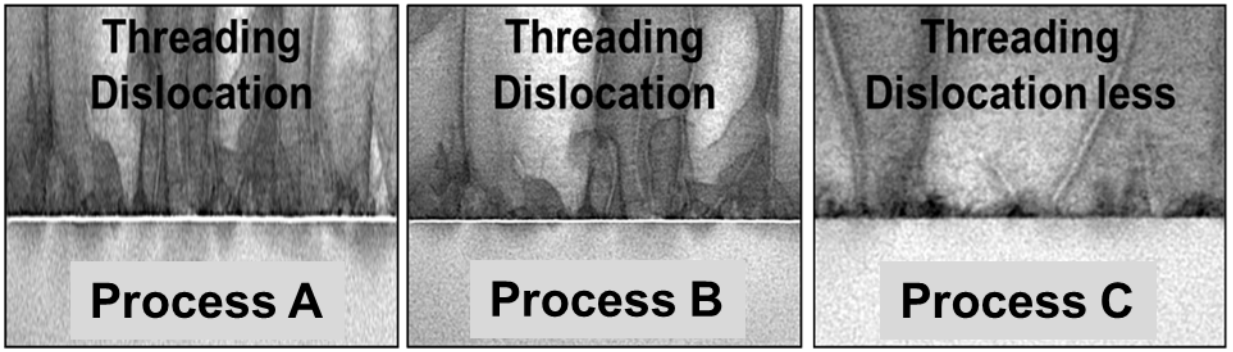
- Wafer bow trend chart

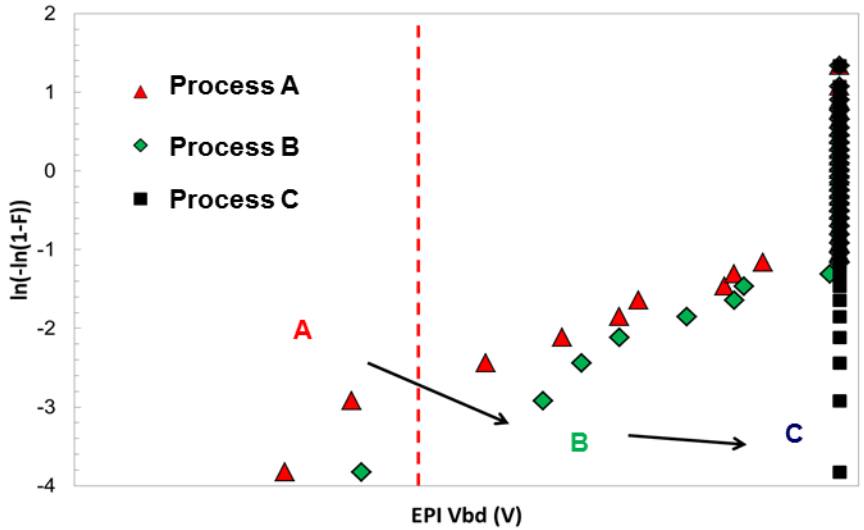


Dislocation Density

- Critical layers optimization







Matching Method

Tool Matching by TSMC report function

Step1: FAC / Hardware matching

Step2: Critical Parts COA Matching

Step3: Software/ Recipe matching

Step4: SPC Matching

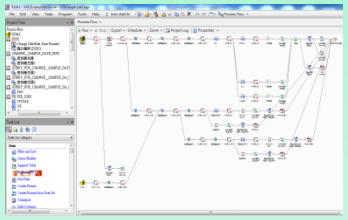
Step5: WAT/Cp yield Matching

PRS Match Function

Matching Result

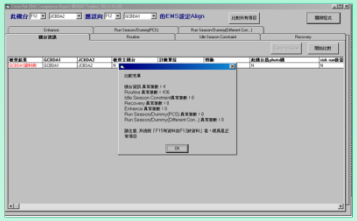
Item	Golden Tool	New Tool	Compare Result
RMS	Tool A	Tool B	PASS
EMS	Tool A	Tool B	PASS
CPS	Tool A	Tool B	PASS

COA Dashboard

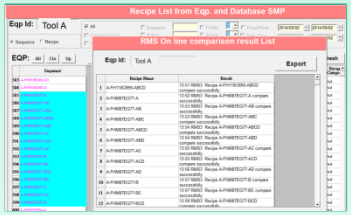


Matching Result

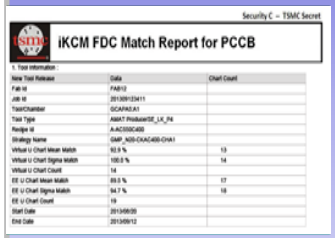
Defense All in One



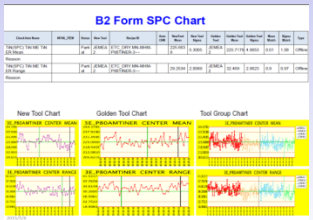
Matching Result



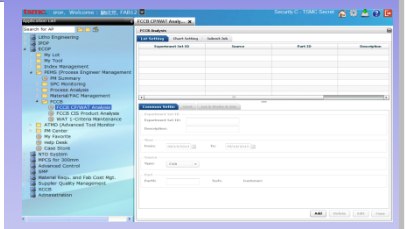
SPC Matching System



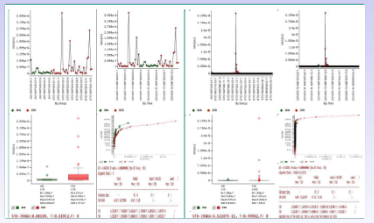
Matching Result



One click Report



Matching Result

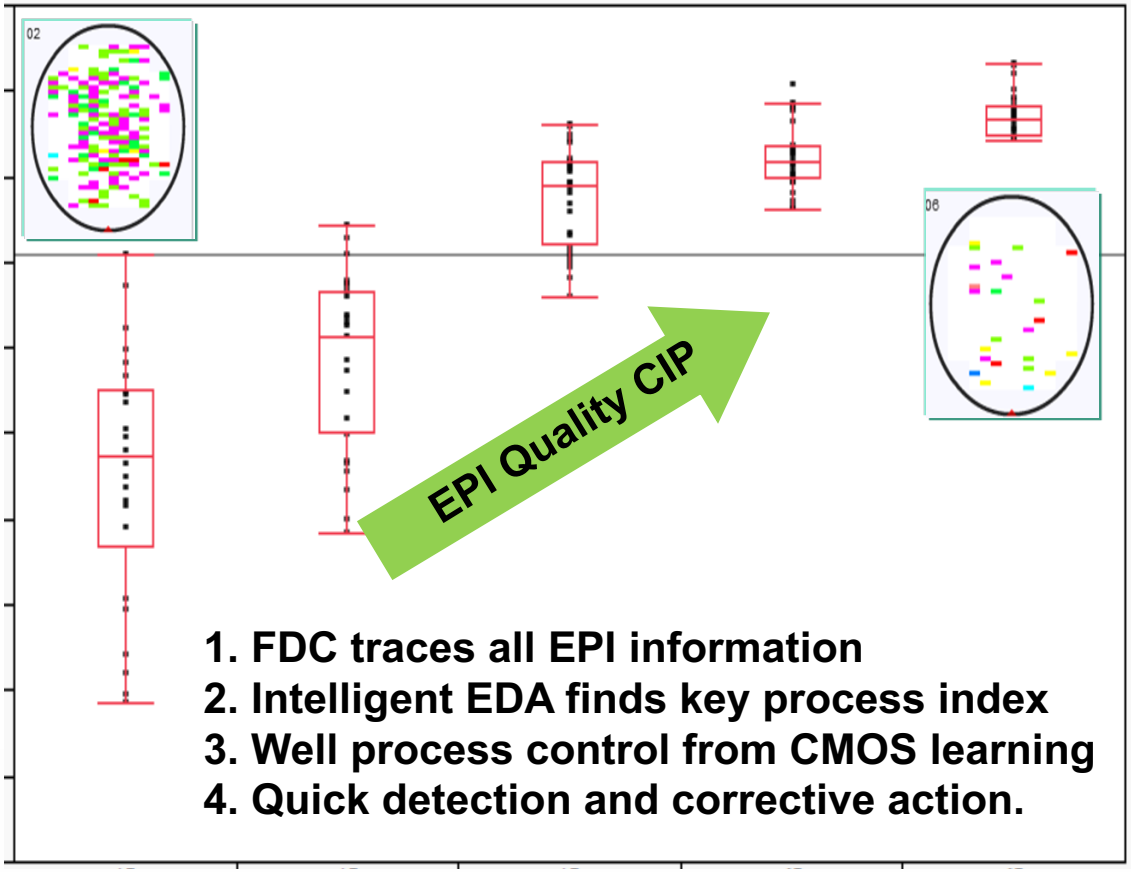


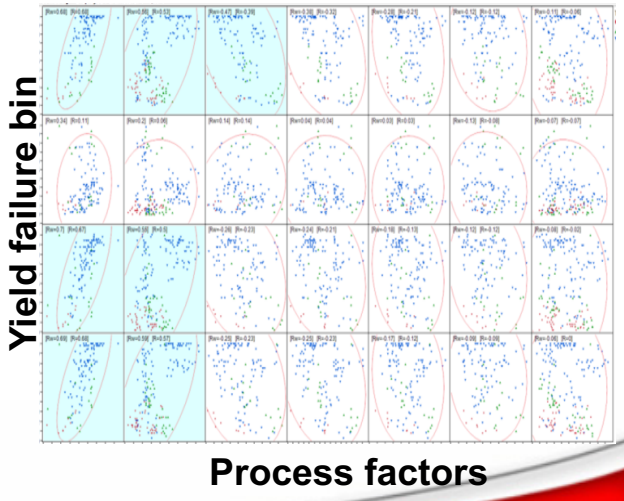
Input Control

Output Matching

Yield Improvement

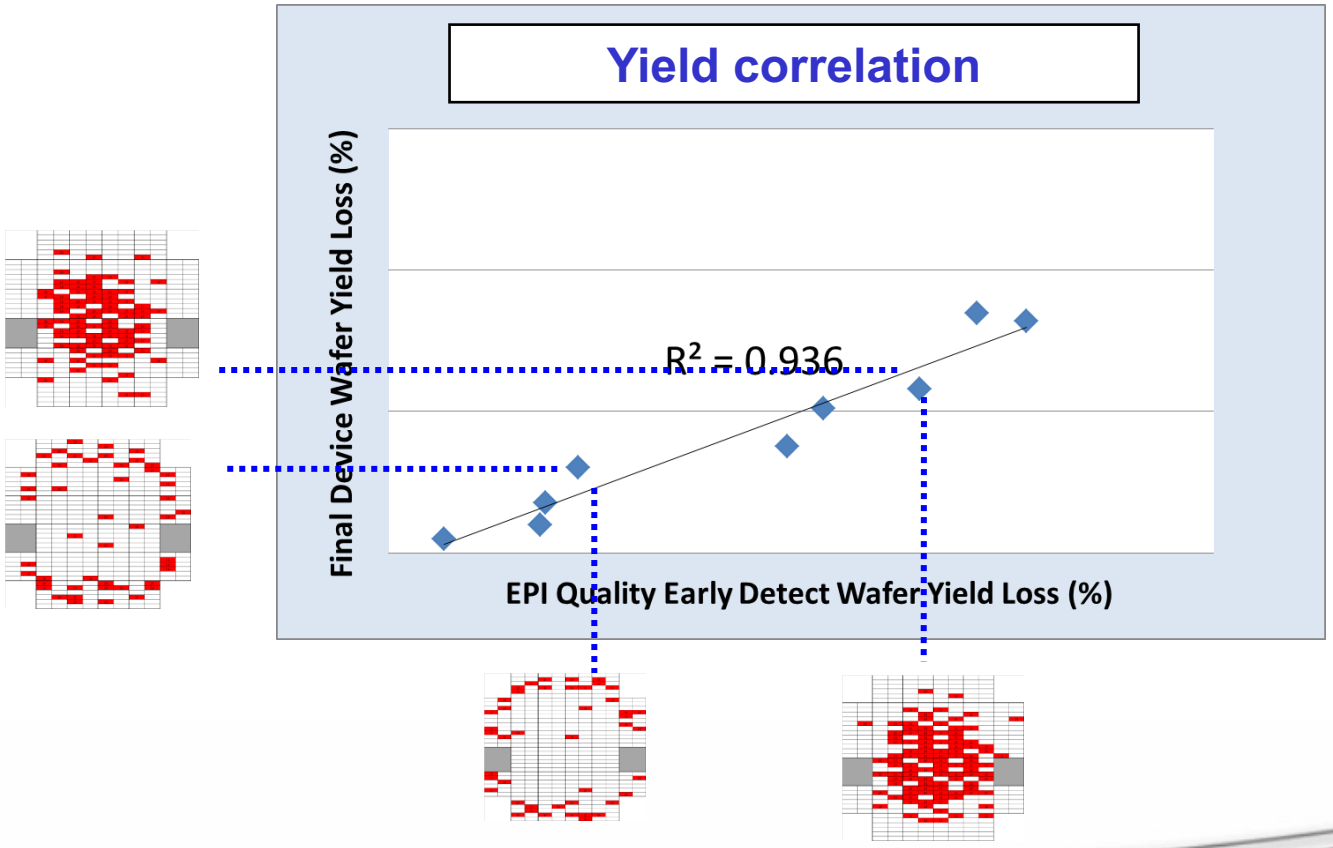
- MoCVD GaN on Si multi layers epitaxy more than several thousands parameters collected for yield analysis
- Leveraged CMOS iEDA system for quick yield learning





Yield Improvement

- EPI electrical quality early detection methodology, Cycle time is improved from xx days to 1 day.
- Speed up the learning curve of EPI yield improvement



Summary

- GaN on Si production launched since 2015 with good cycle time, yield and performance
- The most advanced CMOS manufacture process control and yield enhancement systems are adopted.
- Customer/tsmc/OSAT supply chain collaboration are critical for product grade
- Continuously performance enhancement and cost reduction to stay ahead of competition.