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End-to-End Yield Management for Compound Semi

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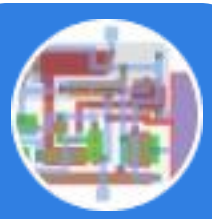
PDF Solutions: Leading the Digital Transformation of Semiconductor Manufacturing

PDF Solutions: End-to-End Data Connectivity, Control and Analytics for Systems and Semiconductor Companies

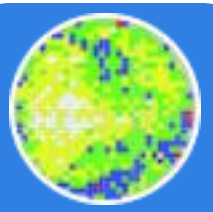
Leading provider of comprehensive analytics solutions for semiconductor manufacturing

We collect and create data from across the supply chain. Then we use AI to enable deeper insights and rapid improvements in yield, quality and operational efficiency.



IC Design

Fab



Sort

Assembly

Final Test

System

Enterprise

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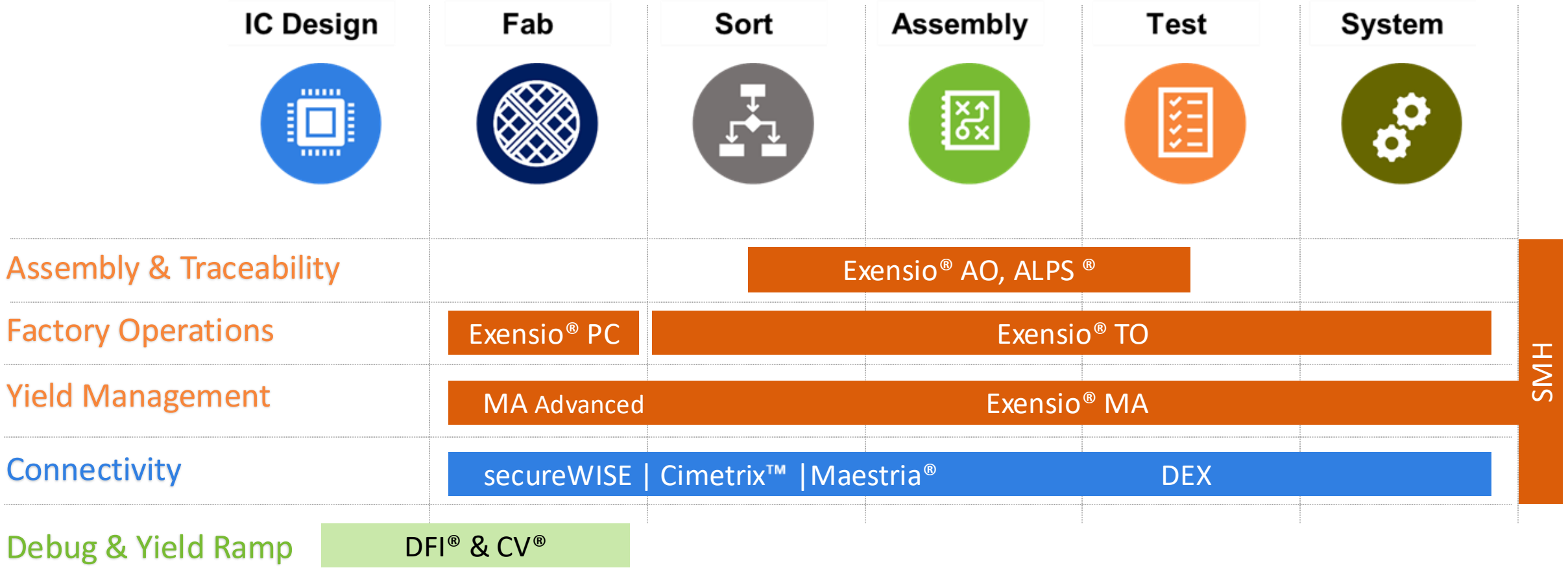
PDF Solutions overview



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Data Collected in Semiconductor Manufacturing

- Design Data
  - Chip
  - Reticle
- WIP / MES
- Equipment logs & traces
- Lot Genealogy
- Inline
  - Metrology
  - Inspection
- WAT / PCM
- Wafer Sort
  - Bins
  - Parametric
  - BIT
- Traceability
- Die Bins
- Process Data
- PCB / System Level Testing
- In-field monitors
- RMA

terabytes of data per day; often 15+ yr retention

Legend
- BIT: built-in test
- MES: manufacturing exec. sys.
- PCM: process control monitors
- WIP: work in progress
- WAT: wafer acceptance test
- RMA: returned merchandise auth

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Customer Base in Compound Semi

Select DM's with a focus on compound semi		Fab Technology			
Customer	Description*	Si	SiC	GaAs	GaN
A	In top 10 in Power IC's & modules	✓	✓		
B	In top 10 suppliers of RFIC	✓		✓	
C	In top 10 suppliers of RFIC	✓		✓	✓
D	In top 5 suppliers of LED's	✓	✓	✓	✓
E	In top 10 in Power IC's & modules	✓	✓		
F	In top 10 in Power IC's & modules	✓	✓		✓
G	In top 3 GaN DM				✓
H	In top 10 in Power IC's & modules	✓	✓		
I	In top 10 in ADAS and IoT	✓	✓		✓
J	In top pure-play foundry for SiC	✓	✓		
K	Niche power IC	✓	fabless		

Notable customers as of 2024-E

Other technologies, (e.g. InP) omitted due to the low wafer volume

Big Data Analytics

is deployed in

12 large manufacturers

IDM / Fabless / Foundry

+ Material Suppliers

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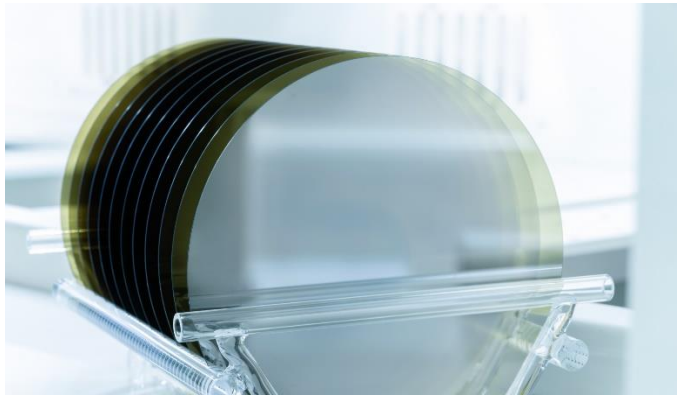
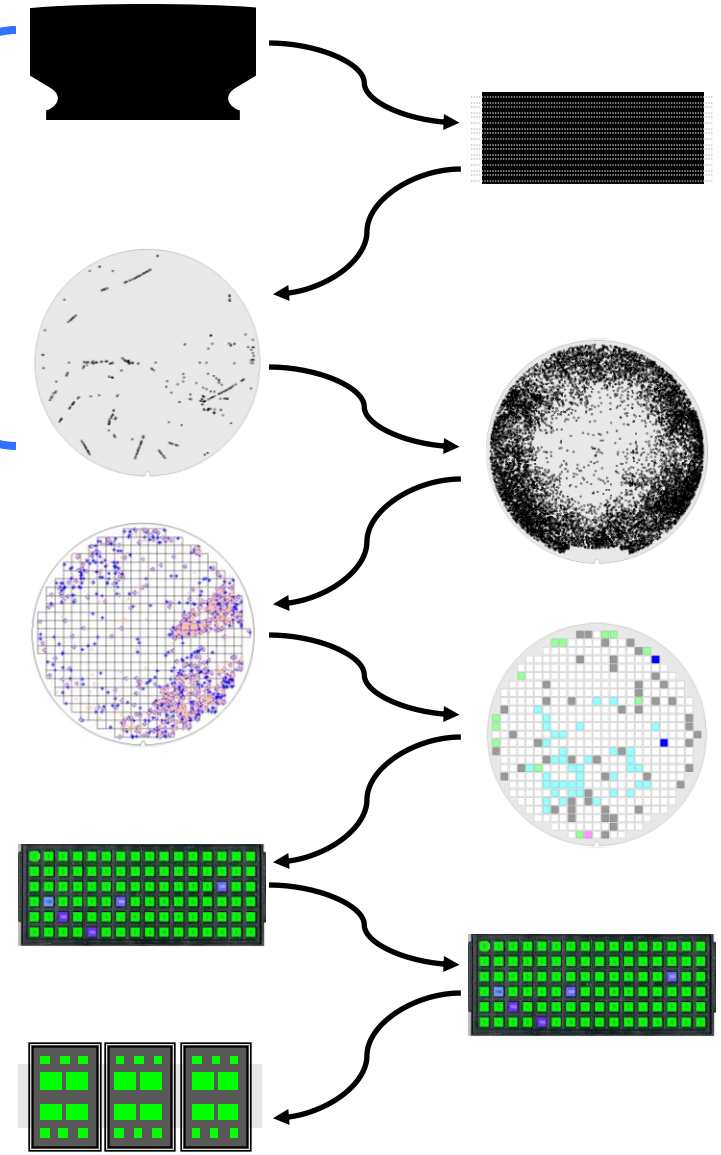
Example of SiC Manufacturing

source: CompoundSemiconductors.net, 2017



source: SICC, 2024

>30%
of the final
product cost



- Boule Growth
- Cutting
- Grind / Polish
- Epitaxy
- Wafer Frontend
- Backside Process
- Wafer Burn-In
- Electrical Sort
- Assembly
- Final Burn-In
- Final Test

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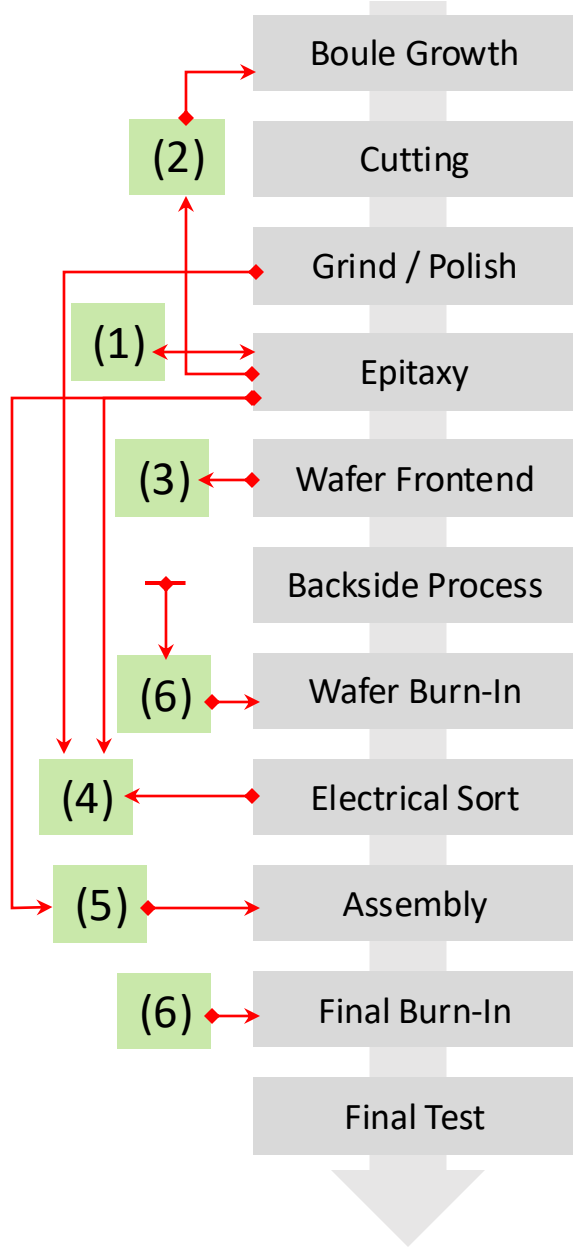
Examples of End-to-End Analytics

#	Use Case
1	Defect stacking and re-binning for root-cause analysis
2	Reconstructing boule defectivity from epitaxial defects
3	Etch process parameters to metrology correlation
4	Substrate defect yield impact & Defect Kill ratio analysis
5	Die screening and ink-out maps for automotive
6	Predictive Burn-In based on PCM and Probe data

Applying production-proven tools for Compound Semiconductors



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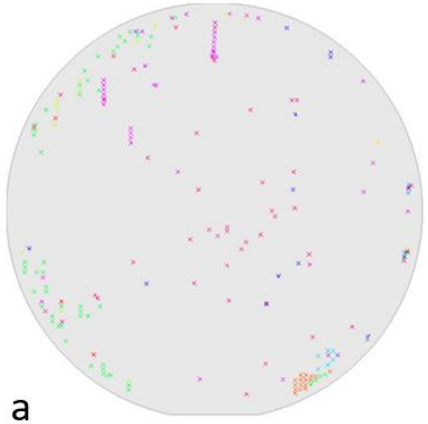
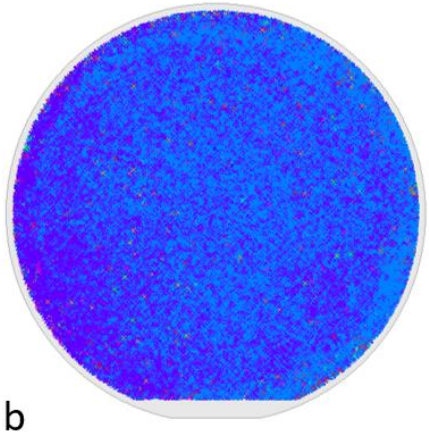
1. Defect Management for Root-Cause Analysis

Too little data



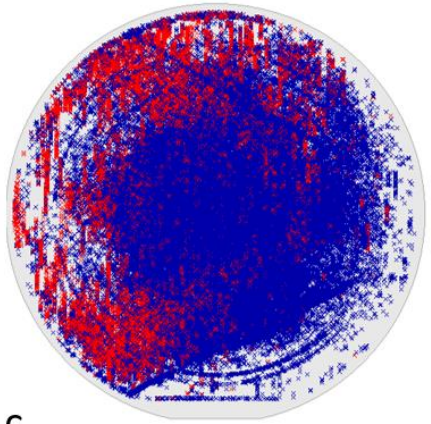
a

Too much data



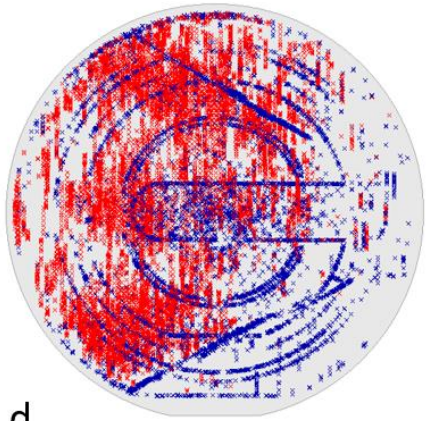
b

Just enough data



c

Actionable data



d

#	stacking by	filtering by
a	---	---
b	+epi product	---
c	+substrate supplier	+defect type
d	+epi reactor	+defect size

Identified epi process issues that are substrate-dependent

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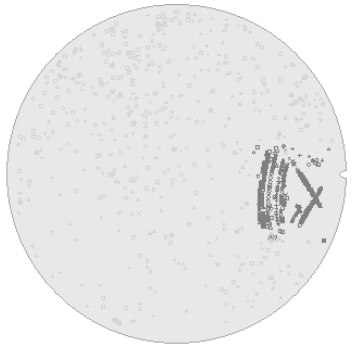
2. Puck defectivity from epitaxial defects

Data Aggregation

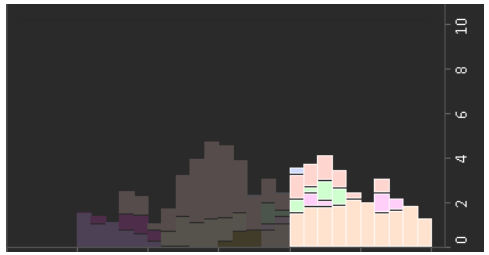
stack by substrate supplier

stack across pucks with high defectivity at epi

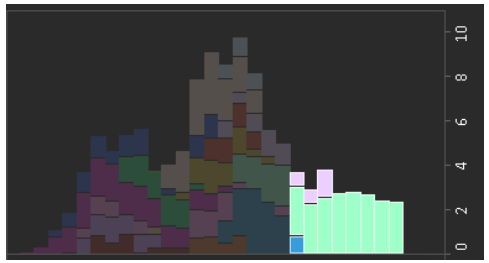


Multi-Variate Screening

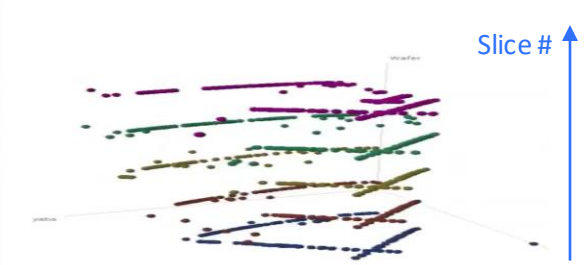
pre-epi: attribute A



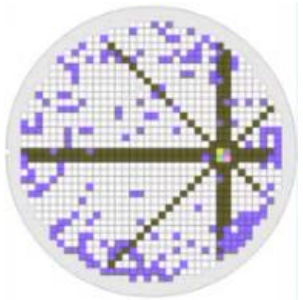
post-epi: attribute B



Crystal defects that were not detected by incoming QC



Ink map



Identified supplier quality issues
Improve “ink” rules

(2)

- Boule Growth
- Cutting
- Grind / Polish
- Epitaxy
- Wafer Frontend
- Backside Process
- Wafer Burn-In
- Electrical Sort
- Assembly
- Final Burn-In
- Final Test

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3. Etch Parameters to Metrology Correlation

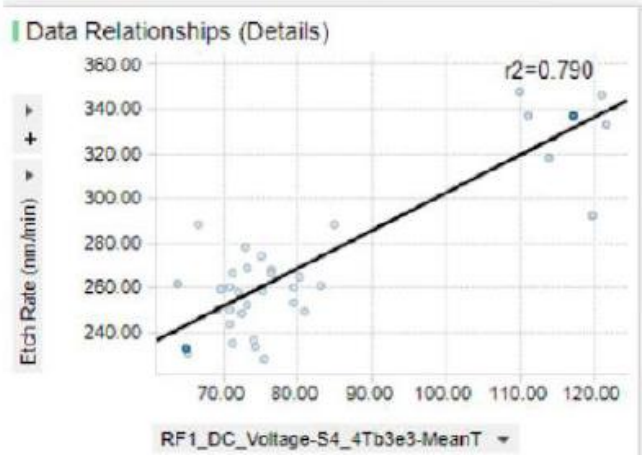
Problem: InP etch exhibits high excursions in etch rate

Univariate Corr. Screening

Data Relationships (Linear Regression)

Y (numerical)	X (numerical)	r
Etch Rate (nm/min)	RF1_DC_Voltage-S4_4Tb3e3-MeanT	1.9
Etch Rate (nm/min)	RF1_DC_Voltage-S4_4Tb3e3-Area	1.8
Etch Rate (nm/min)	RF1_DC_Voltage-S4_4-Max	5.7
Etch Rate (nm/min)	RF2_Reflected_Power-S4_4-Area	1.4
Etch Rate (nm/min)	RF2_Reflected_Power-S4_4-MeanT	1.8
Etch Rate (nm/min)	RF1_DC_Voltage-S4_4-Min	1.3
Etch Rate (nm/min)	RF1_Reflected_Power-S3_3-Max	2.7
Etch Rate (nm/min)	RF2_Forward_Power-S4_4Tb3e3-M...	7.5
Etch Rate (nm/min)	Foreline_Pressure-S3_4-Max	1.5
Etch Rate (nm/min)	RF1_Reflected_Power-S4_4-Max	3.9
Etch Rate (nm/min)	Helium_Flow-S2_2-Max	8.2
Etch Rate (nm/min)	RF1_DC_Voltage-S4_4Tb3e3-StdDe...	1.1
Etch Rate (nm/min)	RF1_Reflected_Power-S4_4-Area	2.5

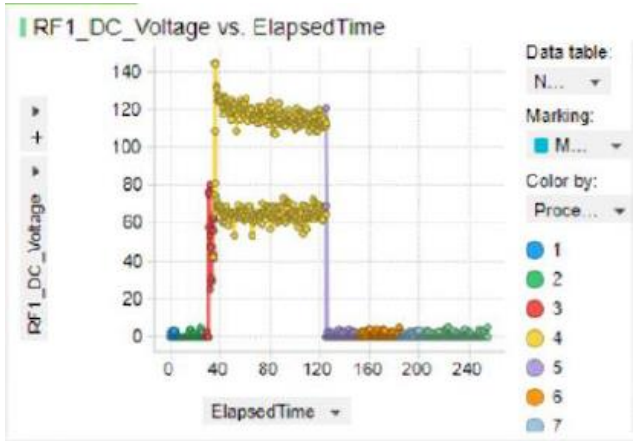
Model the Dependency



Automated root-cause analysis

- Equipment traces are extracted as indicators
- Indicators correlated to process outcomes
- Excursions in outcomes are tied to the excursions in equipment trace data

Compare vs "Golden" Chamber



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4. Defect Yield Impact & Defect Kill ratio analysis

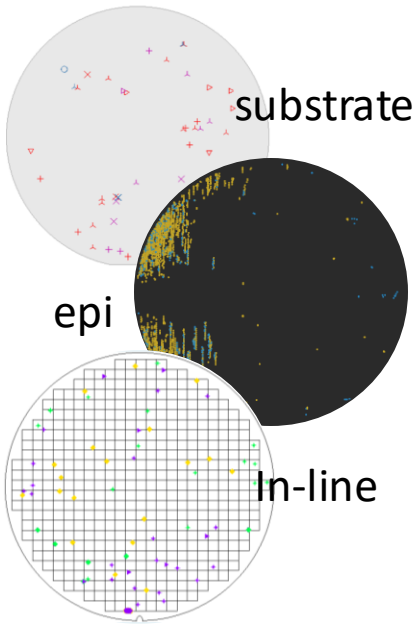
In the Silicon World

	PASS	FAIL
CLEAN	a	b
DIRTY	c	d

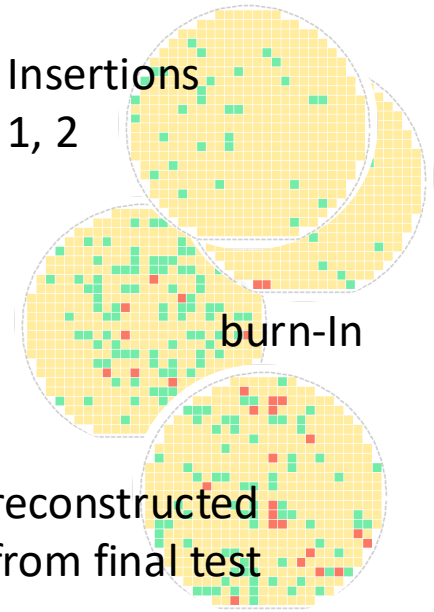
$$KR = 1 - \frac{Y_D}{Y_C}$$

$$= 1 - \frac{c}{a} \cdot \frac{a+b}{c+d}$$

In Compound Semi



KR



Complexity / Defectivity / Data Volume / Traceability
→ better models are needed

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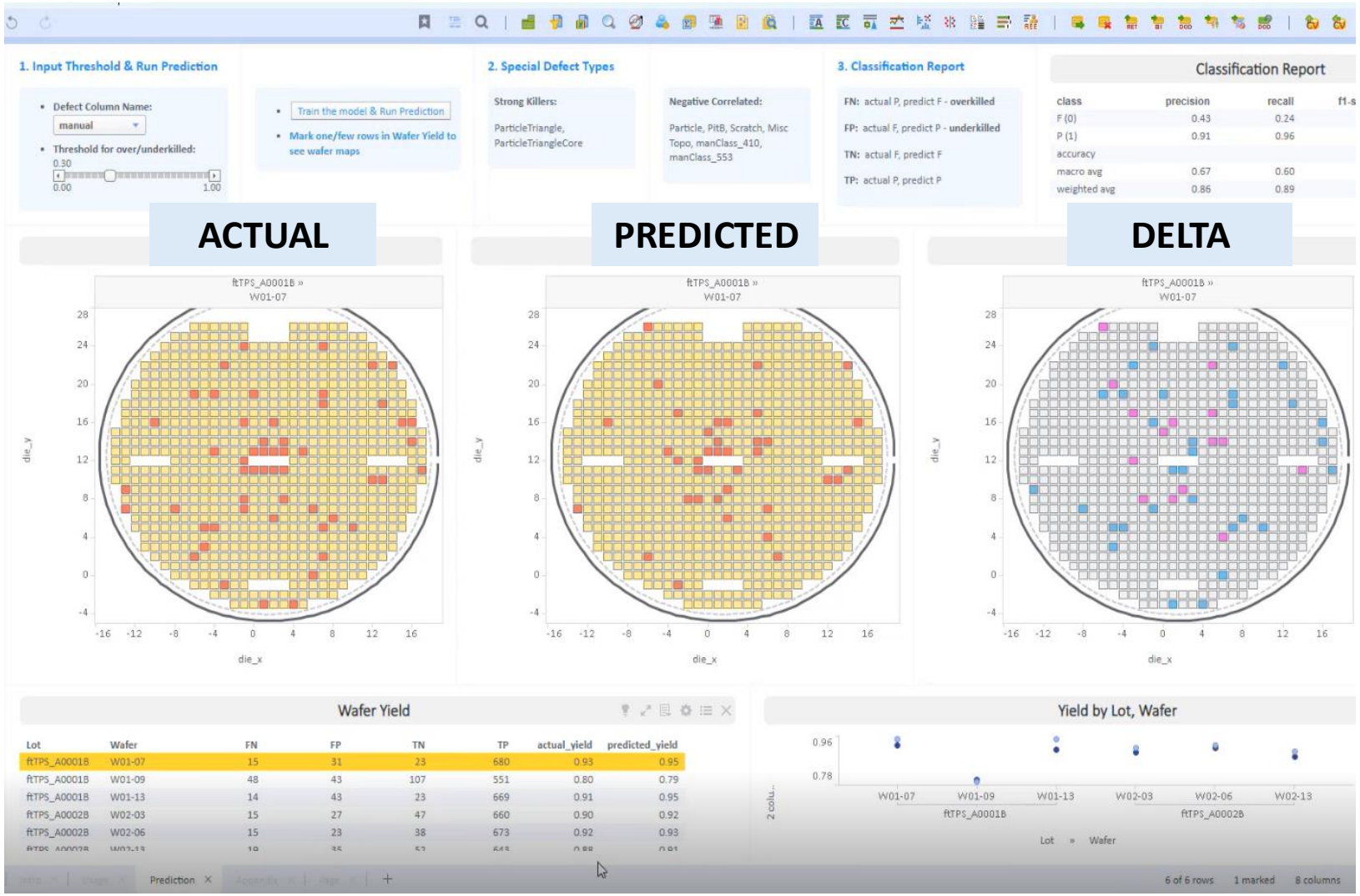
4. Defect Yield Impact & Defect Kill ratio analysis

- **Using defect maps to predict die state (pass/fail)**

- **Used for:**
  - SiC epi substrate grading
  - Epi supplier benchmarking
  - Substrate-product assignment



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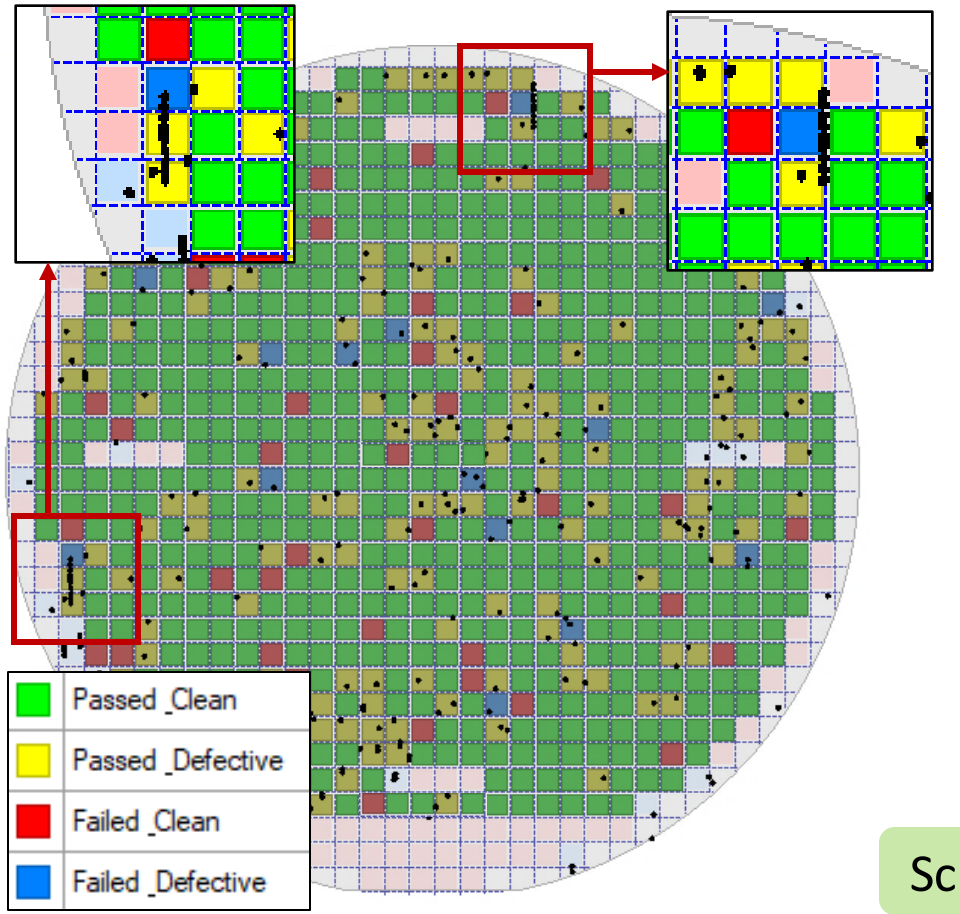
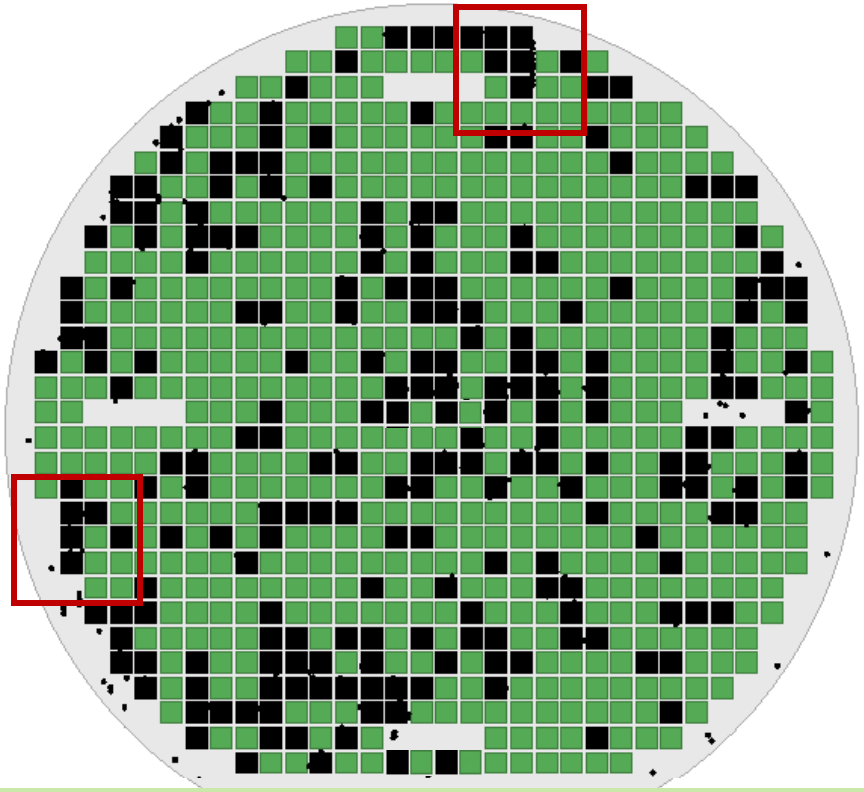
5. Die screening and ink-out maps for automotive

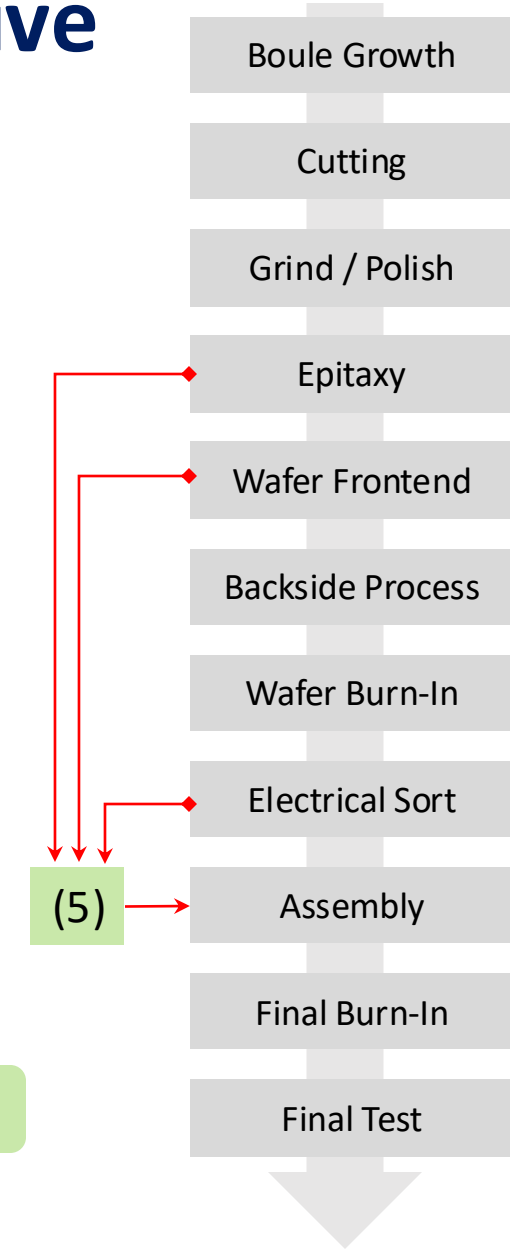
Probe-Defect Map



Ink-out map for assembly



Screen-out defective die for yield and quality



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Under the Hood: Big Data Platform

Information Security and IP Controls

AI/ML
- Guided Analytics
- Advanced Insights for Manufacturing
- Edge Analytics
- ModelOps

Data Intelligence
- End-to-end traceability
- Feature extraction
- Semiconductor specific data models

Control
- Process Control
- Test Control
- Assembly Control

Integration Services
- Sapience Manufacturing Hub
- Data Exchange Network (DEX)

IoT Software

PDF Created Data
- Design Characteristics
- In-Field Data
- pdFasTest
- eProbe

Customer Data
- Process & Eq. Data
- Fab Data
- Assembly Data
- Test Data

Fab Equipment and Fabless Integrations based on Standards

API s

Enterprise Integrations (Data Lakes, ERP, PLM, CRM..)

Integrated solution to accelerate production ramp, improve overall yield, quality, and efficiency for semiconductors

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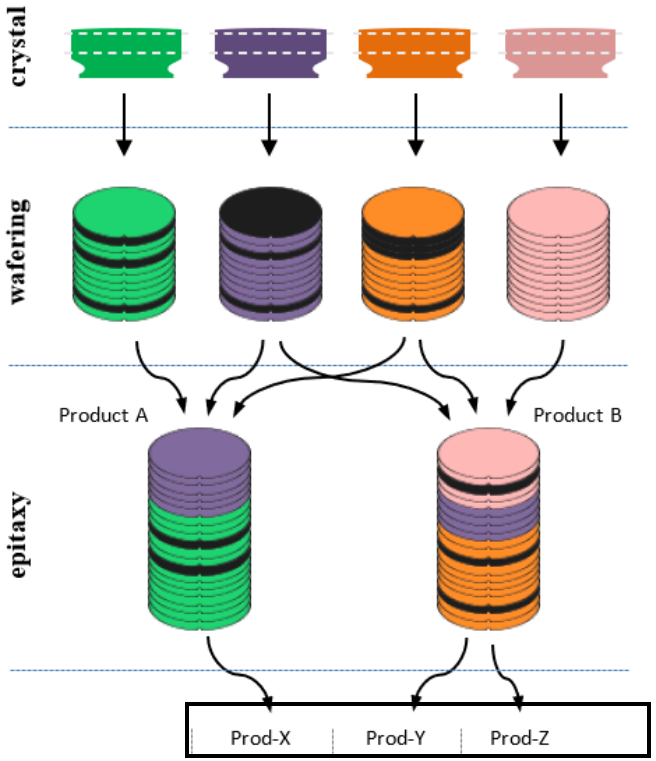
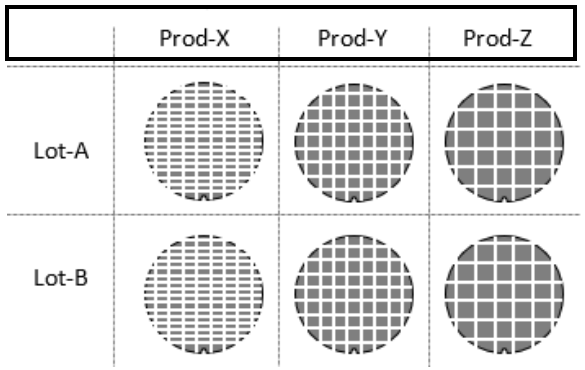
Under the Hood: Full Traceability

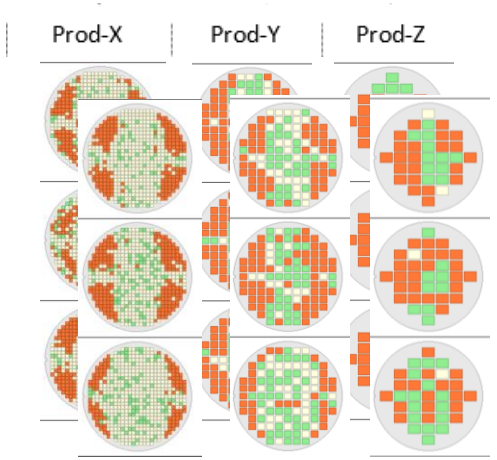
Material Manufacturing



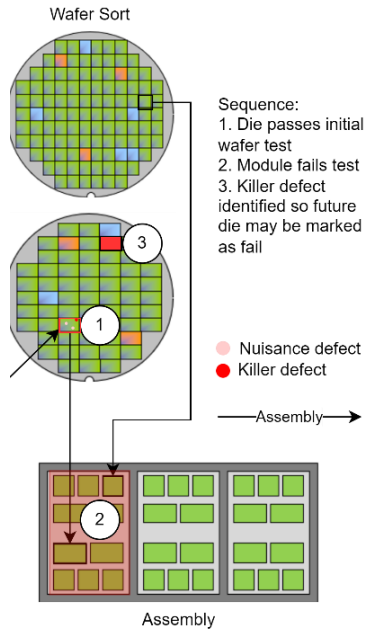
Front-End



Wafer Sort / BI



Assembly and Final Test



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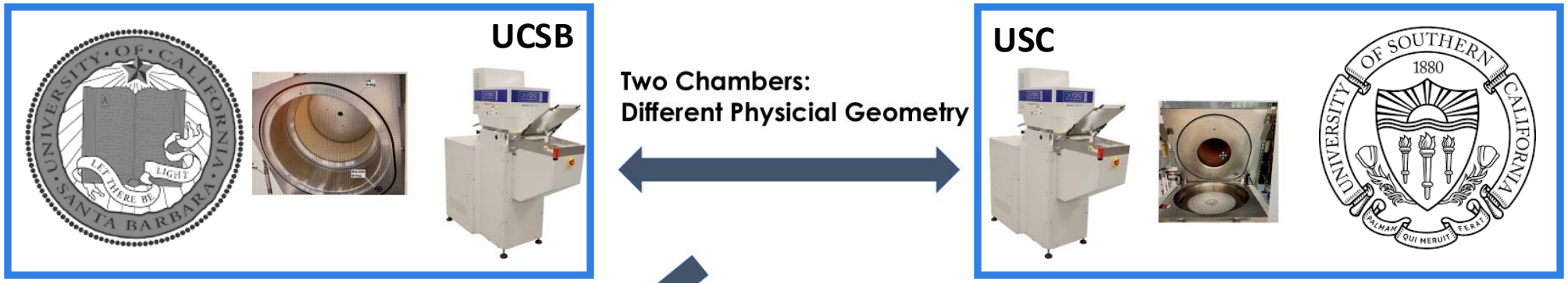

Demonstration of a <u>one-shot process transfer</u> between etch tools

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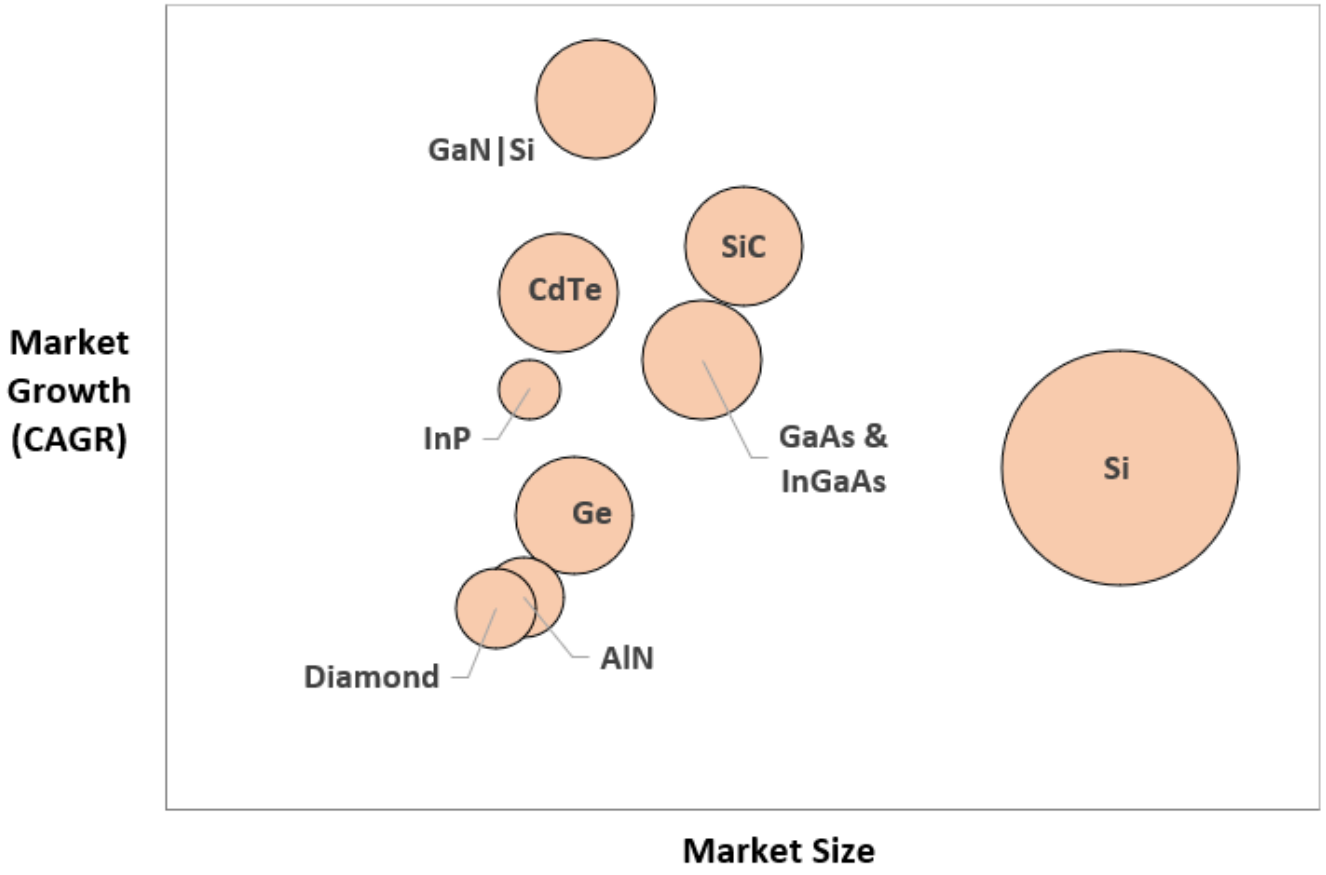
Final Notes

- Compound Semi industry is decades behind CMOS in maturity
- But progress can be accelerated using data analytics

Take your next step



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