PDF / SOLUTIONS™

2023 PDF Users Conference:

AI for tomorrow's manufacturing and R&D

Location:
Santa Clara Marriott - 2700 Mission College Boulevard Santa Clara, California 95054 USA

Automotive Solutions

25th October 2023

This presentation and discussions resulting from it may include future product features or fixes, or the expected timing of future releases. This information is intended only to highlight areas of possible future development and current prioritizations. Nothing in this presentation or the discussions stemming from it are a commitment to any future release, new product features or fixes, or the timing of any releases. Actual future releases may or may not include these product features or fixes, and changes to any roadmap or timeline are at the sole discretion of PDF Solutions, Inc. and may be made without any requirement for updating. For information on current prioritizations and intended future features or fixes, contact sales@pdf.com.

Automotive Market is growing fast

- **Increasing semiconductor percentage in cars**

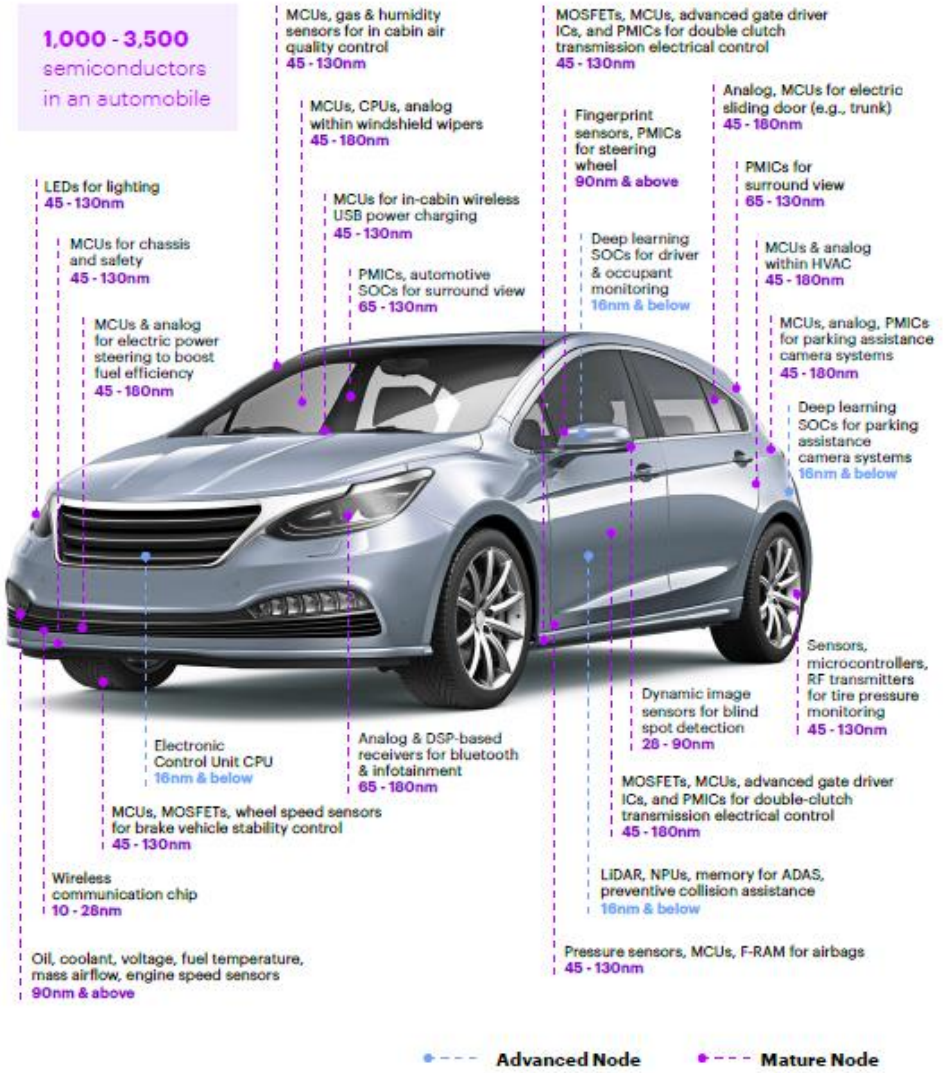
Exhibit 24: Semiconductor worldwide revenue by end vertical, sales (source: Gartner)

End vertical	Example	% of total 2020	% of total 2025E	2025 revenue projection	2021E-2025E% CAGR
Automotive	ADAS, Infotainment Chassis	8.3%	12.0%	$80.2B	12.4%
Communication	Smartphones	32.9%	31.5%	$210.3B	3.0%
Consumer	TVs, Digital Set-Top Box	10.4%	10.5%	$70.3B	2.6%
Data processing	PCs, Servers, Storage Media	37.7%	33.8%	$225.6B	1.6%
Industrial	Automation, Healthcare, Security	10.7%	12.1%	$80.7B	8.5%

Overall Automotive 2025: 80B USD, 12.4% CAGR

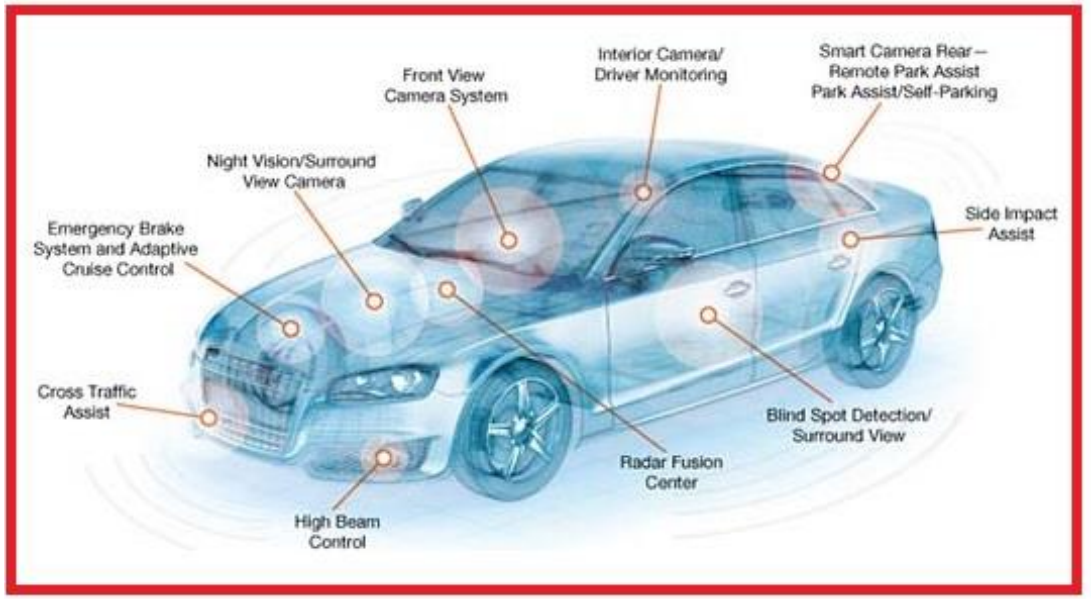
Source: Accenture

Exhibit 34: Subset of advanced & mature nodes in an automobile



New technologies driving Automotive Market

EVs



Advanced Driver Assistance System Applications ~ NEW TECH (mytech2u.blogspot.com)

ADAS

Increased semiconductor percentage and complexity of the car

Health Check

Health Check to Enable Zero Defect across Supply Chain

- **PDF provides a comprehensive health check to help you assess readiness to achieve Zero Defects for your automotive semiconductor products**
- **Assessment based on**
  - AEC-Q004 standard
  - Industry benchmarks
  - Subject matter expertise
- **White paper**
  - Compare across industry
  - Customized feedback to you

https://go.pdf.com/AutomotiveHealthCheck

Health Check: Basic and Advanced

- **What do we mean by basic & advanced?**
- **Basic = mature technologies**
  - Planar transistors ~22nm & above
  - Single die packages
- **Advanced = newer technologies**
  - 16nm FINFET & beyond
  - Multi-chip packages

- **Note: “Basic” in automotive does not mean *easy***

Mapping between PDF Health Check vs AEC Q004

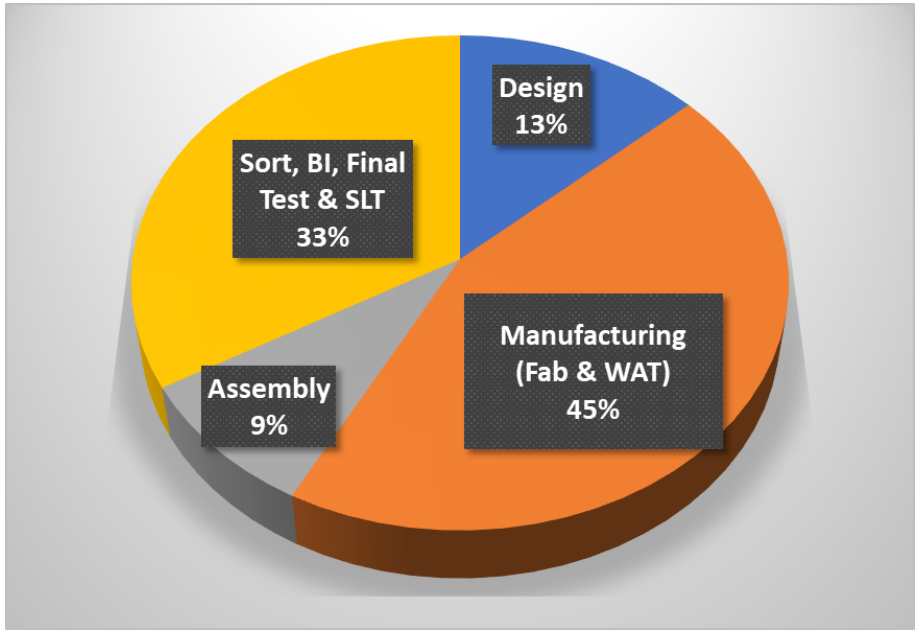
Automotive Electronics Council (AEC) Q004

Section	Sub sections							
3.0 Product Design	3.1 Design Failure Mode Effects and Analysis (DFMEA)	3.2 Redundancy	3.3 Built-in Self Test (BIST)	3.4 Design for Test (DFT)	3.5 Design for Analysis	3.6 Design for Manufacturing (DFM)	3.8 Simulation & Modeling	3.9 Characterization
4.0 Manufacturing*	4.1 Process FMEA	4.2 Statistical Analysis of Variance	4.3 Control Plan	4.4 Statistical Process Control (SPC)	4.5 Lot Acceptance Gates	4.6 Audits		
5.0 Test	5.1 Part Average Testing (PAT)	5.2 Statistical Bin Yield Analysis	5.3 Data Collection Storage and Retrieval	5.4 Screens				
6.0 Application & Capability	6.1 Industry Standards	6.2 Environmental Stress Testing	6.3 Stress Strength Analysis	6.4 Systems Engineering	6.5 Product Derating			
7.0 Continuous Improvement Methods	7.1 Wafer Level Process monitoring	7.2 Process & Product Improvements	7.3 Product Reliability Monitoring	7.4 Defect Monitoring				
8.0 Problem Solving	8.1 Problem Solving Techniques	8.2 Failure Analysis Process						

Part of Health Check

Not Part of Health Check

Part of Health Check



**Important to be able to audit your foundry. If they use PDF, then this will be easy.*

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Health Check Highlights: Design

Category	New Entrants		Incumbents		Best in Class Incumbents	
	Basic	Advanced	Basic	Advanced	Basic	Advanced
Design	69%	44%	86%	52%	95%	75%
Fab Mfg	59%	40%	92%	70%	100%	100%
Packaging	74%	65%	94%	88%	95%	100%
Test	71%	55%	74%	54%	95%	83%

- **Differences between New Entrants and Incumbents**
  - Surprising big gap in basic design techniques
    - Example: Fault coverage
- **Differences between Incumbents & Best in Class**
  - Gap in advanced design techniques
    - Not all use fault localization
    - Not all have in-chip sensors

Health Check Highlights: Fab

	New Entrants		Incumbents		Best in Class Incumbents	
Category	**Basic**	**Advanced**	**Basic**	**Advanced**	**Basic**	**Advanced**
Design	69%	44%	86%	52%	95%	75%
Fab Mfg	59%	40%	92%	76%	100%	100%
Packaging	74%	65%	94%	88%	95%	100%
Test	71%	55%	74%	54%	95%	83%

- **Differences between New Entrants and Incumbents**
  - Large gap in process control knowledge
    - New entrants are fabless
    - Big advantage for IDM incumbents & experienced fabless companies
- **Differences between Incumbents & Best in Class**
  - Lack of margin WAT structures for fabless incumbents

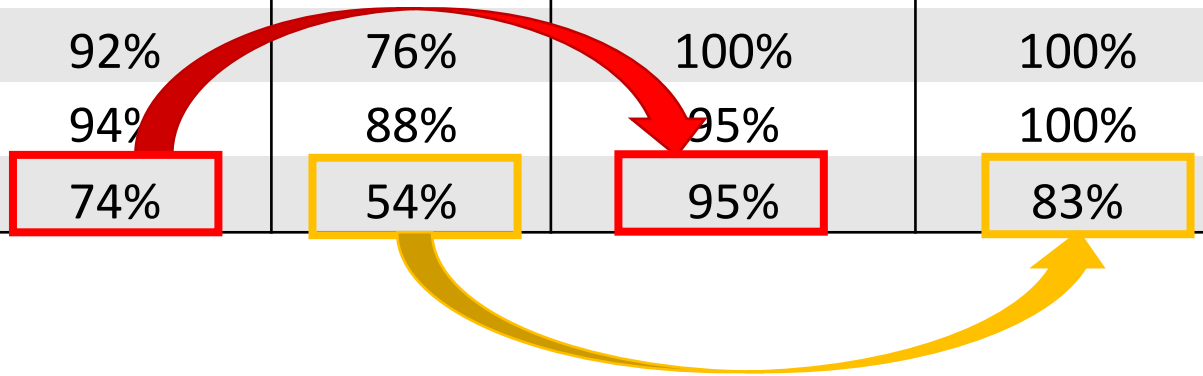
Health Check Highlights: Packaging

Category	New Entrants		Incumbents		Best in Class Incumbents	
	Basic	Advanced	Basic	Advanced	Basic	Advanced
Design	69%	44%	86%	52%	95%	75%
Fab Mfg	59%	40%	92%	76%	100%	100%
Packaging	74%	65%	94%	88%	95%	100%
Test	71%	55%	74%	54%	95%	88%

- **Differences between New Entrants and Incumbents**
  - Large gap in assembly process control knowledge
    - New entrants are fabless
    - Big advantage for IDM incumbents & experienced fabless
- **Differences between Incumbents & Best in Class**
  - Best in Class fully adopt assembly traceability

Health Check Highlights: Test

	New Entrants		Incumbents		Best in Class Incumbents	
Category	**Basic**	**Advanced**	**Basic**	**Advanced**	**Basic**	**Advanced**
Design	69%	44%	86%	52%	95%	75%
Fab Mfg	59%	40%	92%	76%	100%	100%
Packaging	74%	65%	94%	88%	95%	100%
Test	71%	55%	74%	54%	95%	83%



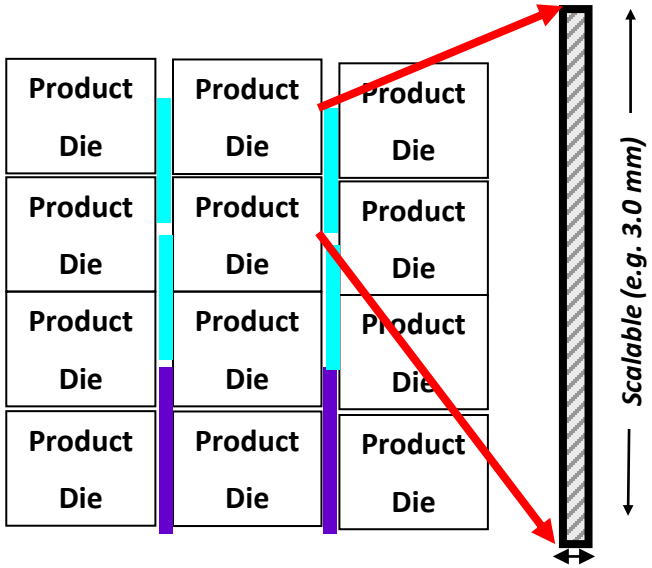
- **No Significant Differences between New Entrants and Incumbents**
  - Test is the easiest place to close the gap, especially for fabless
- **Differences between Incumbents & Best in Class**
  - Best in Class wide adoption of both Escape Prevention & Outlier Detection
  - Incumbents use, but not as completely

Health Check Results: Overall

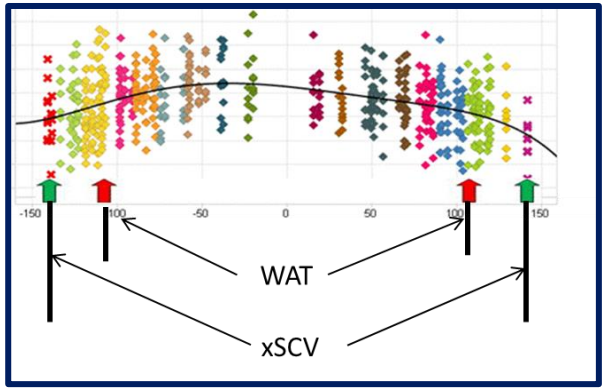
	New Entrants		Incumbents		Best in Class Incumbents	
Category	**Basic**	**Advanced**	**Basic**	**Advanced**	**Basic**	**Advanced**
Design	69%	44%	86%	52%	95%	75%
Fab Mfg	59%	40%	92%	76%	100%	100%
Packaging	74%	65%	94%	88%	95%	100%
Test	71%	55%	74%	54%	95%	83%

- **Some surprising strengths**
  - Most companies use on-chip PVT sensors
  - Widespread adoption of cloud storage
  - Most use ECID for traceability
- **Areas for Improvement – New Entrants**
  - Fault Coverage (!)
  - Details of Fab & Assembly Process Control
- **Areas for Improvement – Incumbents**
  - Fault localization
  - Adoption of traceability
  - Margin WAT
  - Quality Shield

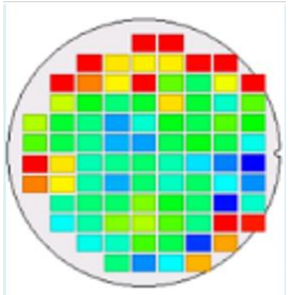
ScribeCV – PDF's Solution for Margin WAT



5th generation
pdFasTest-F380+
256 dual port channel arch.
High V & pulse generation



Yield learning & monitor wider wafer coverage



Scribe CV®

Device, Yield, Parametric, Leakage

Exensio Advanced Quality & Ops Path

Offline Reporting
- *Floor Monitoring*
- *OEE reporting*
- *Stoppages / RE losses*

Real Time Rules
- *Outlier Screens (DPAT, GDBN)*
- *Escape Prevention (eg Test count)*

Operational Visibility | **Operations Shield** | **Quality Shield** | **Machine Learning**

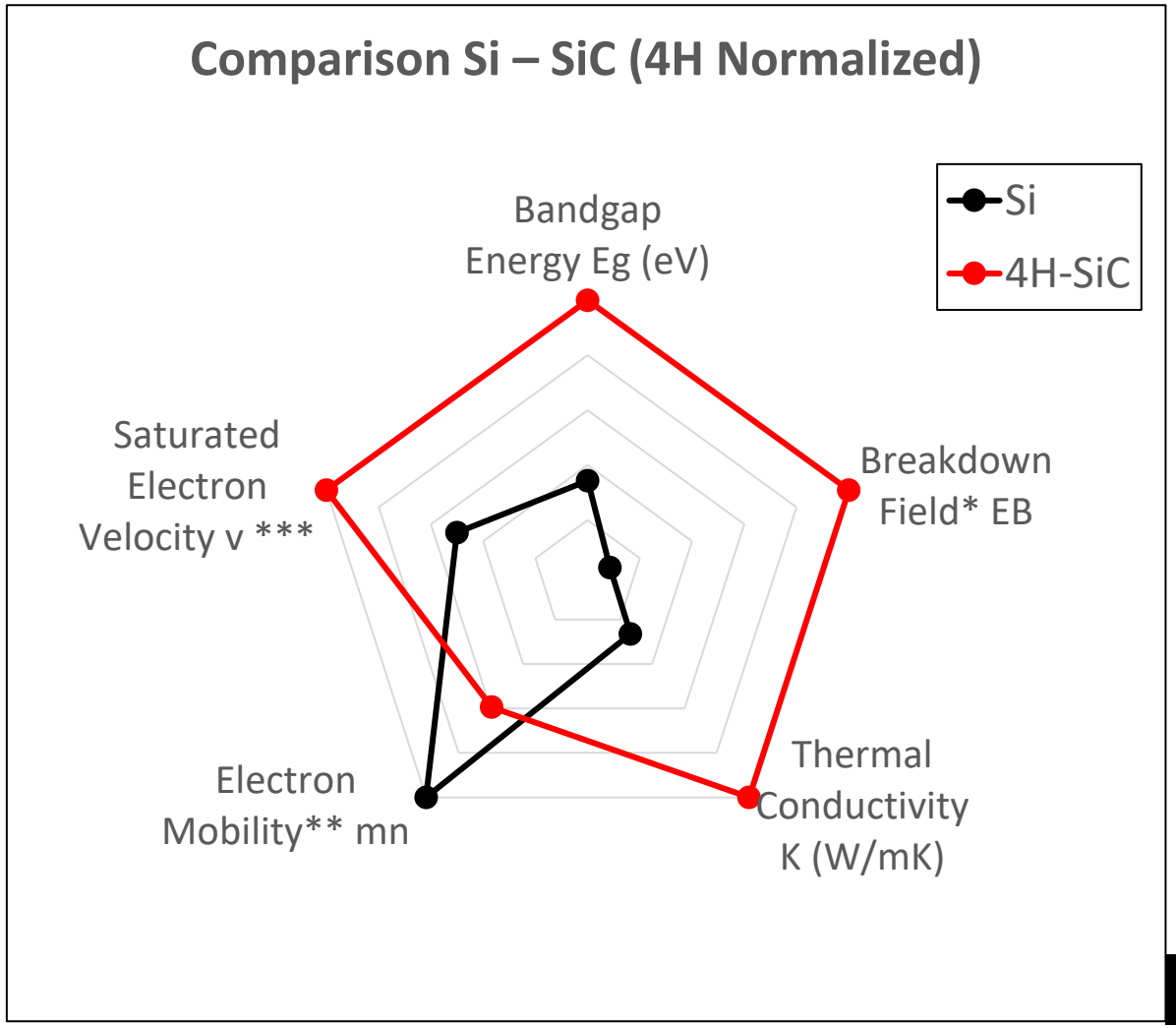
Real Time Rules
- *Site2Site Yield*
- *UPH Limit*

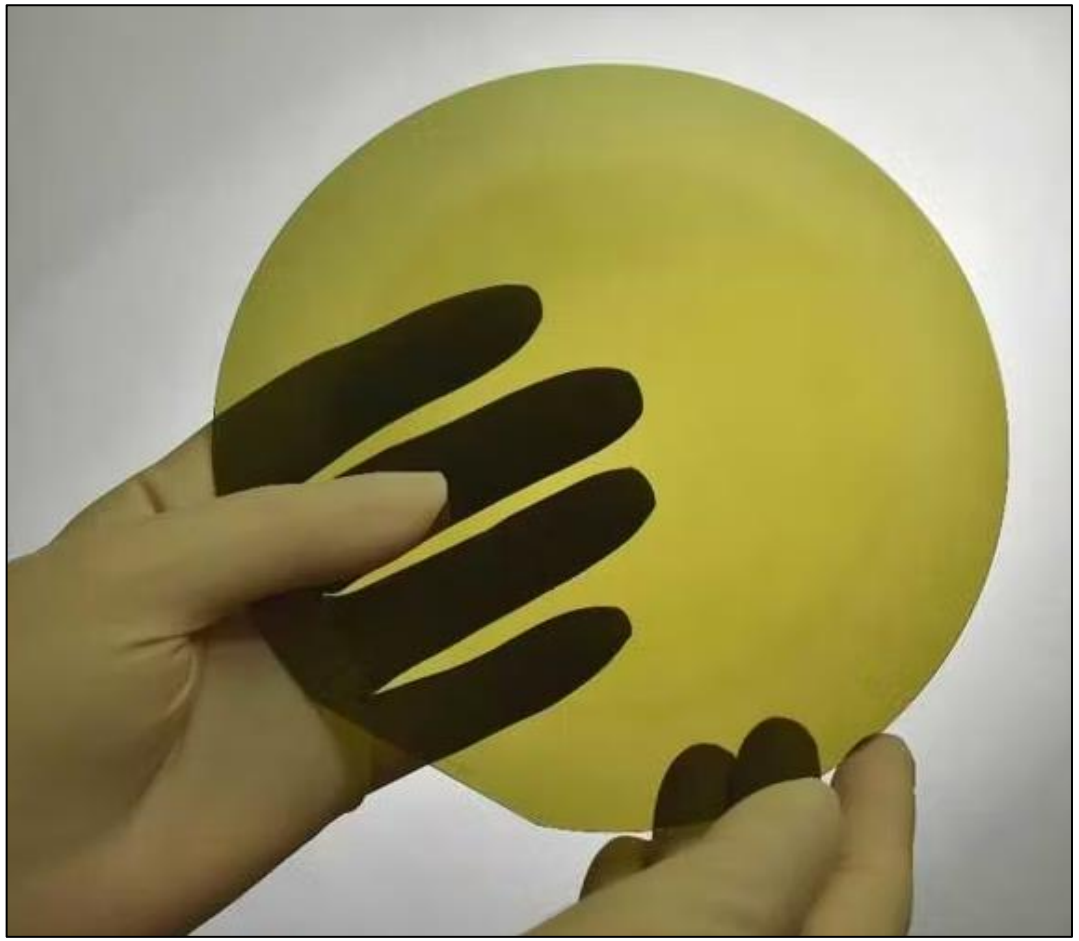
Model Based Prediction
Model Based Screening
- *Predictive Binning*
- *ML Outlier Screening*
- *"Bring Your Own Model"*

BIC Ops

Solutions for SiC Devices

Silicon Carbide - Introduction





source: onsemi

Great for Power IC and RF

Challenges with SiC Manufacturing

- Complicated (in-house vs outsourced) material flow
- Lot reshuffling: wafer & lot genealogy
- High defectivity
- Equipment connectivity (150 & 200 mm)

→ covered in this talk

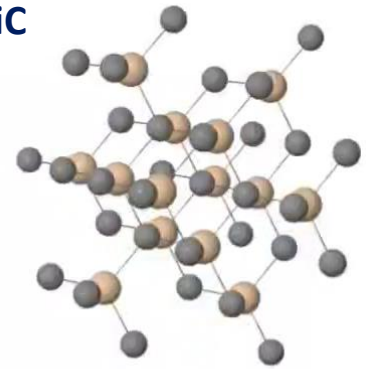
- Small pucks vs large boules
- New types of subsurface defects hard to detect with conventional means
- No wafer scribe or ambiguous wafer ID
- Defect sampling for SEM Review: too many
- Unpatterned vs patterned wafers: registration

→ inquire for more detail

Compound Semiconductor: stoichiometry matters!

>250 polytypes: stacking faults are common

SiC



source: ChemTube3D

SiC Package for Fabs and IDM's

Fault Detection & Classification (FDC)

Traceability & E142

Genealogy for Substrates and Wafers

ModelOps with AI/ML

- Improve crystal (boule) growth
- Manage equipment fleet
- Identify root-cause of defects

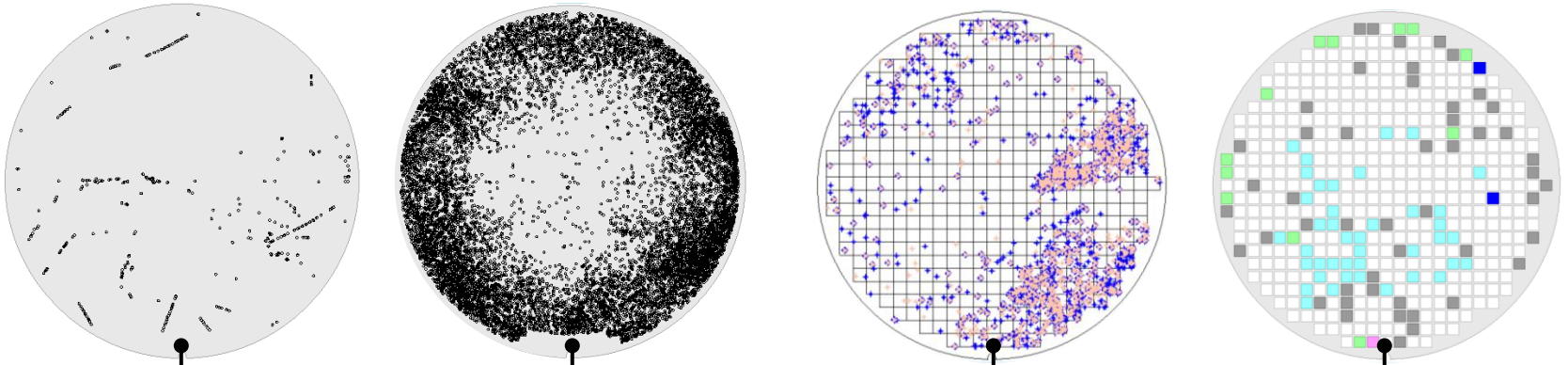
- Predictive burn-in
- Shift-left strategy to increase yield
- Streamline RMA's

'boule' & Substrate → Epi → Wafer Processing → Wafer Test → Packaging Assembly → Burn-in & Final Test

SiC Defectivity

"SiC is where silicon was decades ago…"

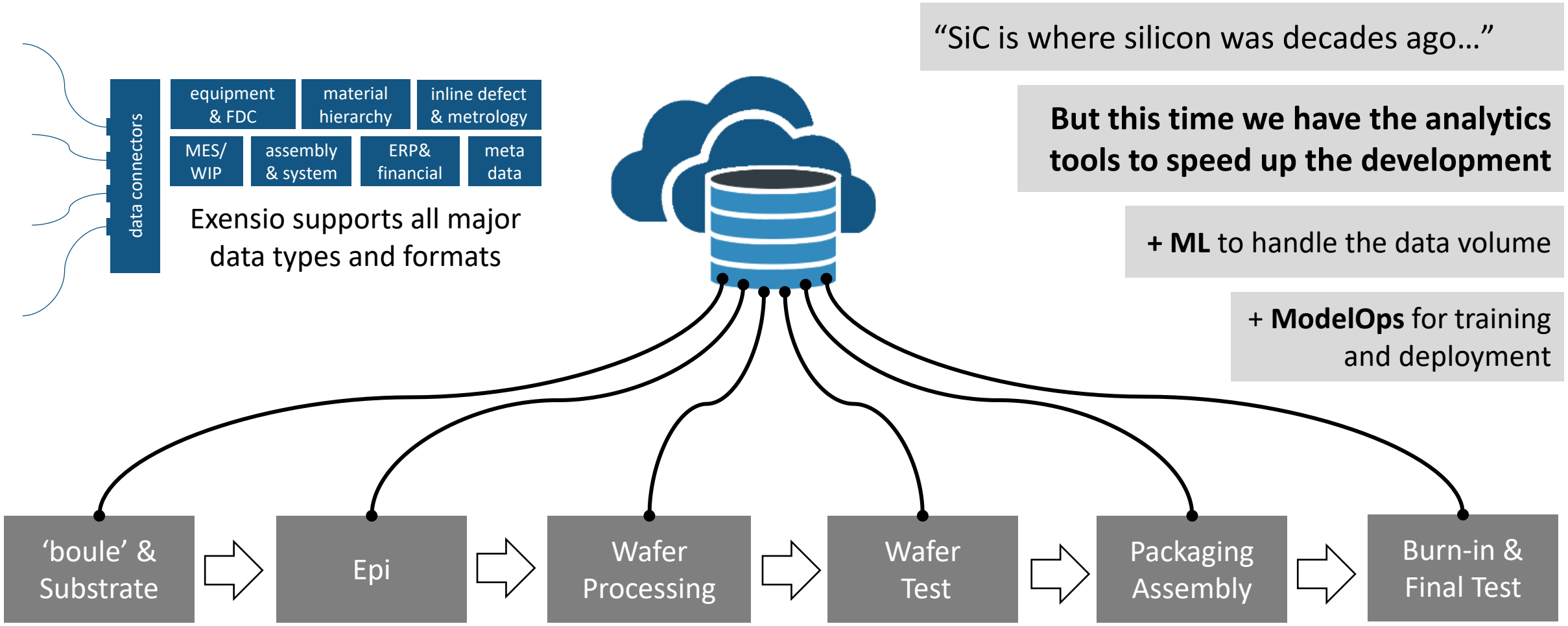
$$$



'boule' & Substrate → Epi → Wafer Processing → Wafer Test → Packaging Assembly → Burn-in & Final Test

Pdf representative data

SiC End-to-End Manufacturing Analytics



"SiC is where silicon was decades ago…"

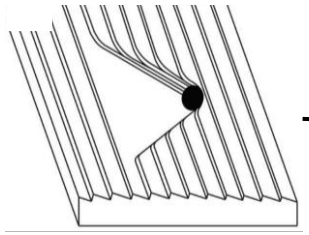
But this time we have the analytics tools to speed up the development

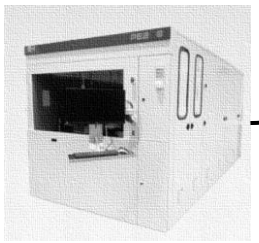
+ ML to handle the data volume

+ **ModelOps** for training and deployment

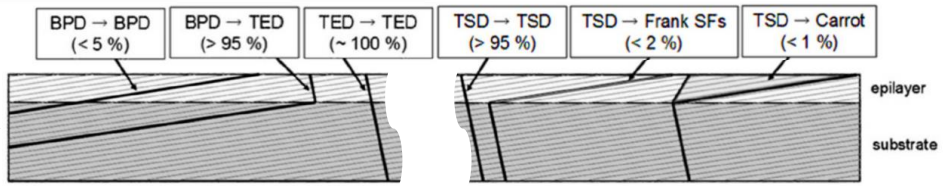
SiC Defect Management: Proactive vs Reactive

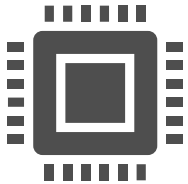
substrate defect





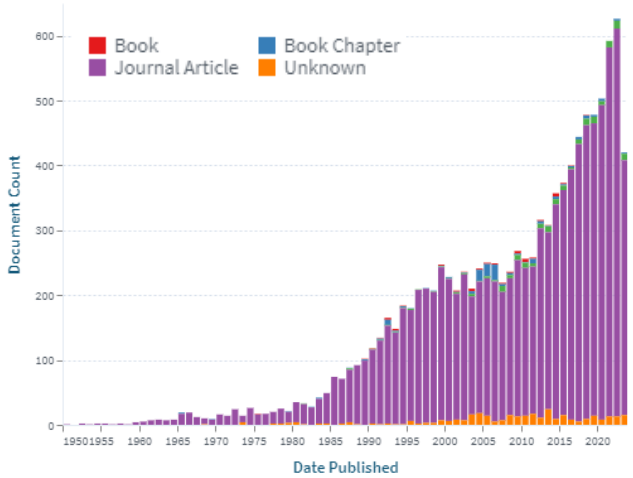
P, T, Si/C, …





Performance & Reliability

>11,000 scholarly works on SiC defects



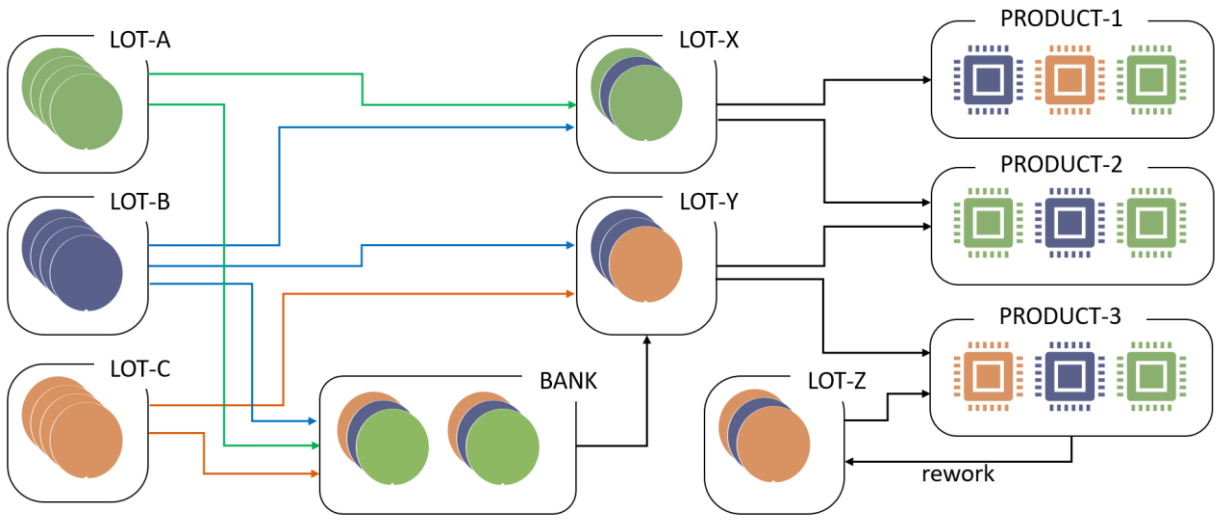
Solutions

- End-to-End Analytics
- AI/ML Infrastructure
- Predictive Burn-In
- Shift-Left Strategy

Chen *et al. Nanoscale Research Letters (2022)*
Zhao, *Nanotechnol. Precis. Eng. 3, 229–234 (2020)*
La Via F, et al, Appl. Phys. Rev. 1 031301 (2014)

Managing Complexity with Full Traceability

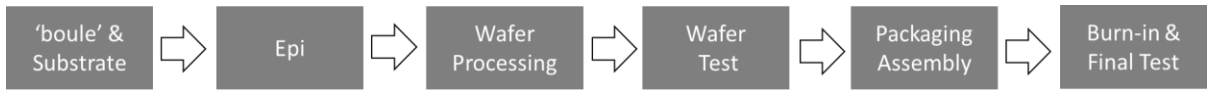
Complex Material Flow



In-house vs dual supplier:
3^6 (>700) possible flows

Complex Supply Chain

varying outsourcing strategies



Solutions

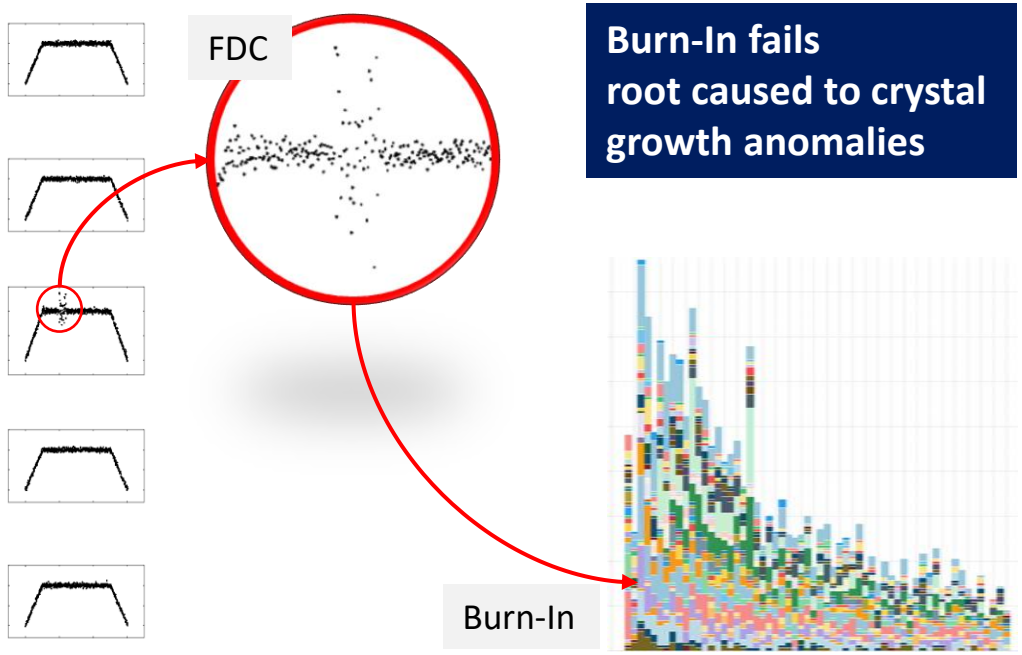
- Exensio Assembly Operations
- Device Tracking
- Substrate & Lot Tracking
- SEMI E142 implemented

Deployment Examples in SiC Manufacturing

IDM "C":
True End-to-End Deployment

IDM "B":
Fab, Sort & Assembly

IDM "A":
Exensio Manufacturing Analytics – Fab only



Burn-In fails root caused to crystal growth anomalies

'boule' & Substrate → Epi → Wafer Processing → Wafer Test → Packaging Assembly → Burn-in & Final Test

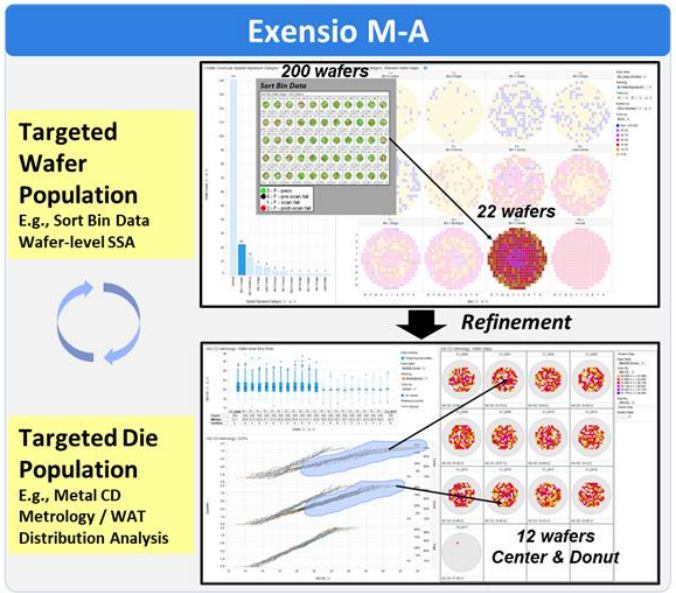
Solutions for ADAS ICs

NPI & FA Diagnostics with Siemens Tessent + Exensio

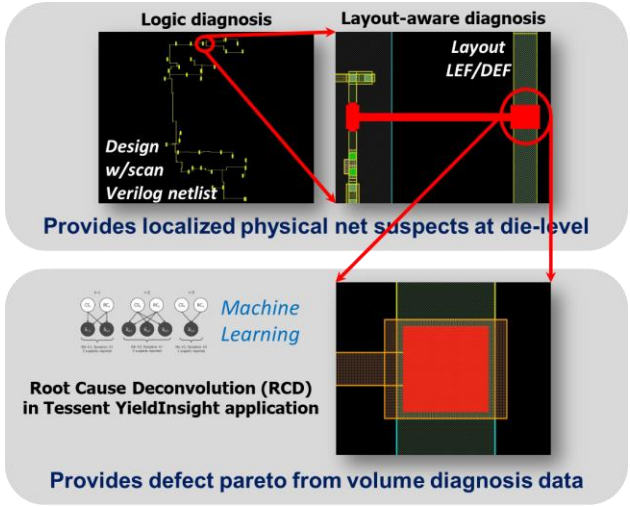
Locate & Identify Root Cause of Logic Failures

Locate and Identify Root Cause of Memory Failures

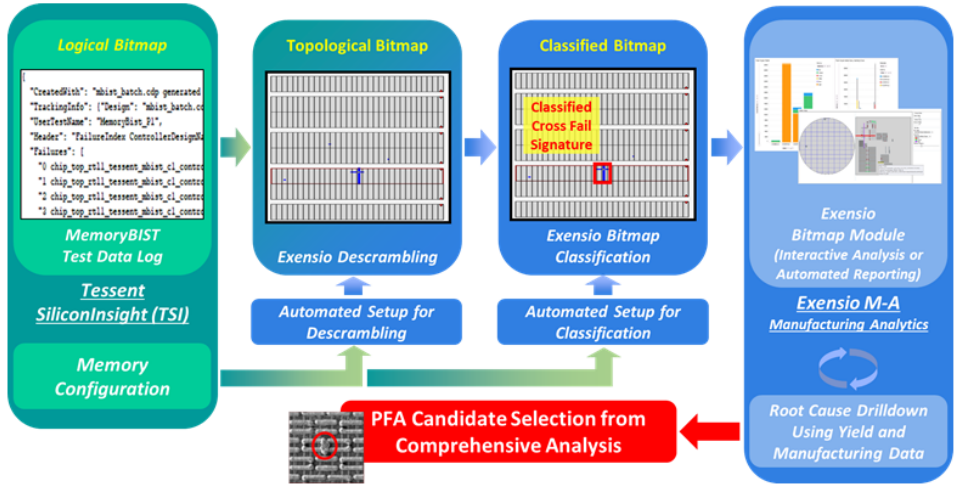
Exensio M-A: Home in on target population for biggest impact



Tessent YieldInsight: Localize defects for more effective logic PFA



Tessent SiliconInsight and Exensio M-A: Simplify and routinize effective memory bitmap

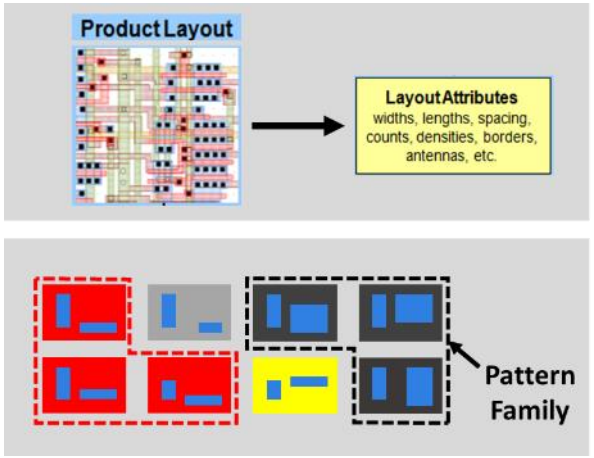


Partnership with Tessent for BIC debug and FA

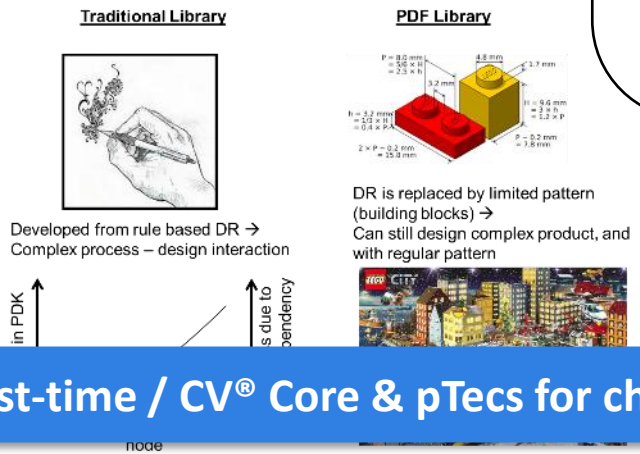
Design to Enable Zero Defect

Identify and Reduce Layout dependency

FIRE: identify all layout patterns in design

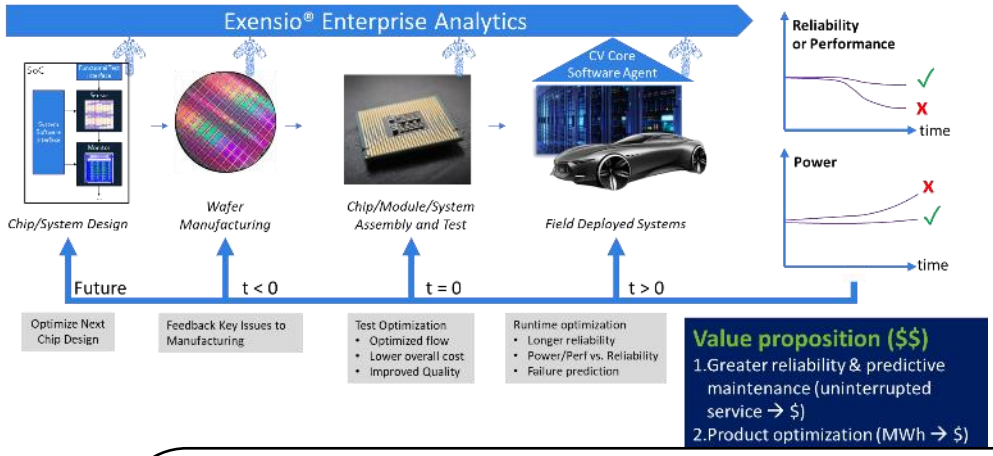


Templatyzer: reduce library pattern count by 10X



Embed in-chip sensors for monitoring

CV® Core: in-chip reliability monitor



proteanTecs: Monitor health & performance of chips, from design to field.

FIRE/Templatyzer for right-first-time / CV® Core & pTecs for chip-level sensing

CV® Core for Automotive

CV® Core Sensor for Automotive Applications

PDF/SOLUTIONS™

Circuit Performance

Circuit Aging

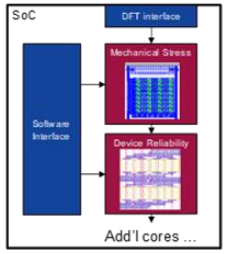
Package Performance

Traditional PVT Sensors

proteanTecs

DESIGN

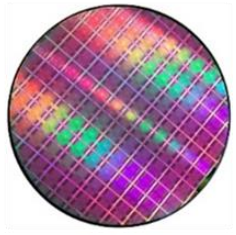
Chip Design



CV Core Insertion

BUILD

Wafer Manufacturing



Sort yield/parametrics correlation
PCM/Spice correlation

PACKAGING

Chip/Module/System Assembly and Test

Sort to FT/SLT correlation for Pkg/Test optimization
Die mission profile based aging readout (t=0)

MONITOR

Field Deployed Systems

Exensio CV Core Edge

In-field performance monitoring and mission profile optimization (t>0)

Exensio CV Core Data Processor

Sensor FOM Results

Configurations

DEX node

DEX node

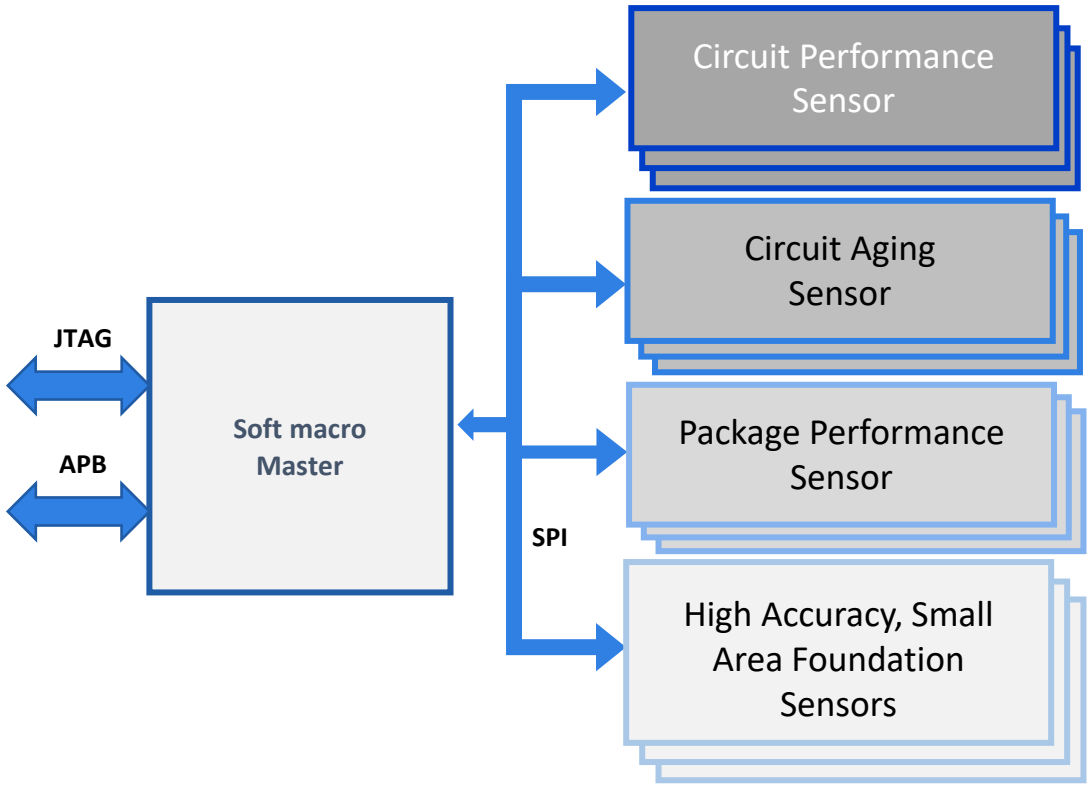
DEX node

Exensio Manufacturing Analytics

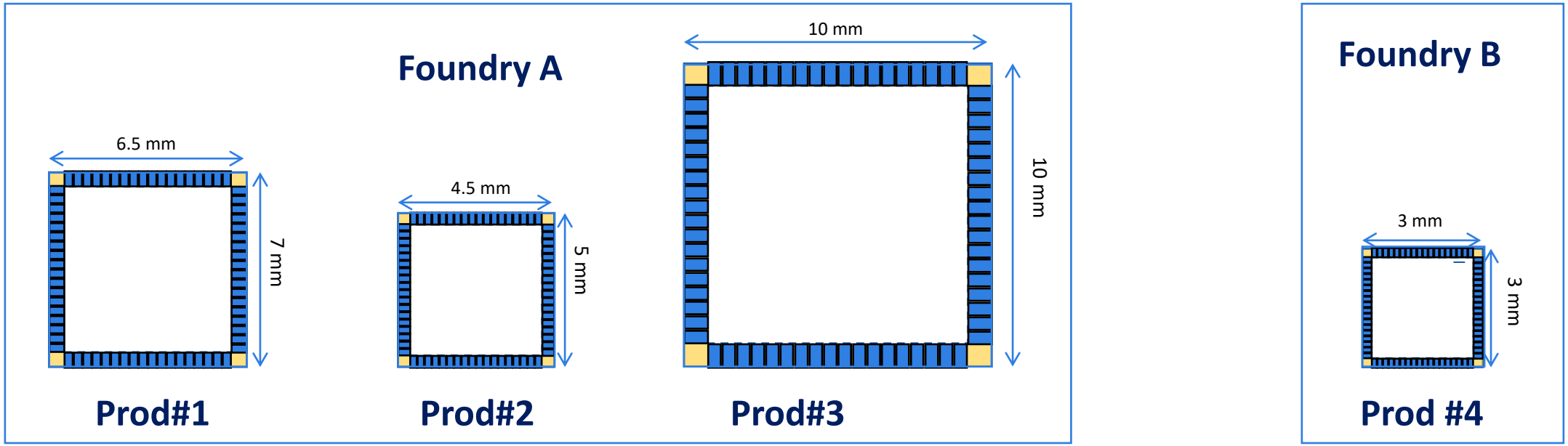
Customer System & Analytics

Exensio CV® Core System

Problem	Solution	CV® Core Offering
Test Escapes	Adaptive Test	Full Suite
Reliability Fails	Selective Burn-in	Circuit Aging Sensors
Advanced Package Complexity	Package Optimization	Package Performance Sensors
High Cost of Fails	Final Test Yield Prediction	Full Suite

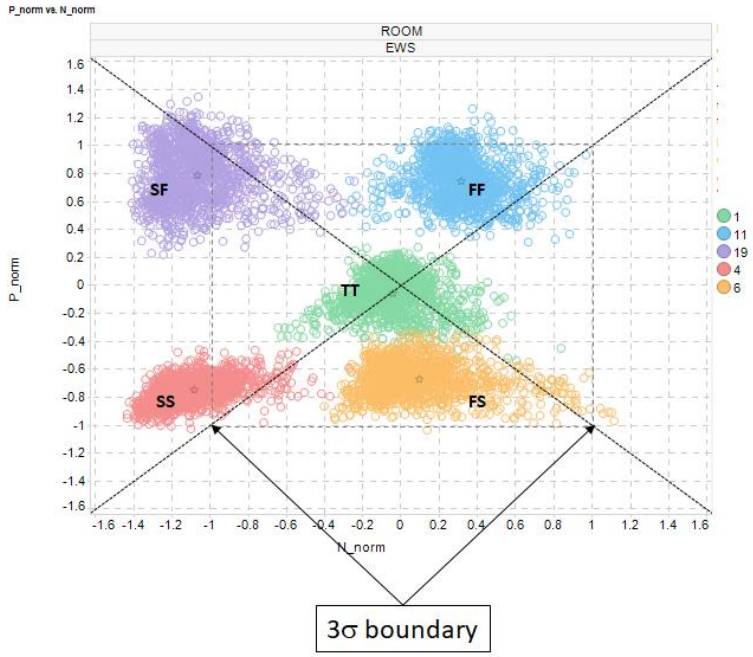


Already implemented in multi-million units of ADAS SoCs

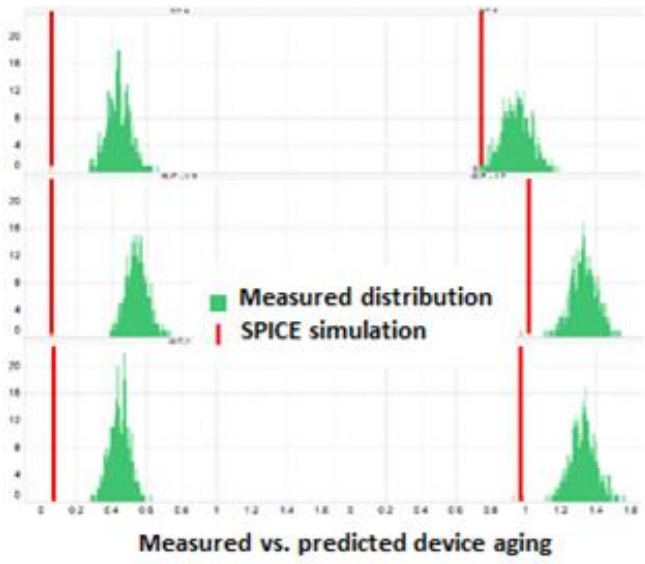


Macro name	Controller Macro	Sensor Macro	Interface	Aging Sensor	Performance Uniformity & Mechanical Stress	PVT sensor
Prod#1	Hard macro	Hard macro (combined w/ controller)	JTAG	1	1	N
Prod#2	Soft macro	Hard macros	JTAG + APB	1	7	N
Prod#3	Soft macro	Hard macros	JTAG + APB	1	8	N
Prod#4	Soft macro	Hard macros	Custom SPI	14	14	Y

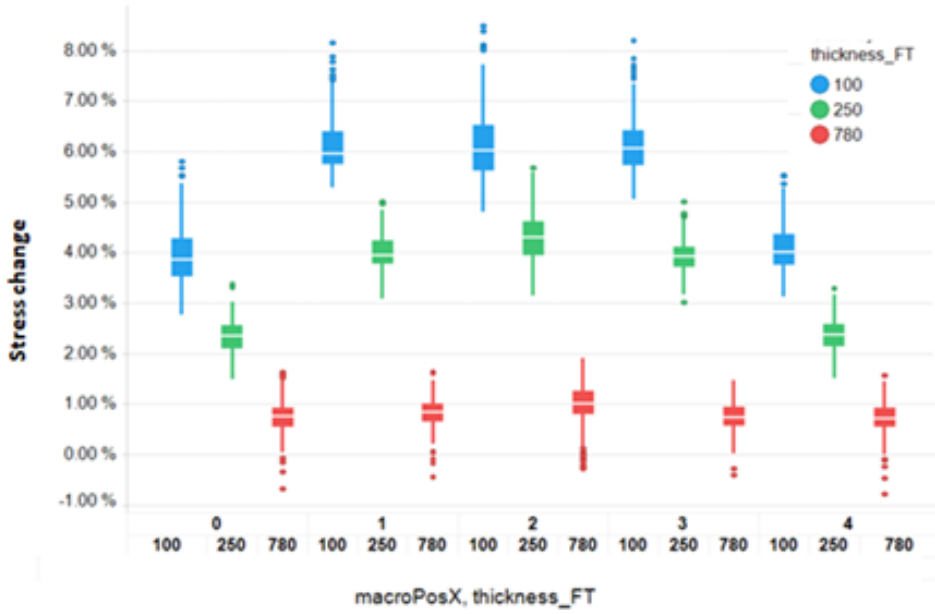
CV® Core: A view into the health of die fundamentals



Die performance across corners



Die-specific aging response

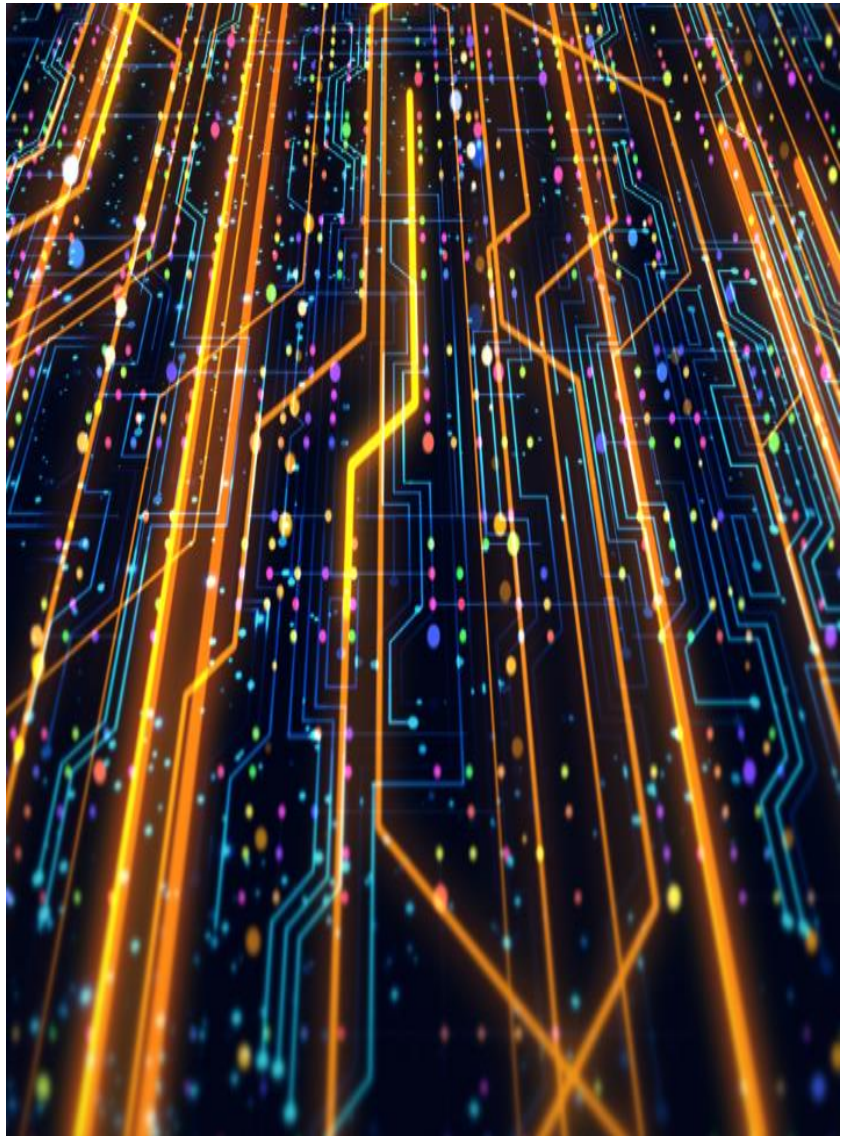


Die mechanical stress dependency

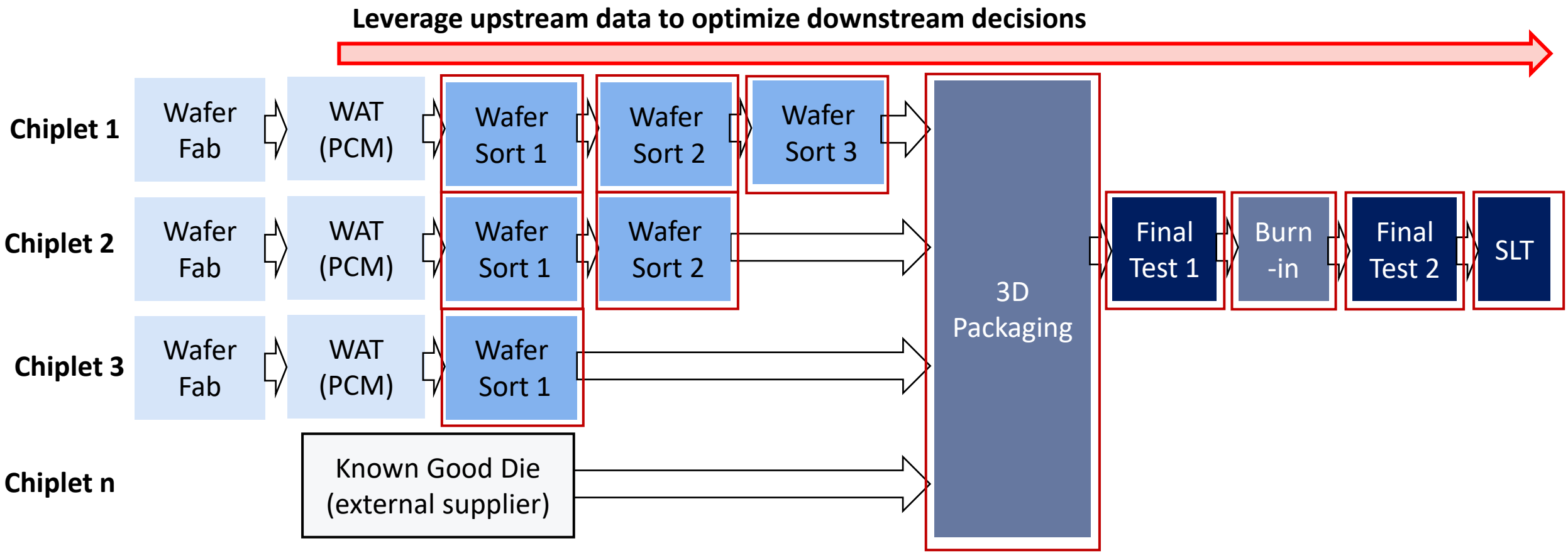
Machine Learning

Machine Learning – Insights

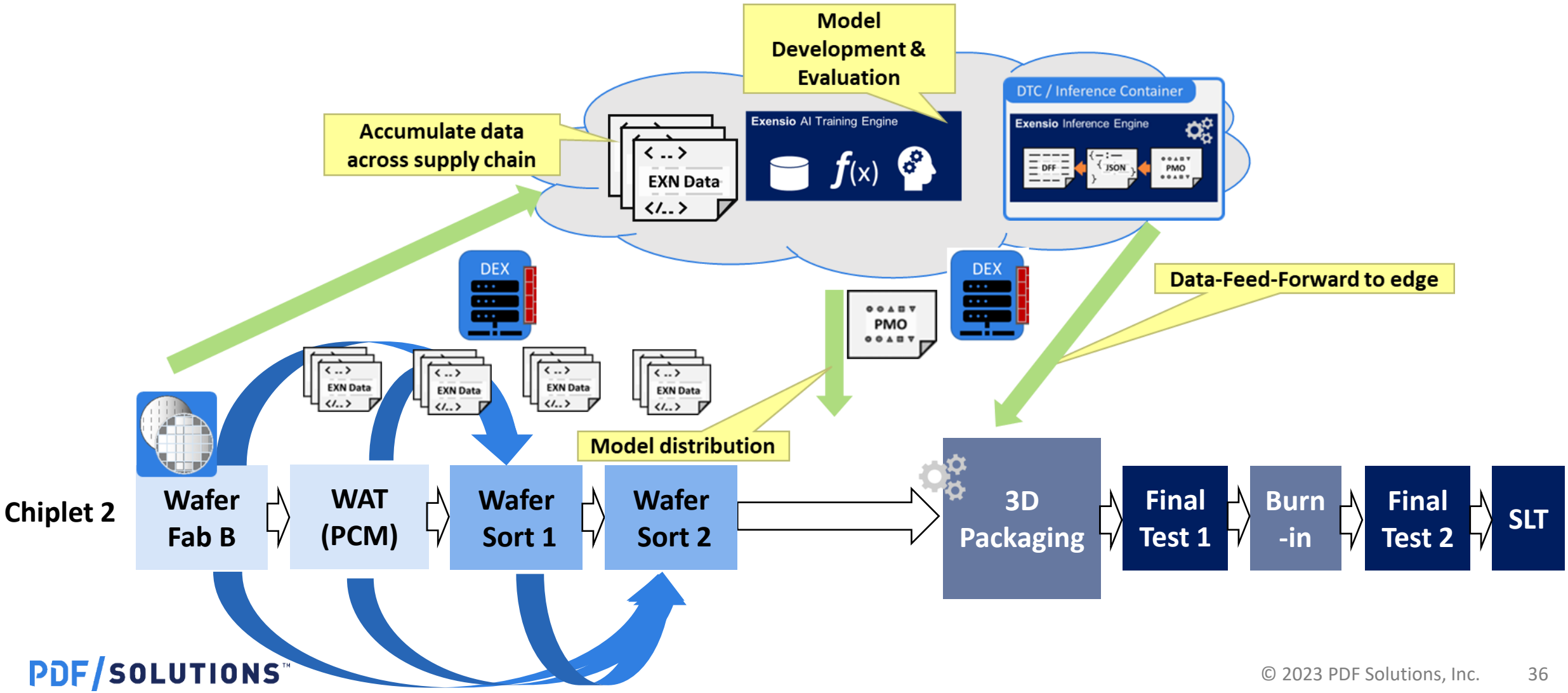
- **Automotive electronics is getting more complex**
  - Processes, Packages, Chiplet interactions, etc.
- **No longer good enough to look at steps in isolation**
  - Correlating across stages brings new learning
- **Those new technologies generate more data**
- **ML can find correlations that the best engineers miss**



The system in package testing challenge

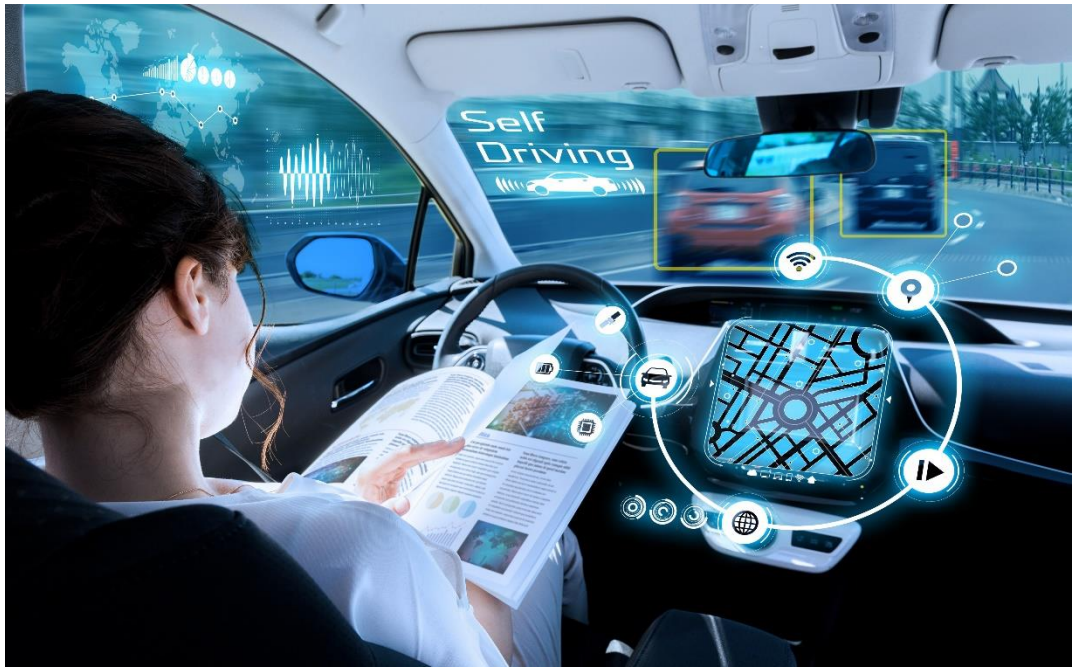


Exensio ML solution to scale prediction model training and deploy inference engine at the edge



Conclusion

- **Electrification & ADAS driving rapid growth**
- **Many new entrants**
- **PDF: broadest and deepest analytics solution**
- **With specialized offerings**
  - SiC package for EV products
  - Advanced tools for ADAS &
- **Machine Learning for applicable insights, across manufacturing steps**



Thank You

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