Packaged Systems Research for Advanced Vehicle Electronics @CAVE3

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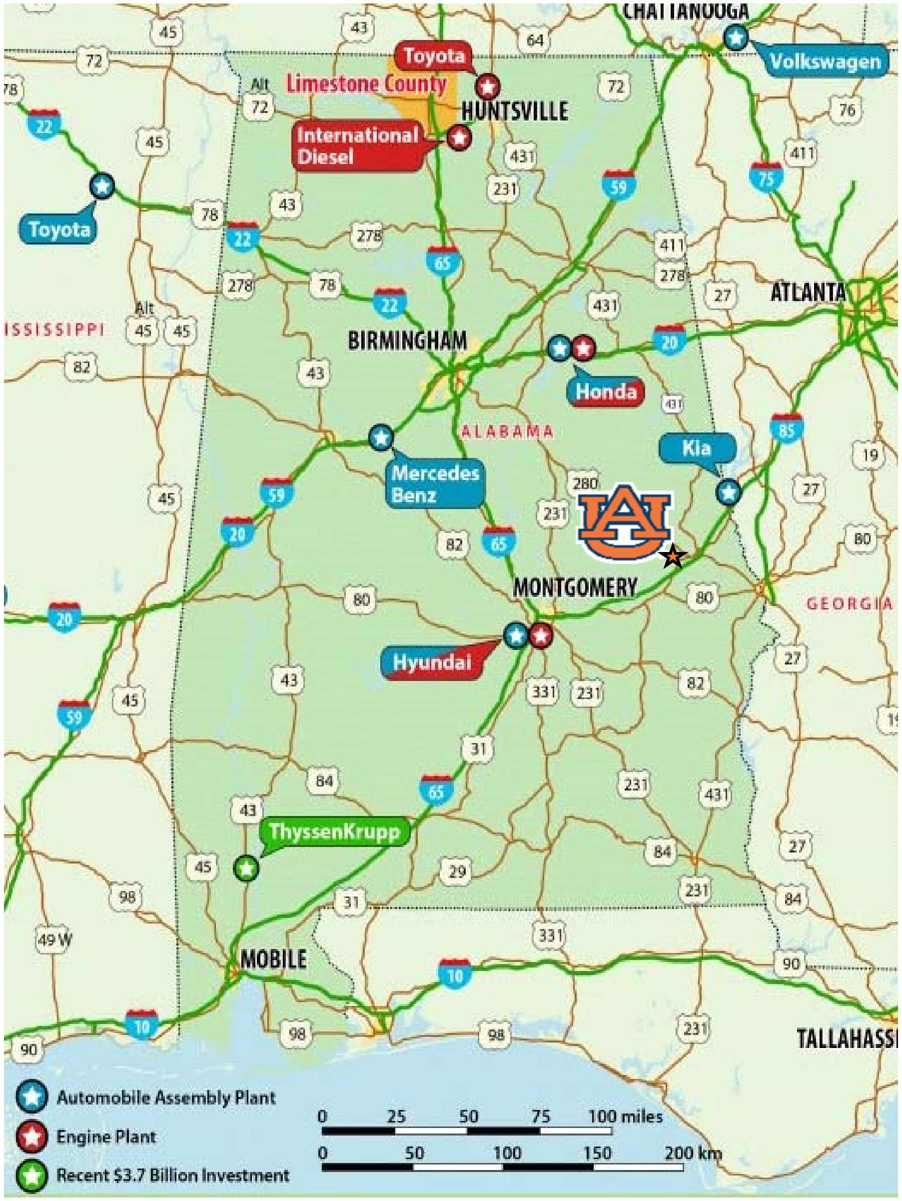
Automotive Companies



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- CAVE^3
- What is NSF-CAVE^3
- Research Thrusts
  - Component Reliability
  - Connector Reliability
  - Flip Chip and Underfills
  - Harsh Electronics Systems and Manufacturing
  - Lead free Soldering
- Research Highlights
  - Lead Free
  - Prognostics
  - Shock & Vibration
  - Tin Whiskers
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The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE^3) at Auburn University is dedicated to working with industry in developing and implementing new technologies for the packaging and manufacturing of electronics with special emphasis on the cost, harsh environment and reliability requirements of the vehicle industry.

Center personnel work directly with the member companies to identify challenges and opportunities for new materials, processes and approaches to the production of electronics. The member companies select the research projects. Semi-annual project reviews, visits, monthly updates and frequent phone calls maintain a close interaction between the industrial members and Center researchers. CAVE^3 currently has 30 members teamed up with Auburn representing material, component, equipment and electronics assembly companies.

Researcher Spotlight

Prognostic health management (PHM) is a method for assuring the reliability of a system by monitoring the system in real time as it is used in the field. As the system wears out, but before failure, information that facilitates decision making about the future use of the system is delivered to the user. Learn more about this exciting technology here.

News

Call for Papers for IEEE PHM Conference, June 2012

Mechanical engineering professor appointed to National Academies committee

New mechanical engineering building opens with state of the art facilities

Awards

CAVE3 Student Wins Best Poster Award at IPACK 2011

Center faculty named IEEE fellow

CAVE3 Faculty Guest Editor for Special Issue of ASME Journal of Electronic Packaging on PHM

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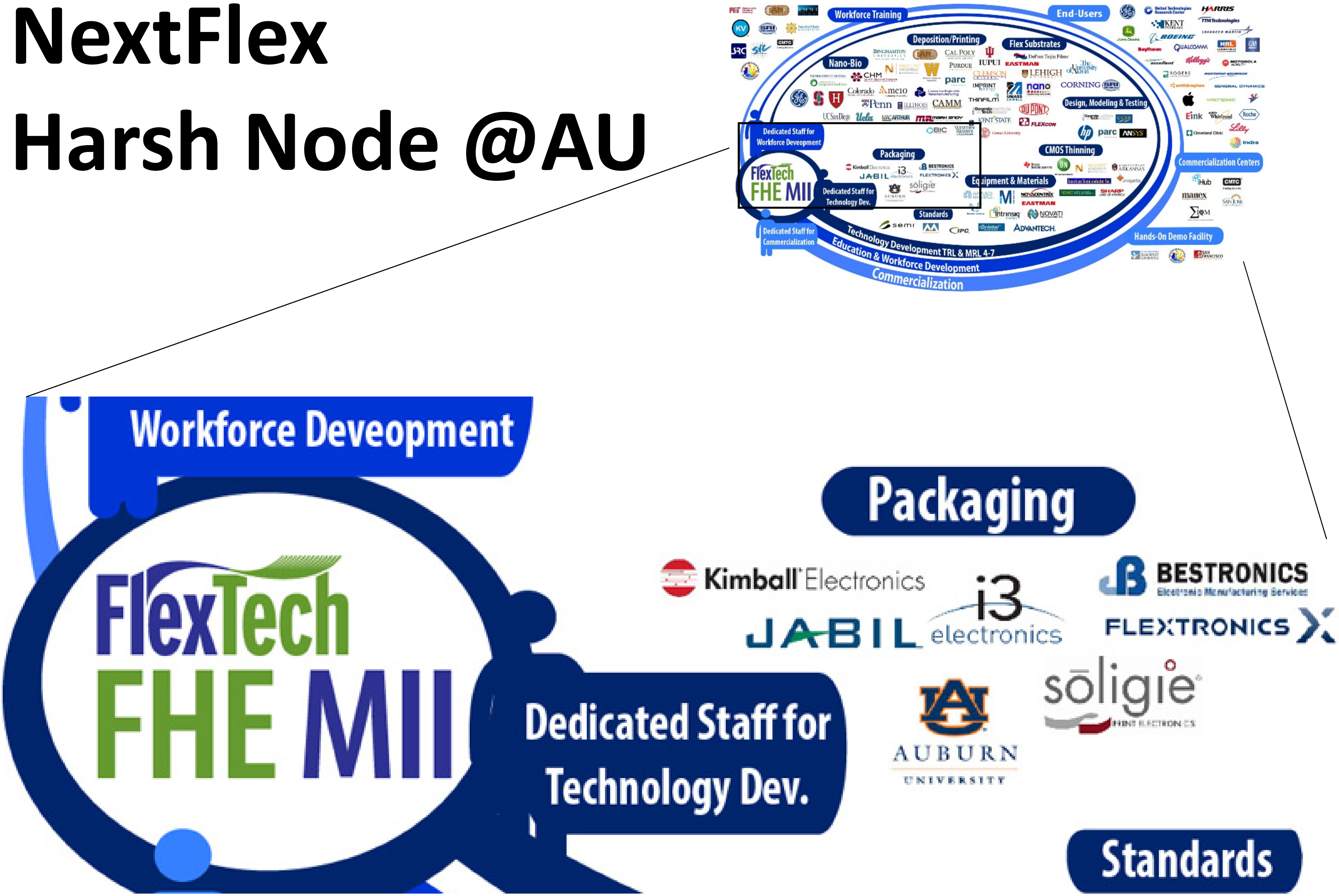
NextFlex
Harsh Node @AU



Goals AU Harsh Node of NextFlex

- ☐ Accelerate technology adoption into harsh-environment products by developing and commercializing advanced manufacturing technologies.
- ☐ Leverage electronics industry and high performance printing industry, both US industrial and academic areas of strength.

The five FHE core manufacturing focus areas are included below:

1. Device Integration and Packaging
2. Materials:
3. Printed Flexible Components and Microfluidics
4. Modeling & Design
5. Standards, Test & Reliability

Impact on Economic Development

The Institute is a Economic Development Activity intended to:

- ☐ Create a strong healthy ecosystem in flexible electronics.
- ☐ Take TRL4 technologies and cross valley between laboratory research and product development.

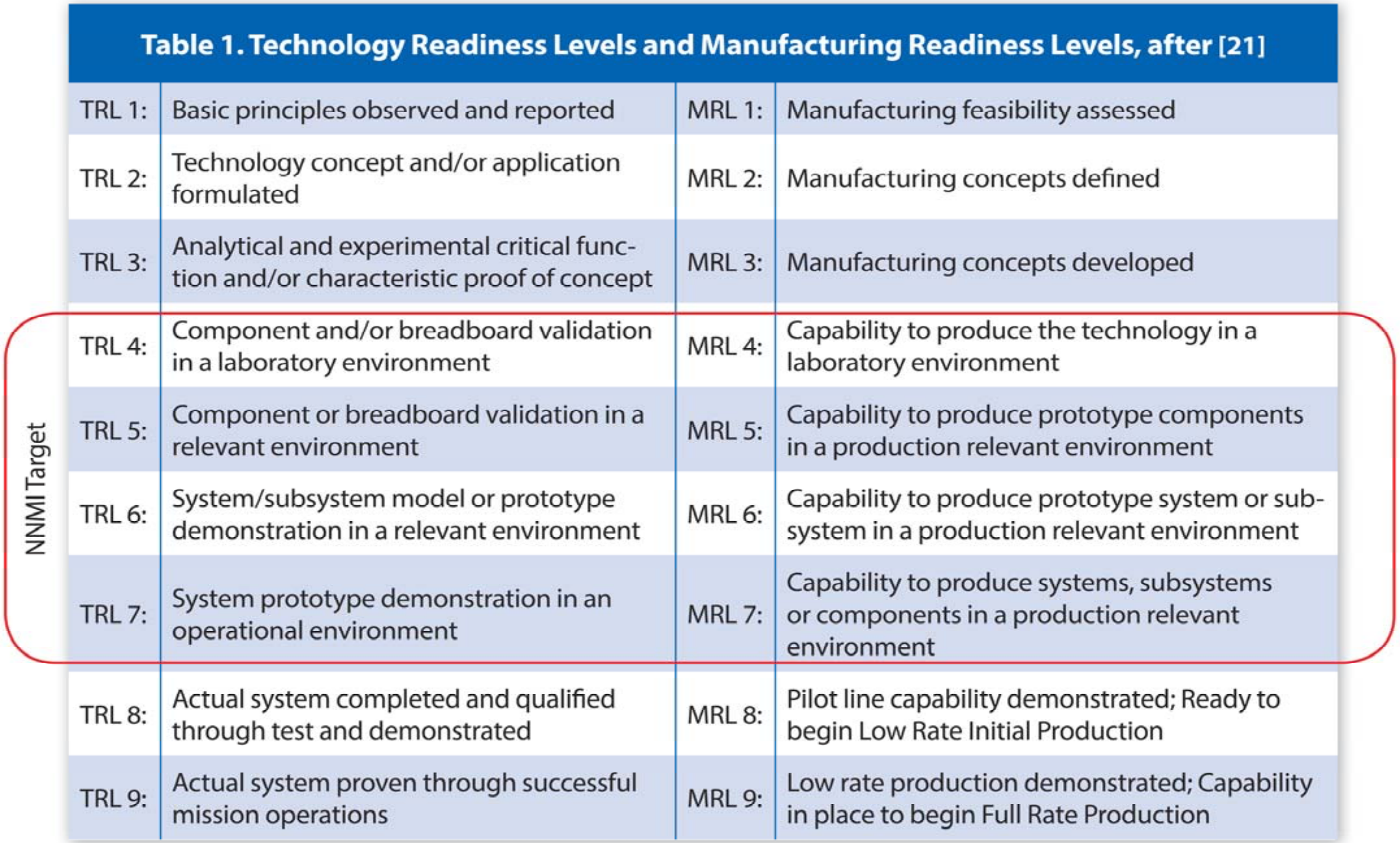
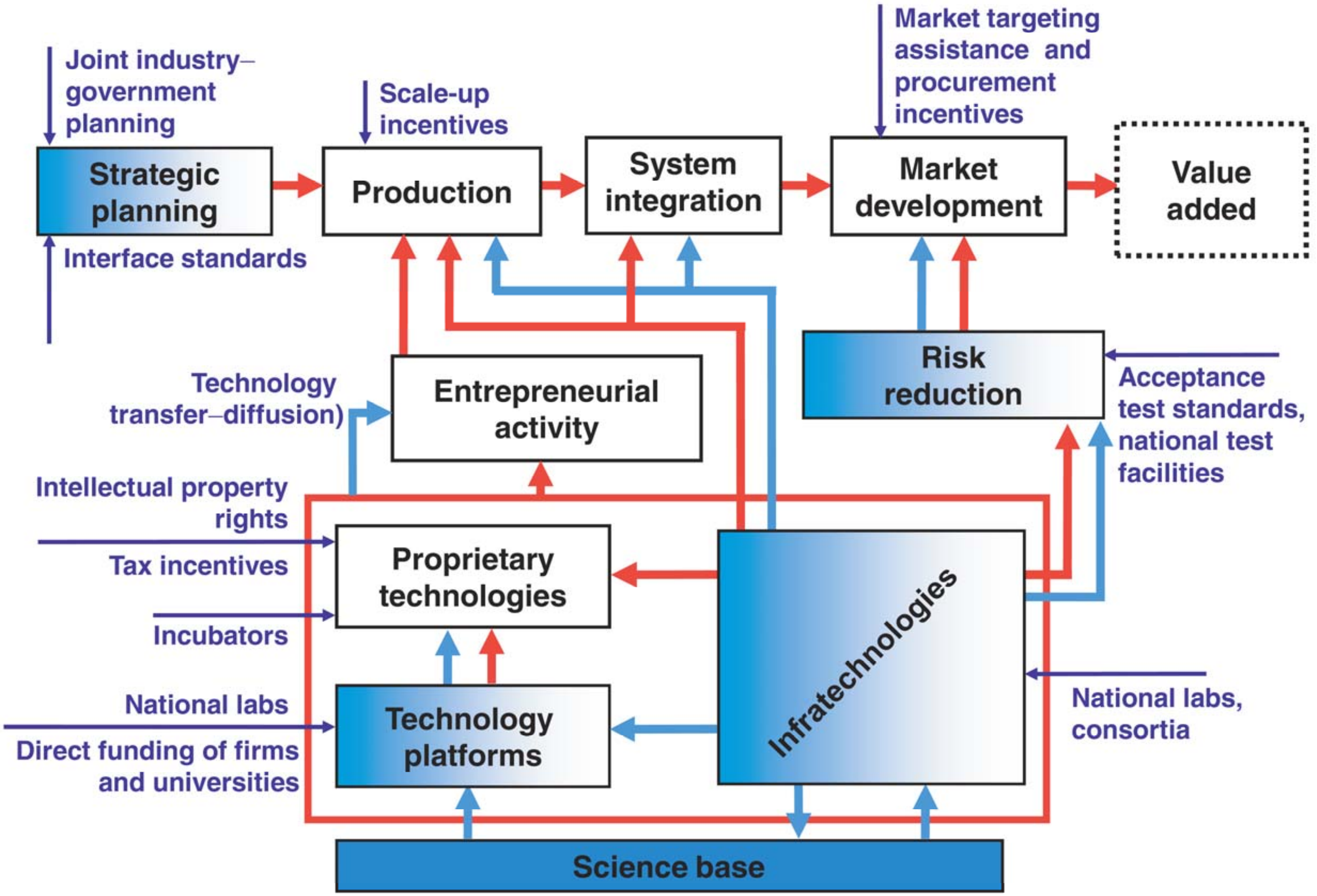


Table 1. Technology Readiness Levels and Manufacturing Readiness Levels, after [21]

TRL 1:	Basic principles observed and reported	MRL 1:	Manufacturing feasibility assessed
TRL 2:	Technology concept and/or application formulated	MRL 2:	Manufacturing concepts defined
TRL 3:	Analytical and experimental critical function and/or characteristic proof of concept	MRL 3:	Manufacturing concepts developed
TRL 4:	Component and/or breadboard validation in a laboratory environment	MRL 4:	Capability to produce the technology in a laboratory environment
TRL 5:	Component or breadboard validation in a relevant environment	MRL 5:	Capability to produce prototype components in a production relevant environment
TRL 6:	System/subsystem model or prototype demonstration in a relevant environment	MRL 6:	Capability to produce prototype system or subsystem in a production relevant environment
TRL 7:	System prototype demonstration in an operational environment	MRL 7:	Capability to produce systems, subsystems or components in a production relevant environment
TRL 8:	Actual system completed and qualified through test and demonstrated	MRL 8:	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production
TRL 9:	Actual system proven through successful mission operations	MRL 9:	Low rate production demonstrated; Capability in place to begin Full Rate Production

Enabling Infrastructure Technologies



Joint industry–government planning

Scale-up incentives

Market targeting assistance and procurement incentives

Strategic planning

Production

System integration

Market development

Value added

Interface standards

Risk reduction

Technology transfer–diffusion)

Entrepreneurial activity

Acceptance test standards, national test facilities

Intellectual property rights

Tax incentives

Proprietary technologies

Incubators

Infratechnologies

National labs

Technology platforms

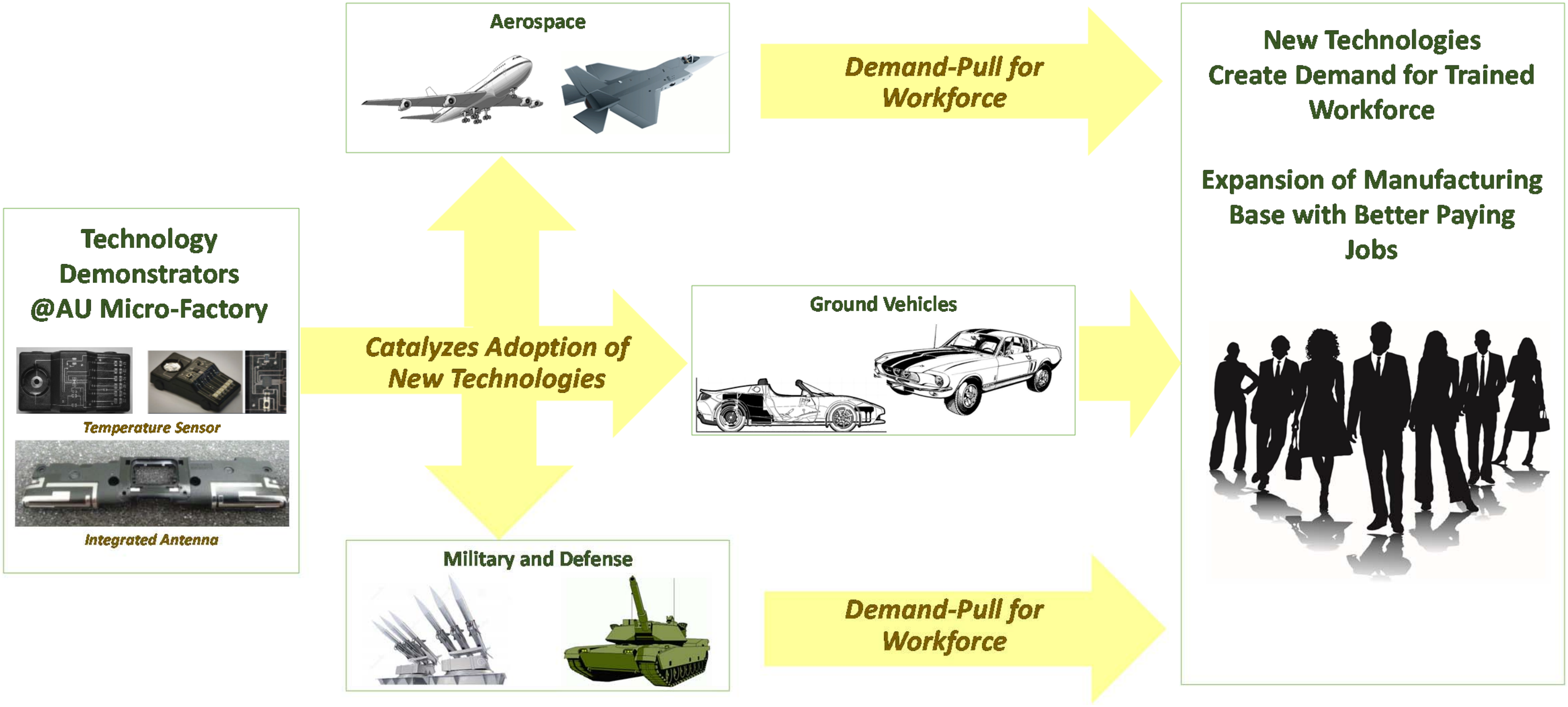
National labs, consortia

Direct funding of firms and universities

Science base

SOURCE: Figure 6, "Managing the entire technology life cycle: Policy roles in response to market failures" in Gregory Tassey, "Beyond the business cycle: The need for a technology- based growth strategy," Science and Public Policy (2013) 40(3):293-315,; *in The Flexible Electronics Opportunity, National Academies Press, 2014*

Model for Making an Economic Impact



Technology Demonstrators @AU Micro-Factory

Temperature Sensor

Integrated Antenna

Catalyzes Adoption of New Technologies

Aerospace

Ground Vehicles

Military and Defense

Demand-Pull for Workforce

Demand-Pull for Workforce

New Technologies Create Demand for Trained Workforce

Expansion of Manufacturing Base with Better Paying Jobs

cave^3

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Fundamental-Research Areas

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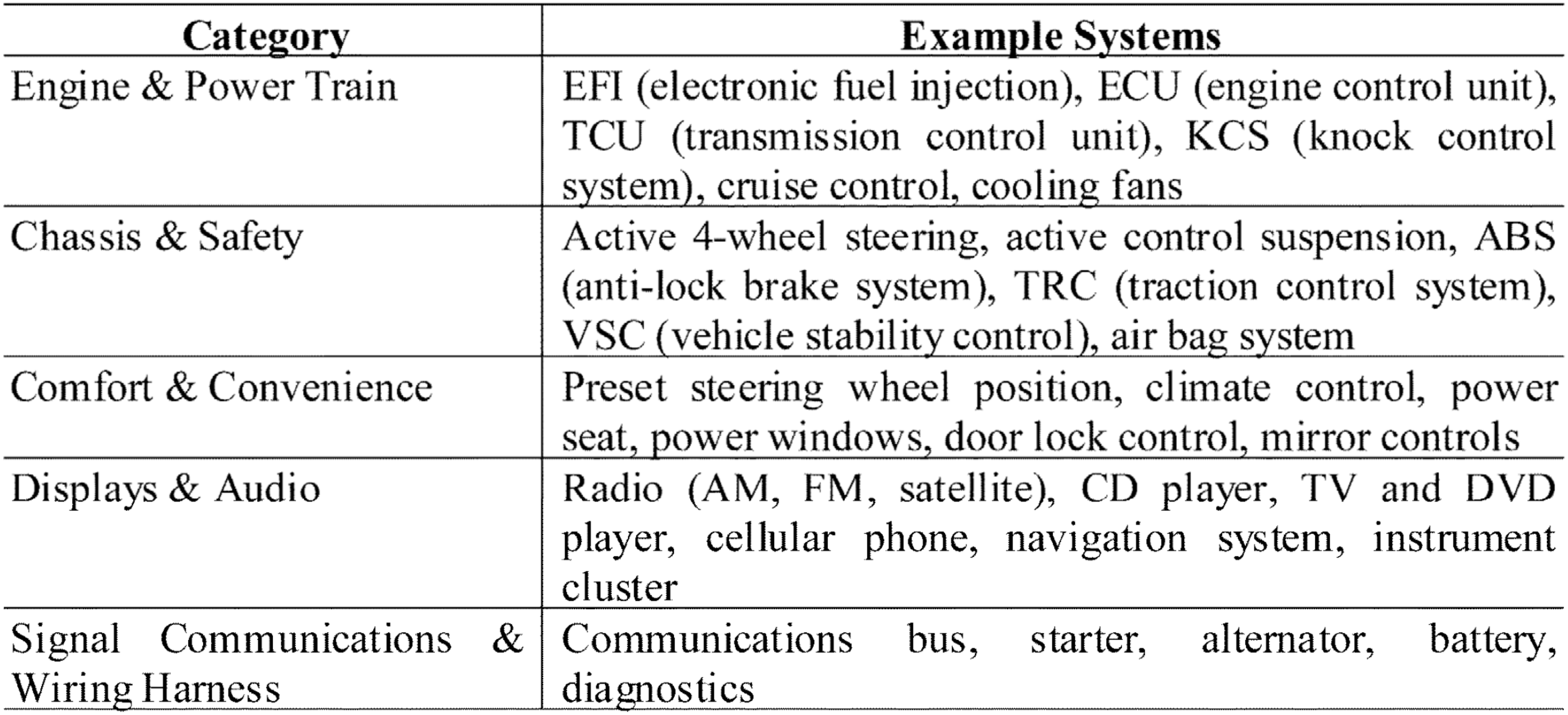
- Chip-Level Interconnects, Flip-Chip and Underfills
- Component Reliability and Prognostic Health Management Systems
- Connectors, and System-Level Interconnects: Degradation and Wear Mechanisms
- Harsh Electronics Systems and Manufacturing
- Leadfree Solders Alloys Constitutive and Wetting Behavior

Traditional Automotive Electronic Systems



Category	Example Systems
Engine & Power Train	EFI (electronic fuel injection), ECU (engine control unit), TCU (transmission control unit), KCS (knock control system), cruise control, cooling fans
Chassis & Safety	Active 4-wheel steering, active control suspension, ABS (anti-lock brake system), TRC (traction control system), VSC (vehicle stability control), air bag system
Comfort & Convenience	Preset steering wheel position, climate control, power seat, power windows, door lock control, mirror controls
Displays & Audio	Radio (AM, FM, satellite), CD player, TV and DVD player, cellular phone, navigation system, instrument cluster
Signal Communications & Wiring Harness	Communications bus, starter, alternator, battery, diagnostics

Johnson, et.al., The Changing Automotive Environment:High-Temperature Electronics, IEEE Transactions On Electronics Packaging Manufacturing, Vol. 27, No. 3, July 2004

Core-Functionality Systems Enabled by Electronics

Driving Assists

- Antilock Braking System
- Traction Control System
- Park Distance Controls
- Power steering
- Power braking
- Electronic Stabilization Programme
- Adaptive Cruise Control
- Electronic Brake Force Distribution
- Rain Sensors

Safety Systems

- Airbags
- Emergency Braking System
- Early Crash Sensors
- Brake Disc Wipers
- Active Rollover Protection System

Source: Actel pioneering new markets for FPGAs in automobiles, EE TIMES

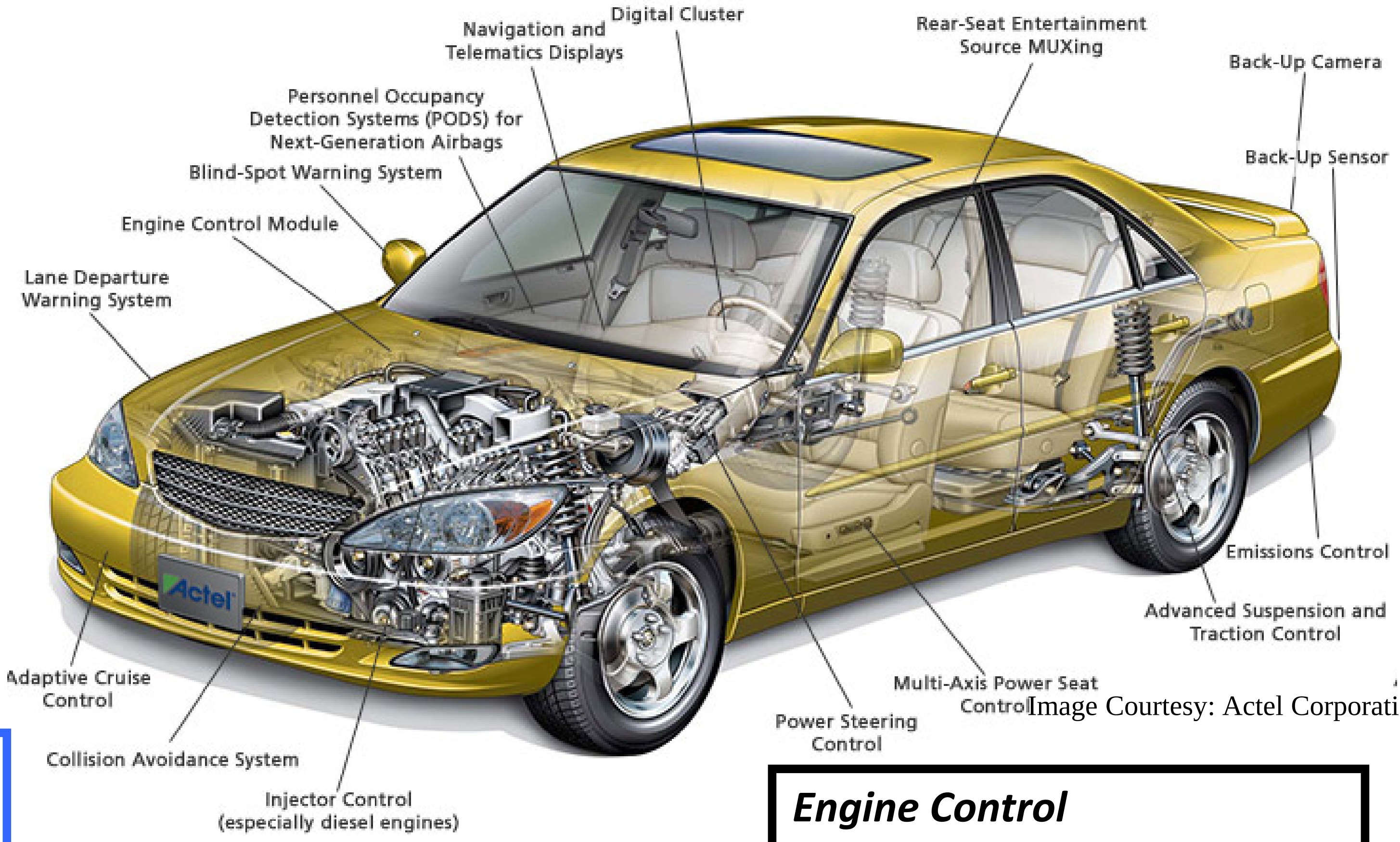


Image Courtesy: Actel Corporation

Engine Control

- ECUs
- Electronic Fuel Injection
- Powertrain Control Module

Navigation & Communication

- GPS
- Parking assist

Propulsion Systems

- Hybrid Engines
- Regenerative Braking

Flexible Electronics Applications

Integration of Sensors into Automotive Surfaces

Product Concepts:
Courtesy of Continental AG

Owning the Connectivity Space in Automotive

4G

USB charging

Over the air software updates

Full telematics control

Enhanced signal quality

Ability to integrate consumer electronics

Wireless charging

Connected devices optimize fleet productivity

WiFi

Bluetooth

Integrated DSRC shark fin antenna

Smart antennas provide optimal RF performance

DSRC (V2V / V2I) antenna + receiver

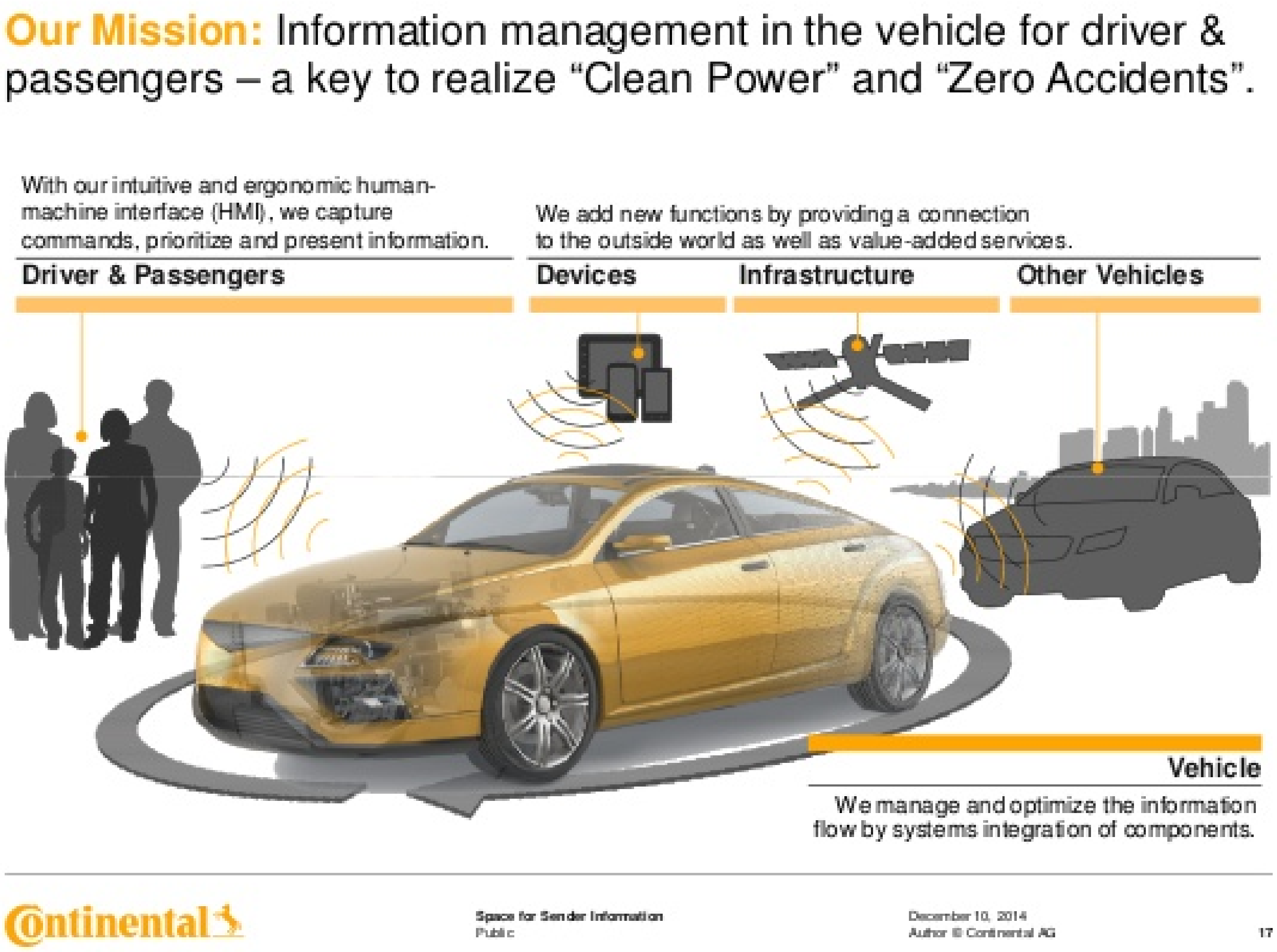
Cellular, GNSS
Antenna + transceiver
Data pipe

Emergency responders

LTE / MiMo antennas enable in vehicle data streaming

● Laird ● Novero ● Both

Laird



Our Mission: Information management in the vehicle for driver & passengers – a key to realize “Clean Power” and “Zero Accidents”.

With our intuitive and ergonomic human-machine interface (HMI), we capture commands, prioritize and present information.

Driver & Passengers

We add new functions by providing a connection to the outside world as well as value-added services.

Devices

Infrastructure

Other Vehicles

Vehicle

We manage and optimize the information flow by systems integration of components.

Continental

Space for Sender Information
Public

December 10, 2014
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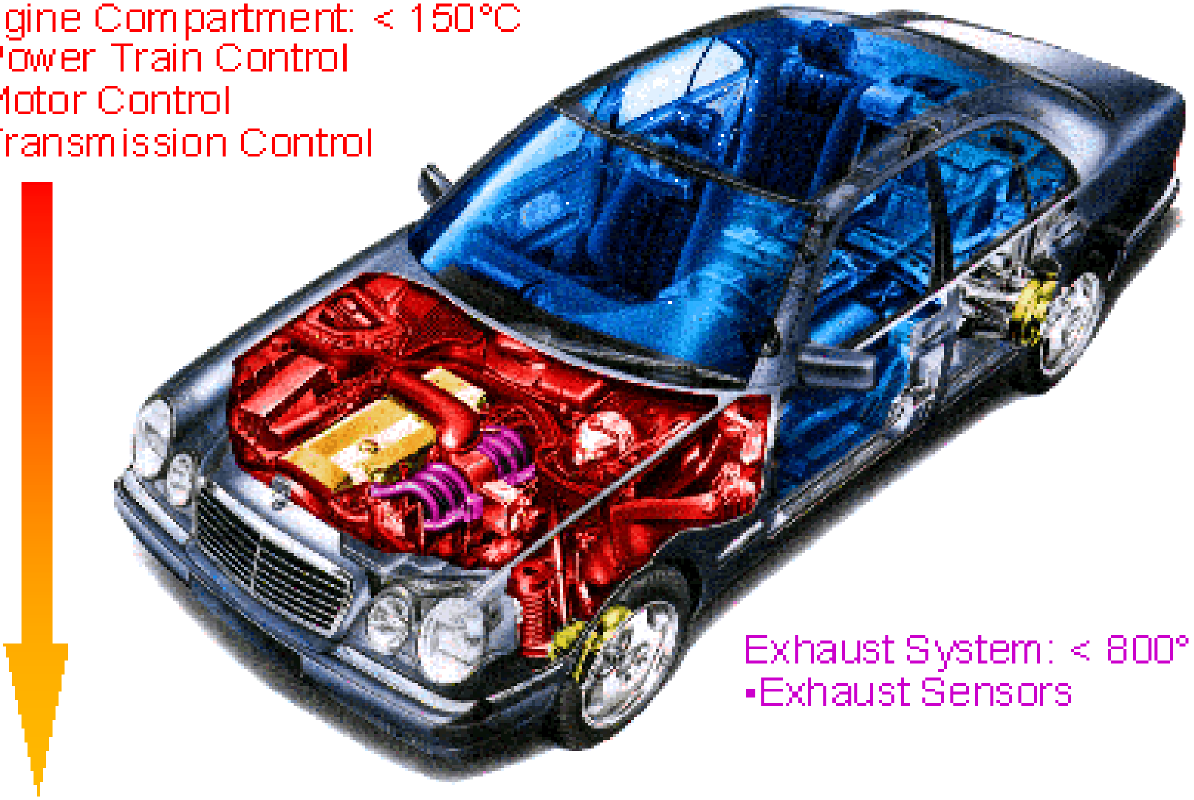
Automotive Temperature Extremes



Combustion Chamber: < 500°C
- Pressure Sensors

Engine Compartment: < 150°C
- Power Train Control
- Motor Control
- Transmission Control

Exhaust System: < 800°C
- Exhaust Sensors

Engine, Transmission: < 200°C
- Engine-mounted ECUs
- Integrated TCUs
- Shift-by-Wire

Wheel Mounted Components: < 300°C
- Brake-by-Wire
- Steer-by-Wire

R. Thompson, *Proc. SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Automotive Temperature Extremes

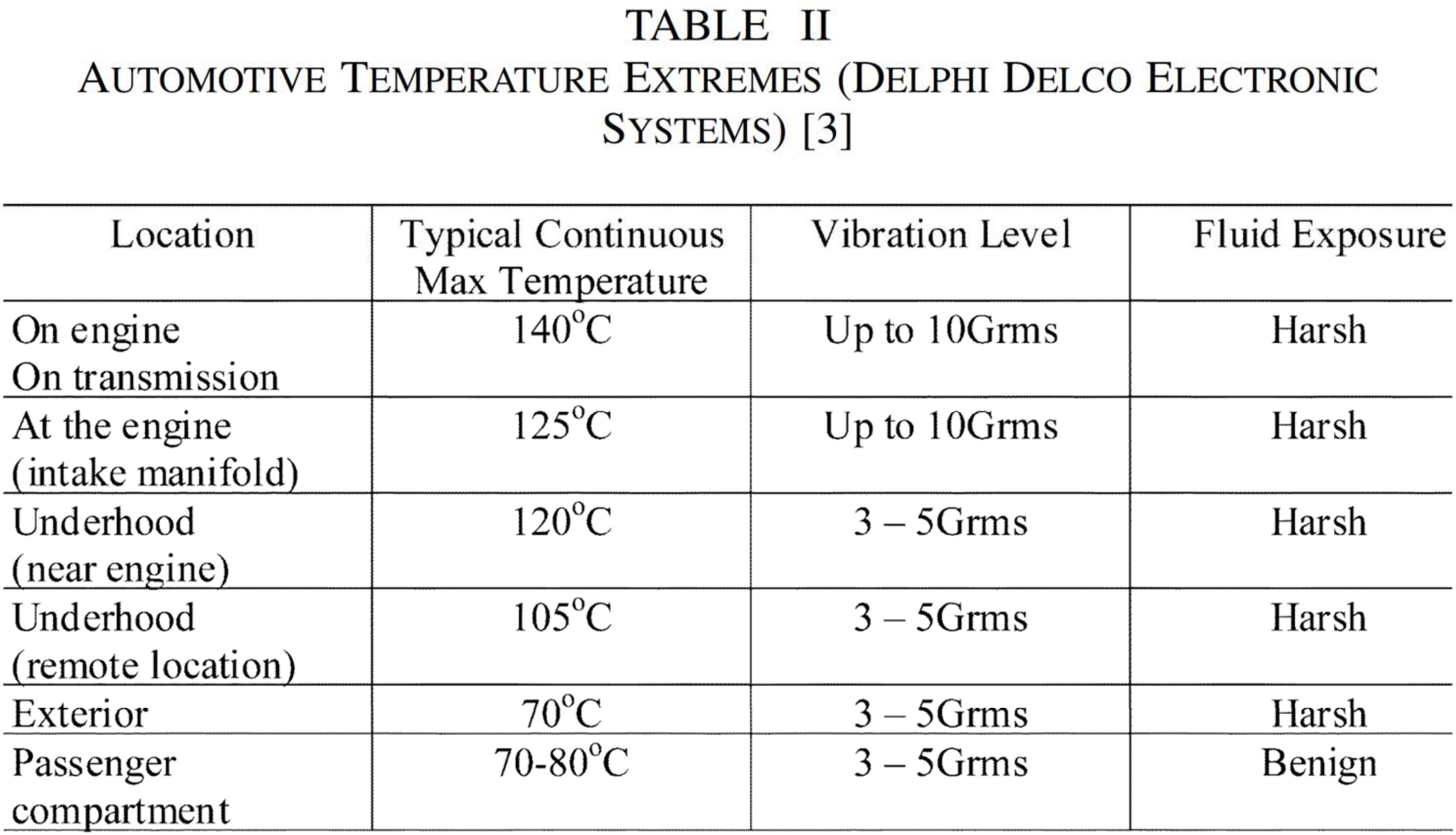


TABLE II

AUTOMOTIVE TEMPERATURE EXTREMES (DELPHI DELCO ELECTRONIC SYSTEMS) [3]

Location	Typical Continuous Max Temperature	Vibration Level	Fluid Exposure
On engine On transmission	140°C	Up to 10Grms	Harsh
At the engine (intake manifold)	125°C	Up to 10Grms	Harsh
Underhood (near engine)	120°C	3 – 5Grms	Harsh
Underhood (remote location)	105°C	3 – 5Grms	Harsh
Exterior	70°C	3 – 5Grms	Harsh
Passenger compartment	70-80°C	3 – 5Grms	Benign

Johnson, et.al., The Changing Automotive Environment:High-Temperature Electronics, IEEE Transactions On Electronics Packaging Manufacturing, Vol. 27, No. 3, July 2004

Automotive Temperature Extremes

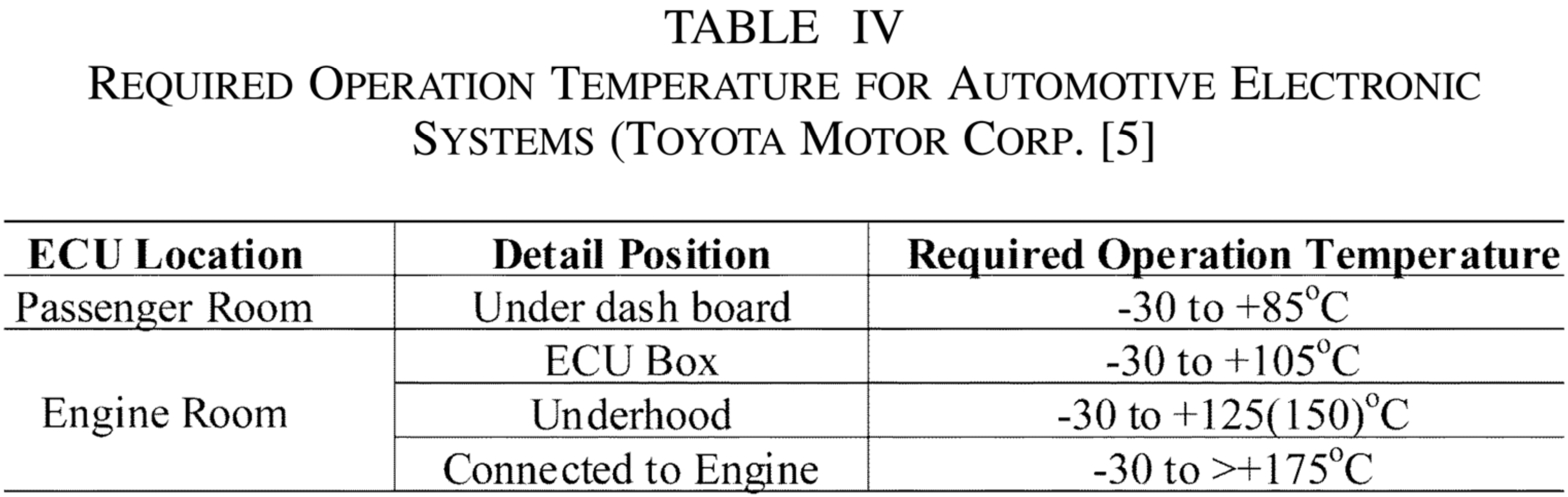


TABLE IV
REQUIRED OPERATION TEMPERATURE FOR AUTOMOTIVE ELECTRONIC SYSTEMS (TOYOTA MOTOR CORP. [5]

ECU Location	**Detail Position**	**Required Operation Temperature**
Passenger Room	Under dash board	-30 to +85°C
Engine Room	ECU Box	-30 to +105°C
	Underhood	-30 to +125(150)°C
	Connected to Engine	-30 to >+175°C

Johnson, et.al., The Changing Automotive Environment:High-Temperature Electronics, IEEE Transactions On Electronics Packaging Manufacturing, Vol. 27, No. 3, July 2004

Automotive Environment

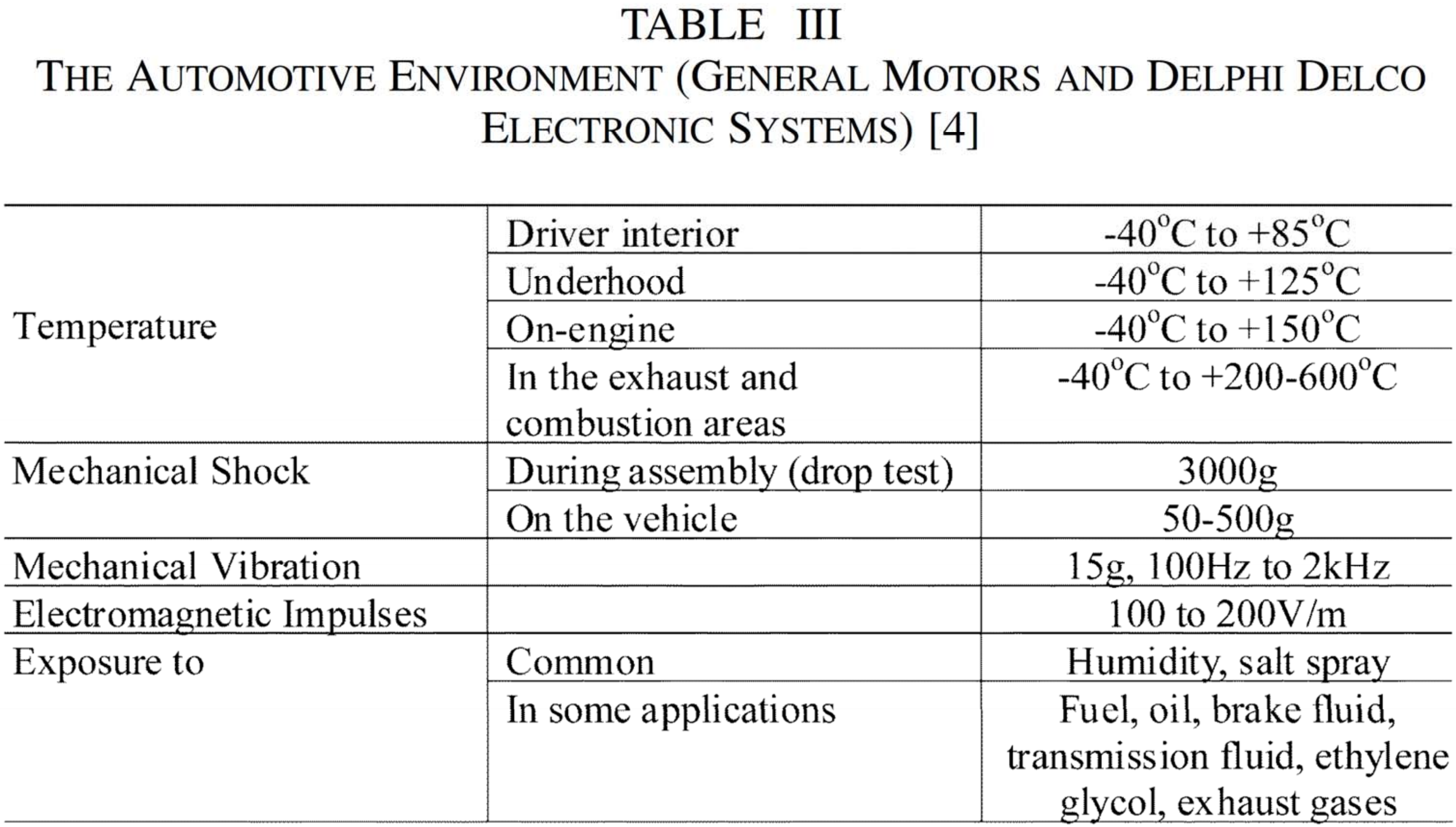


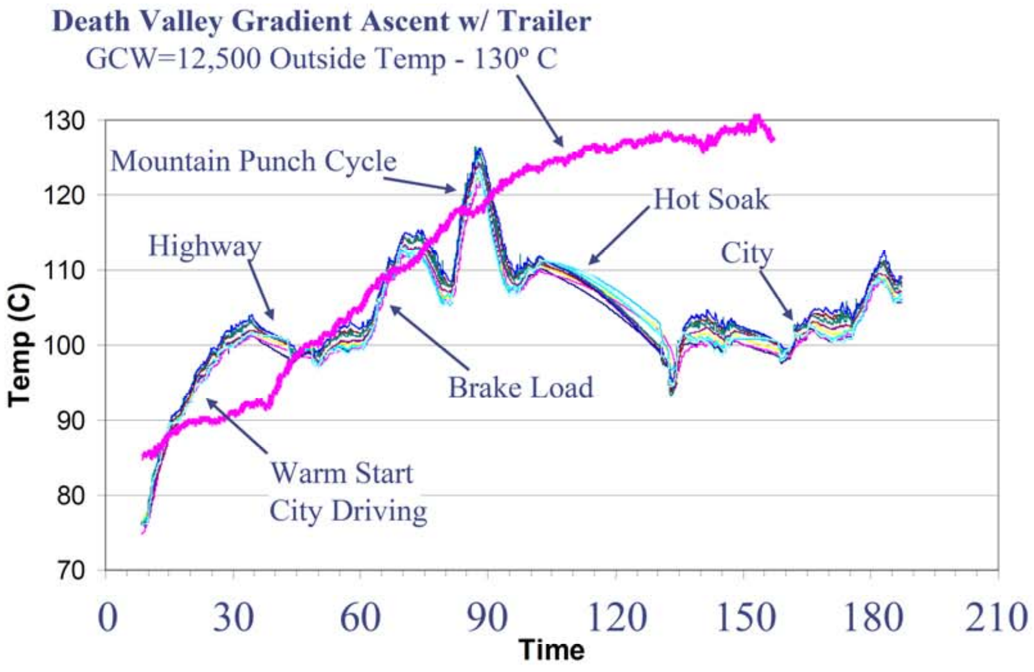
TABLE III
THE AUTOMOTIVE ENVIRONMENT (GENERAL MOTORS AND DELPHI DELCO ELECTRONIC SYSTEMS) [4]

Temperature	Driver interior	-40°C to +85°C
	Underhood	-40°C to +125°C
	On-engine	-40°C to +150°C
	In the exhaust and combustion areas	-40°C to +200-600°C
Mechanical Shock	During assembly (drop test)	3000g
	On the vehicle	50-500g
Mechanical Vibration		15g, 100Hz to 2kHz
Electromagnetic Impulses		100 to 200V/m
Exposure to	Common	Humidity, salt spray
	In some applications	Fuel, oil, brake fluid, transmission fluid, ethylene glycol, exhaust gases

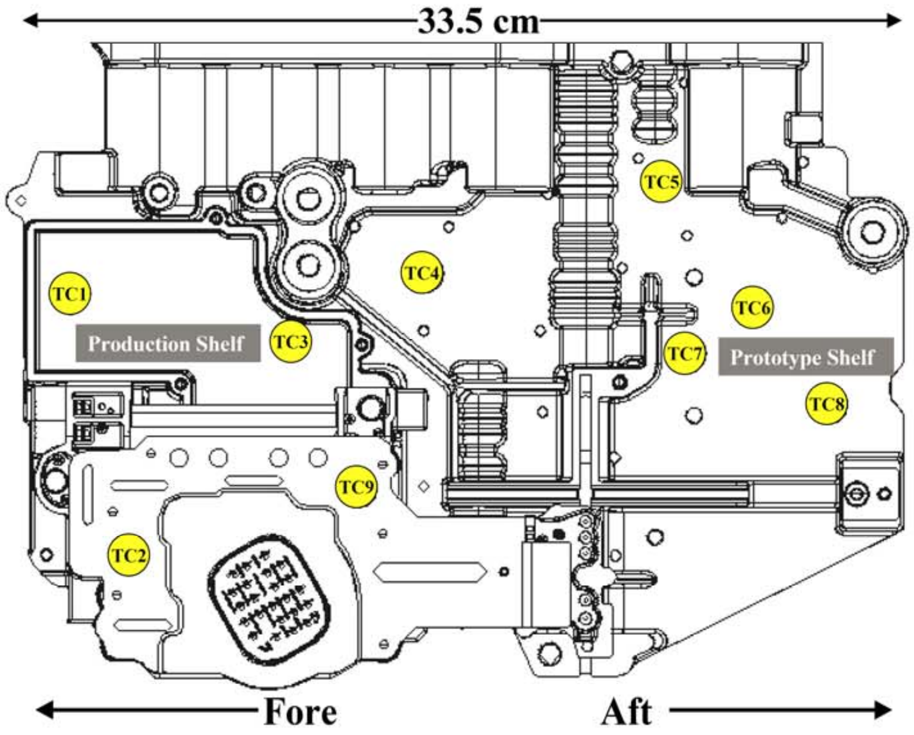
Johnson, et.al., The Changing Automotive Environment:High-Temperature Electronics, IEEE Transactions On Electronics Packaging Manufacturing, Vol. 27, No. 3, July 2004

Automotive Operational Temperatures

Ambient Temperature Characterization



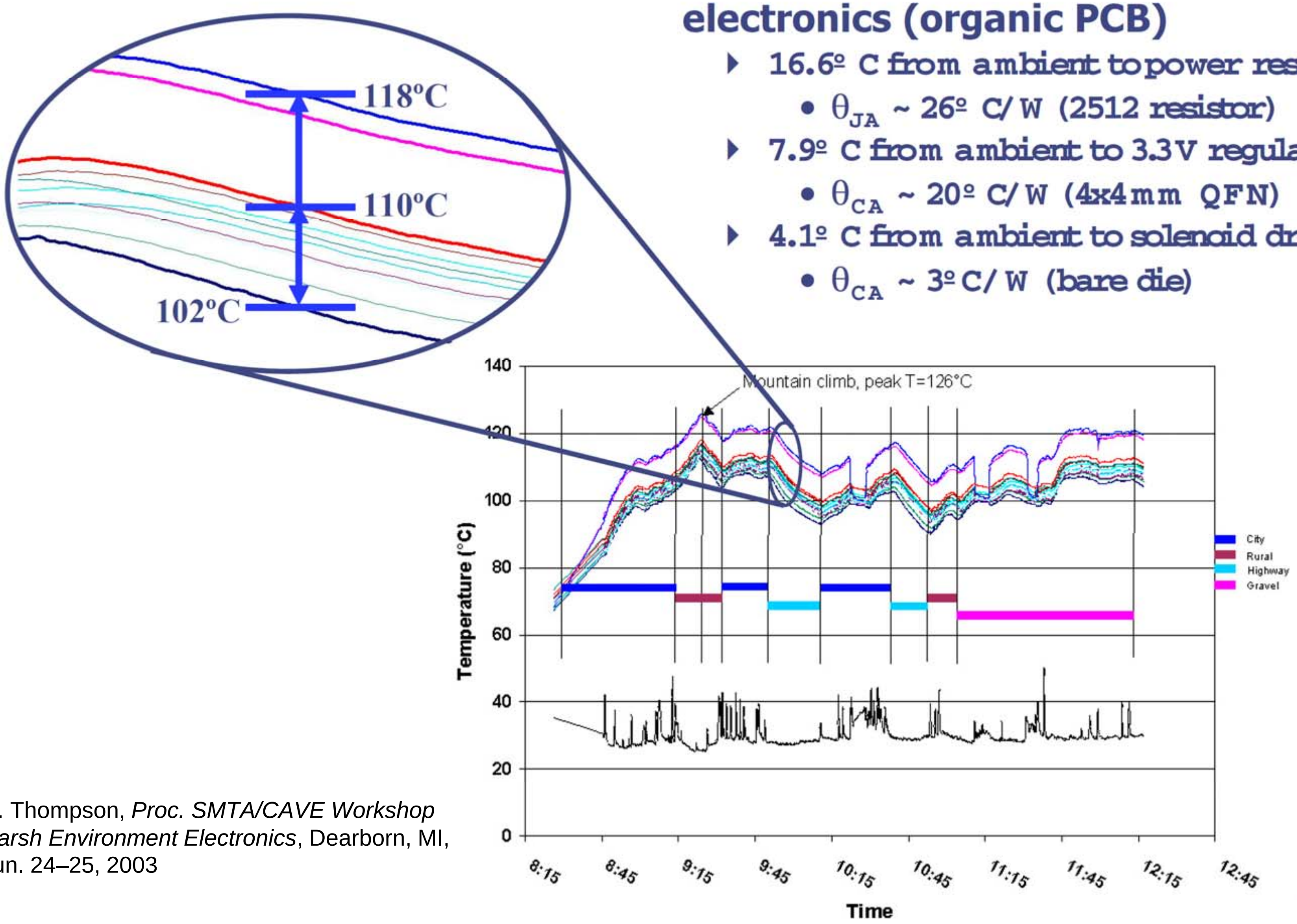
Temperature Instrumentation



R. Thompson, *Proc. SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Automotive Operational Temperatures

- **Max temperature increase for integrated electronics (organic PCB)**
  - 16.6º C from ambient to power resistor
    - θ_{JA} ~ 26º C/W (2512 resistor)
  - 7.9º C from ambient to 3.3V regulator
    - θ_{CA} ~ 20º C/W (4x4mm QFN)
  - 4.1º C from ambient to solenoid driver
    - θ_{CA} ~ 3º C/W (bare die)

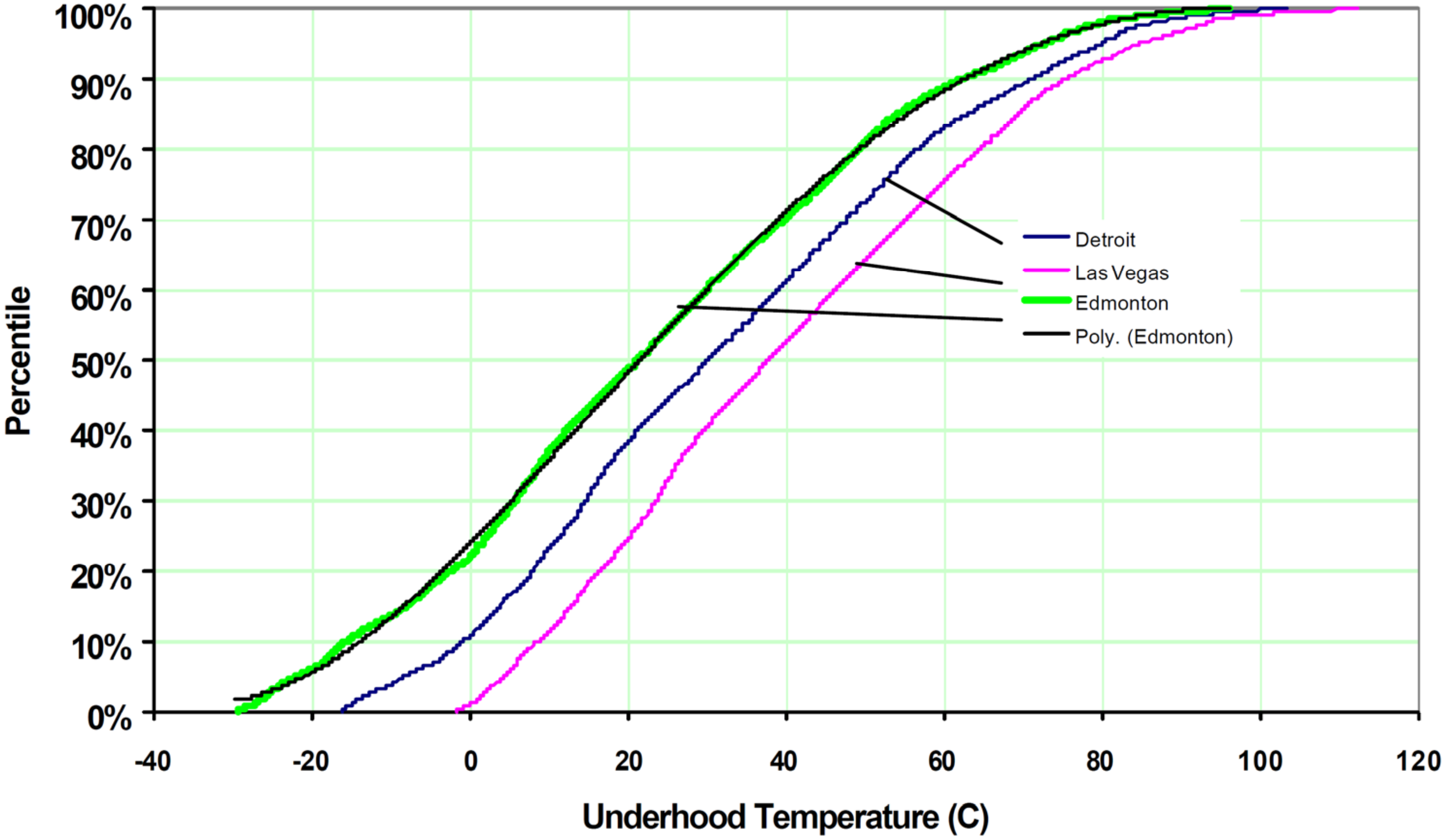


R. Thompson, *Proc. SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Vehicle Speed Influences Under-Hood Ambient Temperature

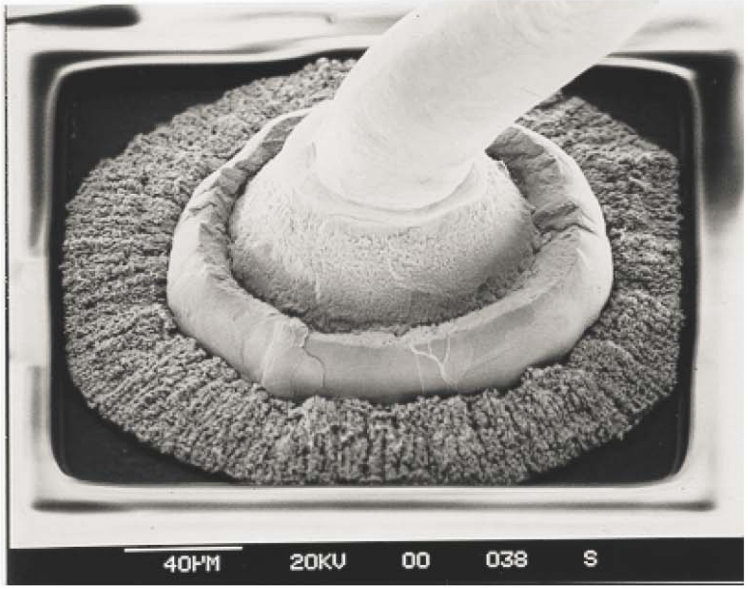
C. Larner, *Proc. Issues of Defining and Designing for the High Temperature Automotive Electronics Environment, SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Under Hood Ambient Temperature Profile
1 Year Interval Modeled

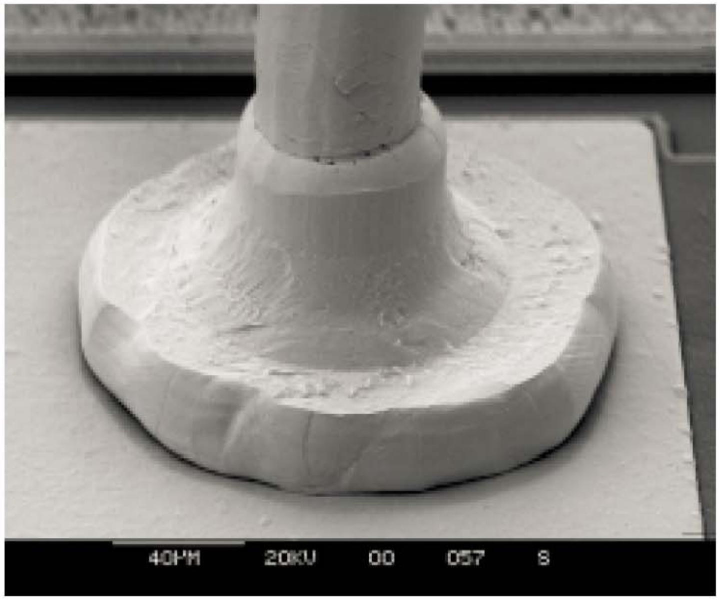


C. Larner, *Proc. Issues of Defining and Designing for the High Temperature Automotive Electronics Environment, SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Al pad with barrier: joint stability at high temperature



Au/Al
after 66h at 300C

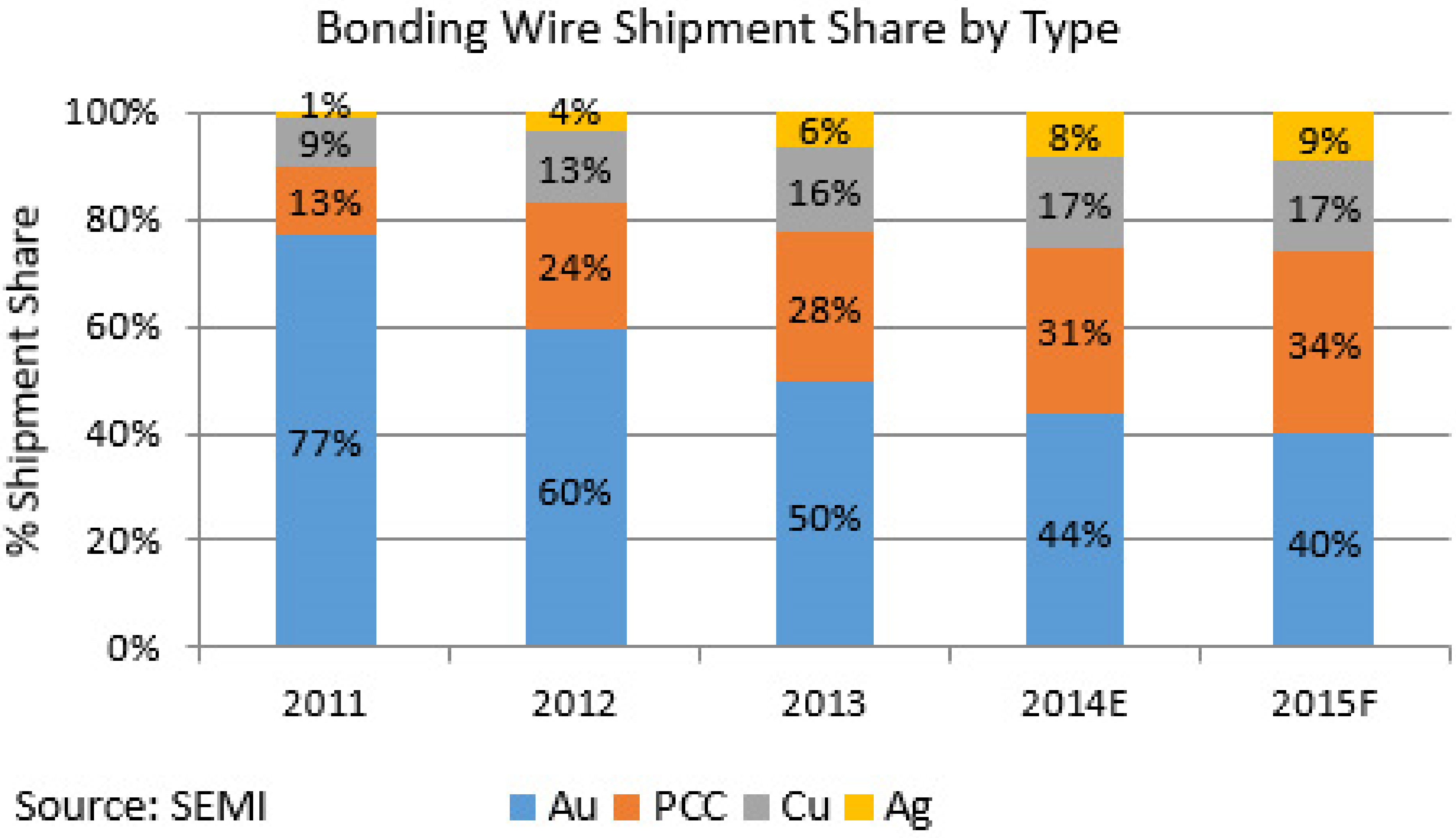


New pad metallurgy
after 500h at 300C

- In this example the absence of joint degradation with the new pad finishing is showed

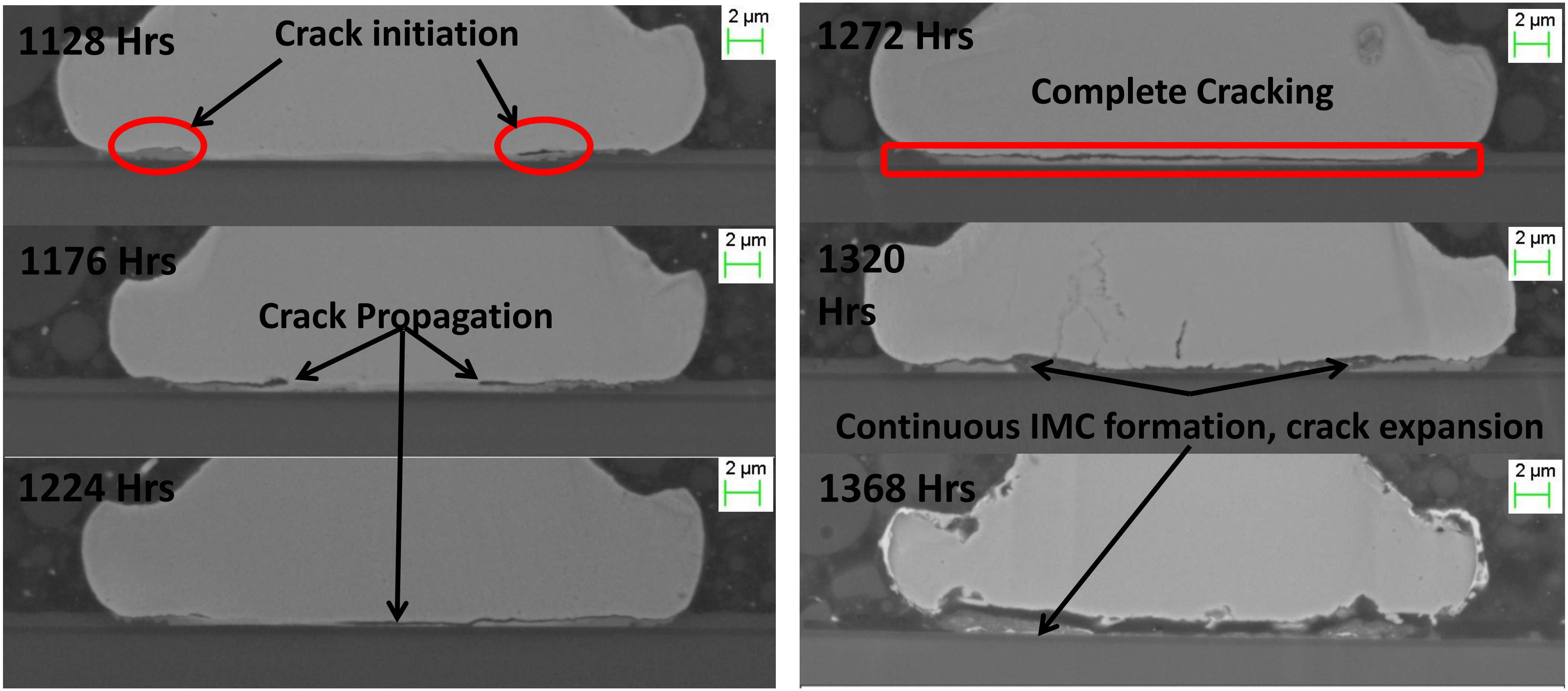
M. Hundt, *Improved Reliability of Gold to Aluminum Bonding in Plastic Packages for High Temperature, High Current Applications*, *Proc. SMTA/CAVE Workshop Harsh Environment Electronics*, Dearborn, MI, Jun. 24–25, 2003

Transition to Cu WB and Ag WB



Source: SEMI

Crack Initiation and Propagation



1128 Hrs

Crack initiation

1176 Hrs

Crack Propagation

1224 Hrs

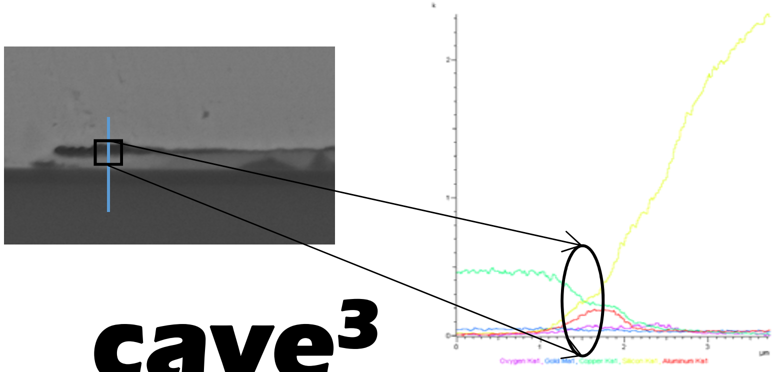
1272 Hrs

Complete Cracking

1320 Hrs

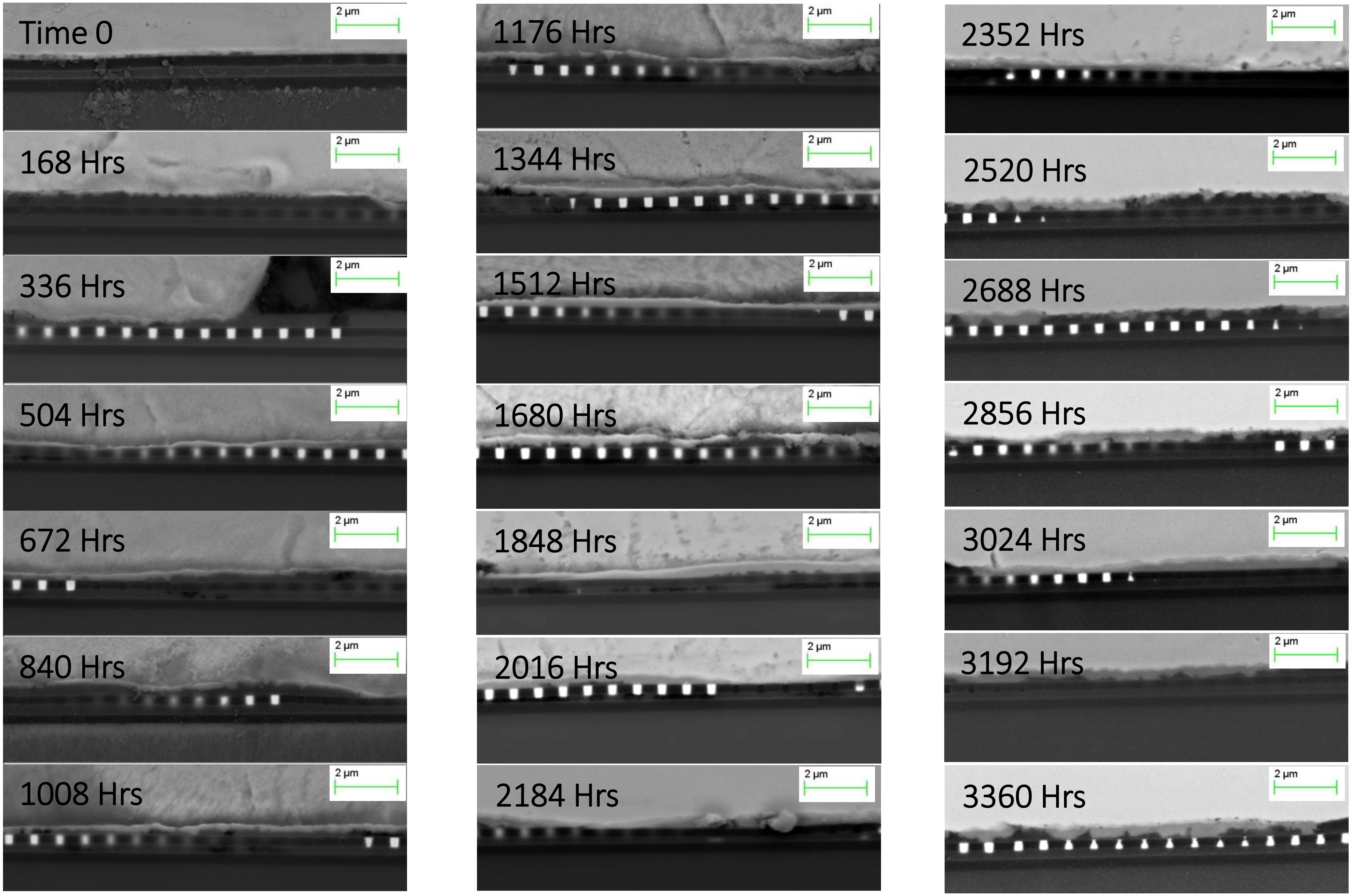
Continuous IMC formation, crack expansion

1368 Hrs

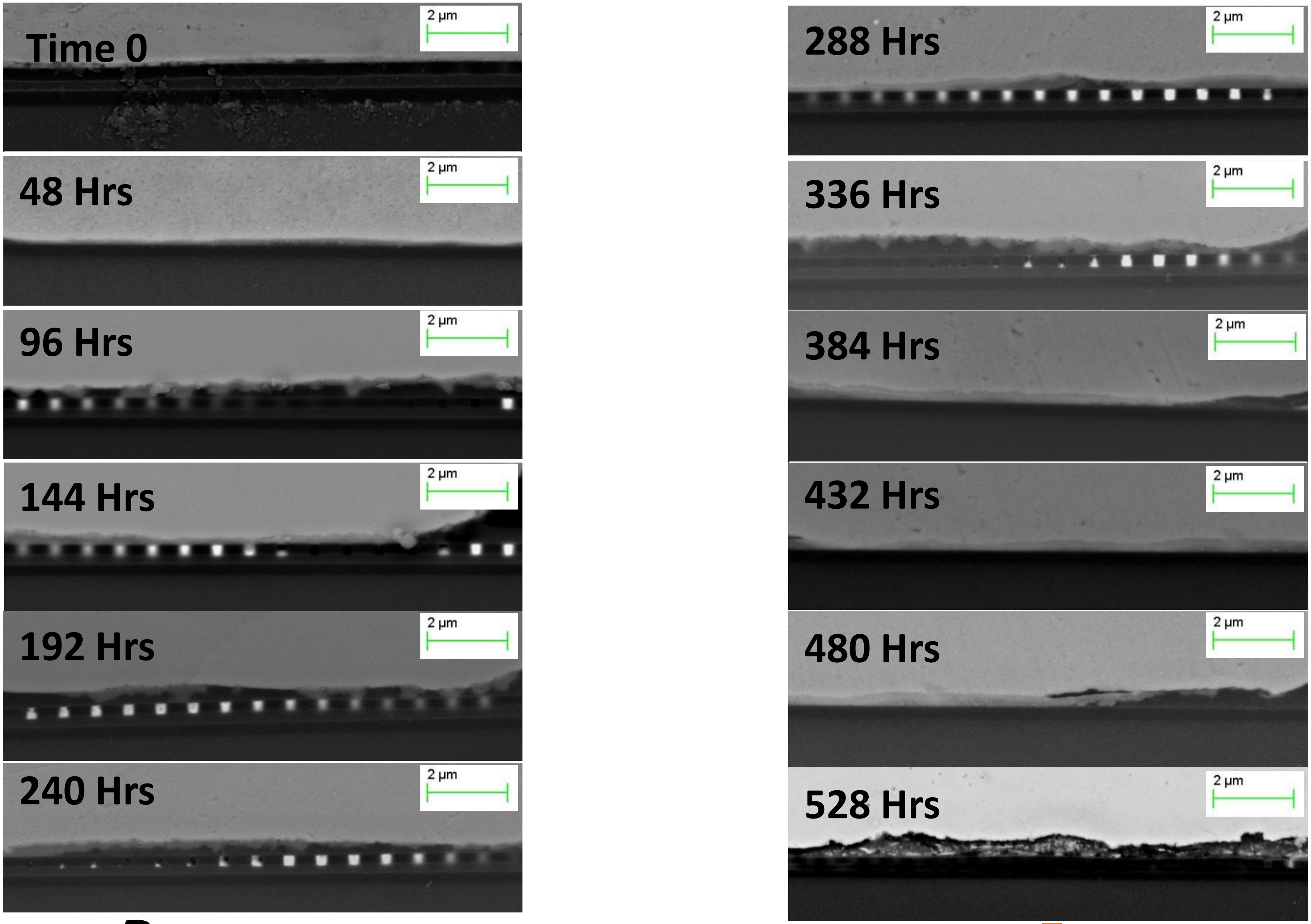


Oxidation of Cu-Al intermetallics during operation at high temperature and high humidity may cause oxidation of IMC, followed by crack initiation, and eventual failure.

150°C Thermal Aging



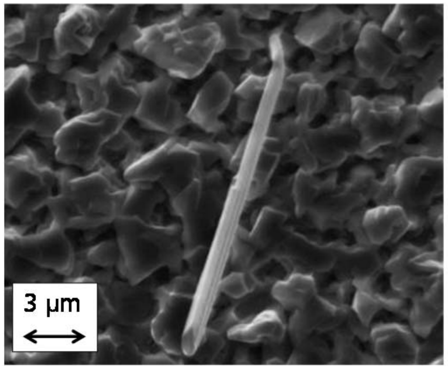
200°C Thermal Aging

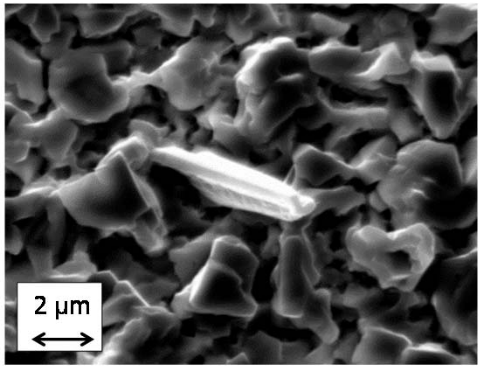


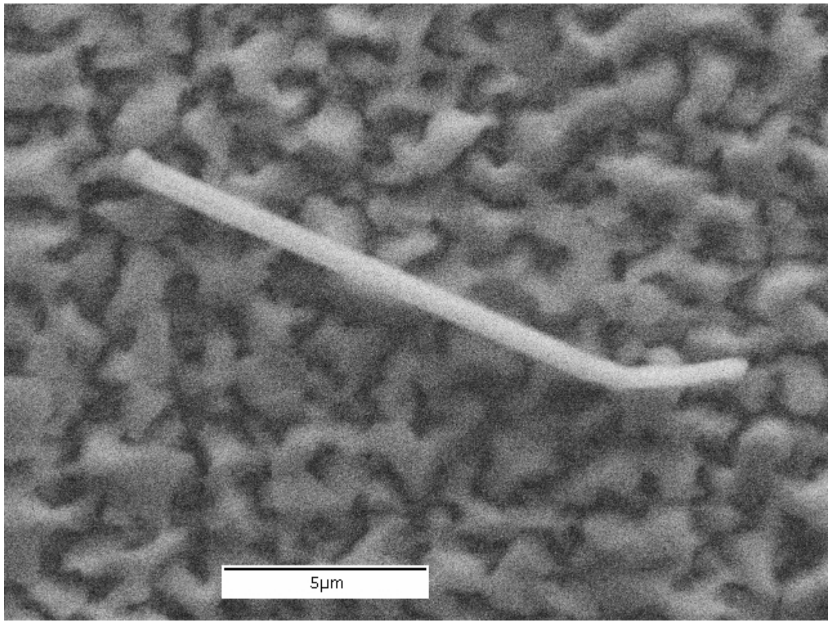
High Voltage Applications in Automotive

- Corrosion is accelerated in the presence of ionic species, such as halide, hydroxyl ions, and elevated temperature.
- Cu and Ag wire is finding increasing applications in high power electronics operating at 50V-300V used for propulsion, transmission and control in emerging hybrid electric (HEV) and electric vehicles (EV).
- Electronics is located under the hood of a car where the temperatures in the neighborhood of 125°C – 175°C can be experienced on a regular basis.
- Presently, there are no life prediction models for Cu-Al and Ag-wirebonding under corrosive high temperature automotive conditions.
- There is need for reliability models and assessment methods which can predict field failures for high voltage, extreme environment applications.

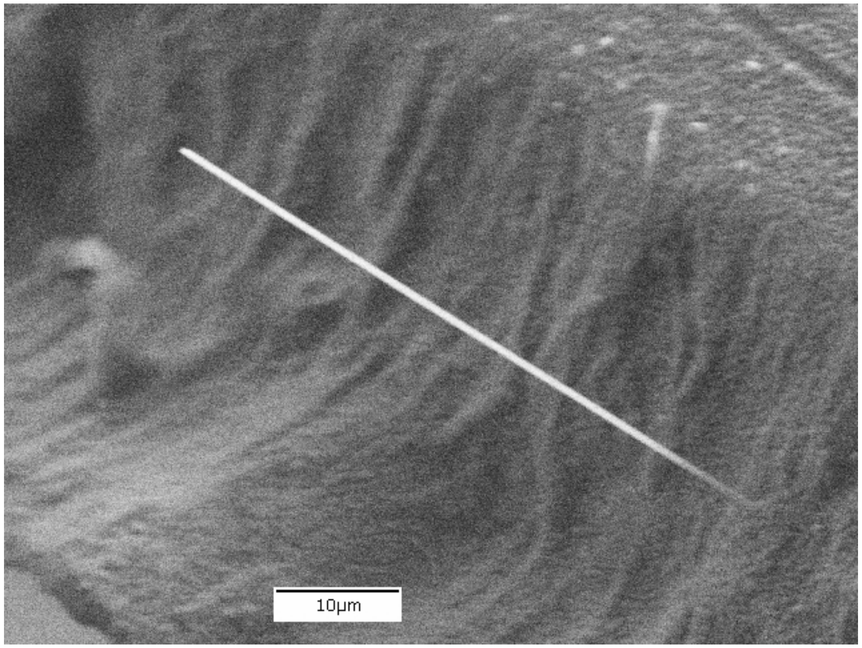
Problem: Rapid Assessment of Propensity for Tin Whisker Formation in Platings





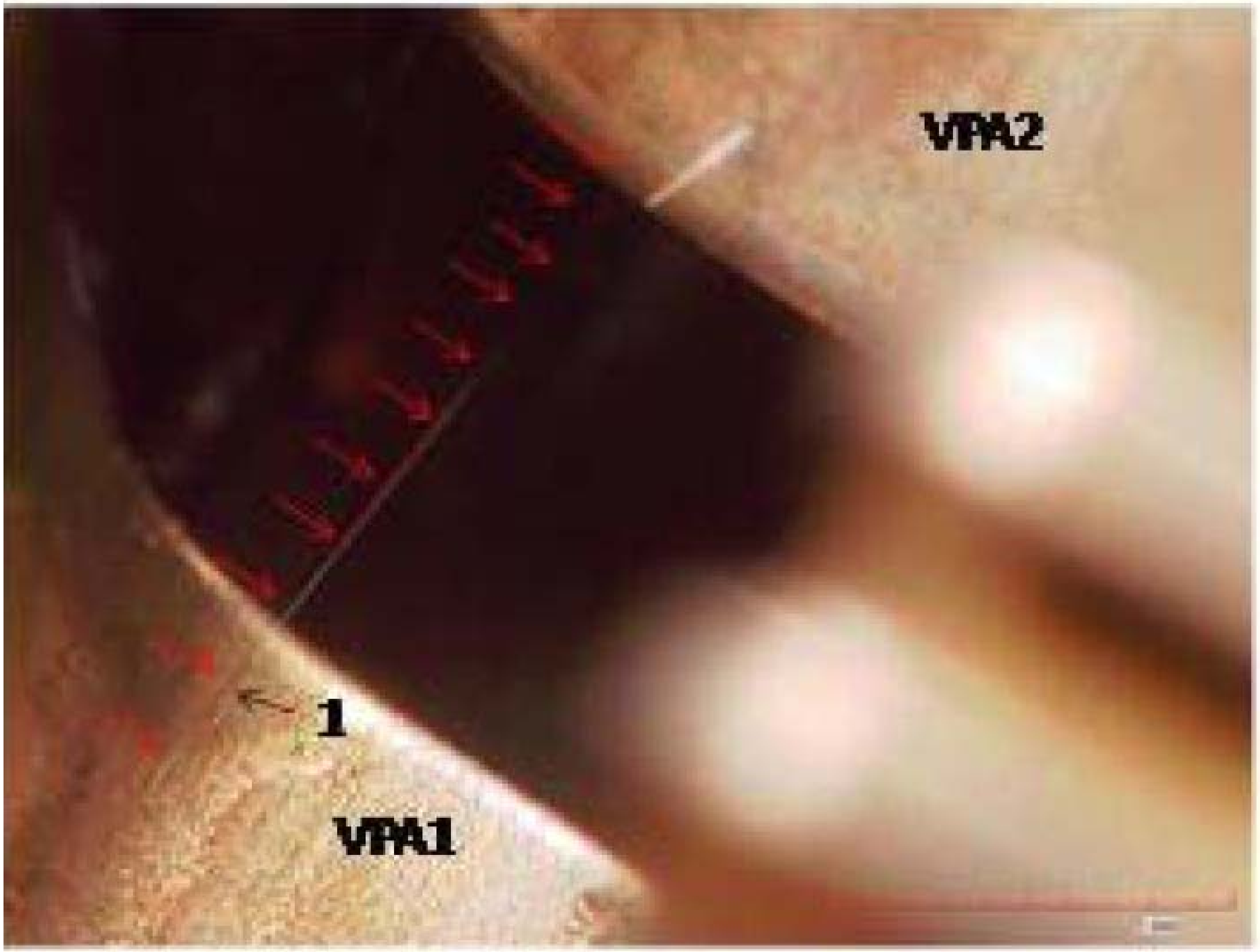


Tensile Stress



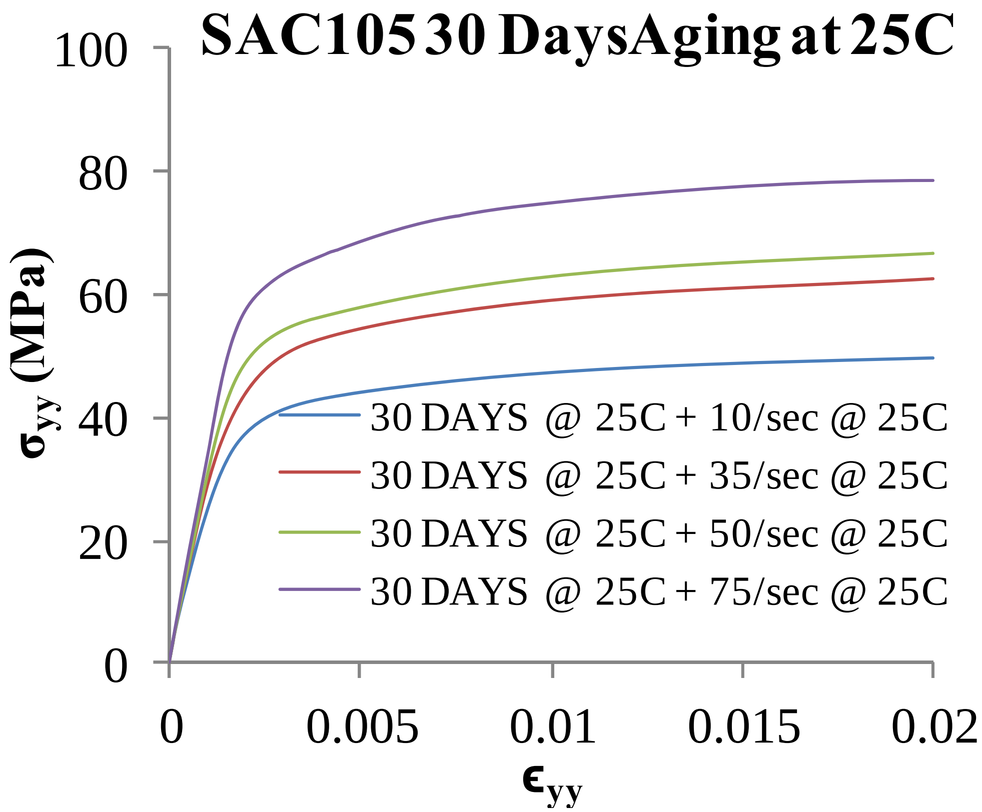
Compressive Stress

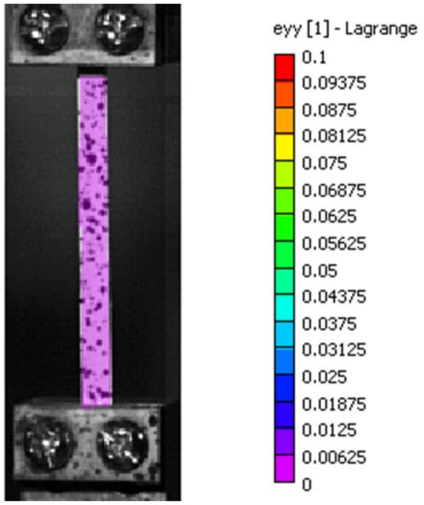
Tin-Whiskers in Tin-Plated Copper Leads soldered to PCBs



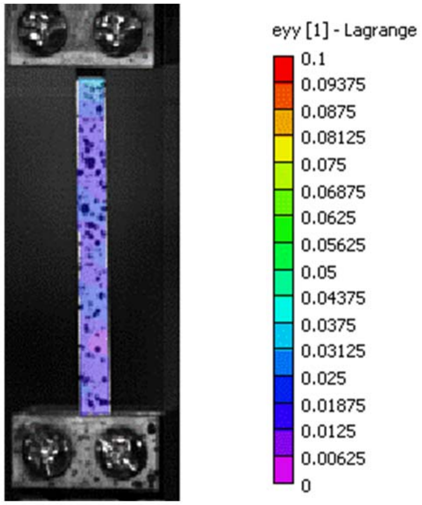
http://www.nhtsa.gov/UA

Problem: Measure High Strain-Rate Properties of SAC Alloys at Strain Rate of 1-100 sec^{-1}





(a)



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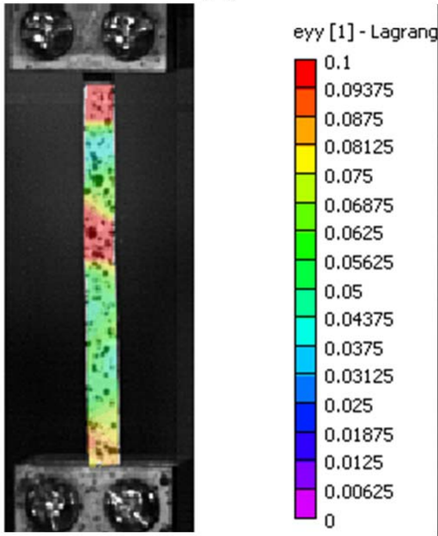

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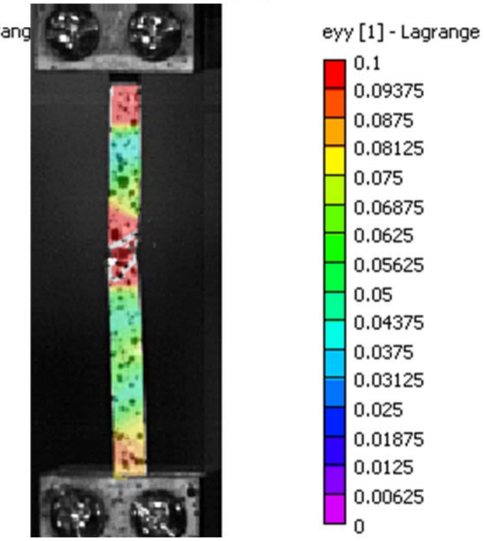
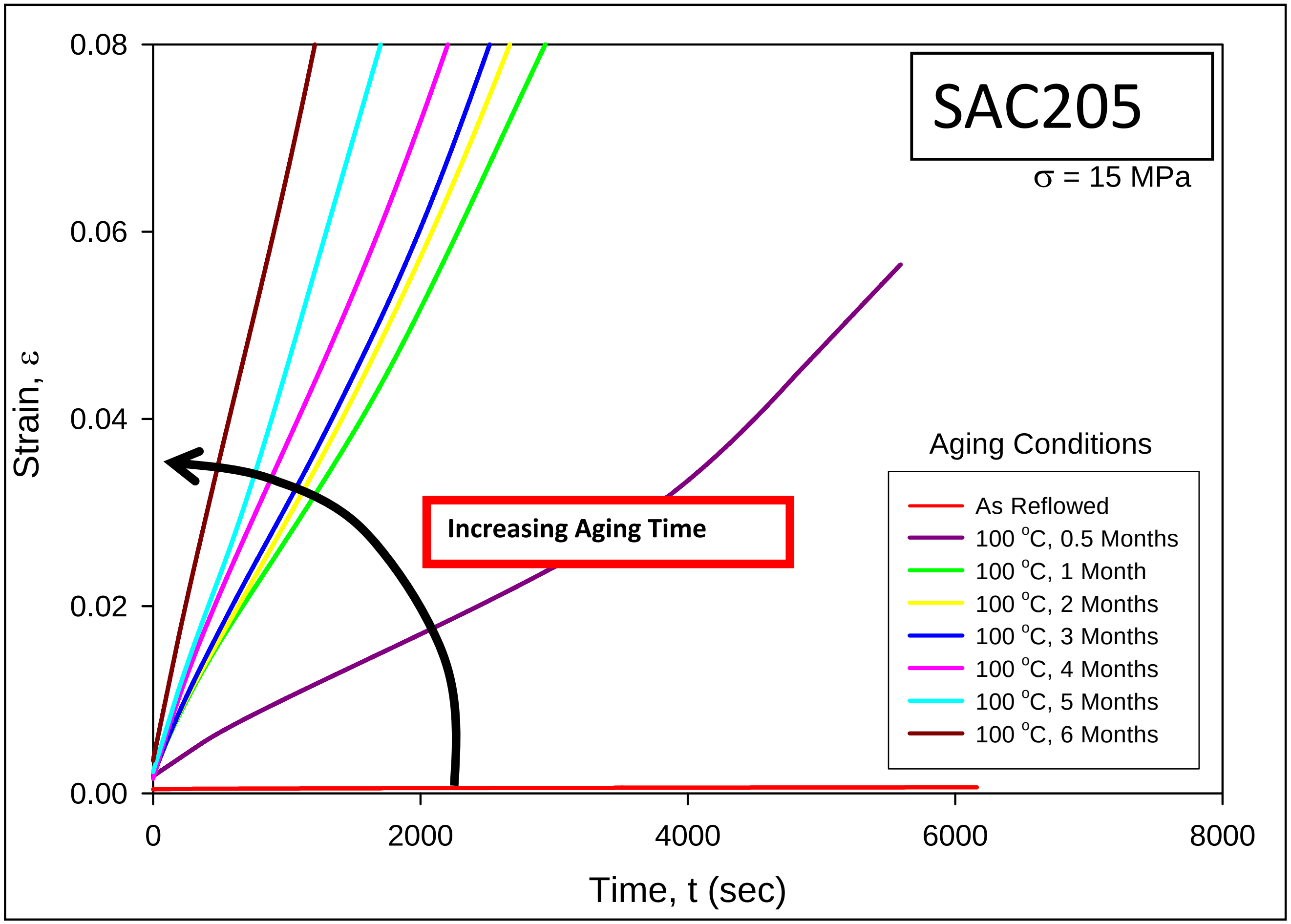


(d)

CREEP

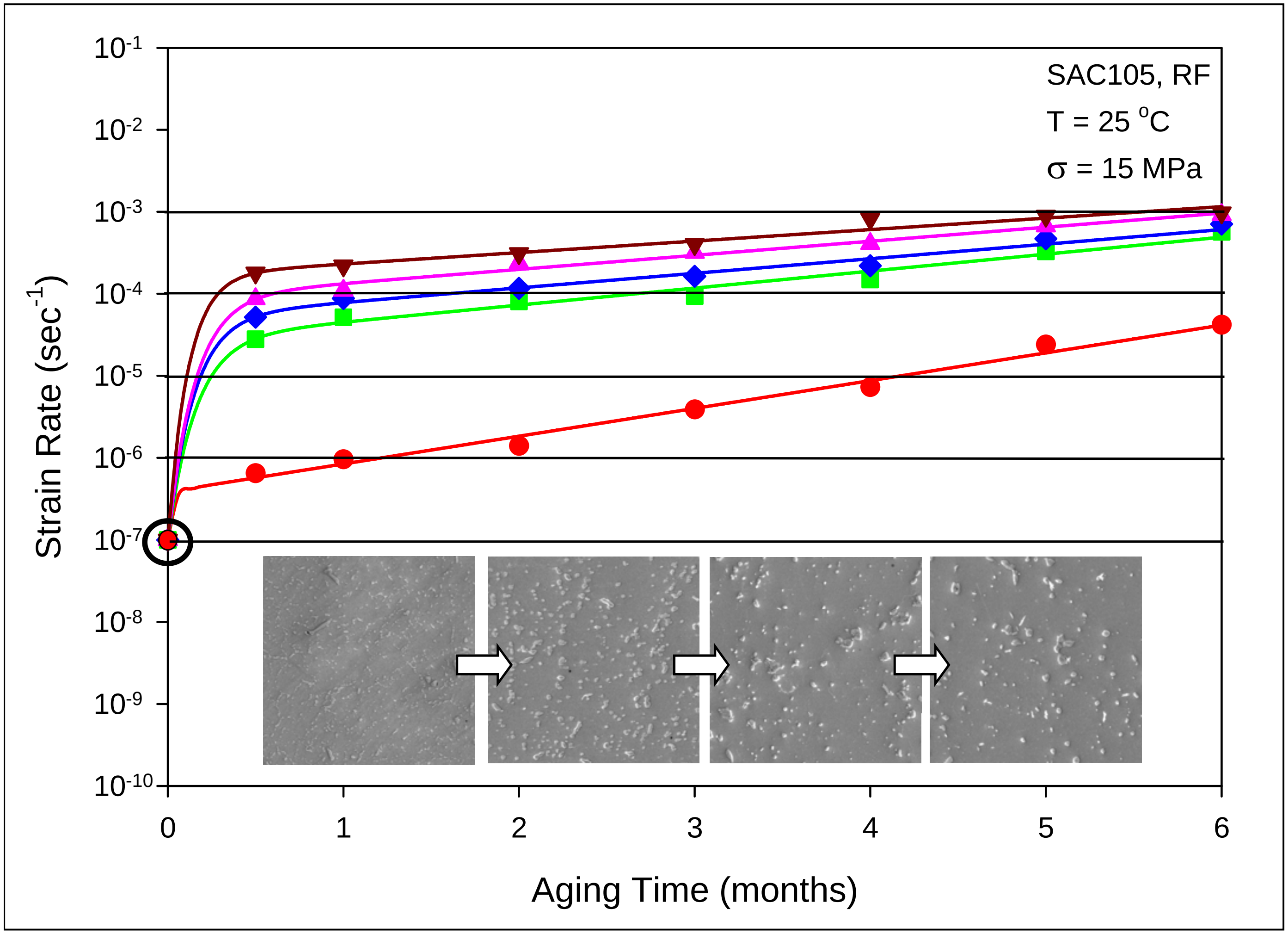
Example Data – Aging at 100 ^oC



CREEP RATE

Effects of Aging - SAC105

Complete data set contains results from all SAC series alloys (SAC 105, 205, 305, 405, and Sn-Pb)



10000X
1000X
100X
10X
1X

Creep Rate Increases by 10,000X

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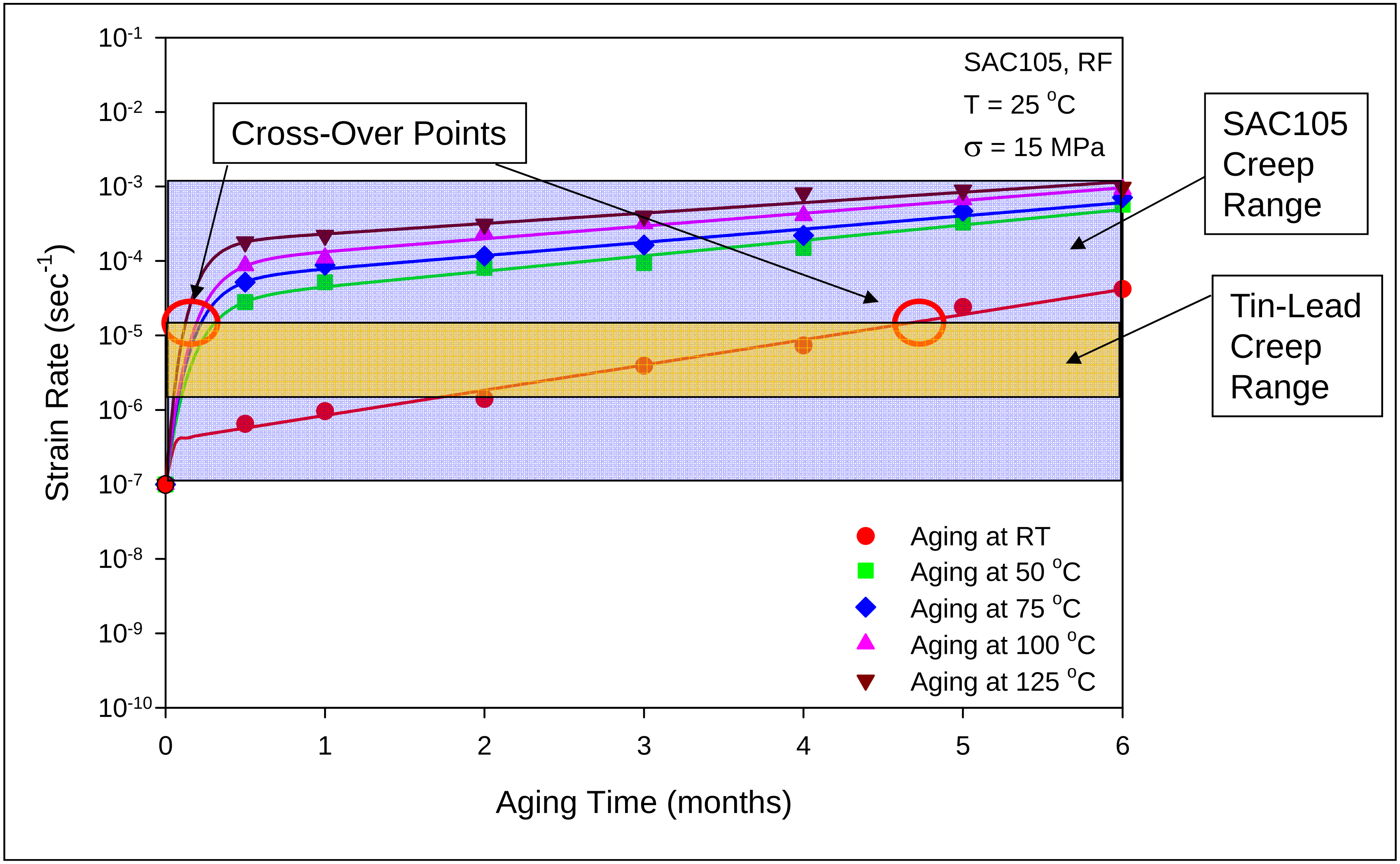
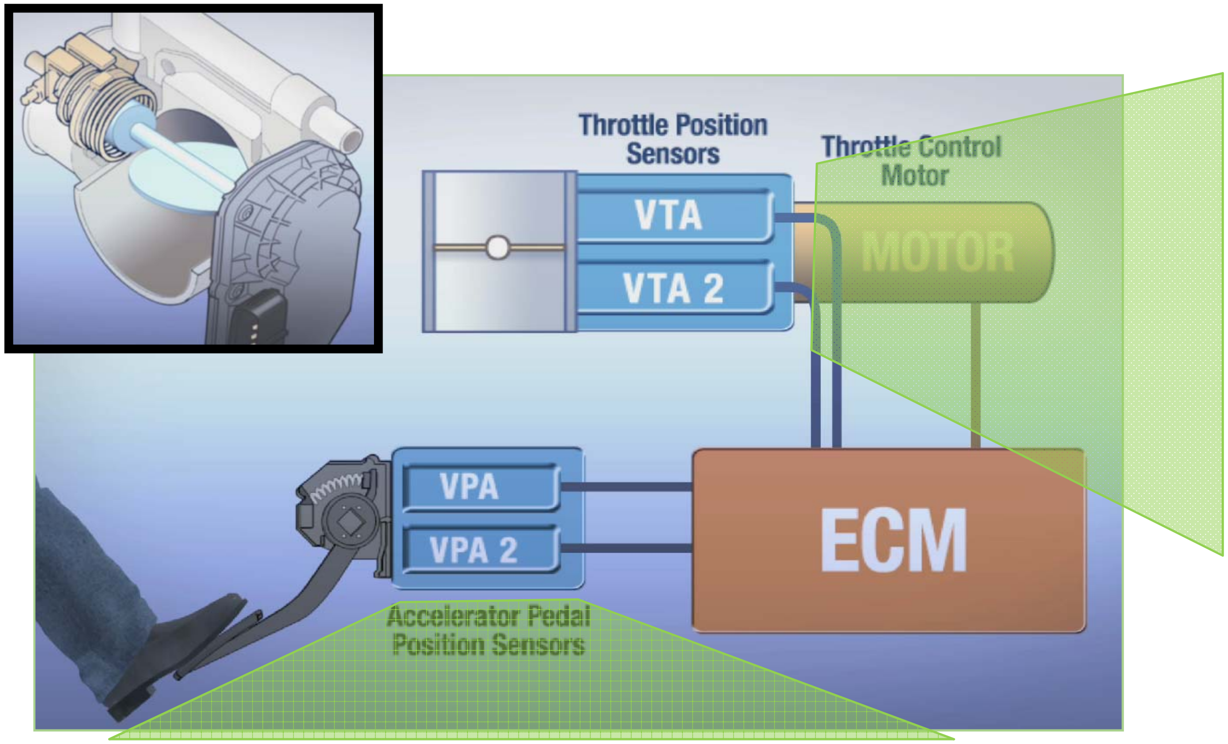
CREEP RATE

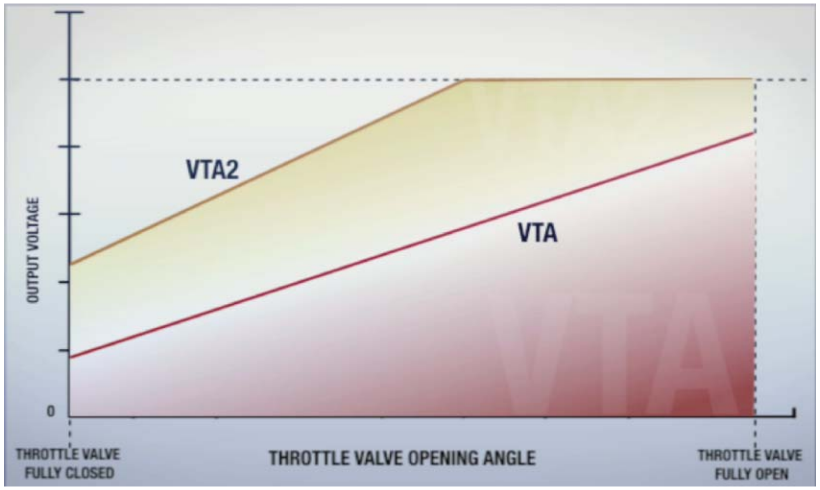
Effects of Aging - SAC105

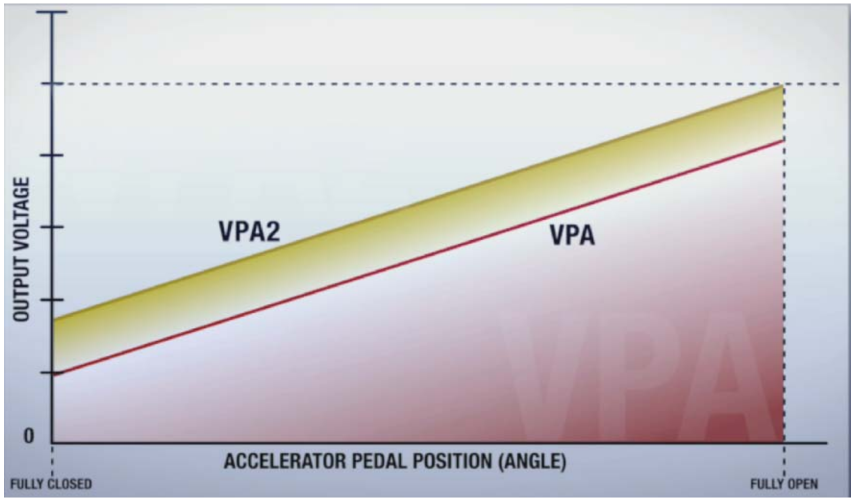
The Time Duration Before the Cross-Over Depends on the Composition of the SAC Alloy and the Aging Temperature. Increased Silver Content Increases the Aging Time Required Before the Cross-Over Occurs.



Engine Control Module







Reference:
Toyota Electronic Throttle Webinar, March 12, 2010

On-Board Diagnostics

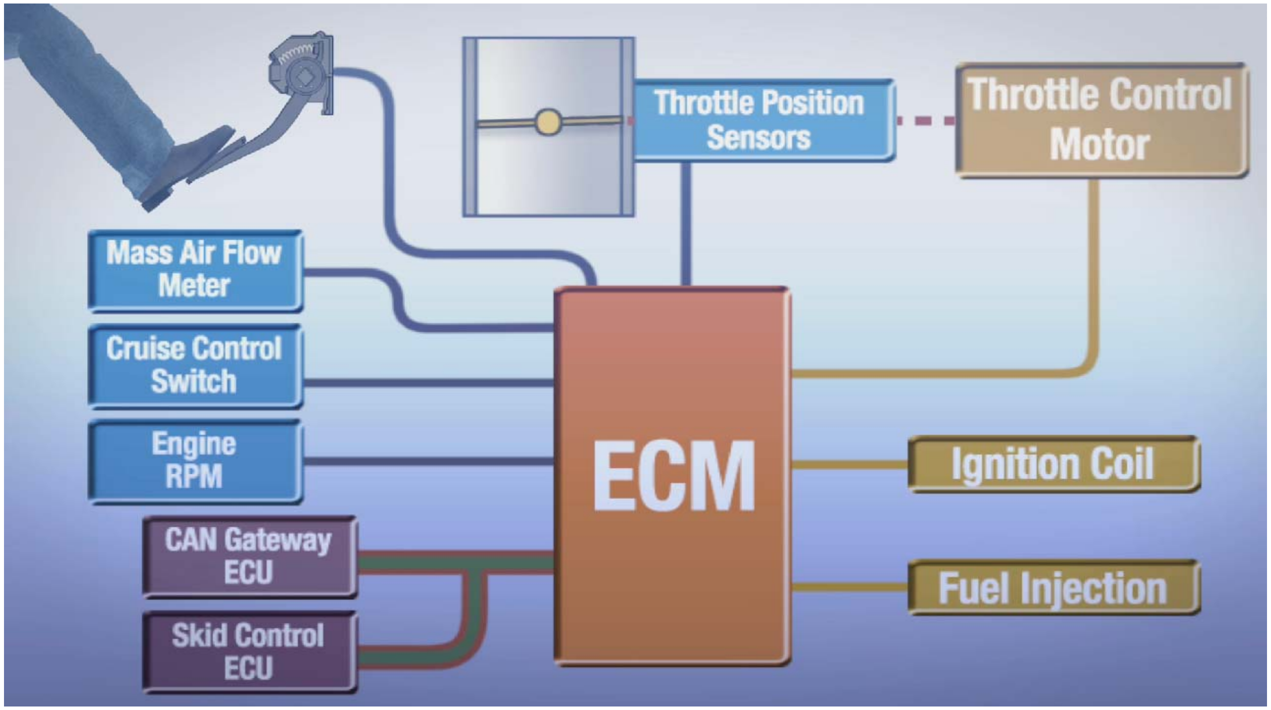
Throttle-Related Fault Codes
P0120 Throttle/Pedal Position Sensor/Switch A Circuit Malfunction
P0121 Throttle/Pedal Position Sensor/Switch A Circuit Range/Performance Problem
P0122 Throttle/Pedal Position Sensor/Switch A Circuit Low Input
P0123 Throttle/Pedal Position Sensor/Switch A Circuit High Input
P0124 Throttle/Pedal Position Sensor/Switch A Circuit Intermittent
P0220 Throttle/Pedal Position Sensor/Switch B Circuit Malfunction
P0221 Throttle/Pedal Position Sensor/Switch B Circuit Range/Performance Problem
P0222 Throttle/Pedal Position Sensor/Switch B Circuit Low Input
P0223 Throttle/Pedal Position Sensor/Switch B Circuit High Input
P0224 Throttle/Pedal Position Sensor/Switch B Circuit Intermittent
P0225 Throttle/Pedal Position Sensor/Switch C Circuit Malfunction
P0226 Throttle/Pedal Position Sensor/Switch C Circuit
Rang
P02
P02
P02
P05
P06
P06

OBD-II User Manual:

“……………**Based on all the input data, the computer determines that the signal from the throttle position sensor is not rational** (does not make sense when compared to the other inputs), and it would fail the rationality test………”

Diagnostics Impact on Electronics Reliability

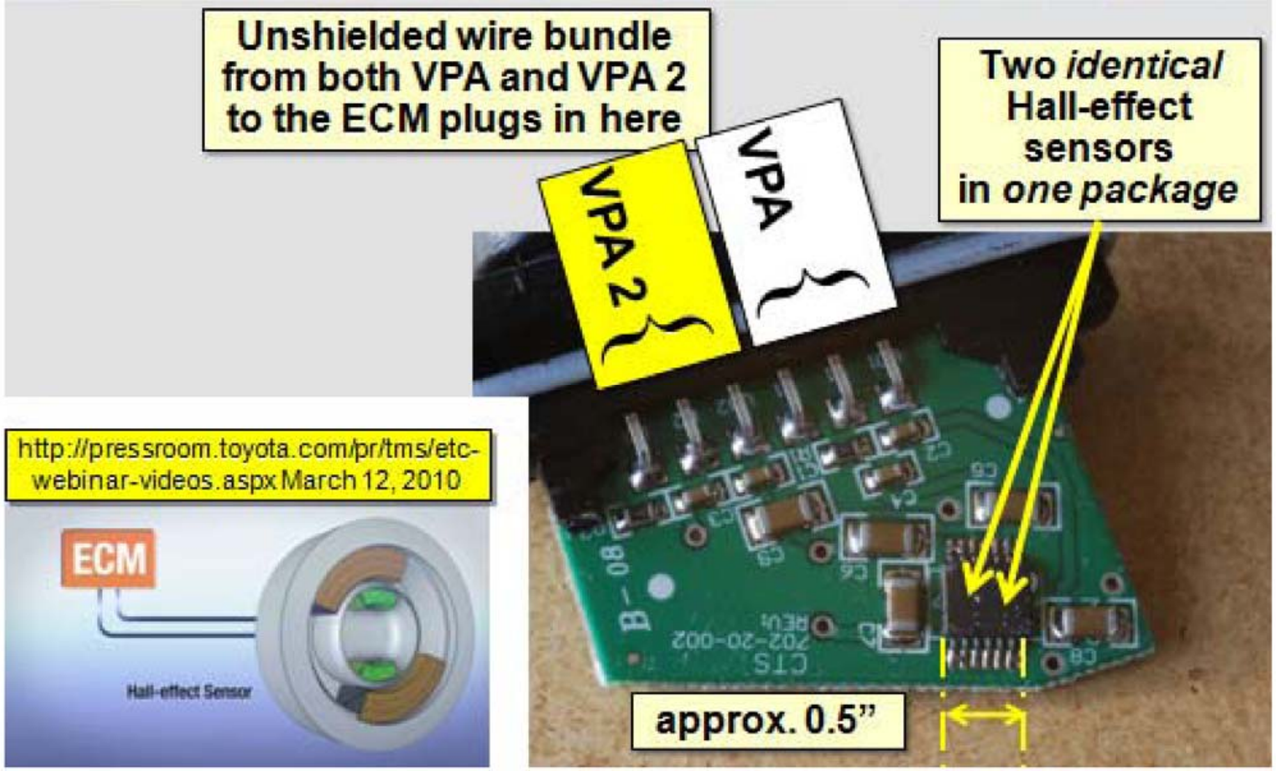
Reference:
Toyota Electronic Throttle Webinar, March 12, 2010



RP1210 standard used to facilitate diagnostics in heavy trucks and similar vehicles. The soldier is holding a ruggedized laptop. The arrow points to the Protocol Adapter with various different physical protocols such as CAN, J1850 (BDLC) and J1708 (UART) depending on the vehicle's ECMs.

Ref: Boys, R, IVSS-2004-APS-01, 2004

Solder Joint Reliability



Unshielded wire bundle from both VPA and VPA 2 to the ECM plugs in here

Two *identical* Hall-effect sensors in *one package*

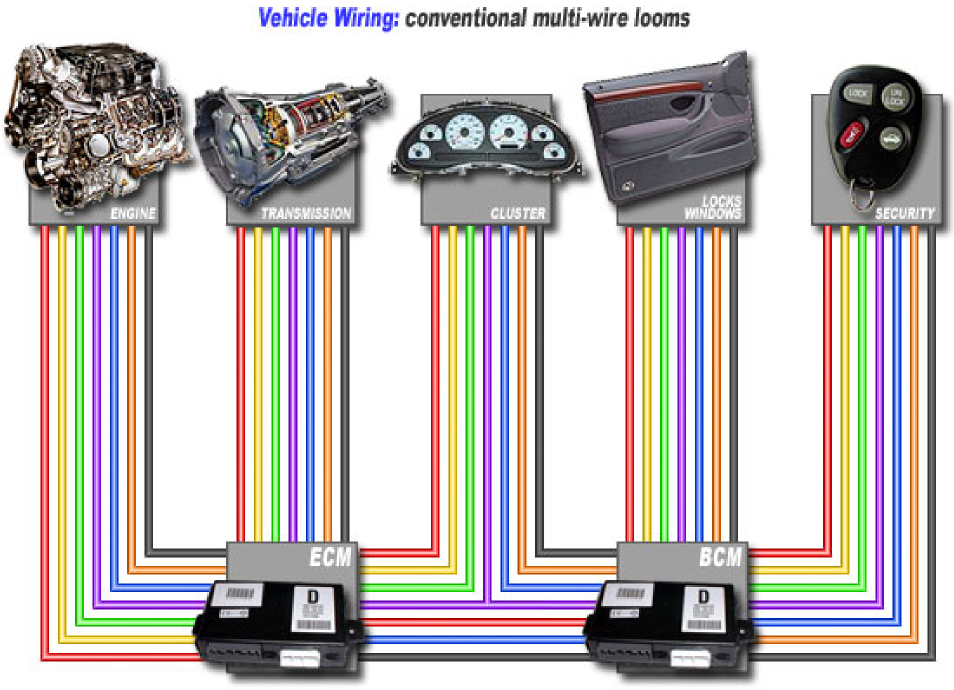
http://pressroom.toyota.com/pr/tms/etc-webinar-videos.aspx March 12, 2010

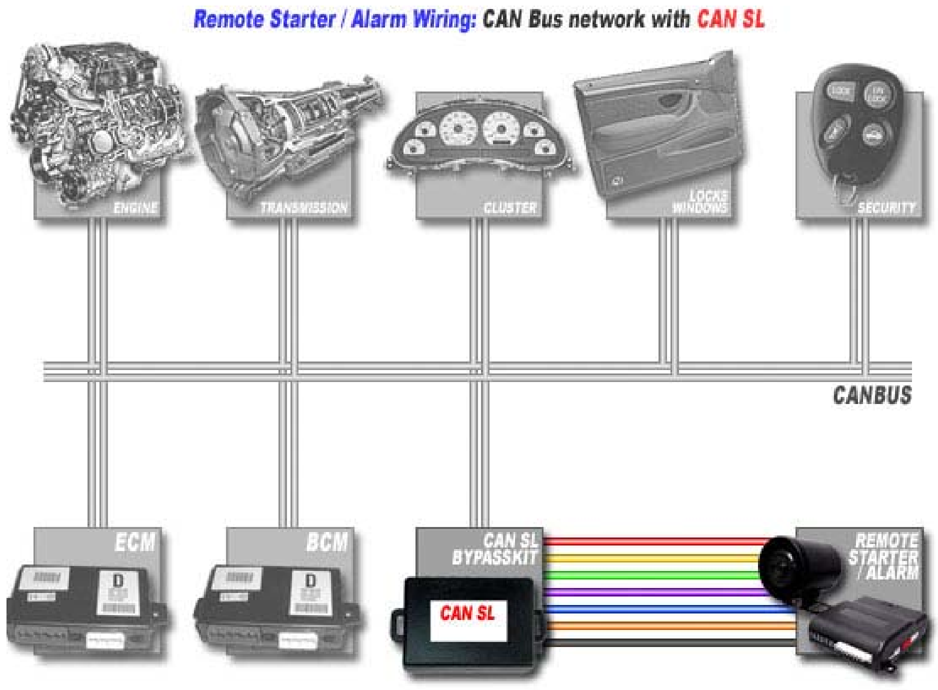
Armstrong, Toyota "sticking pedals" recall a smokescreen?, Apr 12, 2010

"……A particular problem occurs when an EMI shunt-filter component, such as a capacitor, experiences a "dry joint" or a cracked and intermittent solder joint. When the joint is open-circuit, EMI is allowed into the electronic circuit, where it can cause errors or misoperation….."

CAN Bus

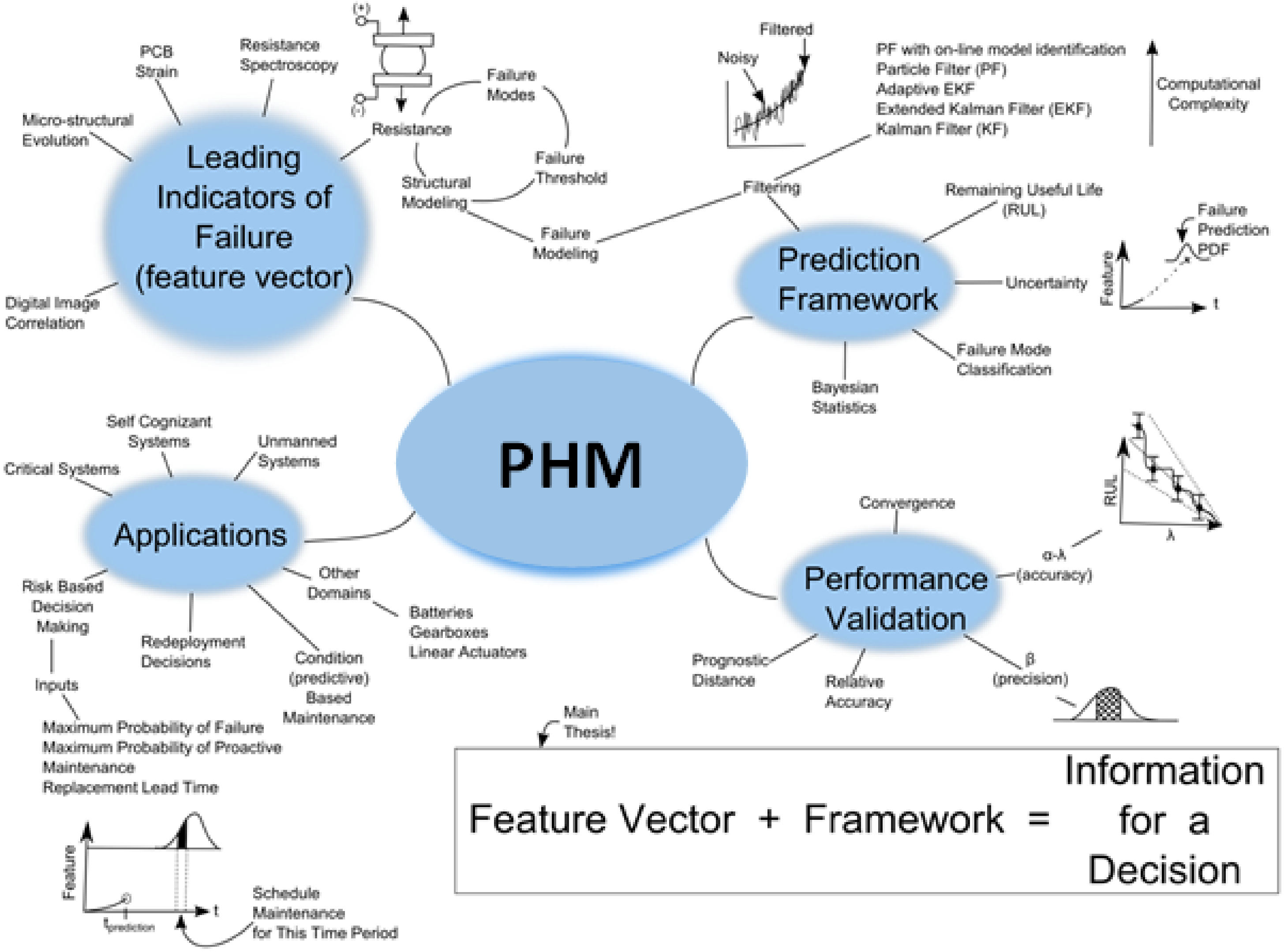
- ☐ Developed by Robert Bosch; Quickly gained acceptance.
- ☐ Serial bus protocol to connect individual systems and sensors as an alternative to conventional multi-wire looms
- ☐ Allows automotive components to communicate on a single or dual-wire networked data bus up to 1Mbps
- ☐ In 2006, over 70% of automobiles sold in North America utilized CAN Bus. In 2008, the SAE required 100% of the vehicles sold in USA to use CAN Bus





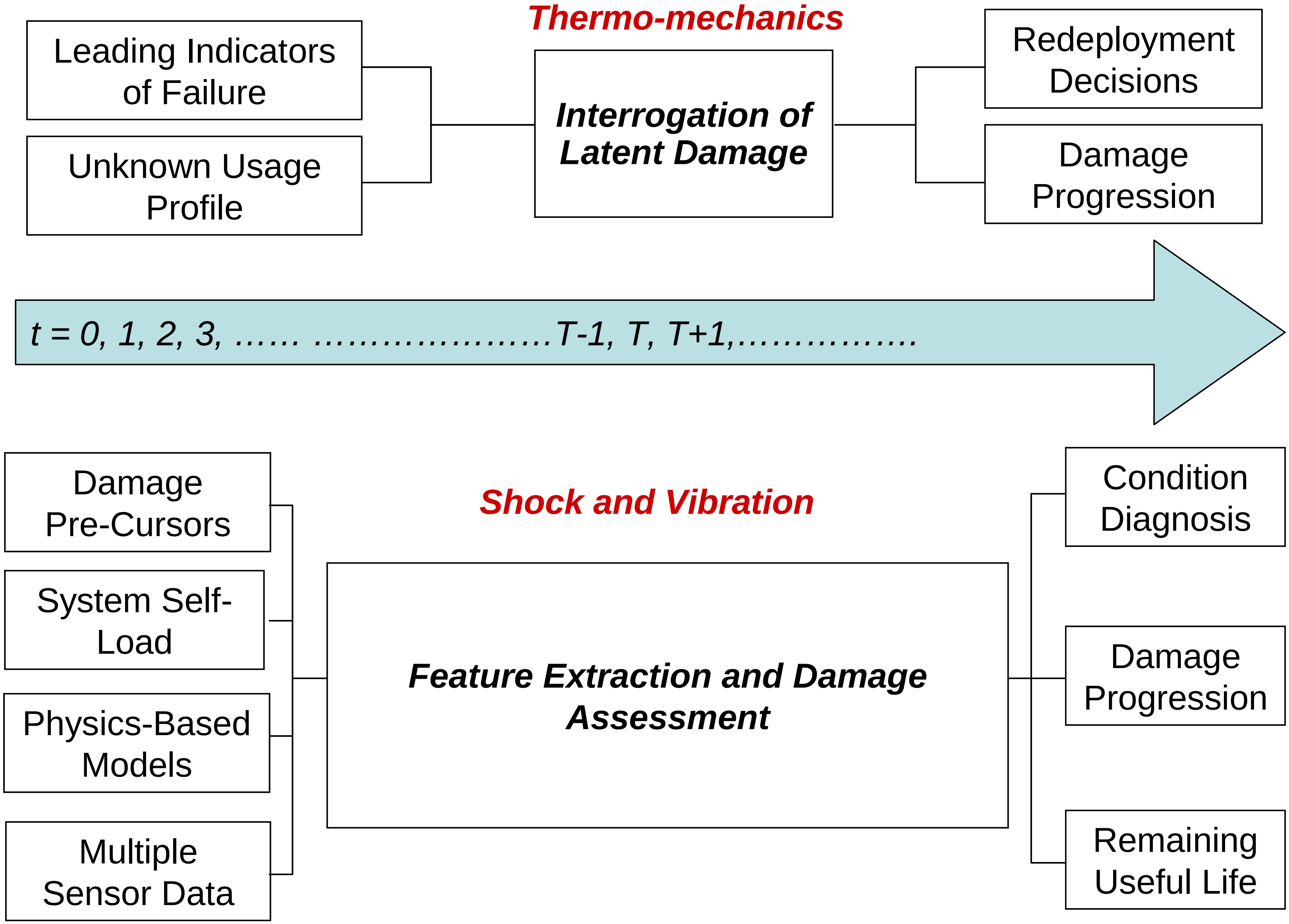
http://canbuskit.com/what.php

Overview of Prognostic Health Management for Systems @CAVE3



Feature Vector + Framework = Information for a Decision

cave^3 Prognostics Framework



Thermo-mechanics

Leading Indicators of Failure

Unknown Usage Profile

Interrogation of Latent Damage

Redeployment Decisions

Damage Progression

t = 0, 1, 2, 3, …… …………………T-1, T, T+1,……………

Shock and Vibration

Damage Pre-Cursors

System Self-Load

Physics-Based Models

Multiple Sensor Data

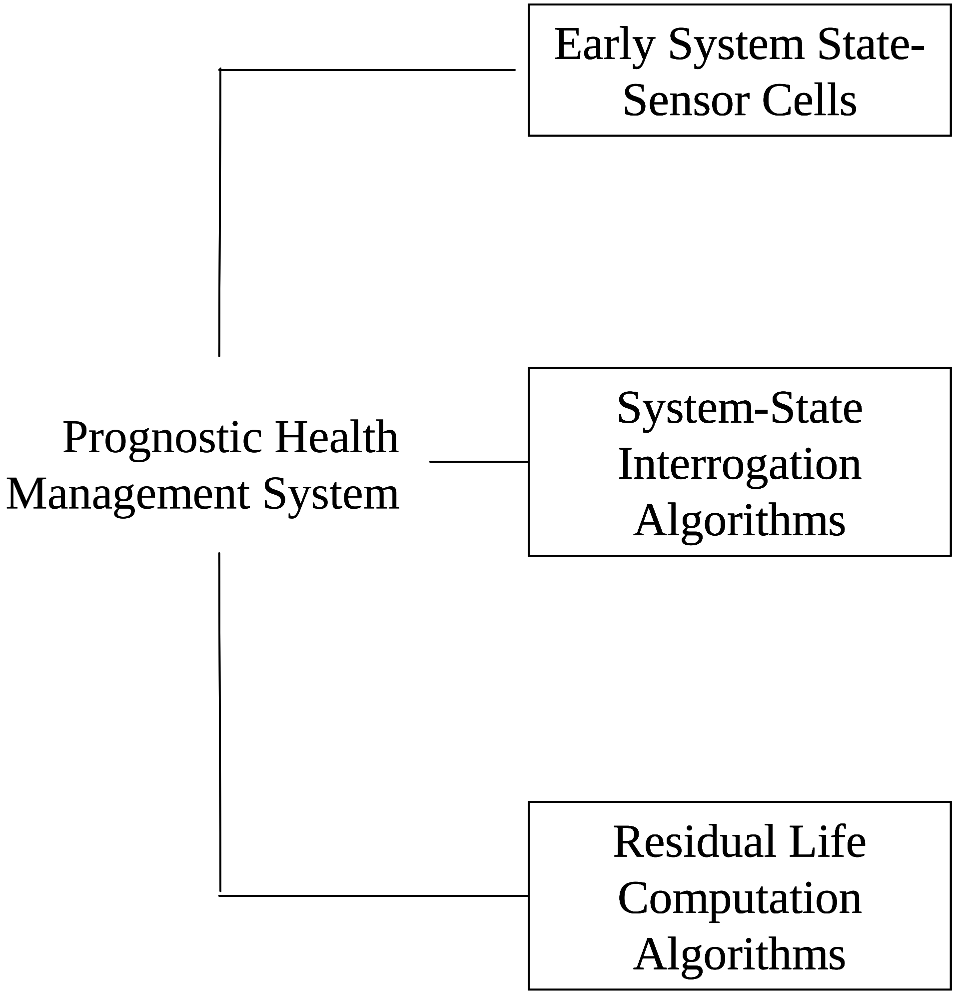
Feature Extraction and Damage Assessment

Condition Diagnosis

Damage Progression

Remaining Useful Life

cave^3 Prognostication Modules



Prognostic Health Management System

Early System State-Sensor Cells

System-State Interrogation Algorithms

Residual Life Computation Algorithms

Condition Monitoring Cells

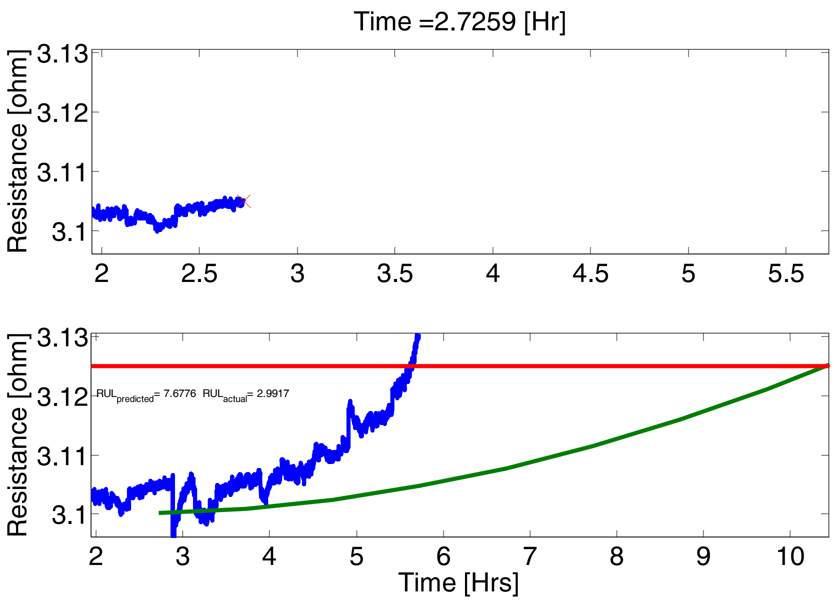
Identical failure mechanisms, separate from functional circuitry, proof self-load, multiple sensor-data.

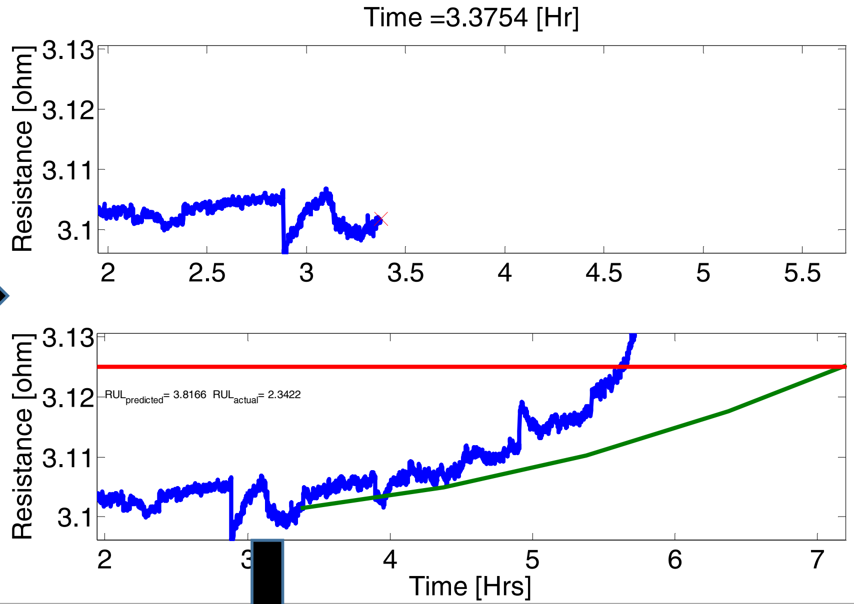
Library of Damage Proxies

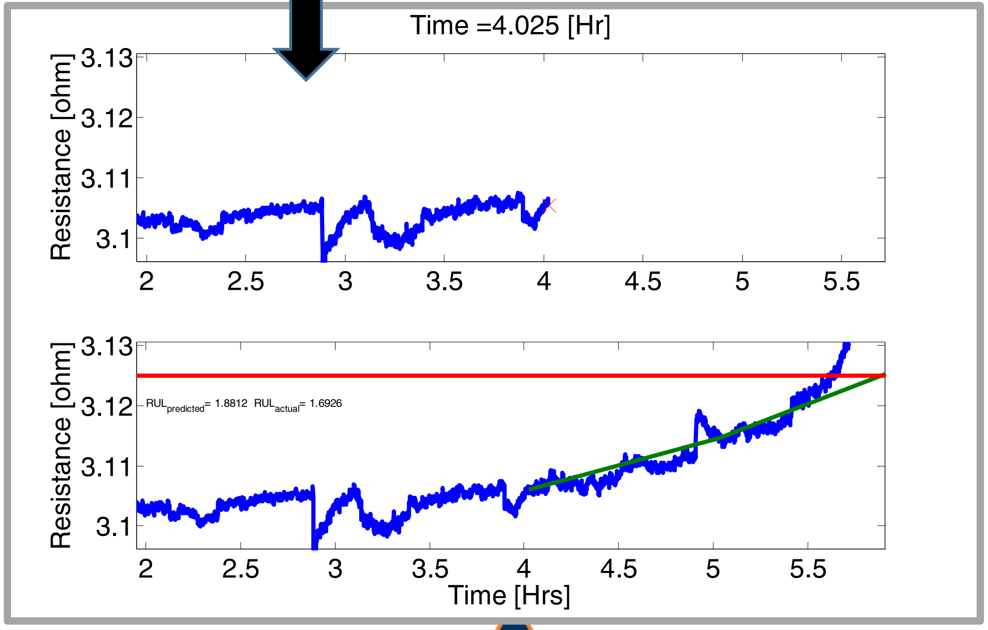
Micro-structural evolution of damage, Feature vectors, physics of damage, time-spectral evolution of damage

Health Assessment and Prognostics

Problem: Remaining Useful Life Assessment of Board Assembly Under Vibration @CAVE3

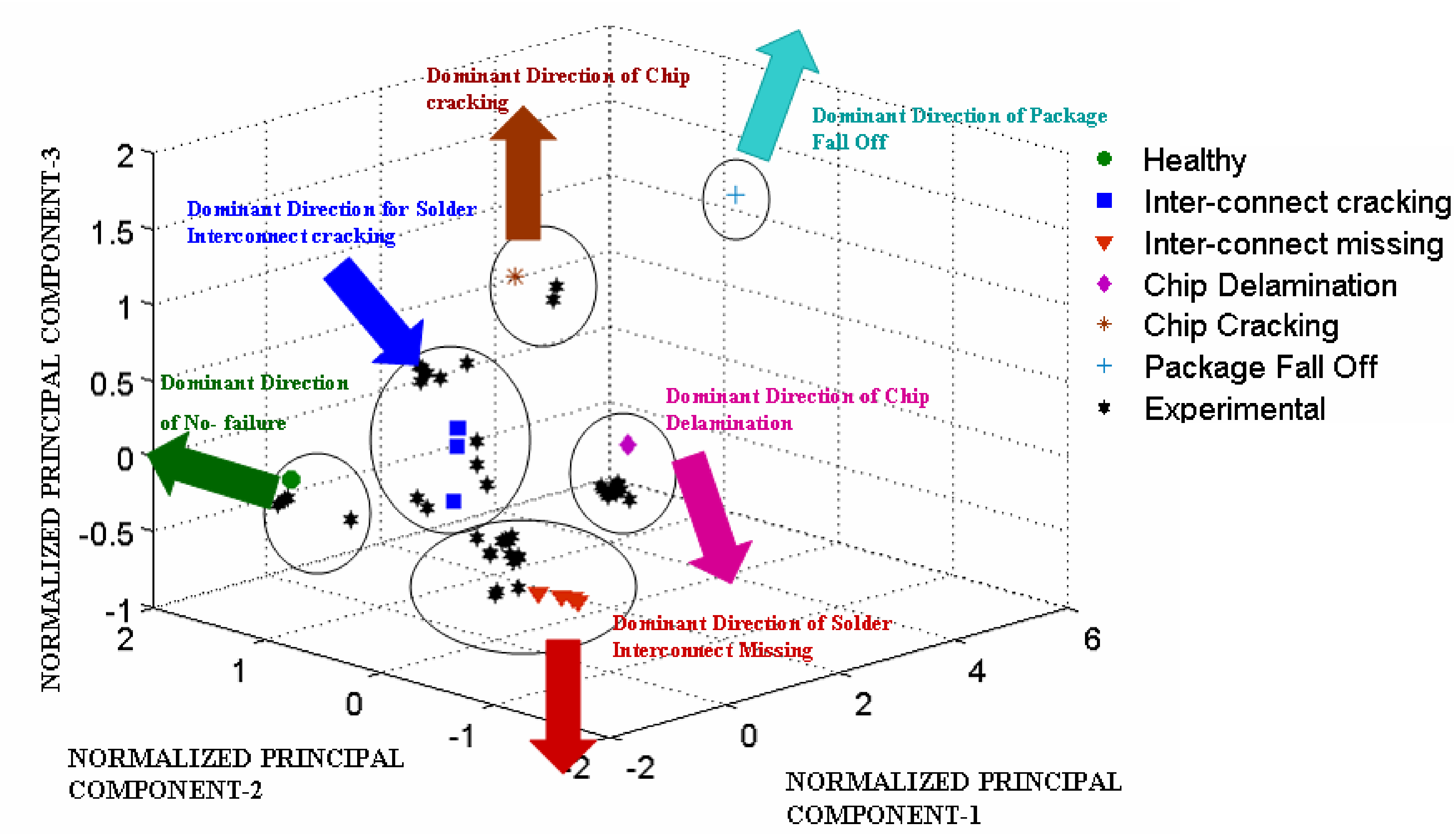






Kalman Filter
Based RUL

Problem: Prognostication of PBGA Assembly Anomalies and Fault Mode Classification @CAVE3



Karhunen Loéve Transform

SSL and Brand Statement

Source: netcarshow.com

LED Package Costs

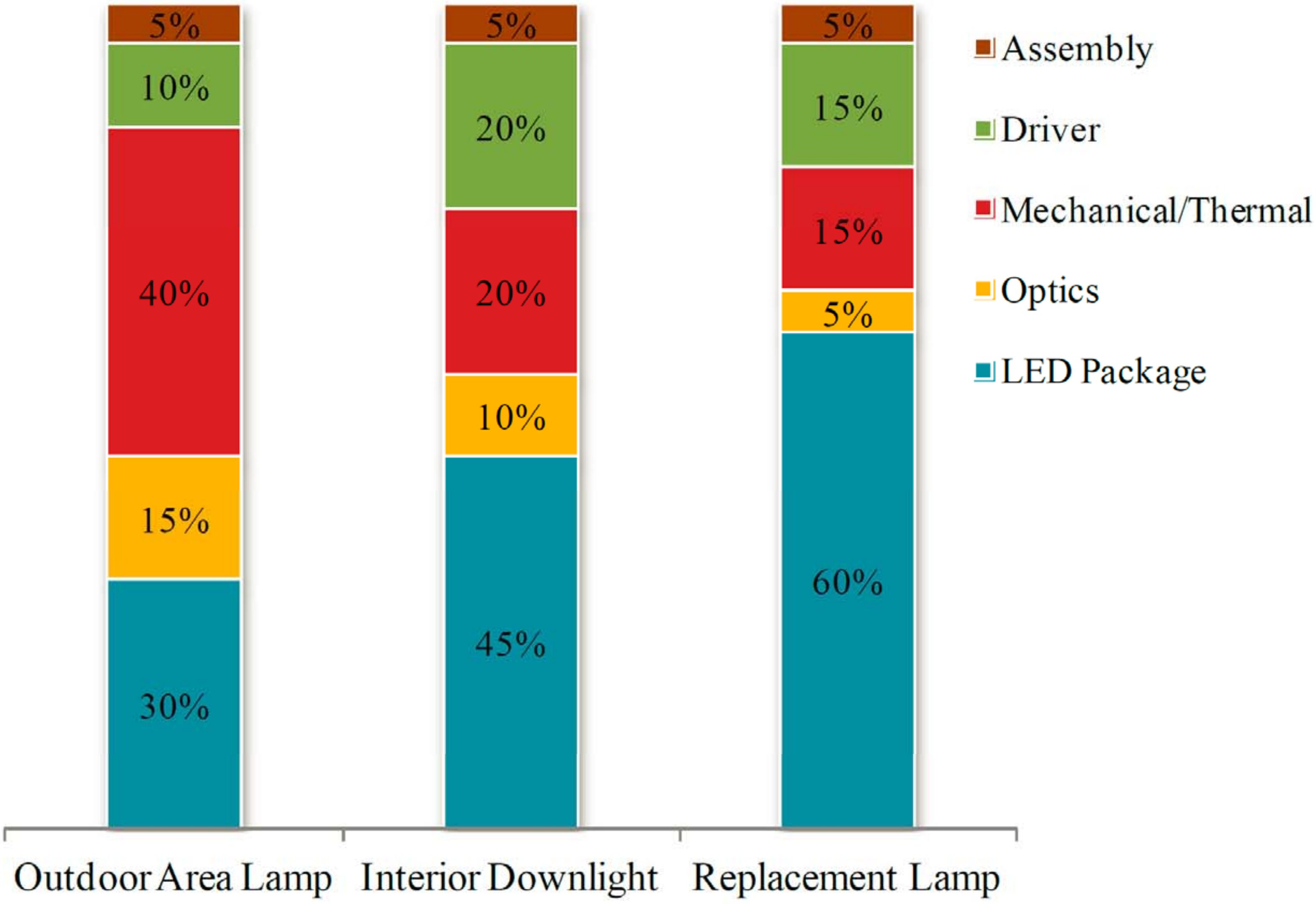
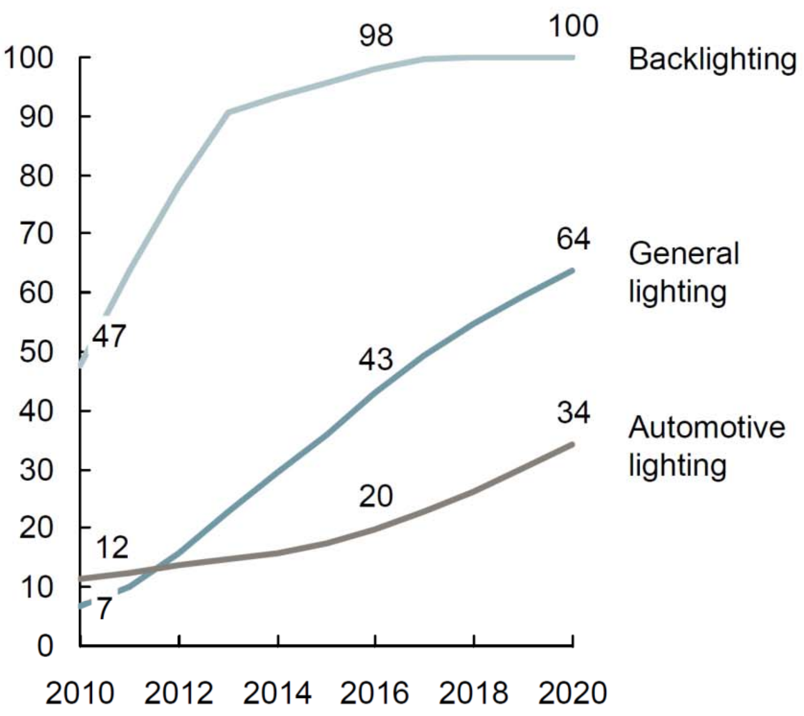


Figure 2-1. Approximate cost breakdowns for LED-based luminaires in 2012
Source: consensus of the 2011/2012 Manufacturing Workshop and Roundtable attendees

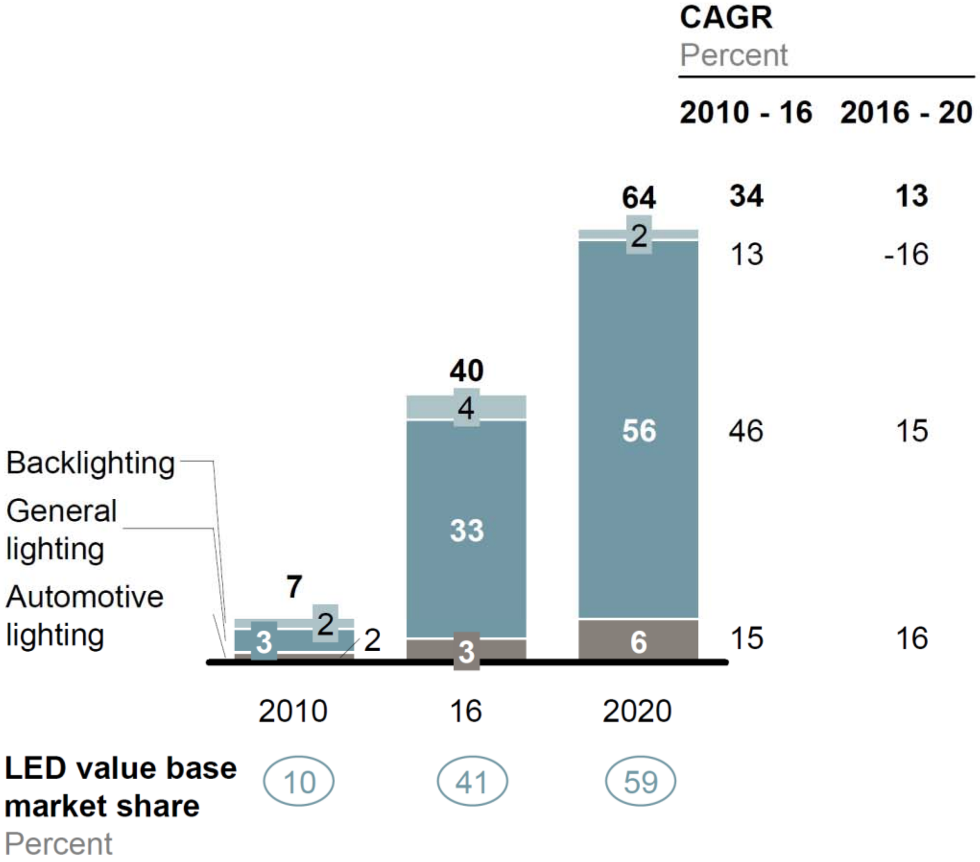
US DOE, Solid-State Lighting Research and Development: Manufacturing Roadmap, pg. 48, August 2012

LED lighting market is expected to increase very rapidly in the coming 10 years

LED value-based market share by sector[1]
Percent



LED lighting market by sector[1]
EUR billions



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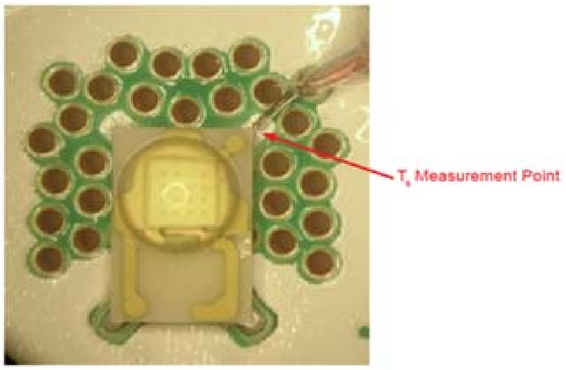
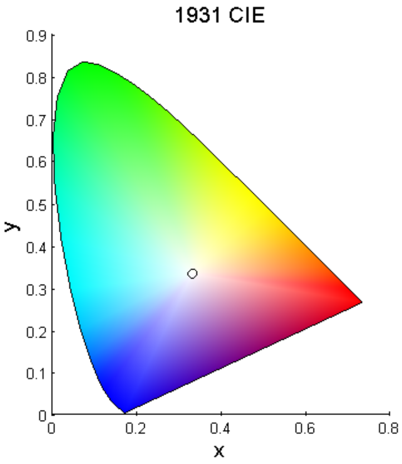
[1] Total general lighting market (new fixture installation market with light sources and lighting system control components [full value chain] and light source replacement market), automotive lighting (new fixture installations and light source replacement), and backlighting (light source only: CCFL and LED package)

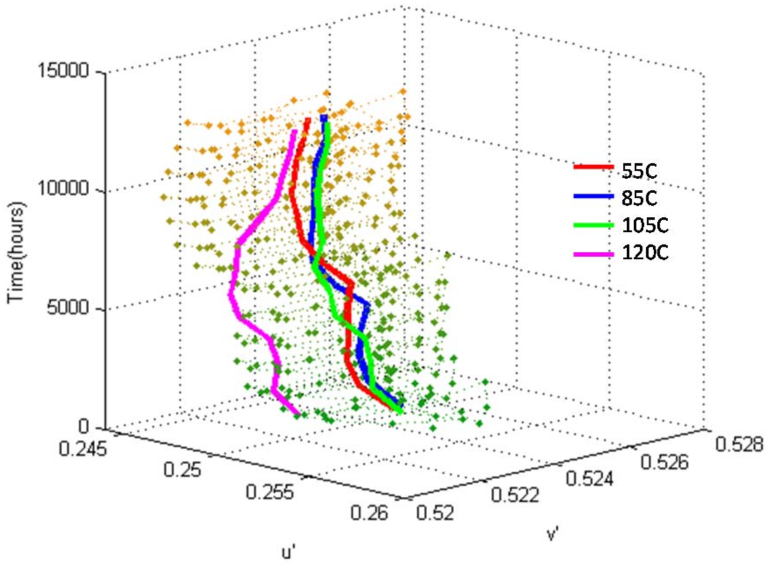
SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

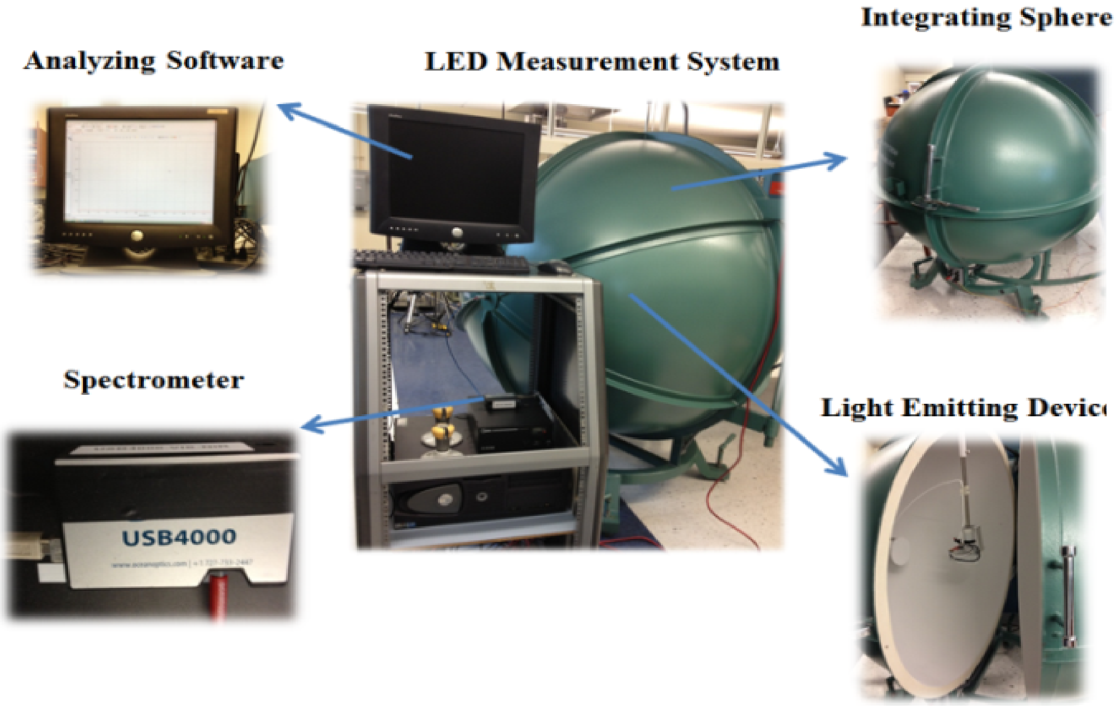
McKinsey & Company, Lighting the way: Perspectives on the global lighting market, 2012

Problem: Predictive Model for Chromaticity Shift and Lumen Degradation in LEDs @CAVE3









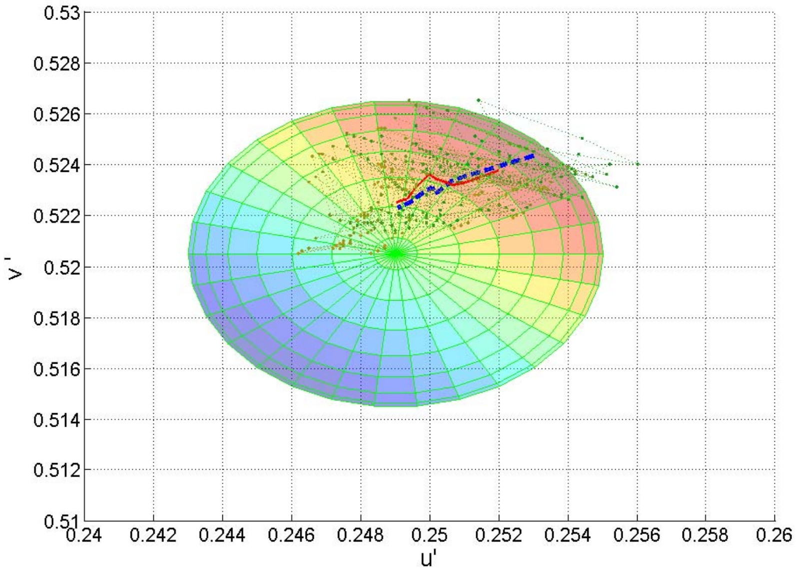
Analyzing Software

LED Measurement System

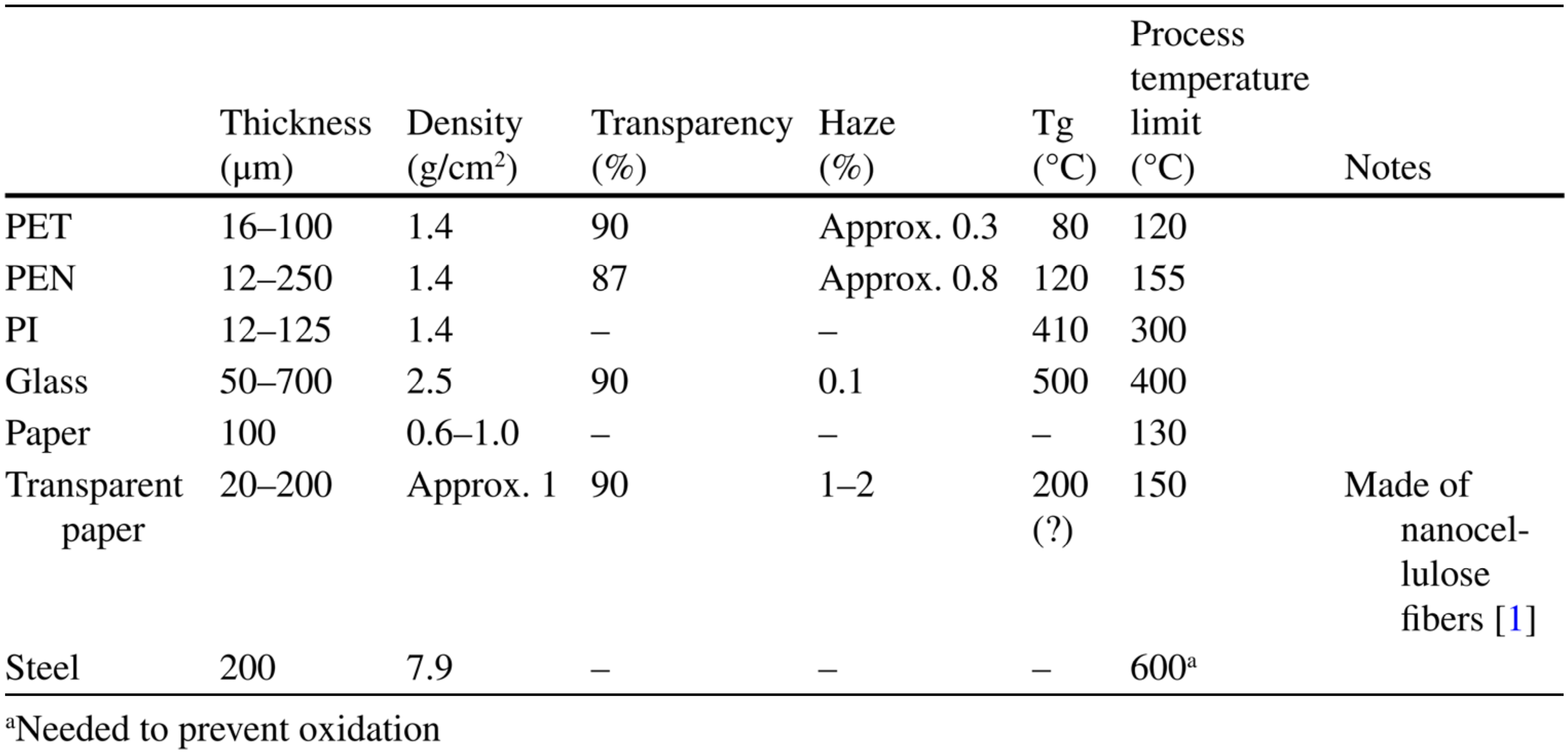
Integrating Sphere

Spectrometer

Light Emitting Devic



Substrates in Flexible Electronics



	Thickness (μm)	Density (g/cm^2)	Transparency (%)	Haze (%)	Tg (°C)	Process temperature limit (°C)	Notes
PET	16–100	1.4	90	Approx. 0.3	80	120	
PEN	12–250	1.4	87	Approx. 0.8	120	155	
PI	12–125	1.4	–	–	410	300	
Glass	50–700	2.5	90	0.1	500	400	
Paper	100	0.6–1.0	–	–	–	130	
Transparent paper	20–200	Approx. 1	90	1–2	200 (?)	150	Made of nanocellulose fibers [1]
Steel	200	7.9	–	–	–	600[a]	

[a] Needed to prevent oxidation

Reference: Introduction to Printed Electronics, K. Suganuma, Springer, 2014

Battery Technology in EV

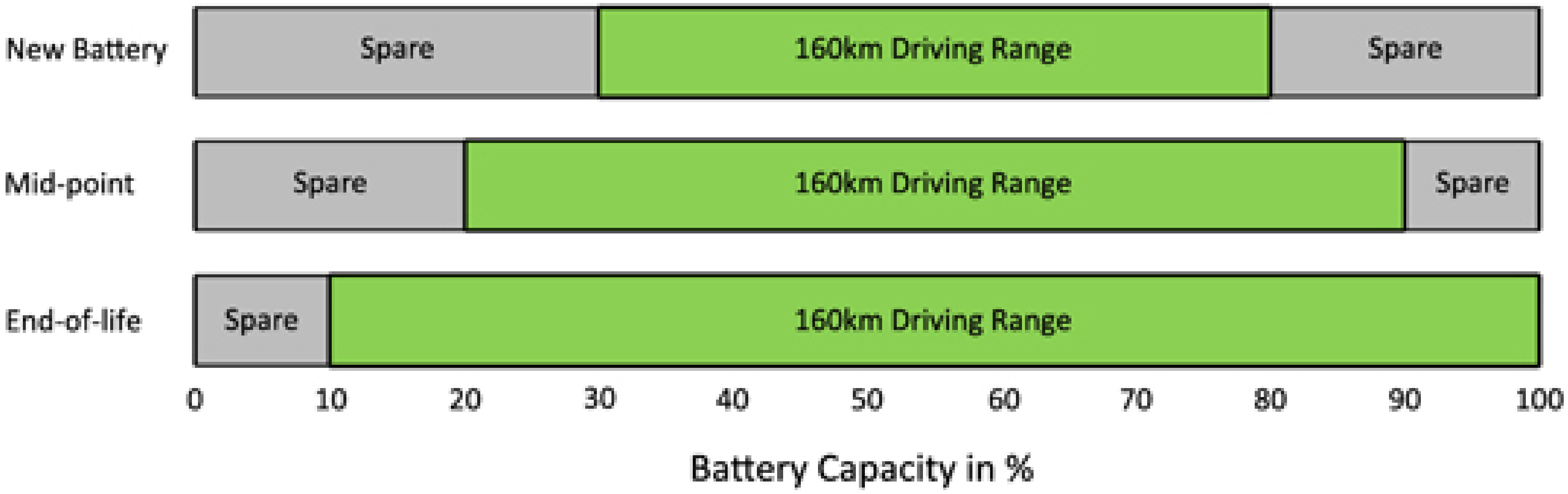
Battery in a Tesla S Model chassis. The 85kWh battery has 7,616 type 18650 cells in parallel/serial configuration.

Source: Tesla Motors

Reference: BU-1003: Electric Vehicle (EV), http://batteryuniversity.com/learn/article/electric_vehicle_ev

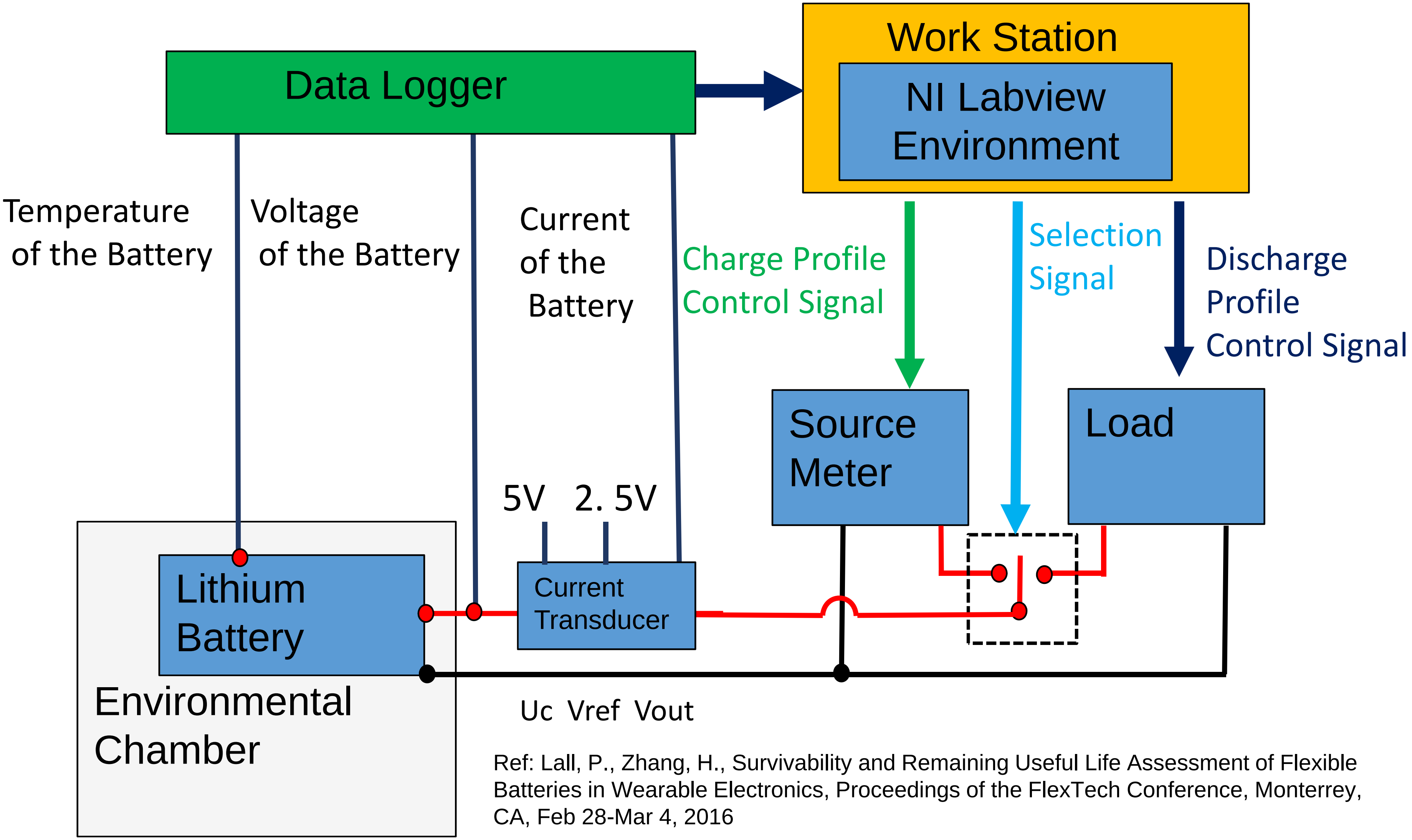
Battery Technology in EV

Driving range as a function of battery performance. A new EV battery only charges to about 80% and discharges to 30%. As the battery ages, more of the usable battery bandwidth is demanded, which will result in increased stress and enhanced aging



Reference: BU-1003: Electric Vehicle (EV), http://batteryuniversity.com/learn/article/electric_vehicle_ev

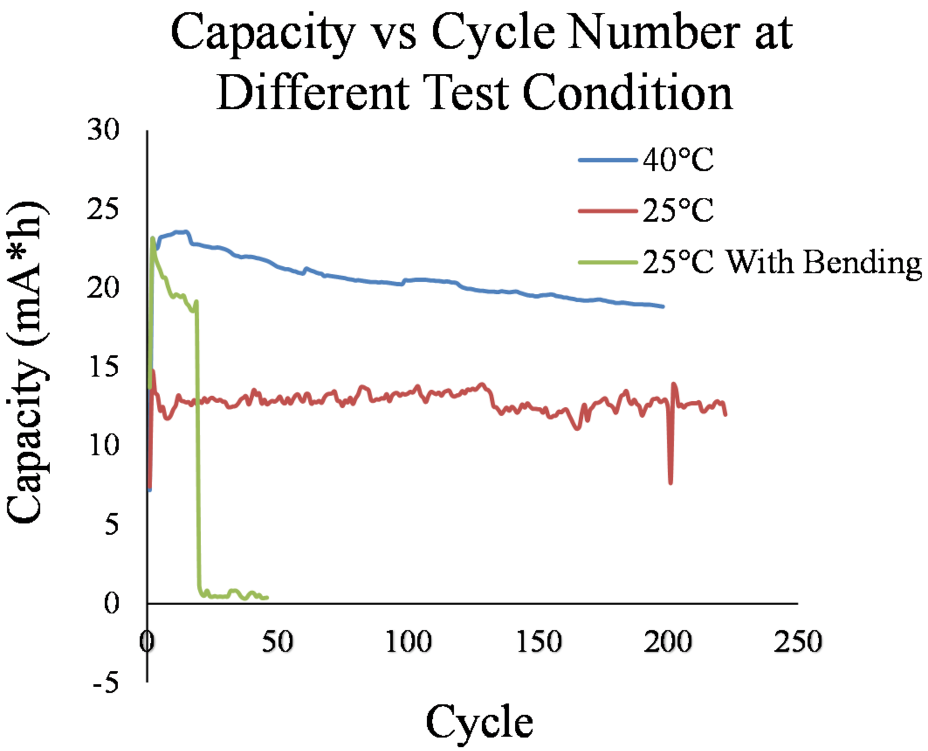
Prognostication of SOC for Batteries @CAVE3

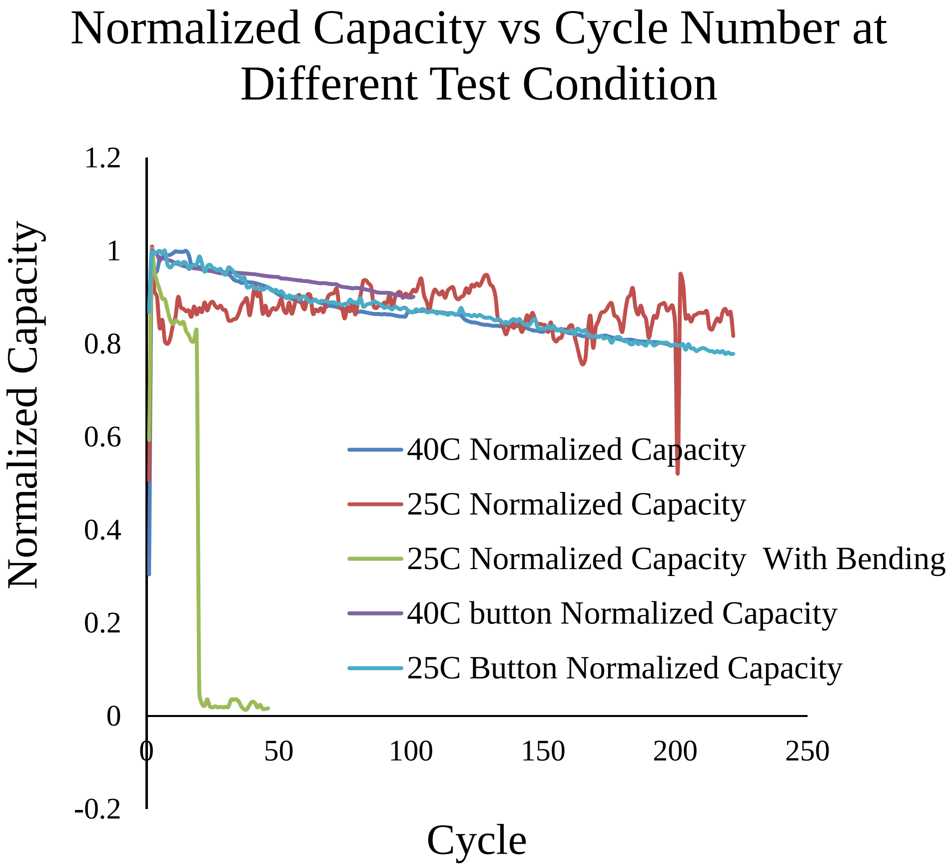


Ref: Lall, P., Zhang, H., Survivability and Remaining Useful Life Assessment of Flexible Batteries in Wearable Electronics, Proceedings of the FlexTech Conference, Monterrey, CA, Feb 28-Mar 4, 2016

Effect of Environment on SOC

Battery Capacity and Normalized Capacity



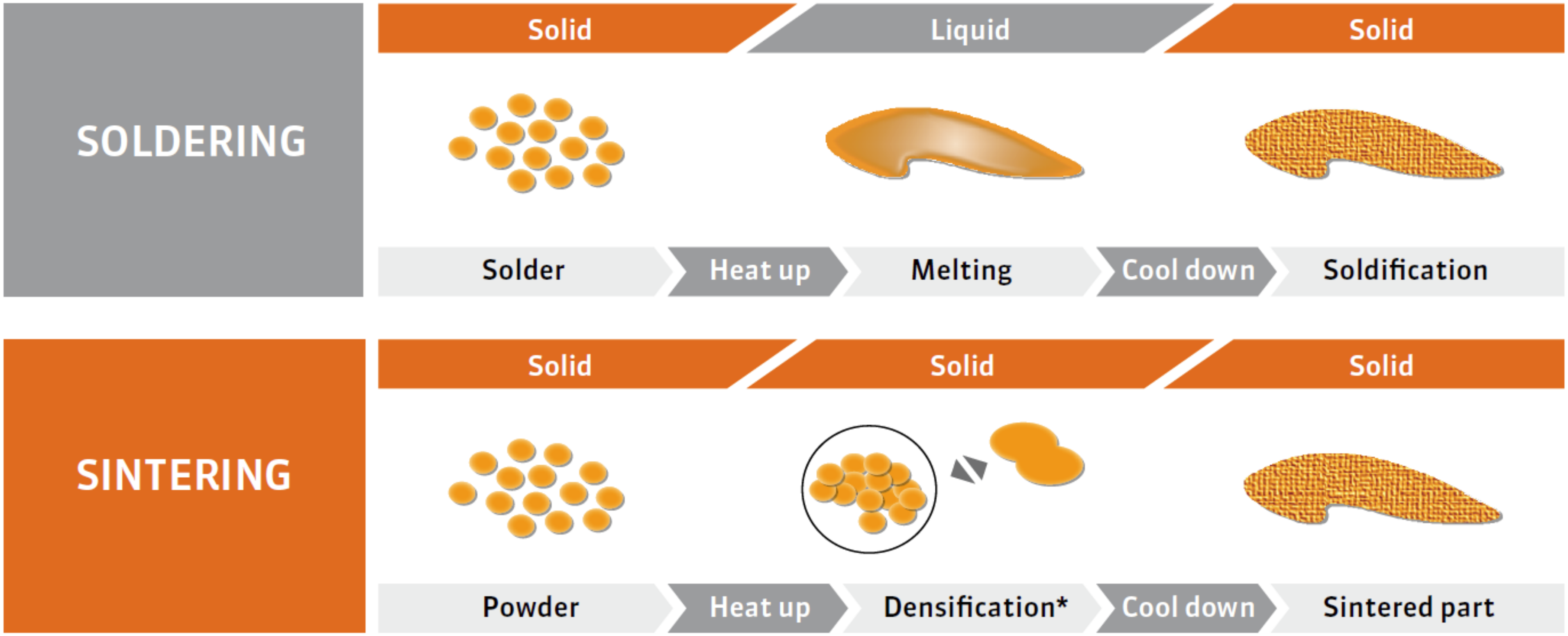


Ref: Lall, P., Zhang, H., Survivability and Remaining Useful Life Assessment of Flexible Batteries in Wearable Electronics, Proceedings of the FlexTech Conference, Monterrey, CA, Feb 28-Mar 4, 2016

Sintering for High Temperature Operation

Sintering is a combined surface, volume, and grain boundary diffusion process

Several processes (densification, grain growth, pore growth / coarsening) take place in parallel



SOLDERING

Solid → Liquid → Solid

Solder → Heat up → Melting → Cool down → Soldification

SINTERING

Solid → Solid → Solid

Powder → Heat up → Densification* → Cool down → Sintered part

Courtesy of Rogers

Sintering Process Flow

Process	Stencil Printing	Drying	Die Pick and Place	Sintering
Equipment	conventional printing equipment	conventional box oven	die placer with heated tooling	sinter press
Parameter	standard parameter	drying in air 10 min. at 100°C	die placement temperature 120°C	sinter pressure 5-30 Mpa sinter temperature 230°C sinter time 3 min. in air

Courtesy of Rogers

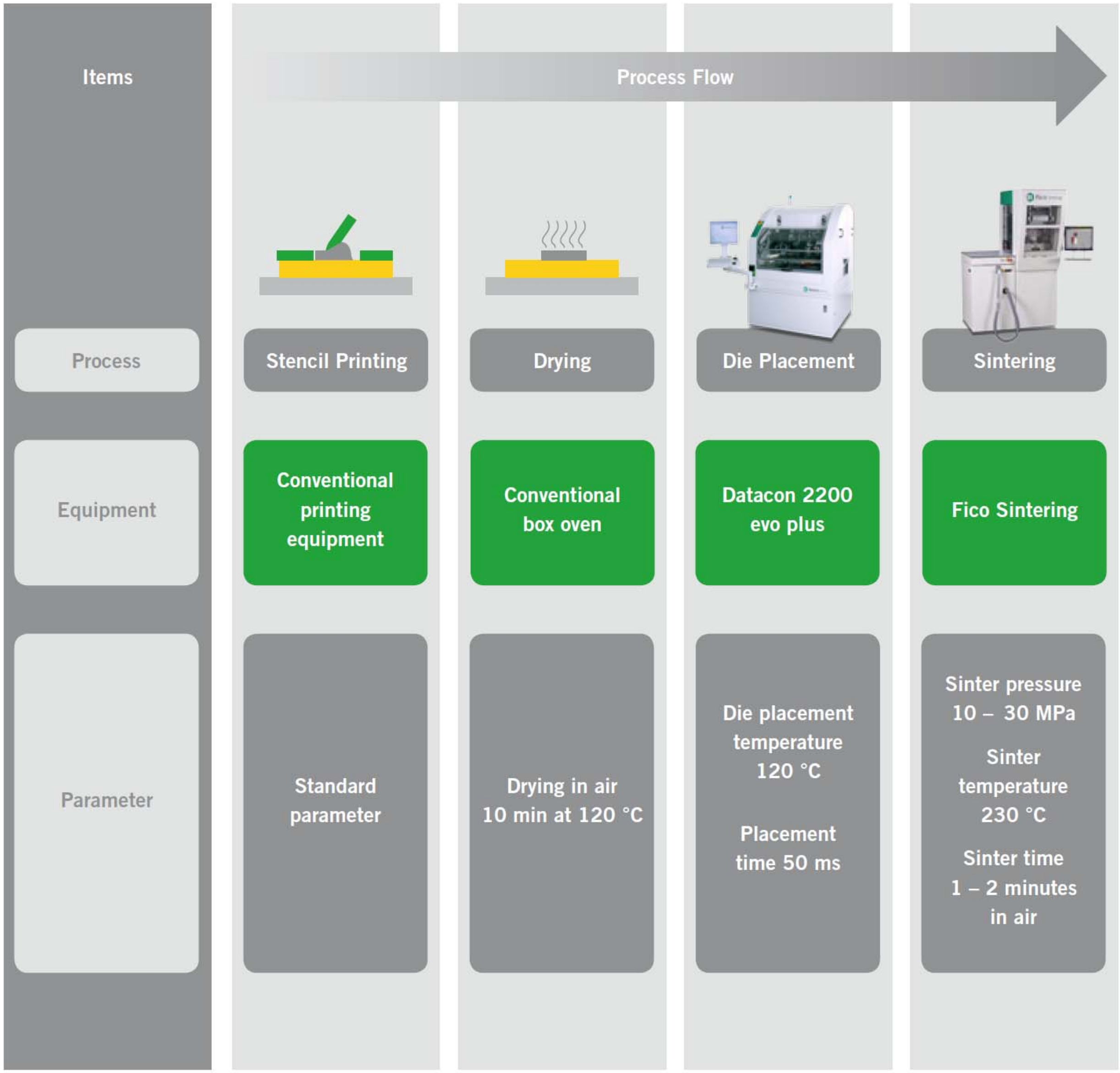
Sinter Silver Paste

Paste = Silver powder mixed
with additives (thinner,
binder, dispersant)

Advantages of Sintered Silver

- ☐ Low sintering temperature
- ☐ (200-300°C)
- ☐ High subsequent reflow temperature (961°C)
- ☐ Formulation is leadfree
- ☐ High thermal and electrical conductivity
- ☐ Ag thermal conductivity is 240 W/mK
- ☐ Sintering joint thickness is in the range of 50-100μm although lower joint thickness is possible

Industrial Sintering Process



Items	Process Flow			
Process	Stencil Printing	Drying	Die Placement	Sintering
Equipment	Conventional printing equipment	Conventional box oven	Datacon 2200 evo plus	Fico Sintering
Parameter	Standard parameter	Drying in air 10 min at 120 °C	Die placement temperature 120 °C Placement time 50 ms	Sinter pressure 10 – 30 MPa Sinter temperature 230 °C Sinter time 1 – 2 minutes in air

Courtesy of Heraeus

Key Parameters for Sintering Joints

Package and Process	**Parameters**
Substrate	Metallization and Metallization Thickness, Plating Process, Surface Roughness, Surface Contamination
Die	Die Metallization and Size
Silver Paste	Nanoparticles, Microparticles, Printing, Dispensing, and Laminating
Die Pick and Place and Paste Drying	Void Ratio, Porosity, Temperature
Sintering Profile	Time, Temperature, Pressure, Heat-Up, Cool-Down
Sintering Atmosphere	Air, Nitrogen

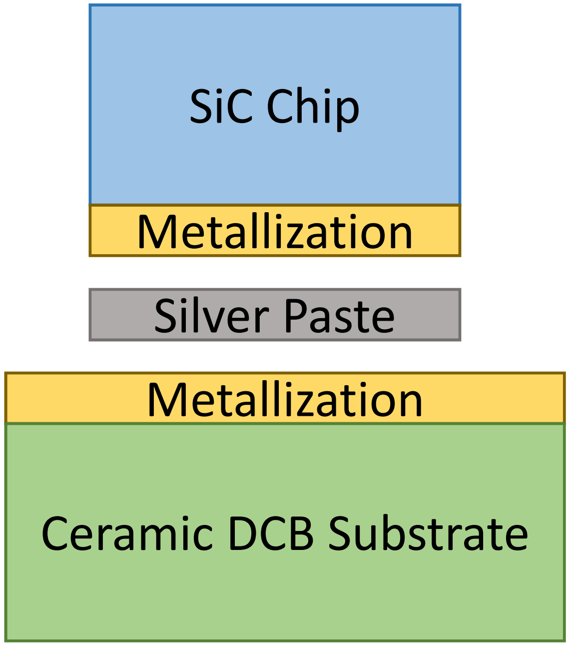
Sinter Silver Paste

Sintering Profile DOE

- ☐ Time (10 min – 30 min)
- ☐ Temperature (200°C, 250°C, 300°C)

Sintering Process

- ☐ Dispense paste on substrate
- ☐ Attach the SiC chip on the silver sintered paste
- ☐ Attachment will be done in a convection oven
- ☐ Samples will be attached to a steel stud, one on each side of the stud for property measurement



SiC Chip

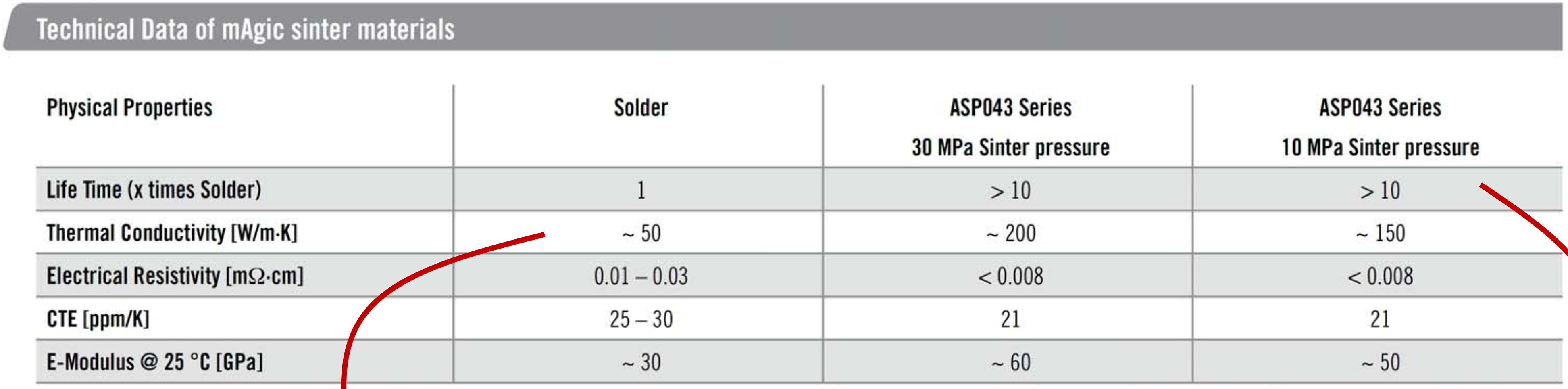
Metallization

Silver Paste

Metallization

Ceramic DCB Substrate

Commercial Sinter Silver Pastes



Technical Data of mAgic sinter materials

Physical Properties	Solder	ASP043 Series 30 MPa Sinter pressure	ASP043 Series 10 MPa Sinter pressure
Life Time (x times Solder)	1	> 10	> 10
Thermal Conductivity [W/m·K]	~ 50	~ 200	~ 150
Electrical Resistivity [mΩ·cm]	0.01 – 0.03	< 0.008	< 0.008
CTE [ppm/K]	25 – 30	21	21
E-Modulus @ 25 °C [GPa]	~ 30	~ 60	~ 50

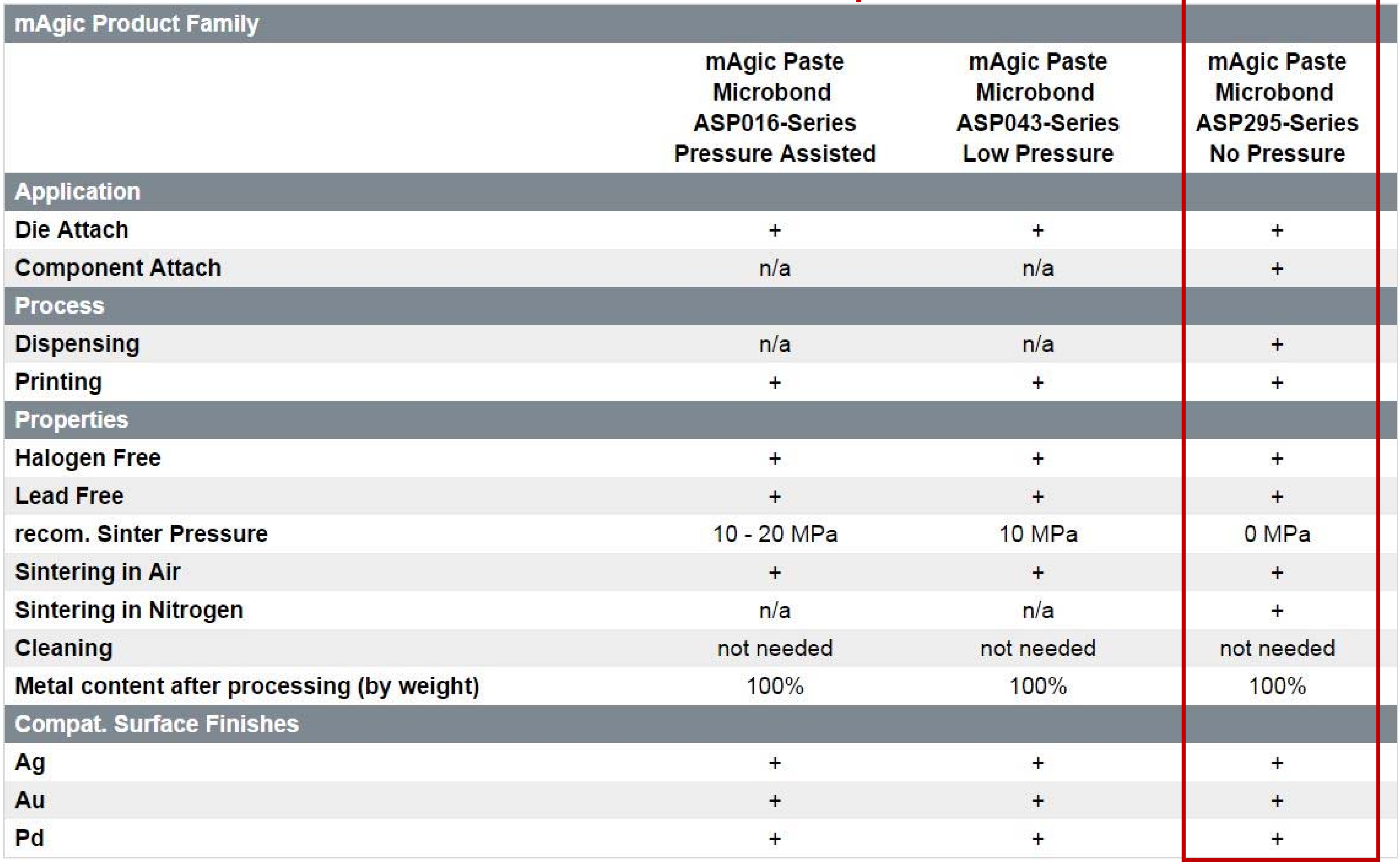
Courtesy of Heraeus

High Thermal Conductivity

High Thermal Fatigue Life

Commercial Sinter Silver Pastes

Some Sinter Silver Pastes Require No Pressure

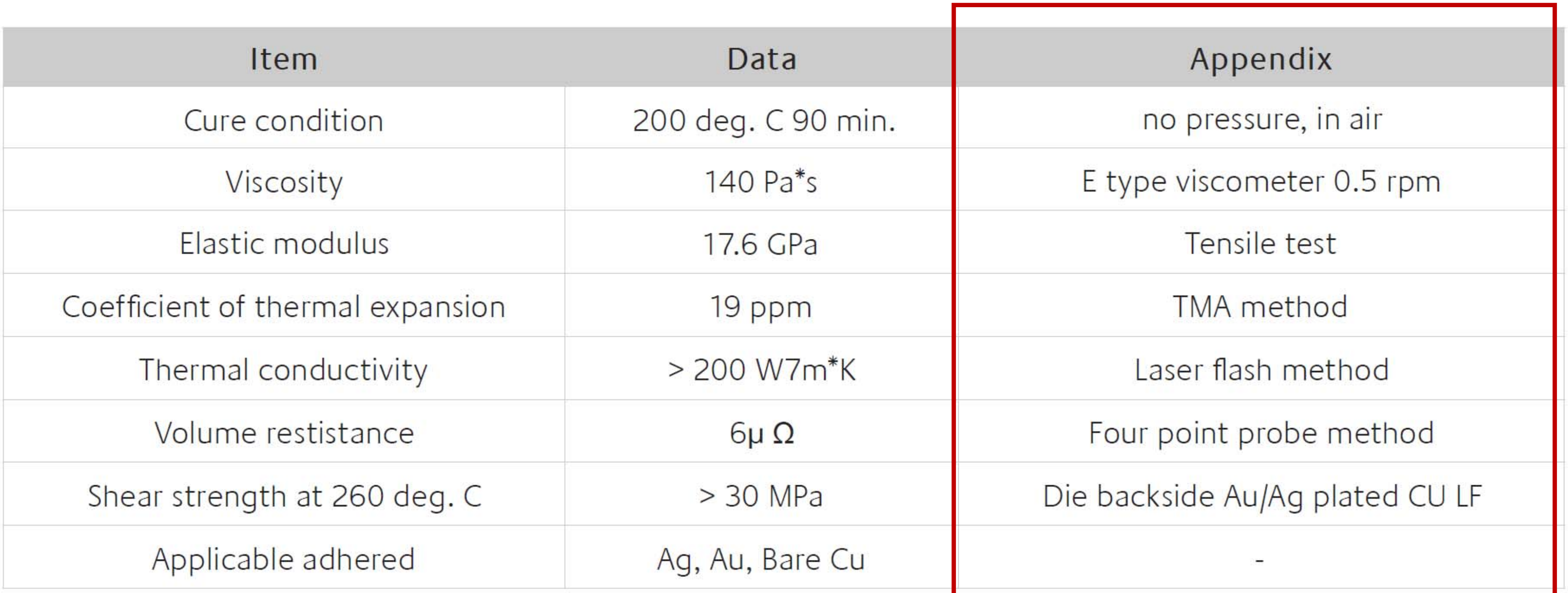


mAgic Product Family			
	mAgic Paste Microbond ASP016-Series Pressure Assisted	mAgic Paste Microbond ASP043-Series Low Pressure	mAgic Paste Microbond ASP295-Series No Pressure
Application			
Die Attach	+	+	+
Component Attach	n/a	n/a	+
Process			
Dispensing	n/a	n/a	+
Printing	+	+	+
Properties			
Halogen Free	+	+	+
Lead Free	+	+	+
recom. Sinter Pressure	10 - 20 MPa	10 MPa	0 MPa
Sintering in Air	+	+	+
Sintering in Nitrogen	n/a	n/a	+
Cleaning	not needed	not needed	not needed
Metal content after processing (by weight)	100%	100%	100%
Compat. Surface Finishes			
Ag	+	+	+
Au	+	+	+
Pd	+	+	+

Courtesy of Heraeus

Commercial Sinter Silver Pastes

Some Sinter Silver Pastes Require No Pressure



Item	Data	Appendix
Cure condition	200 deg. C 90 min.	no pressure, in air
Viscosity	140 Pa*s	E type viscometer 0.5 rpm
Elastic modulus	17.6 GPa	Tensile test
Coefficient of thermal expansion	19 ppm	TMA method
Thermal conductivity	> 200 W7m*K	Laser flash method
Volume restistance	6μ Ω	Four point probe method
Shear strength at 260 deg. C	> 30 MPa	Die backside Au/Ag plated CU LF
Applicable adhered	Ag, Au, Bare Cu	-

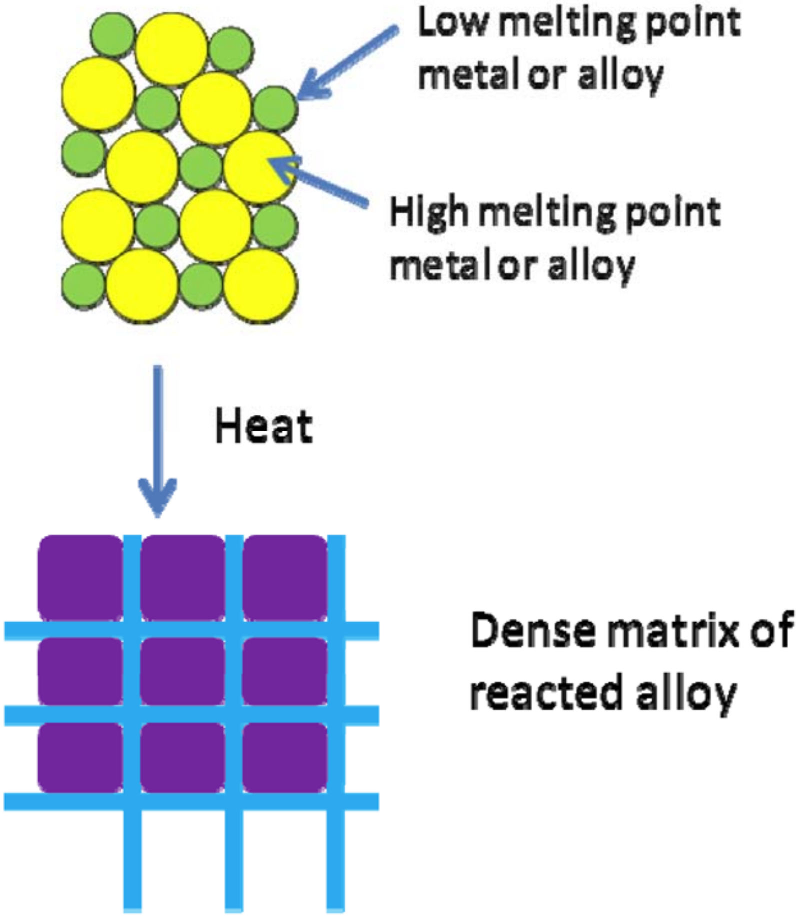
Courtesy of Kyocera

What is TLPS?

☐ Diffusion bonding without application of pressure.

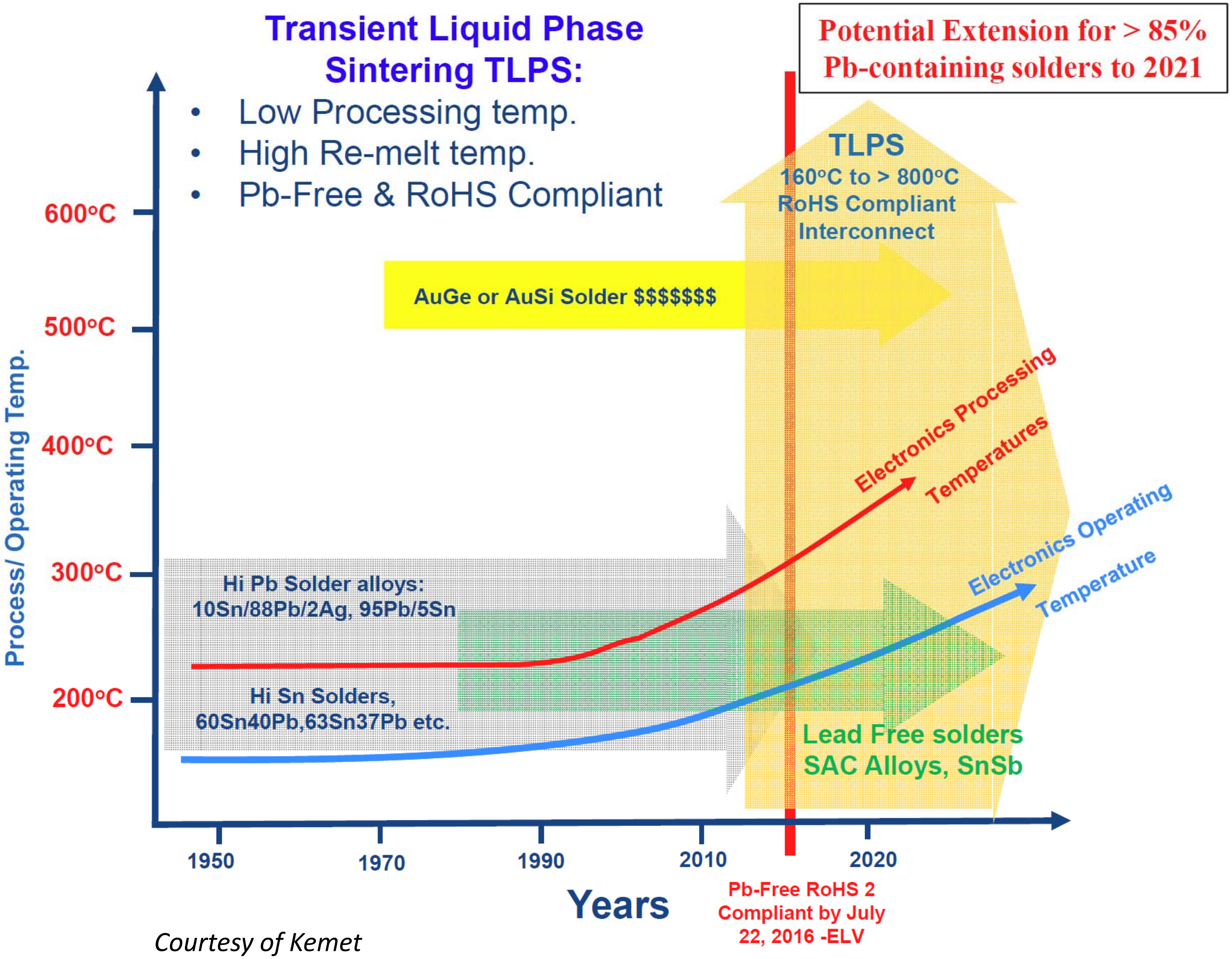
☐ Transient Liquid Phase Sintering (TLPS) is the low-temperature reaction of a low melting point metal or alloy with a high melting point metal or alloy to form a reacted metal matrix.

☐ TLPS forms a metallurgical bond between two surfaces. Depending on the alloy, TLPS may have a re-melt temperature in excess of 600°



Courtesy of Kemet

TLPS vs Lead Containing Solders



Courtesy of Kemet

TLPS Characteristics

- Diffusion bonding without application of pressure.
- Bonding is specific to surface type and TLPS used
- Applied as a paste or preform or plated surface-to-surface
- Active fluxes to clean surfaces, bond oxide/contaminants
- Polymeric binders are retained in the joint
- No rework is possible
- No wetting or fillet formation
- No solder ball formation
- TLPS has much higher re-melt >600°C depending on the specific alloys formed

TLP Material Bonding Pairs

TLP	Processing Temperature	Processing Time	Remelt Temperature
Cu-Sn	280°C	4 min	~ 660°C
In-Ag	175°C	120 min	~ 780°C

Flexible Hybrid Electronics Manufacturing Challenges

Assembly/Integration of Disparate Components

***Challenge*: Processes for device assembly – Integration of foundry-based components with "printed" components**

- Processing at low temperature on conformal, bendable, stretchable, and/or foldable substrates such as textiles, breathable cloths, plastics
- Reliable, high-speed registration techniques for multi-layer devices
- Pick-and-place: handling thinned dies, flex substrates
- Processes for large panel formats enabling multiple (dozens or hundreds) of simultaneous assemblies
- Automated and robotic approaches
- Chip/flex interconnects

Flexible Hybrid Electronics Manufacturing Challenges

System Integration Demonstrations

***Challenge*: Establish performance capabilities for FHE devices through precompetitive Technology Platform Demonstrations**

- Flexible encapsulation approaches, environmental protection
- Thermal management
- Powering component devices
- Physical packaging for manufacturability and survivability
- Common interconnects/component interfaces

Flexible Hybrid Electronics Manufacturing Challenges

Innovative Printing Processes

***Challenge*: Scale-up & optimization of innovative printing processes**

- Finer features for higher input/output count die
- High-throughput & large area printing/deposition systems that can handle wide range of materials/inks and substrates – with enhanced process control
- Deposition on non-traditional substrates (textiles, low-temperature plastics, stretchable materials, breathable) with varying surface energy, roughness, etc.
- Depositing vias in multi-layer circuit boards, precise registration for multi-layer devices

Flexible Hybrid Electronics Manufacturing Challenges

Thin Device Processes

***Challenge*: Scale-up & optimization of thin device processes**

- Matured wafer thinning, epitaxial lift-off, controlled spalling processes
- Higher volume, lower cost processes
- Device designs mitigating interconnect issues on stretchable/flexible substrates

Flexible Hybrid Electronics Manufacturing Challenges

Flex-Hybrid Materials Manufacturability & Scale-Up

***Challenge*: Reproducibility and Scale-Up for FHE Materials**

- Scale-up with flexibility & performance
  - Metals & dielectrics (including electroactive polymers) for sensors, passive components, interconnects, etc.
  - Low-temperature sinter/cure chemistries with benign solvents
  - Non-inks for interconnects, ball-grid arrays, low-temp solders, etc.
- Flexible substrates
  - Temperature/environmental survivability
  - Multilayer designs – through vias for high density interconnects
  - Textile and low-temperature planarization
- Flexible encapsulant materials
- Adhesives

Flexible Hybrid Electronics Manufacturing Challenges

Models & Design Tools

Challenge: **Validated tools & models for accelerated device design**

- Adapting tools currently used by EDA and IC industries for FHE materials, form factors, and applications
- Understanding interplay between functional materials, substrates, and deposition processes
- Developing multi-physics tools (electrical, thermal, mechanical, etc.) to determine device manufacturing layout
- Populating databases with both materials properties and fabrication process parameters

Flexible Hybrid Electronics Manufacturing Challenges

Standards, Testing, and Metrology

***Challenge*: Common industry standards & practices**

- Define mechanical (bending/stretching) and environmental requirements. ID test techniques.
- Interface/interconnect standards to enable plug-and-play assembly of hybrid devices
- Layout/design rules to minimize part count & complexity, minimize power consumption

***Challenge*: In-process & reliability and quality testing**

- In-line, high-speed, automated quality control tools – both performance (e.g., electrical) and registration/geometry
- Test strategies/techniques to ensure long-term reliability in military environments – mechanical, chemical, thermal, etc. testing for durability

Methods for Getting Involved with CAVE^3

Fundamental Research

Join the CAVE^3 Consortium
Members gain access to CAVE^3 resources
Influence research thrusts
Membership requires an annual membership fee.

Application Specific Projects and Services

Engage CAVE^3 in application specific projects.

Professional Development

Engage CAVE^3 in educating workforce. CAVE^3 has a broad range of professional-courses:

- *Prognostics health monitoring*
- *Shock and Vibration Reliability of Electronics*
- *Reliability Assurance*
- *Accelerated Testing*
- *Thermal Design and Management*
- *System Cost Analysis*
- *Supply Chain Management.*