Automotive Packaging –
System Integration and Reliability

Thorsten Meyer, Infineon Technologies
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2. Automotive Quality and Reliability
3. Advanced Packages
   - Trends
   - Example: Tire Pressure Sensor – Fan-Out WLB
   - Example: Modules & Integration
4. Gaps
   - Reliability & Quality
   - Co-Design
   - Material
5. Summary

Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

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   - Example: Tire Pressure Sensor – Fan-Out WLB
   - Example: Modules & Integration
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Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

Megatrends are Shaping the Automotive Market
Significant Increase of Semi Content per Car

Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

ATV Drivers
Translation to Package Technical Requirements

Automated cars

e-Mobility

Connectivity

Functional safety

Increased features (redundancy, storage, performance)

Extended profiles (charging, car sharing)

High power (48V, SiC)

Competitive environment

Miniaturisation ⇔ Higher functional integration ⇔ Enhanced electrical and thermal performance ⇔ Longer reliability assessments

Reduced package costs

Reduced development time (t2m)

Advanced Packages System in Package

Thermally enhanced solutions*

High power density packages

Robust packages

* Integration on system-level with customer

Semiconductors
Use in Automotive Industry







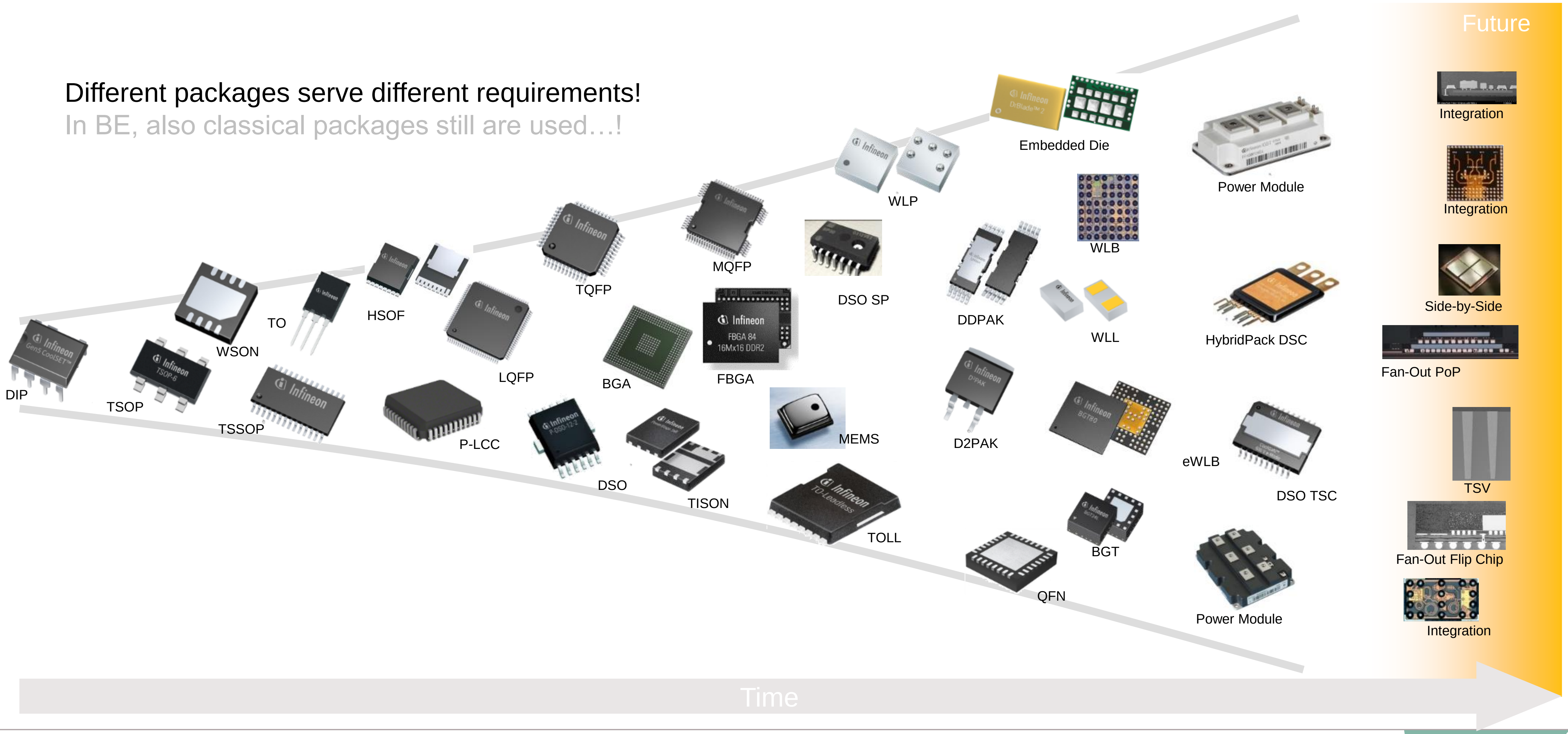
Infotainment	Communication	Safety	Body Electronics	Chassis	Electronic System	Power Train
Dashboard	Comm Systems	Airbag	Control Module	ABS	Alternator	Engine Control
Audio	Local Network	Collision Avoidance	Seat, Window Control	Power Steering	Battery	Transmission
Entertainment	Bluetooth	Parking Assistance	Mirror	Traction Control	Starter	…
GPS	…	Rear Camera	Wiper	Active Suspension	Lightning	
Navigation Display		TPMS	Lightning Control	…	…	
…		…	…			

- ❑ Semiconductors are widely used in Automotive
- ❑ About 80% of innovations in cars enabled by Semiconductors
- ❑ What are the Package Platforms of Automotive Industry today?

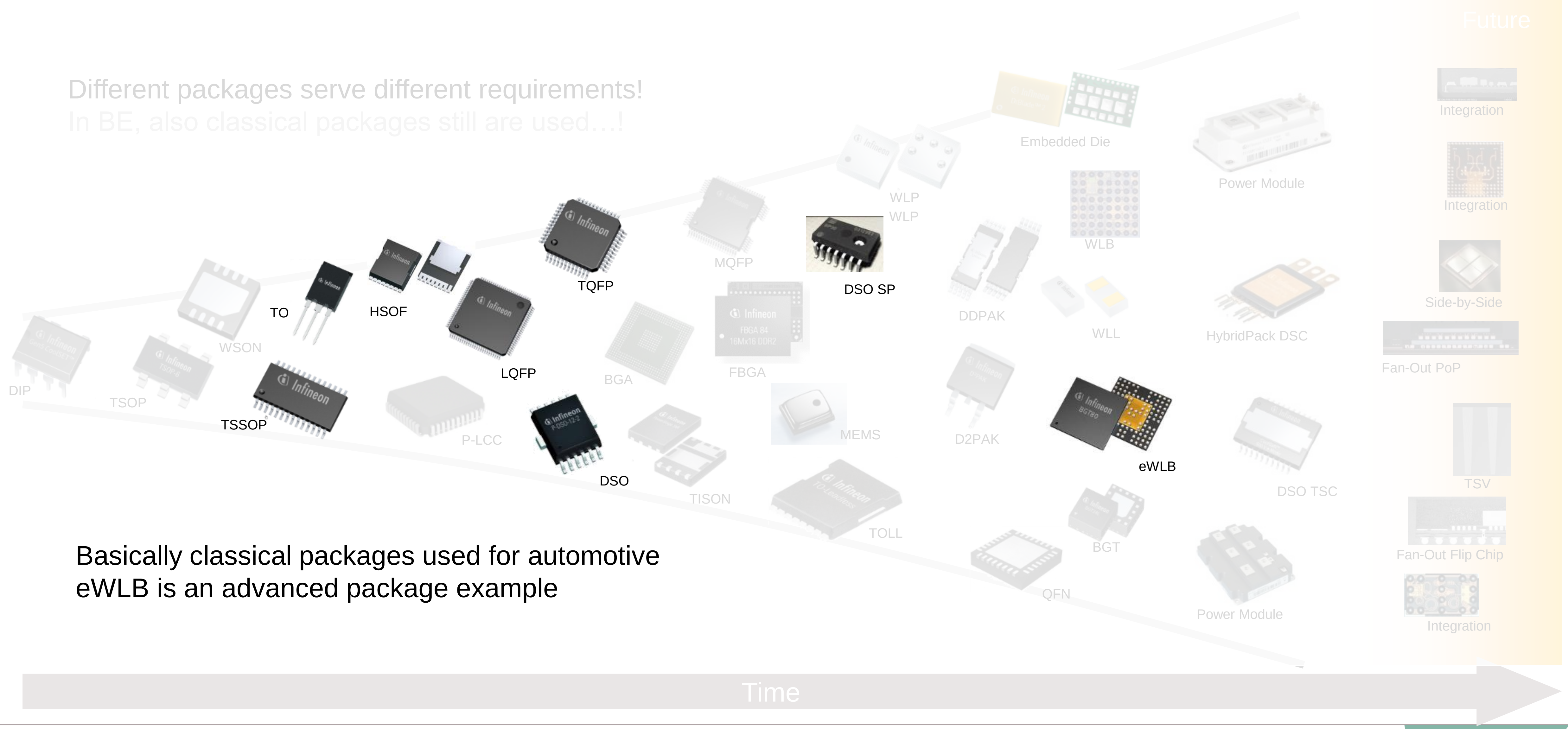
Package Diversity is Growing Over Time
Infineon View

Different packages serve different requirements!

In BE, also classical packages still are used…!

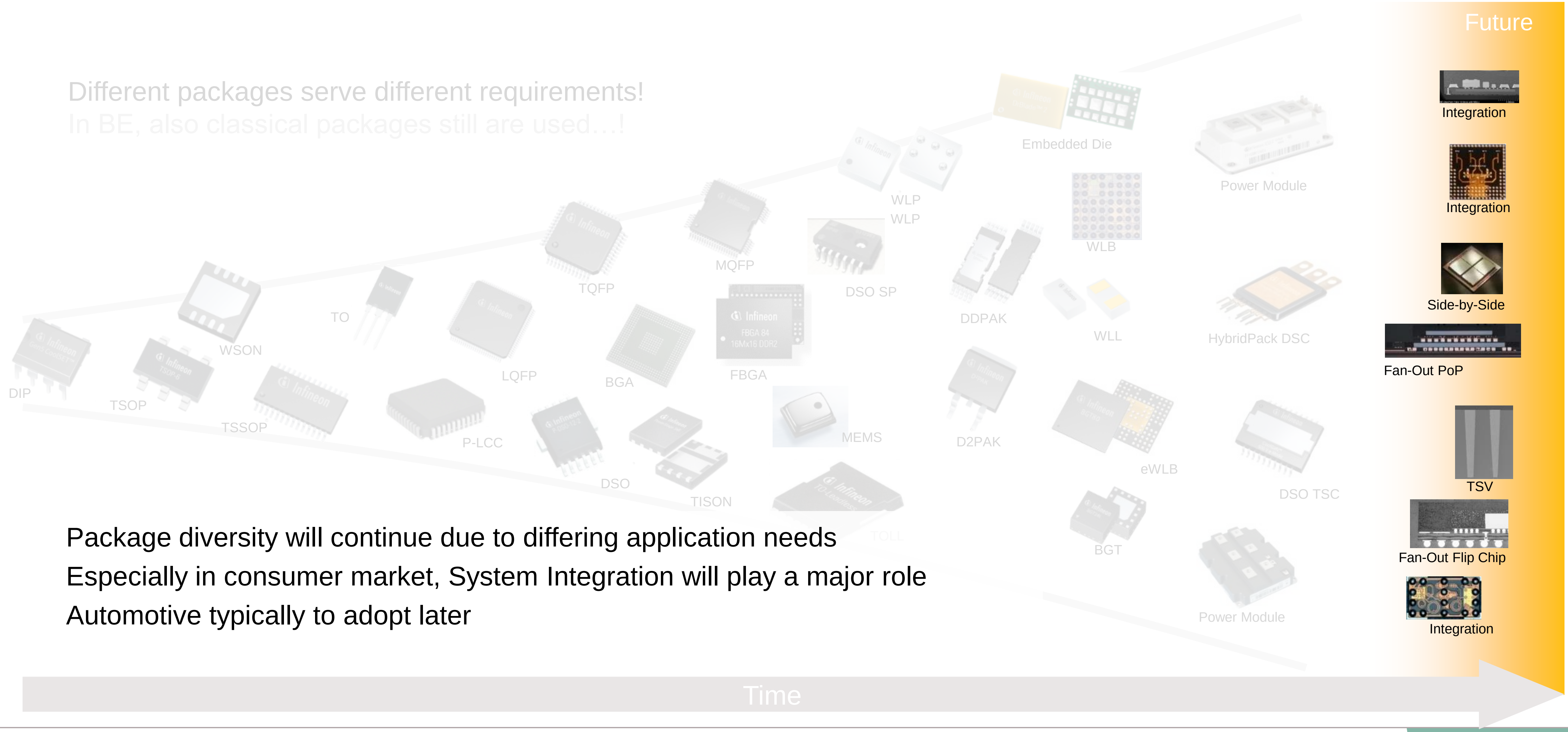


Package Diversity is Growing Over Time
Automotive Qualified



Basically classical packages used for automotive
eWLB is an advanced package example

Package Diversity is Growing Over Time
Heterogeneous Integration

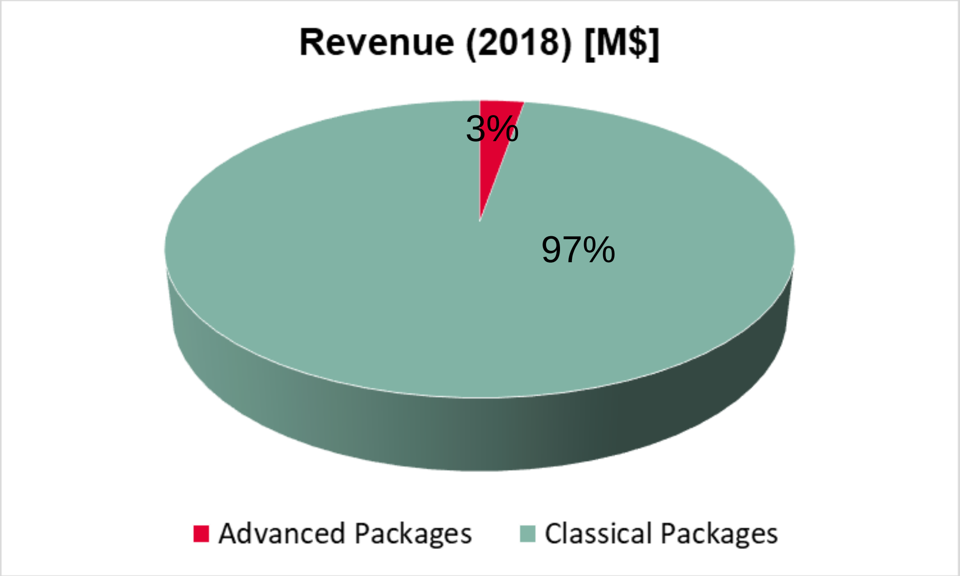


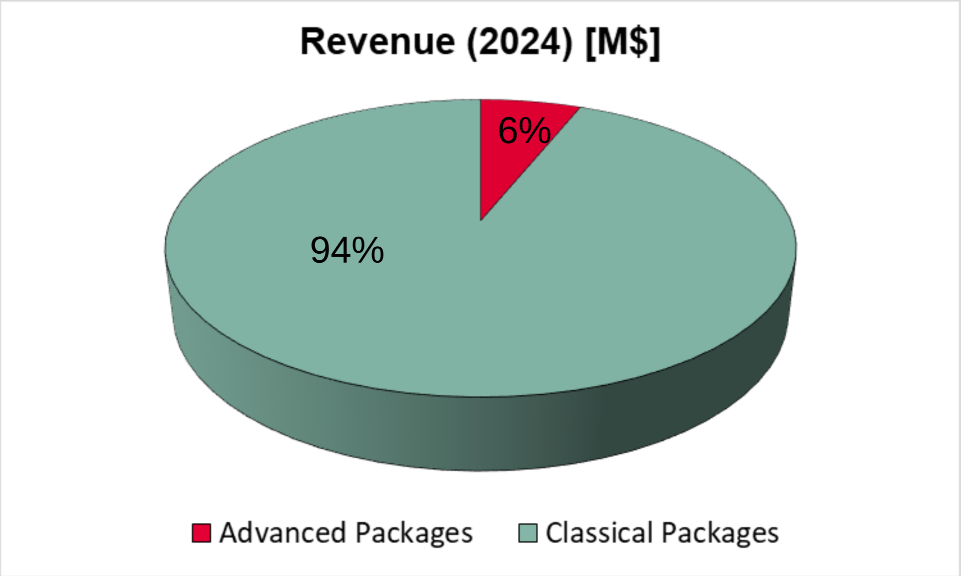
Package diversity will continue due to differing application needs

Especially in consumer market, System Integration will play a major role

Automotive typically to adopt later

Classical vs. Advanced Packages Revenue





- Advanced packaging not heavily used in automotive industry
- Advanced packages: Flip Chip BGA, Embedded Die, Fan-In and Fan-Out Wafer Level Package, SiP
- Reasons for Package selection
  - Cost
  - Automotive quality requirements
  - Automotive reliability requirements
  - …

Based on Yole Development

Content

Automated Driving

Enabling safety towards Vision Zero

Mobility

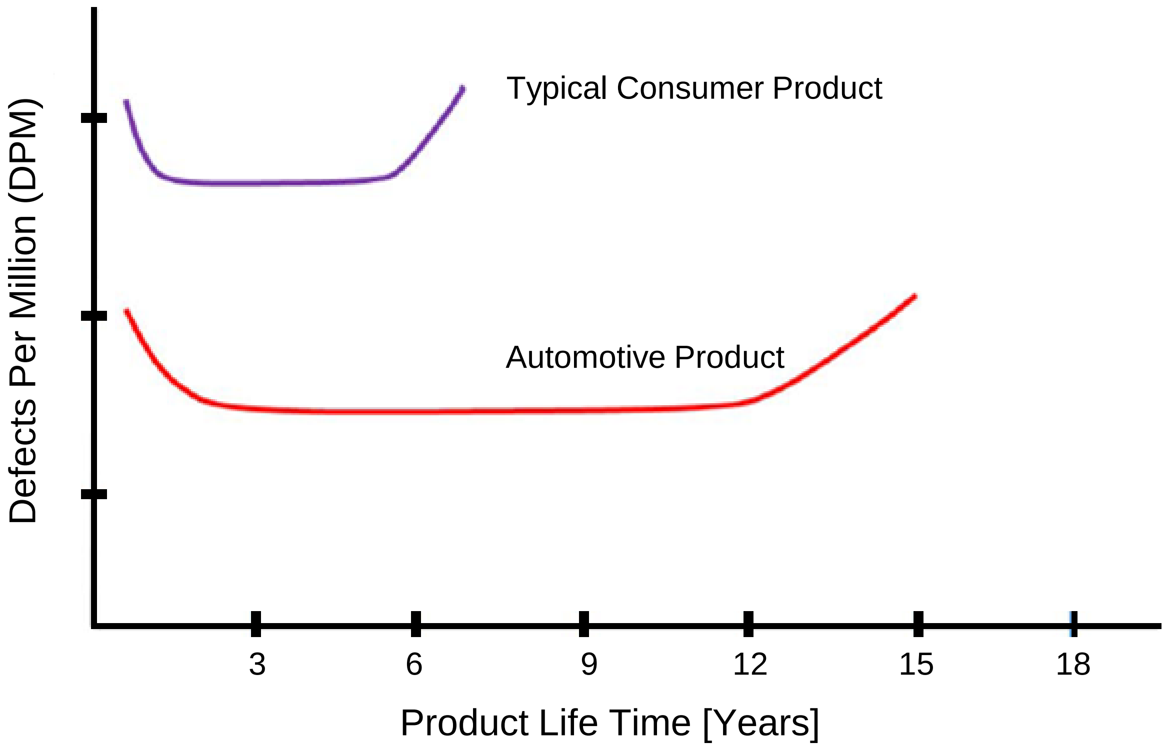
Enabling CO_2 reduction

Connectivity

Enabling the communication of cars

Quality Requirements
Consumer vs. Automotive

- Product lifetime and quality/ reliability are differing between Consumer and Automotive
- Typical consumer electronic components generally manufactured with
  - a different quality/ reliability mindset
  - a shorter useful life span
- One factor in consumer space: tradeoff between time to market and quality;
  - Faster access to higher performance (or new features) invariably requires taking higher risk
- Die and package traceability required in ATV
- Cost issues, especially for is zero defects target in the traditional automotive market
- Differences will have to be carefully considered for
  - new package platforms
  - utilization of commercially available (consumer) systems



Automotive Requirements
Zero Defects

- Zero Defect is a prerequisit for the automotive market
- Zero defect is expected from customer
- Zero Defect principle: No rework – first time right products
- Automotive knowledge and experience – technology, but also development, methodologies, … mindset – will be key to success
- The introduction of new package platforms in automotive market is costly

x 300

x 50

1ppm component defect

300ppm ECU(*) defect

15000 car defects out of 1Mio (1,5%)

(*) ECU: Electronic Control Unit

Meeting Customers Needs
Best-in-class Product Requirements, Design, Manufacturing and Testing

Product quality is more than:

- Temperature range
- Labelling based on demand
- Qualifying to automotive standards: AEC-Q100/ 101
- ...

It's meeting real customer expectations through

- Development processes (e.g. RDDF)
- Design rules (e.g. ADeGo)
- Materials
- Manufacturing processes and process controls
  - the full production chain must be automotive (stability, traceability and deviation management, ...)
  - Failure mechanism based validation & mission profile based qualification
  - Screening, statistical methods and firewalls

AEC-Q100 (= disaster check):
3lots à 77pcs in qualification
→ **10.000dpm**

Up to 100 additional specific measures

Automotive target:
<1dpm
over e.g. **30000h** lifetime

000337

Automotive Requirements
Example: LTI Feature

- Lead Tip Inspection feature often required for automotive packages
- Inspection system used for inspection of proper soldering on board
- Costly process steps for LTI achievement
- BGA packages do not offer this requirement

Side and top view of wetted (top) and non-wetted (bottom) termination of a leadless package

Automotive Requirements
Reliability

Infotainment/ Comfort	Power train	Safety	Lightning	Connectivity
				
Grade 3 & 2 -40°C to +105°C	Grade 1 & 0 -40°C to +150°C	Grade 1 -40°C to +125°C	Grade 1 (ext) -40°C to +125°C Grade 3 & 2 (int) -40°C to +105°C	Grade 3 & 2 -40°C to +105°C

- Five main application groups are showing very different needs and operating conditions
- In these five applications, you can find specific electronic devices (e. g. LEDs in lighting)
- Some electronic devices can be found in several groups with different specs
  (e. g. MCUs in safety vs. MCUs in infotainment)

Source: Yole Development

Reliability Requirements
Example: Autonomous Driving

Autonomous Driving

- New requirements due to full autonomous driving will bring additional challenges to packaging
- Additional operating states beside driving and parking:
  - On-grid parking
  - Vehicle-Preconditioning (battery as well as driver comfort like cabin heating)
  - Charging
- Today: 8.000 hours on-time
  Tomorrow: 121.500 hours on-time
- Requirements:
  - Understanding of material physics (CTE issue, mm-wave material properties,
  - Understanding of customer requirements (e. g. reliability, grade, …)
  - Complexity management required (CBPI)

→ Adapted Mission Profiles
→ Generation of Failure Models
→ Understanding of acceleration models
→ Predictive Maintenance

Consequences of Future Mission Profiles
Example: Car Sharing Use

Assumed circumstances for a car sharing use

- Charging/ Preconditioning versus driving timeshare assumed 2:1
- Avg. speed 25 km/h (Urban Area Use)
- Car sharing maximum usage of 8 h driving per day
- Mechanical optimization enables 500.000 km total mileage

Resulting Mission Profile

- 20.000 h Driving
- 40.000 h Charging / Preconditioning
- 7 years lifetime
- Mission profiles
  - Driving: Grade 0
  - Charging: Grade 1

Assumptions

- Arrhenius model
- $E_a = 0.7$ eV
- $T_{stress} = 150$ °C
- Self heating 15 °C

Assumed Mission Profile*

$T_{ambient}$ [°C]	Time [h]
-40 °C	3.600
23 °C	12.000
65 °C	26.000
85 °C	13.000
115 °C	3.200
120 °C	400
135 °C	1.600
140 °C	200

- Resulting HTSL stress test duration: 4,866 h
- Consequence: 5,000+ hours single stress to cover lifetime

Automotive quality and reliability have impact on cost, t2m and package platform selection

Source: Uli Abelein, Infineon

Content

Automated Driving

Enabling safety towards Vision Zero

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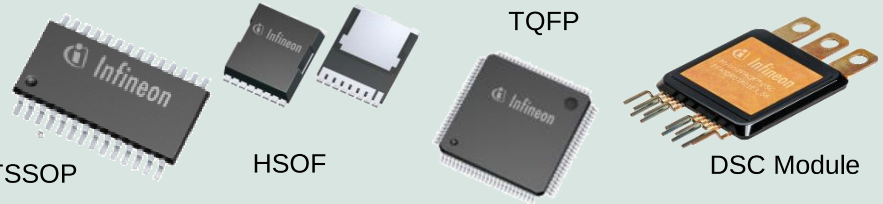
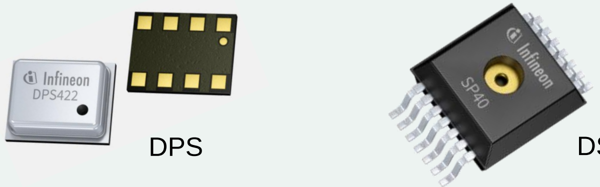
Automotive Package Future Adoption

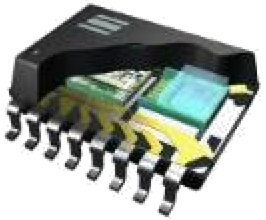
Application	Actual	Future
Power	 TQFP, TSSOP, HSOF, DSC Module	More System in Package (SiP) solutions including Embedded Die Technologies for performance reason, more Power Modules
MEMS & Sensors	 DPS, DSOSP	More System in Package (SiP) for dimension reduction and performance increase; sensor integration
Computing	 QFN, BGA	Flip Chip BGA for ADAS and infotainment for dimension reduction and performance increase; chiplets
Radar, mmWave	 eWLB, Flip Chip	More SiP (e. g. antenna integration), miniturization

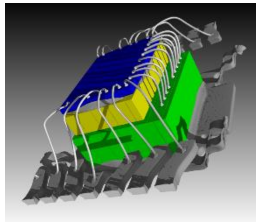
System in Package Integration Example: Tire pressure Sensor

TPMS – Conceivable Integration Roadmap towards SiP

Sensor package

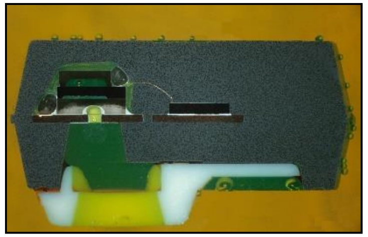
- Sensor chip
- Include acceleration
- **Driver ASIC**





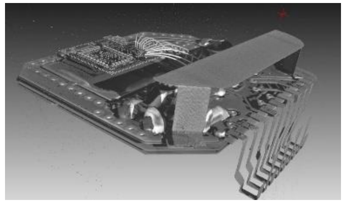
- Sensor chip
- Driver ASIC
- **Transceiver ASIC (incl. Matching)**
- **Resonator (Clock)**

- Sensor chip
- Driver ASIC
- Transceiver ASIC (incl. Matching)
- Resonator (Clock)
- **Tire ID**
- **Antenna**



- Sensor chip
- Driver ASIC
- Transceiver ASIC (incl. Matching)
- Resonator (Clock)
- Antenna
- **Power supply**

- Sensor chip
- Driver ASIC
- Transceiver ASIC (incl. Matching)
- Resonator (Clock)
- Antenna
- **Energy harvesting**

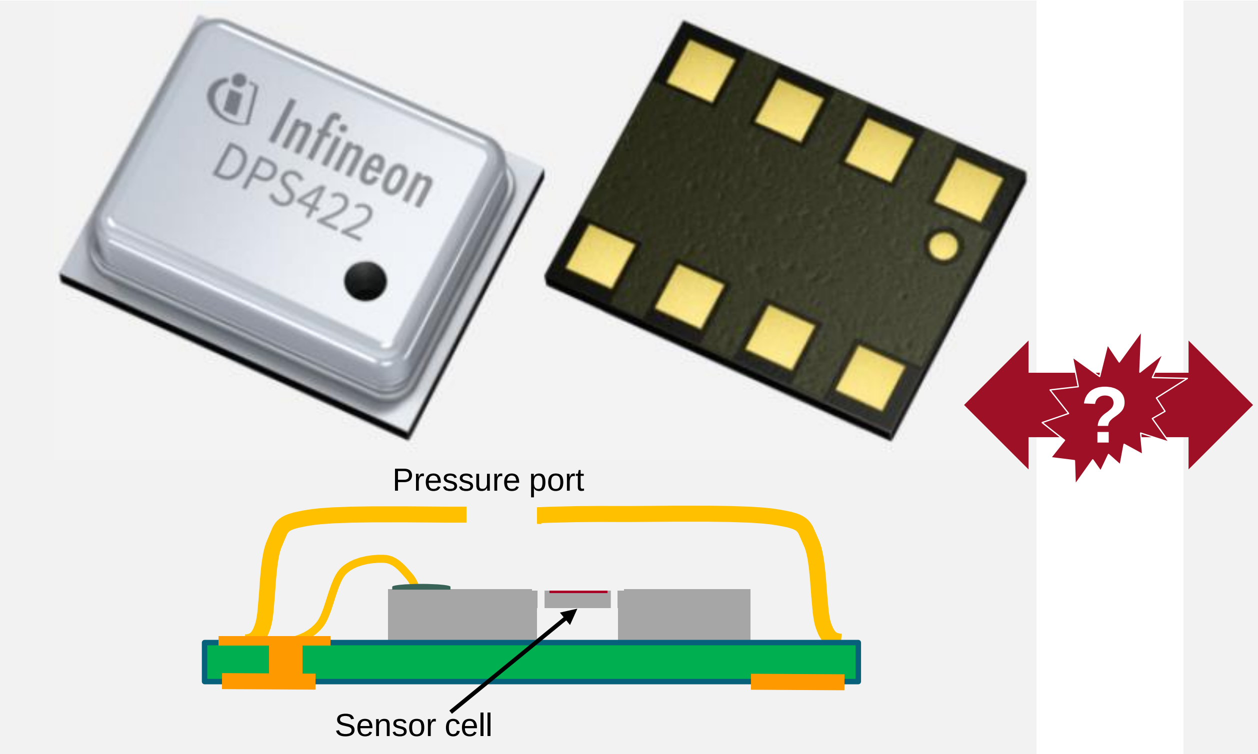


EC funded project eCubes

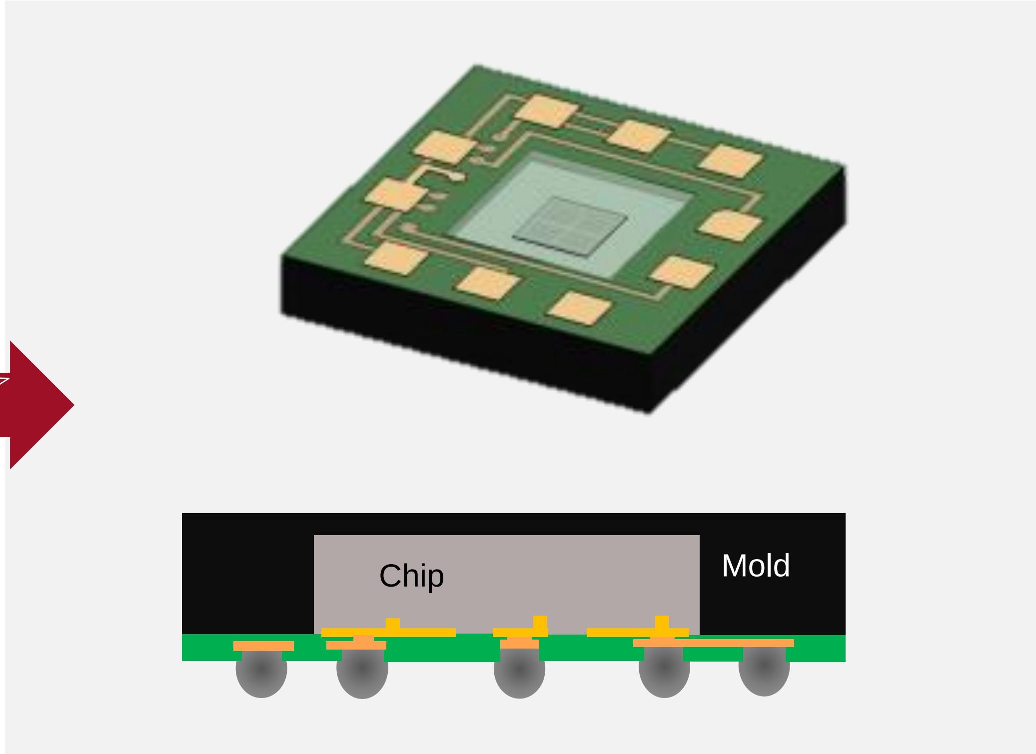
MEMS Pressure Sensor
Fan-Out Wafer Level Package

- Fan-Out WLB based MEMS Pressure Sensor
  - Integration capability
  - Cost down (small package)
- Development for consumer market first, transition to automotive

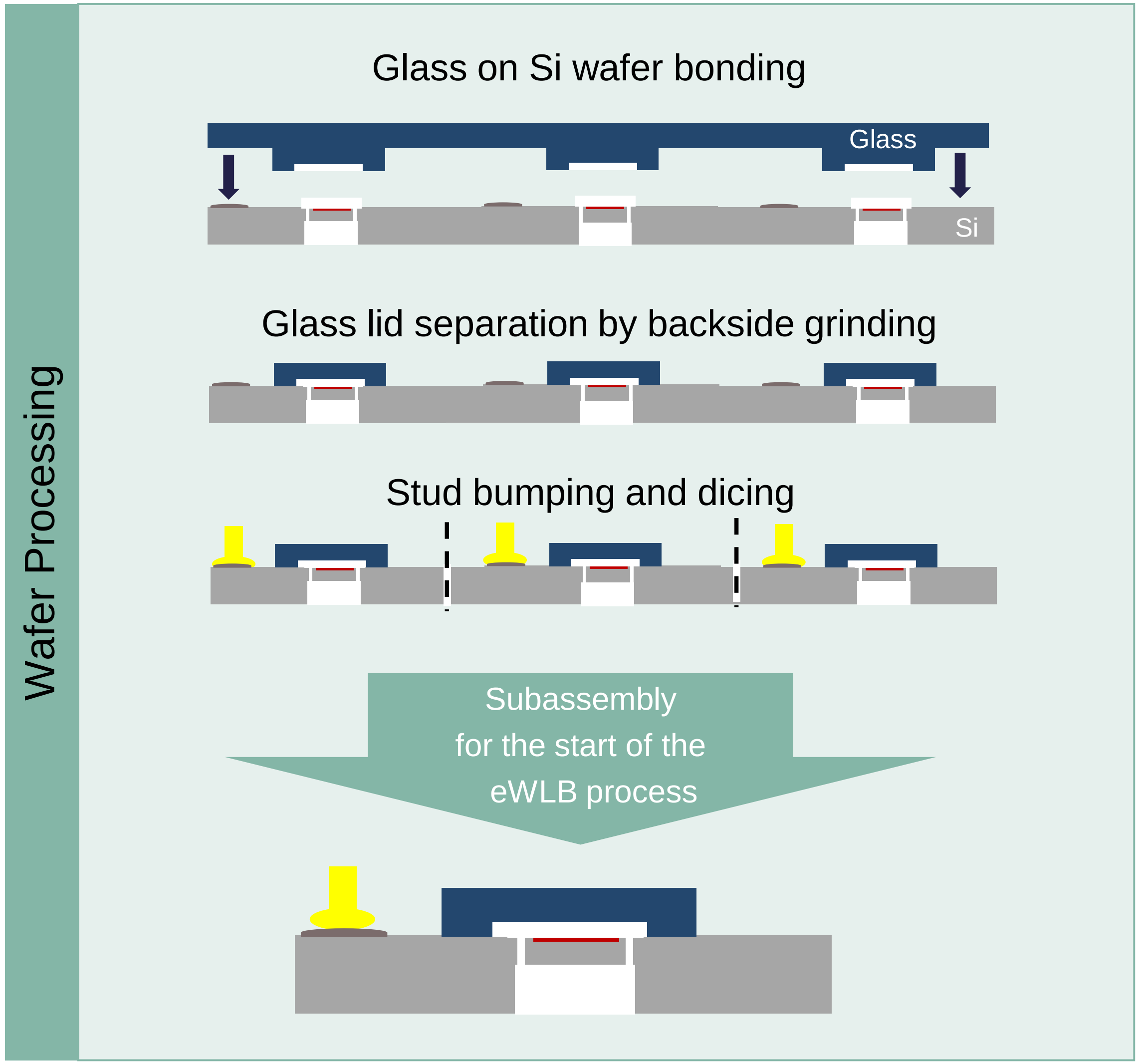
Today

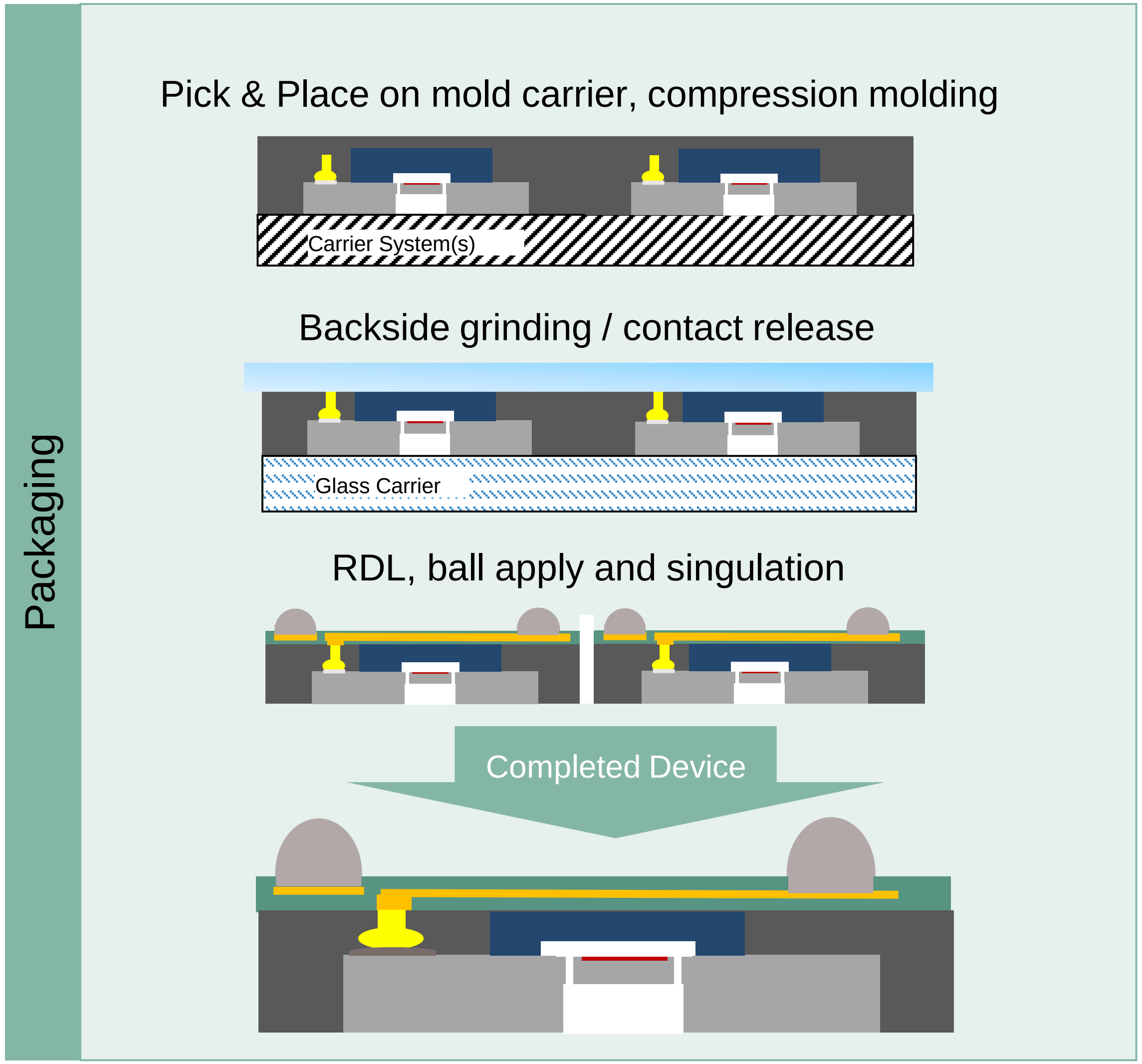


Tomorrow (potential)



MEMS Pressure Sensor in eWLB Process Flow

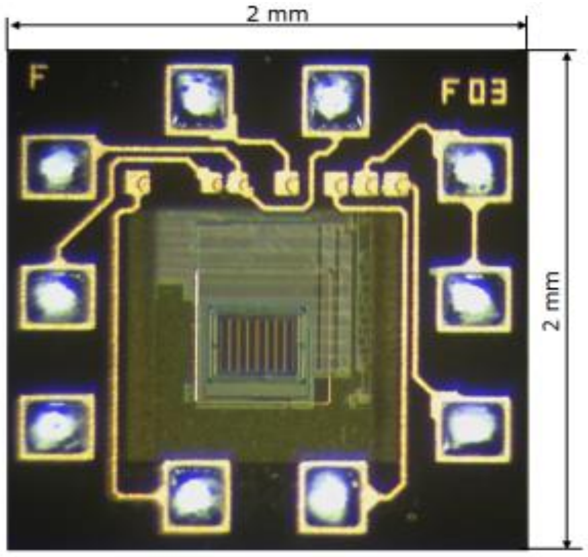


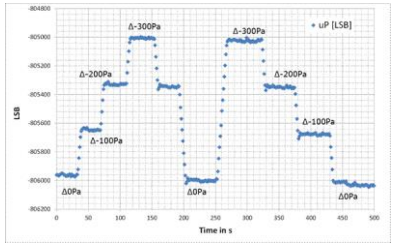


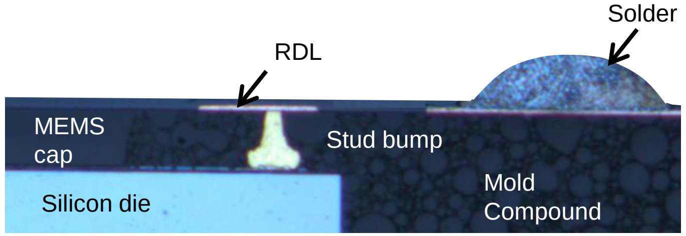
MEMS Pressure Sensor in eWLB
Stress Decoupling of MEMS

Infineon

Demonstrator



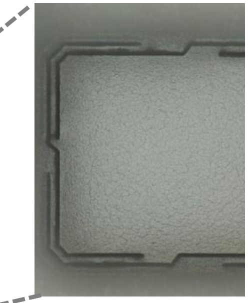


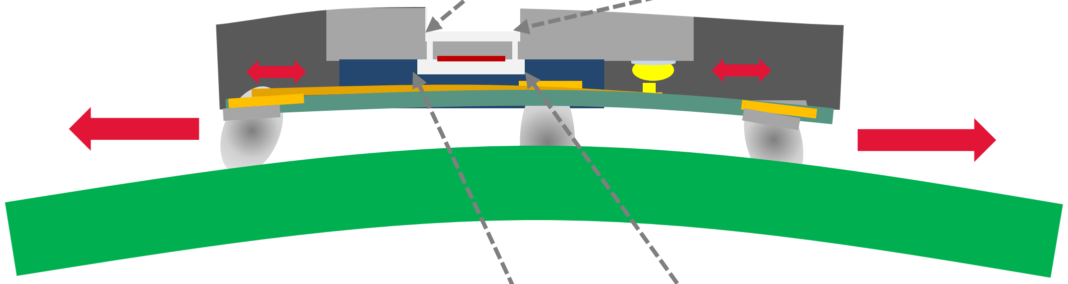


MEMS pressure sensor in eWLB

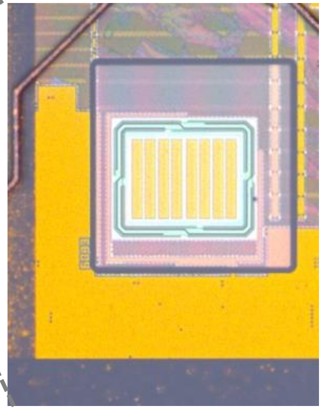
Development issue

- ❑ Stress Decoupling of MEMS
- ❑ Thermomechanical stress
  (CTEs: Si, moldcompound, board)





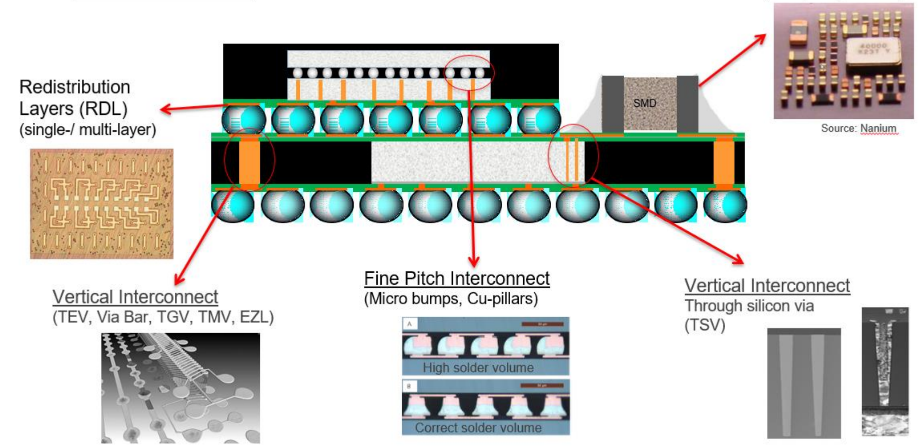
Introduction of stress decoupling structures („spring-suspensions“)



Decouple the MEMS structure from environmental mechanical stress impact

MEMS Pressure Sensor in eWLB
MEMS-specific Toolbox Features

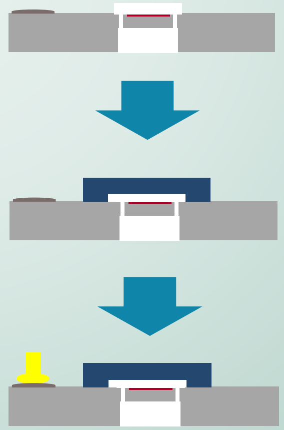
- Multiple functional elements in a visionary SiP example
- Provision of functional elements is crucial



MEMS-pressure sensor in Fan-Out eWLB

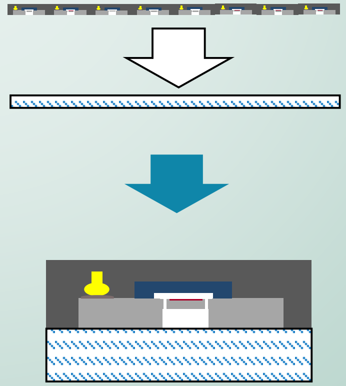
- Development of toolbox required
- Specific toolbox elements for MEMS
- Reliability also to be considered (consumer → automotive)

Capping & Stud Bump



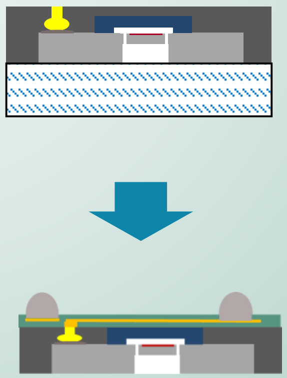
- Cap is a special building block for MEMS
- Stud bump used for pressure contact or Flip Chip

Temporary Carrier



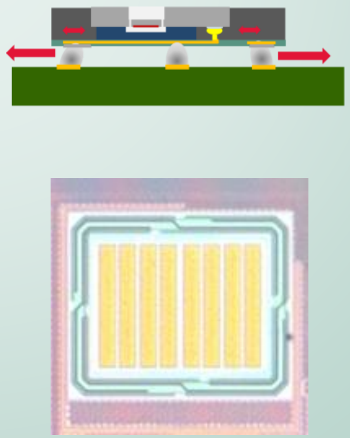
- Carrier systems for multi-material wafers with different CTEs

RDL over Stud bump



- Redistribution is a standard building block
- Contact on stud bump is a special requirement

Stress Decoupling

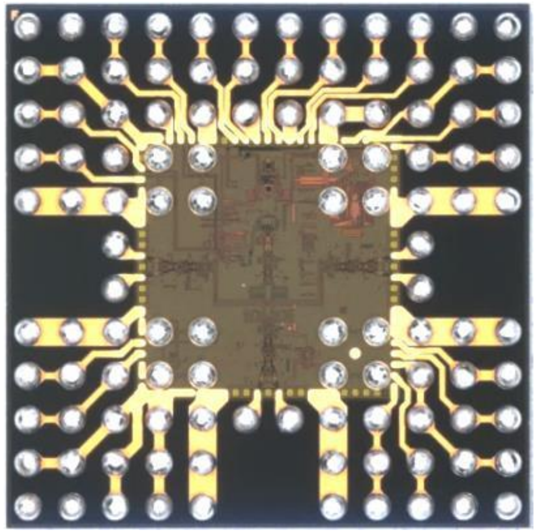


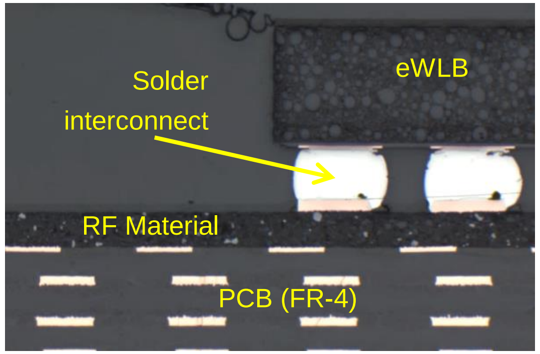
- Stress decoupling often is relevant for MEMS packaging

Other functional elements/ building blocks:

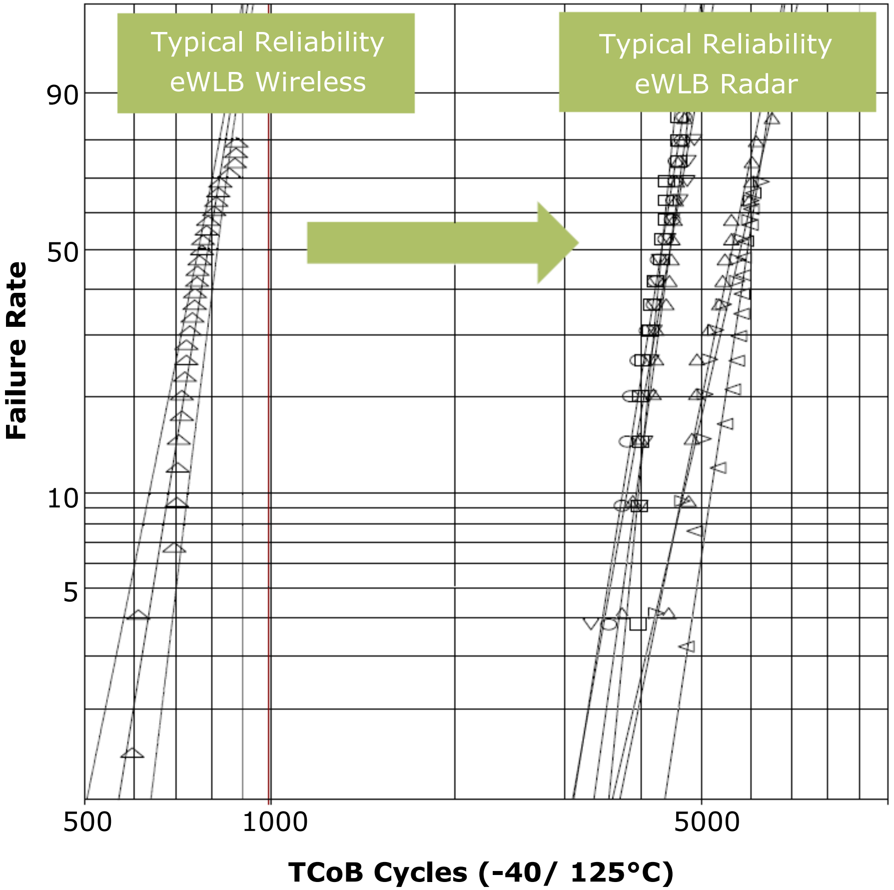
- Vertical interconnect
- Passives
- Shielding
- Antenna
- …

eWLB Radar
“Consumer Package” Serving the Automotive Market


eWLB Radar



eWLB Radar
Cross section on board



- TCoB performance increase for Automotive
- Redundant electrical connections concept

eWLB Radar Thermo-Mechanical Performance
Overview of Typical TCoB Characteristics

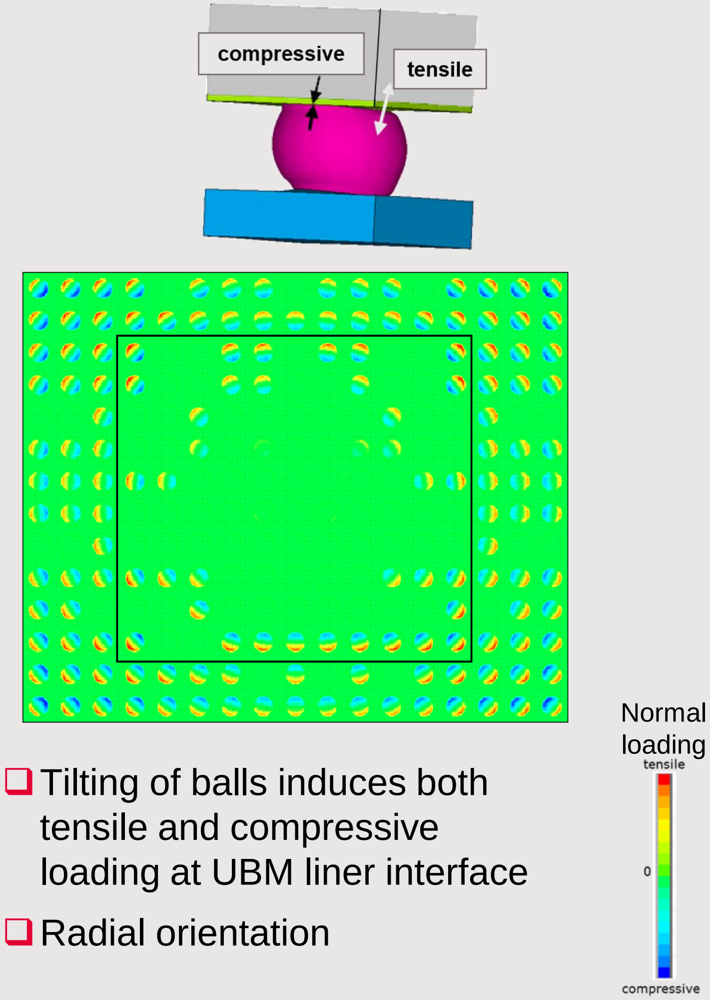
Low High

Measure	Thermo-mechanical performance (TCoB)									
Underfill/ corner glue					**Without**					With
Package size & redundancy		x1.0 no red.		x0.9 2-fold	**x1.0 2/3-fold**	x0.6 no red.	x1.1 3-fold		x0.6 3-fold	
Δ Temp		190K			**165K**				125K	
Ball size		x0.8			**x1.0**		x1.2			
UBM & ball alloy					**UBM & SAC**	Alloy ball				
Package thickness					**x1.0**	x0.5				
w/o UBM & ball alloy					**Alloy ball**					
w/o UBM		w/o UBM			**w/ UBM**					
Board housing		w/ housing			**free board**					
Solder mask design on board		SMD			**NSMD**					
RF board material	C	B			**A**					

- Different measures providing different reliability improvement potential

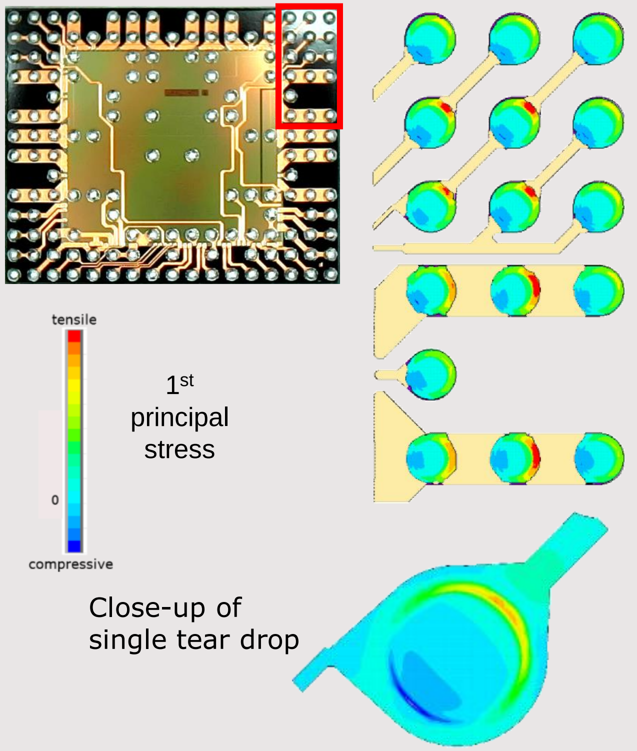
eWLB Radar Thermo-Mechanical Performance
Simulation of Fatigue Modes

UBM fatigue



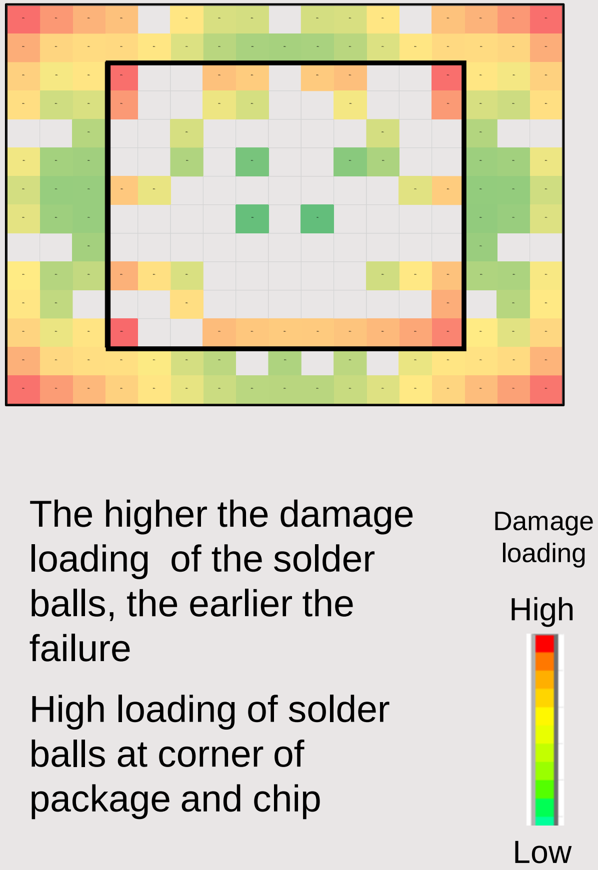
- Tilting of balls induces both tensile and compressive loading at UBM liner interface
- Radial orientation

RDL fatigue



- 1st principal stress in the RDL
- Higher stress for wider RDL connections
- Radial orientation

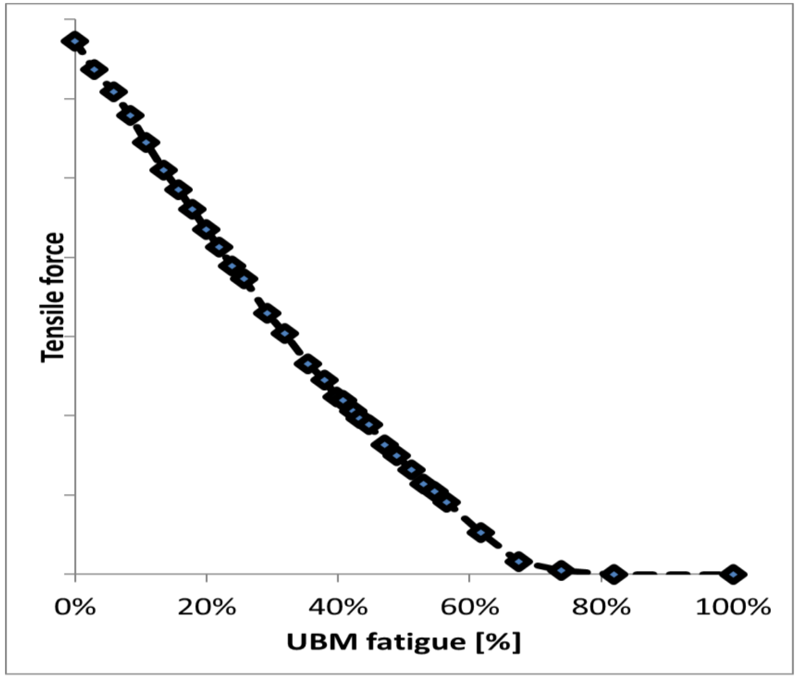
Solder joint fatigue

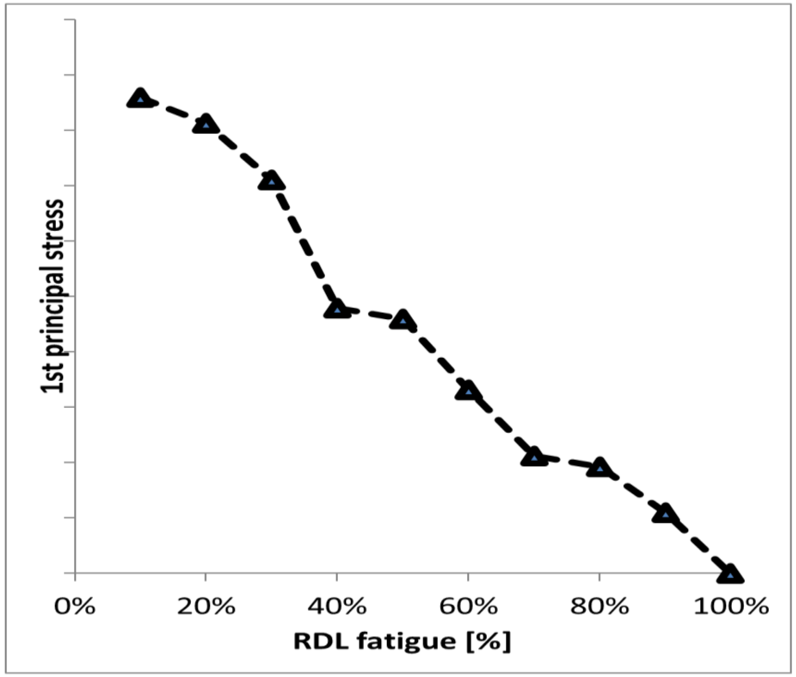


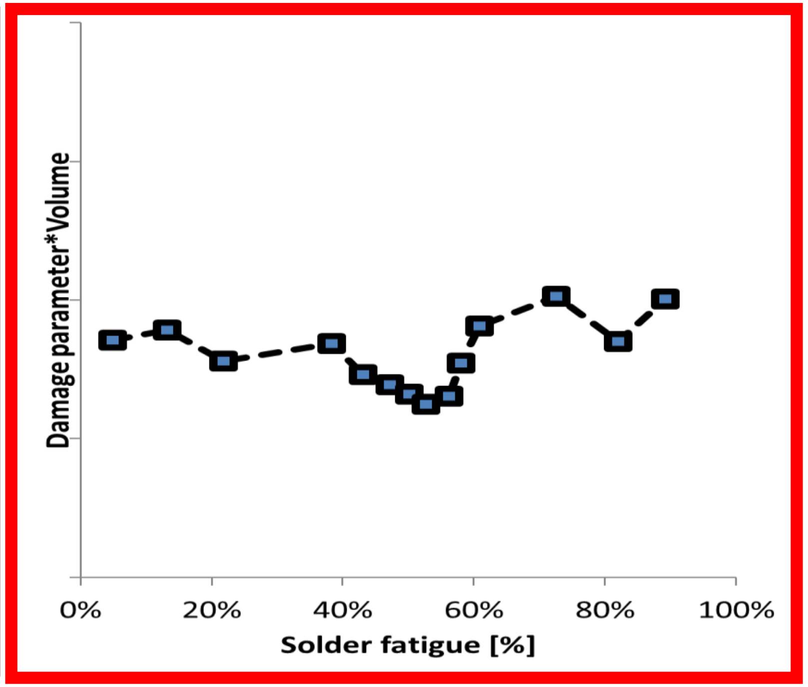
- The higher the damage loading of the solder balls, the earlier the failure
- High loading of solder balls at corner of package and chip

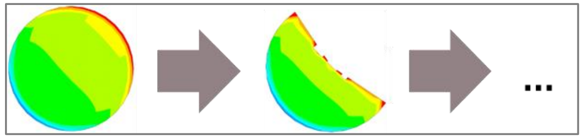
eWLB Radar Thermo-Mechanical Performance Simulation and End-of-Life Assessment

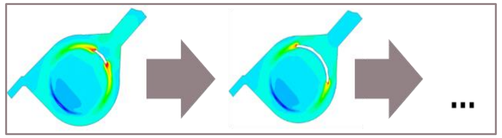
UBM fatigue	RDL fatigue	Solder joint fatigue

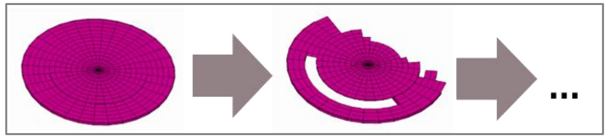








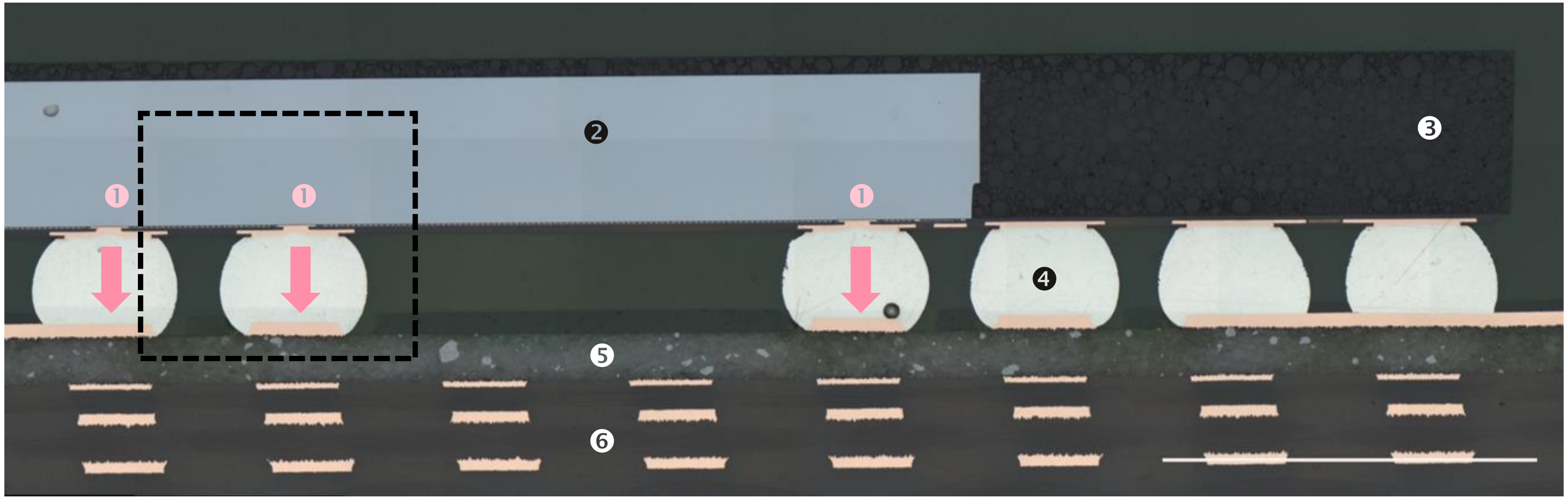




- Simulation of driving force for each fatigue mode with increasing level of fatigue:
  - ⇨ Only solder fatigue shows a driving force which does not reduce
  - ⇨ **Only solder fatigue will cause end-of-life**

“Consumer” Package for Automotive
Advanced Package eWLB

eWLB Radar cross-section



❶ Thermal ball
❷ Silicon
❸ Mold compound
❹ Solder balls
❺ RF-sheet
❻ FR4-layers

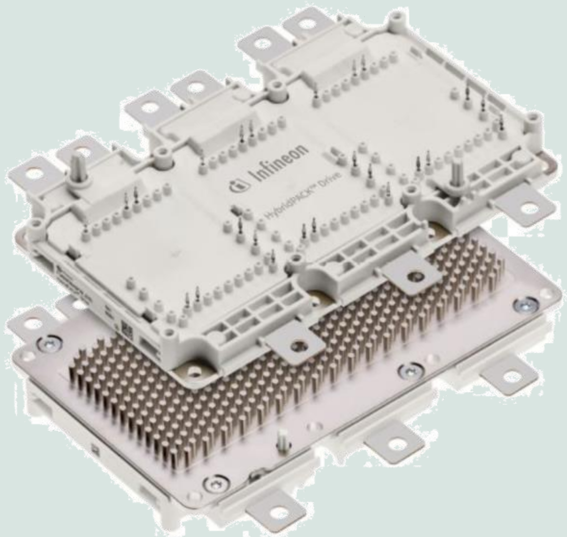
- ❑ Typical fatigue modes after TCoB are solder ball fatigue, UBM fatigue and RDL fatigue
- ❑ Solder fatigue has not reducing driving force and can cause end-of-life failure

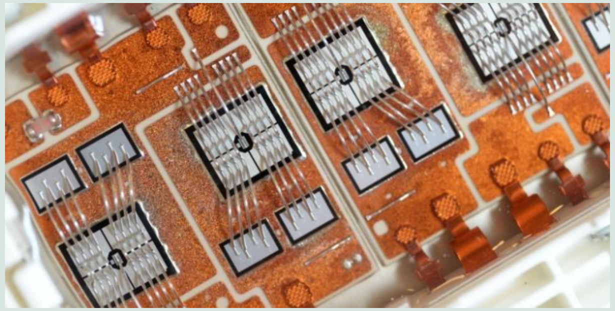
- ❑ Use of consumer packages for automotive requires adaptations in the package in order to achieve customer requirements (automotive quality & reliability)

Integration in Automotive Power Modules

HybridPACK™

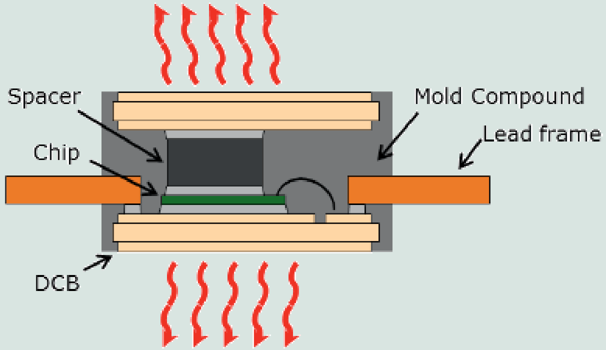
- Main inverter for eMobility, hybride Electric Vehicles and drives
- Drive module with IGBT and diode
- Automotive qualified
- Power module for Hybrid- and Electric Vehicle applications





HybridPACK™ DSC

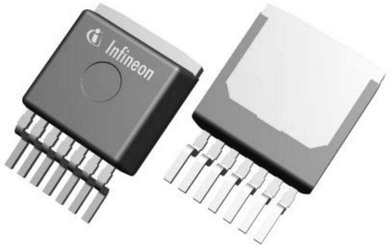
- Infineon’s new innovative solution for the main inverter of hybrid and electric vehicles (IGBT module)
- Application: Main inverter, onboard charger and auxiliaries
- Automotive qualified
- Increased power density due to double-sided cooling, higher-temperature operations and lower losses



Structure of HybridPACK™ DSC

Integration in Automotive NovalithIC™

- NovalithIC™ is an example for today's integration solutions in automotive
- Smart integrated half-bridge in a single package
- Classical leadframe based packages are used



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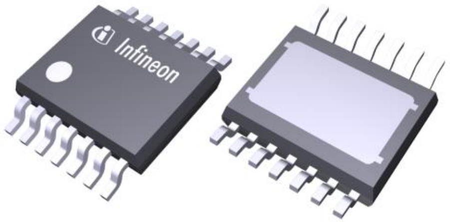
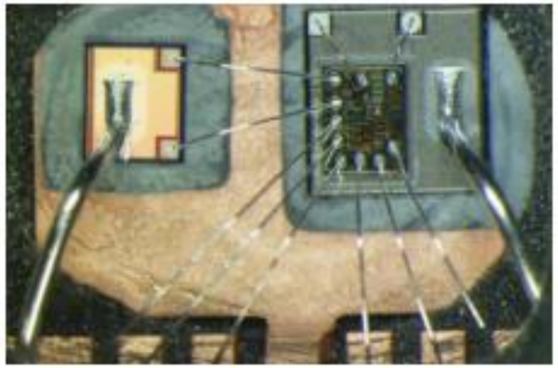


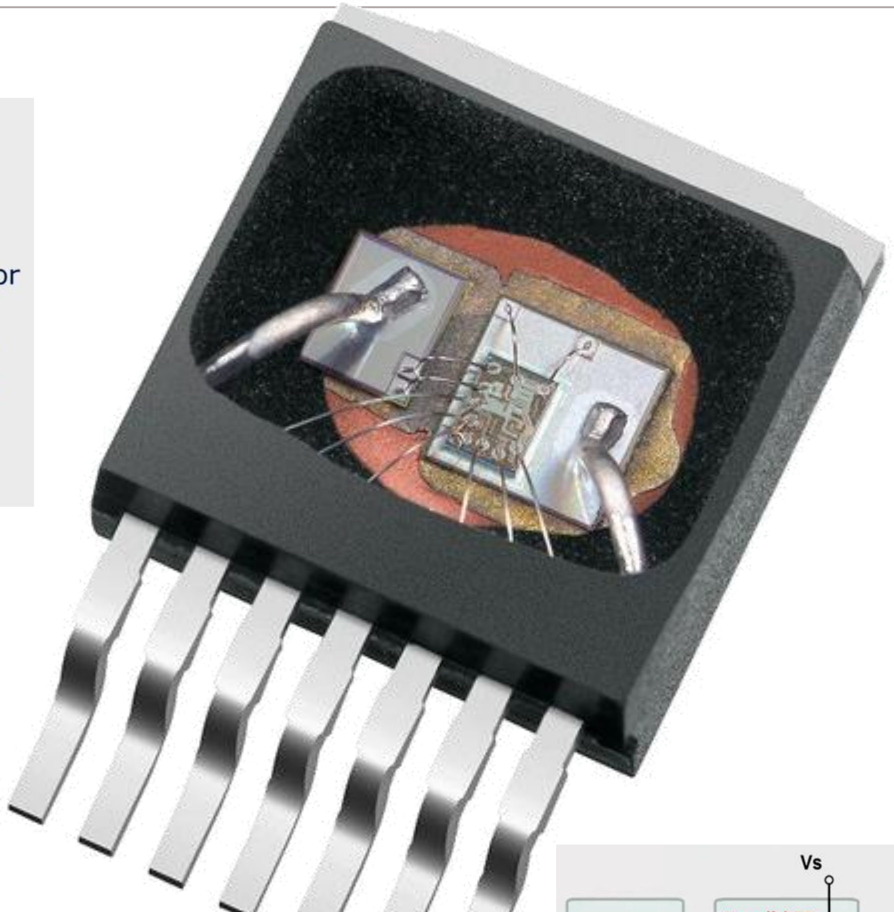
TSDSO

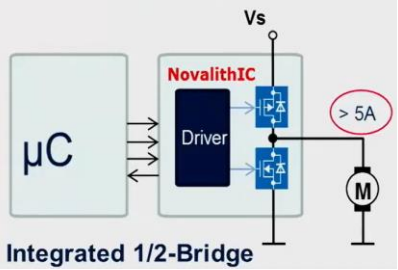
- Standard die attach methods
- Wire bonded (Al)
- Automotive qualified
- 2019: More than 500Mio components shipped



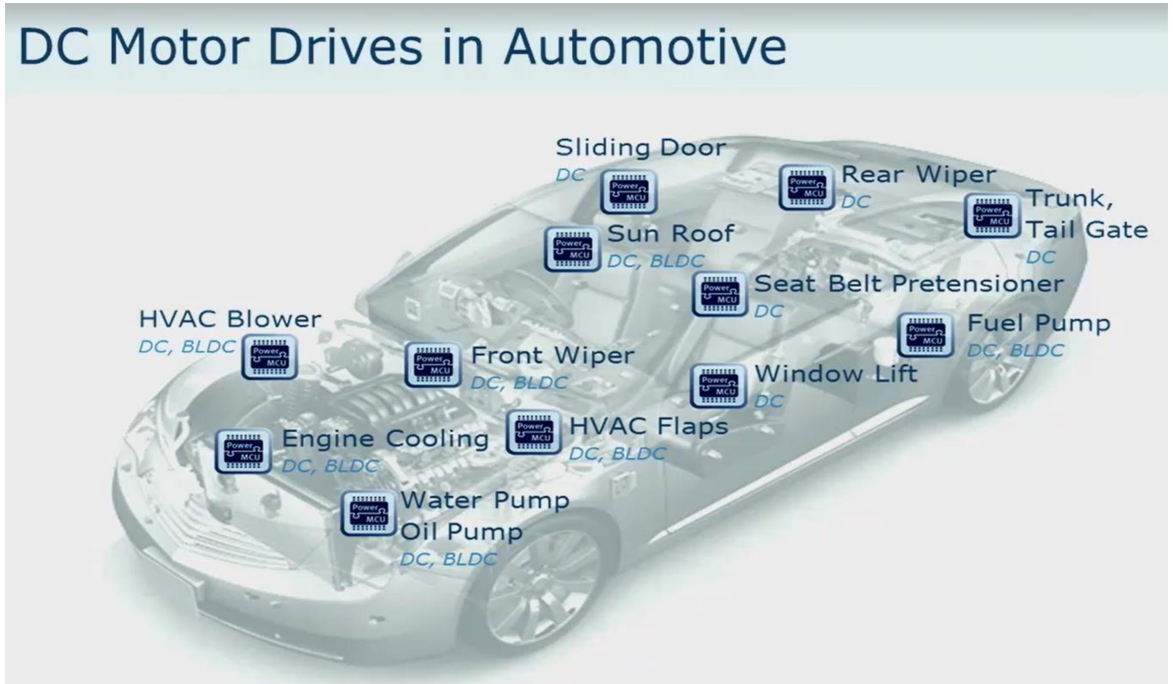
NovalithIC™

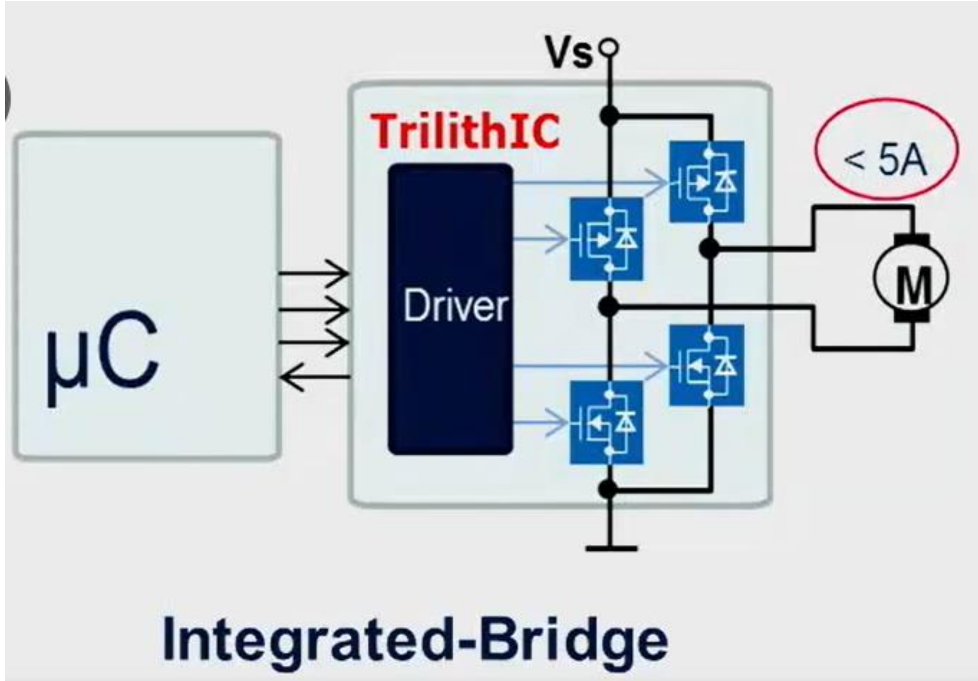
- Integrated Half Bridge
- **PWM capability**
- **Logic-Level Input**
- **Current limitation**
- **Adjustable slew rates** for optimized EMI
- **Current sense** capability
- **Over-temperature shut down**
- **Integrated Dead-Time** generation

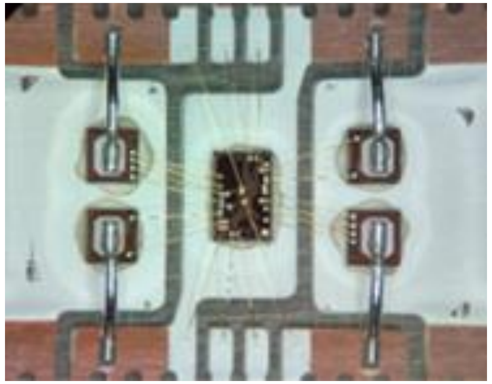




Integration in Automotive TrilithIC™







- Full bridges driver, automotive qualified
- Five dies in package for full bridge
- Classical DSO300 package
- For space saving, optimized diagnostic and protection (e. g. over-temperature (OT), over-current (OV) and short circuit (SC) protection included)

Integration in Automotive
Hetergeneous Integration Roadmap (HIR)

Based on

HETEROGENEOUS INTEGRATION ROADMAP

Quality and reliability at reasonable cost are main reasons for slow adoption of advanced packages including SiP solutions

Challenges from HIR Roadmap

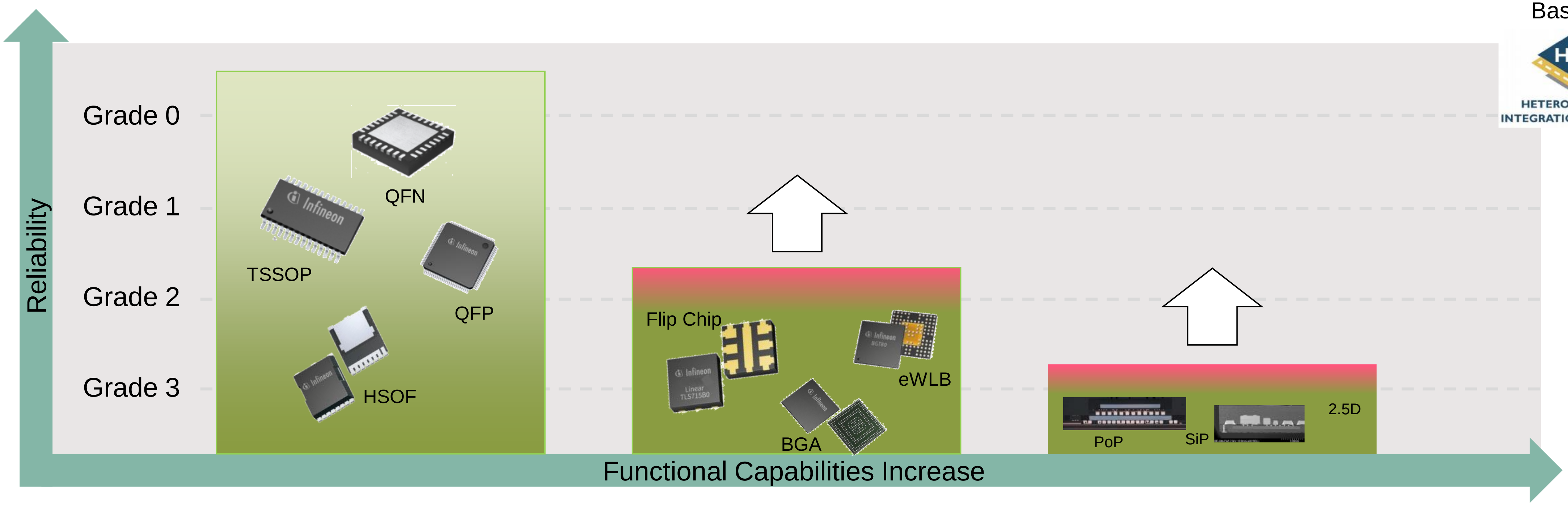
- New materials
  - Development and optimization of new materials will be needed in all of the areas in automotive IC packaging
- Infotainment/ADAS:
  - Processor/ memory integration
  - Thermal requirements, ambient conditions
  - Qualification requirement, especially safety for ADAS
- Sensors
  - Cost effective packaging
  - Performance requirements
- EV/ HEV segment
  - Component technologies in electric cars that include the inverter, battery charger and the battery
- Highly efficient power packaging

Content

Technical Challenges
Reliability and Quality

Based on

HIR HETEROGENEOUS INTEGRATION ROADMAP



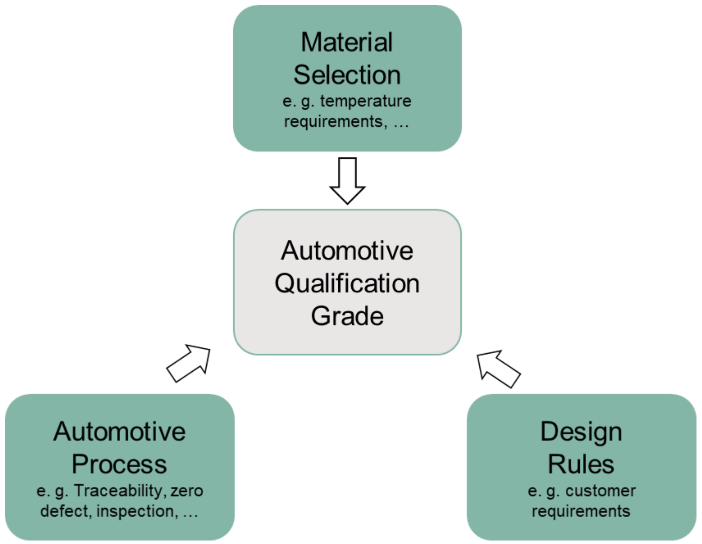
- Meeting high automotive reliability standards still is a gap for advanced packages and SiP
- Significant investments required for design optimization, suitable materials and package assembly & test processes
- Mission profile and real-use condition understanding required

- Understanding of design, materials and processes is a prerequisite to meet the high-temperature, harsh environment conditions and high usage-life requirements of the automotive industry

Technical Challenges
Reliability and Quality

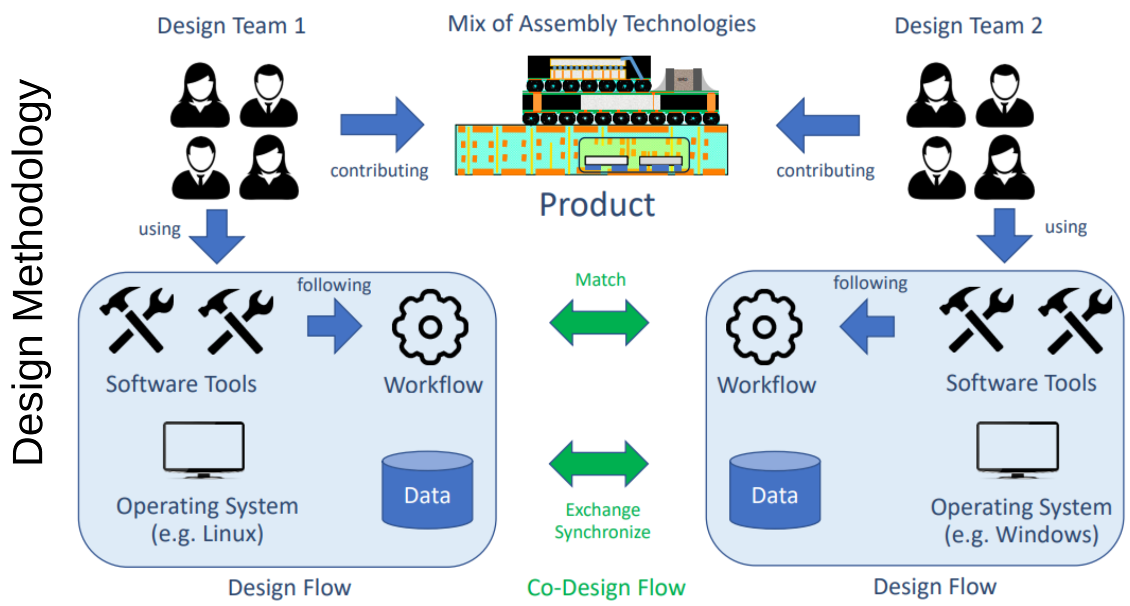
- Three main components to achieving Automotive Grade certification
    - materials selection
    - substrate and assembly design rules
    - robust manufacturing systems

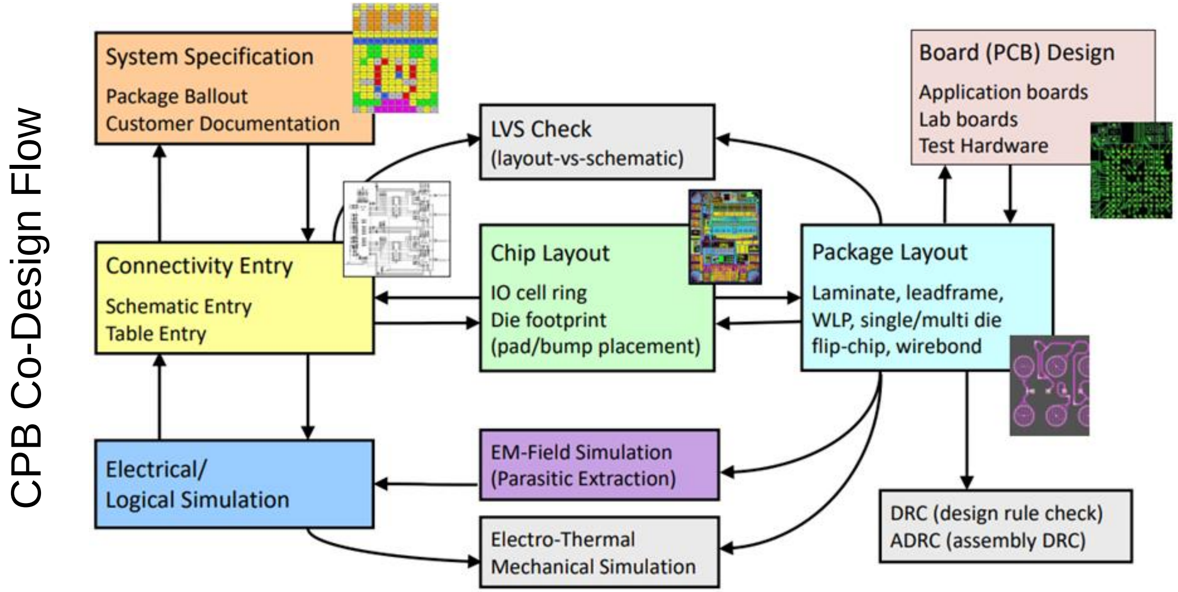
- Product quality means meeting customer expectations through
    - Development processes (e.g. RDDF)
    - Design rules (e.g. ADeGo)
    - Materials
    - Manufacturing processes and process controls
        - the full production chain must be automotive (stability, traceability and deviation
        - management, ...)
        - Failure mechanism based validation & mission profile based qualification
        - Screening, statistical methods and firewalls



- Automotive Grade standards IATF 16949, AEC-Q100 and AEC-Q200

Chip/ Package/ Board Co-Design Flow
Modular Design Environment





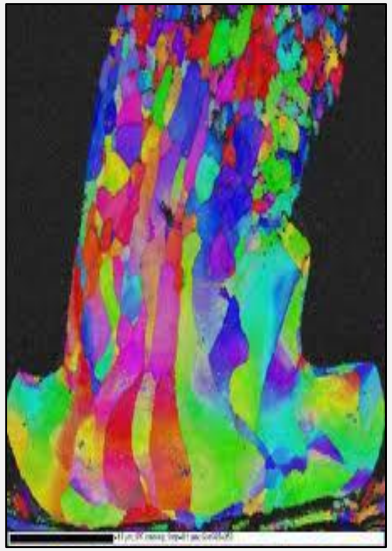
Design of Heterogeneous Integration Products requires …… a Modular Design Environment

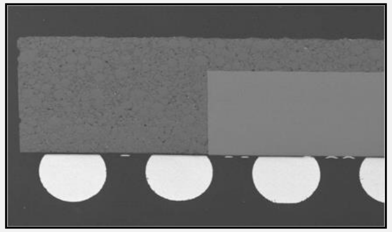
- ❑ Modularization in
  - Assembly Technology
  - Design Tools
  - Configuration (Assembly Design Kits –ADKs)
  - Data Exchange (standardized file formats)
  - Design Environments (Windows vs Linux/ Inter-company data exchange)
  - Work Flows

Package Materials
Continued Understanding

- Wire bonding
  Al and Au to Cu, Ag wiring (e.g. Pd coated), Clip, (TSC, DSC)
- Green, lead-free packaging
  (move from PbSn => SnAgCu (SAC) or other lead-free solutions, halogen-free mold-compound, …)
- Composite materials e.g. advanced mold compound (> 200°C)
  (liquid mold compounds, e.g. flip chip underfill, fine filler MC)
- Dielectrics e.g. isolation in film RDL or (C, L, transformers, …)
- Barrier layers e.g. diffusion barrier, ...
- Adhesives e.g. for die attach, …
- Sinter materials and nano-materials (Ag, Cu, …)
- New research: investigation of Cu composites
- Panel FO Technology
- …

In the next 10 years, package material change will continue
Understanding of materials is crucial…





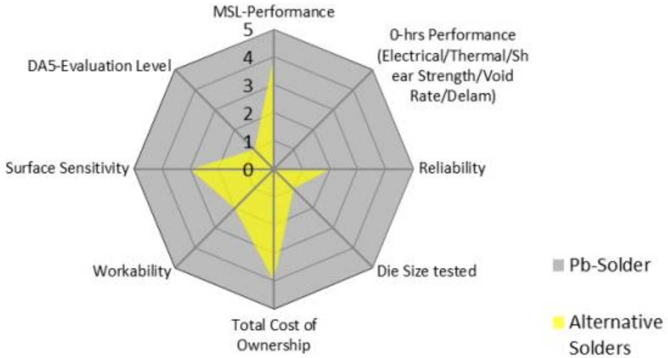
Based on ITRS Roadmap

Package Materials Example
Lead Solder Replacement

- Today's lead-free material technologies for semiconductor applications (die attach) are not ready to substitute Leaded High Melting Temperature Solders as drop-in solution
- Substantial development efforts have been running for more than 11 years; 145 materials from more than 13 suppliers evaluated
- Close to 50 of those materials were selected for extensive testing by DA5 member companies
- None of the materials proved valuable as a general Pb-replacement solution
- Material evaluations continue in close cooperation with material suppliers

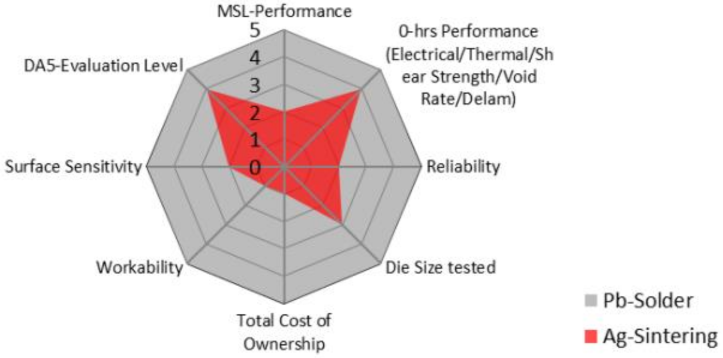
- Impact on reliability is already clearly visible in the spider diagrams

Alternative Solders vs. Pb-solder



(rating: 0 unknown, 1 very poor, 2 poor, 3 fair, 4 good, 5 very good: as good as Pb-solder)

Ag Sintering vs. Pb-solder



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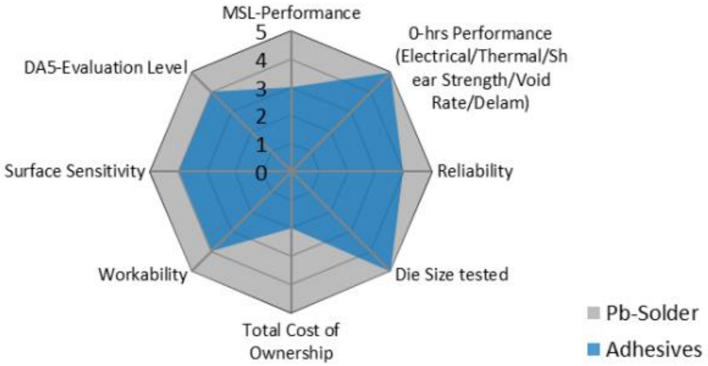
Adhesives vs. Pb-solder



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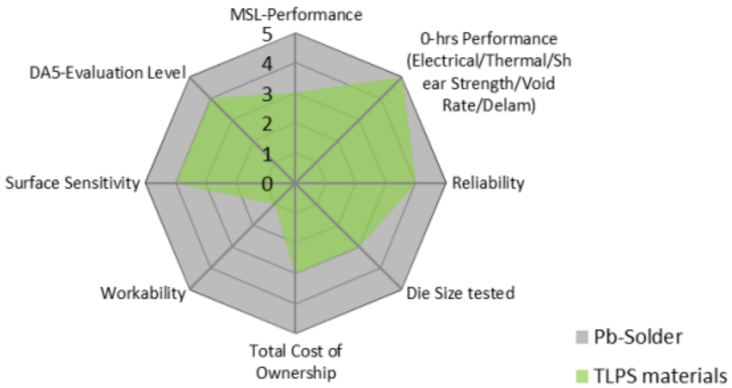
TLPS materials vs. Pb-solder



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Content

1. Automotive Package Platforms
2. Automotive Quality and Reliability
3. Advanced Packages
    - Trends
    - Example: Tire Pressure Sensor – Fan-Out WLB
    - Example: Modules & Integration
4. Gaps
    - Reliability & Quality
    - Co-Design
    - Material
5. **Summary**

Summary

- Automotive arena provides a huge growth opportunity, and it is already happening…
- Automotive requirements are specific and will need adjustments for developing and enabling effective package solutions
- Recent megatrends in the automotive industry lead to significantly extended lifetime requirements for vehicle electronics
- Advanced packages in Automotive with a niche existence, but increasing
- System Integration still is restricted to classical packages, more to come in future
- Packaging technology will make the difference

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