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SiP in Advanced Automotive Packaging

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Outline

- Automotive market drivers
- Automotive requirements
- Enabling package technologies
  - Package roadmap
  - Advanced high performance packages
  - 5G Aip/ ADAS packages
- Automotive package reliability requirements
- Summary

Automotive Then and Now

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Worlds first car

The **Benz Patent-Motorwagen**, built in 1885, is widely regarded as the world's first production that is, a vehicle designed to be propelled by an internal combustion engine. The original cost of the vehicle in 1885 was approximately 150 US dollars, 1L engine, 2/3 HP. Zero electronics.

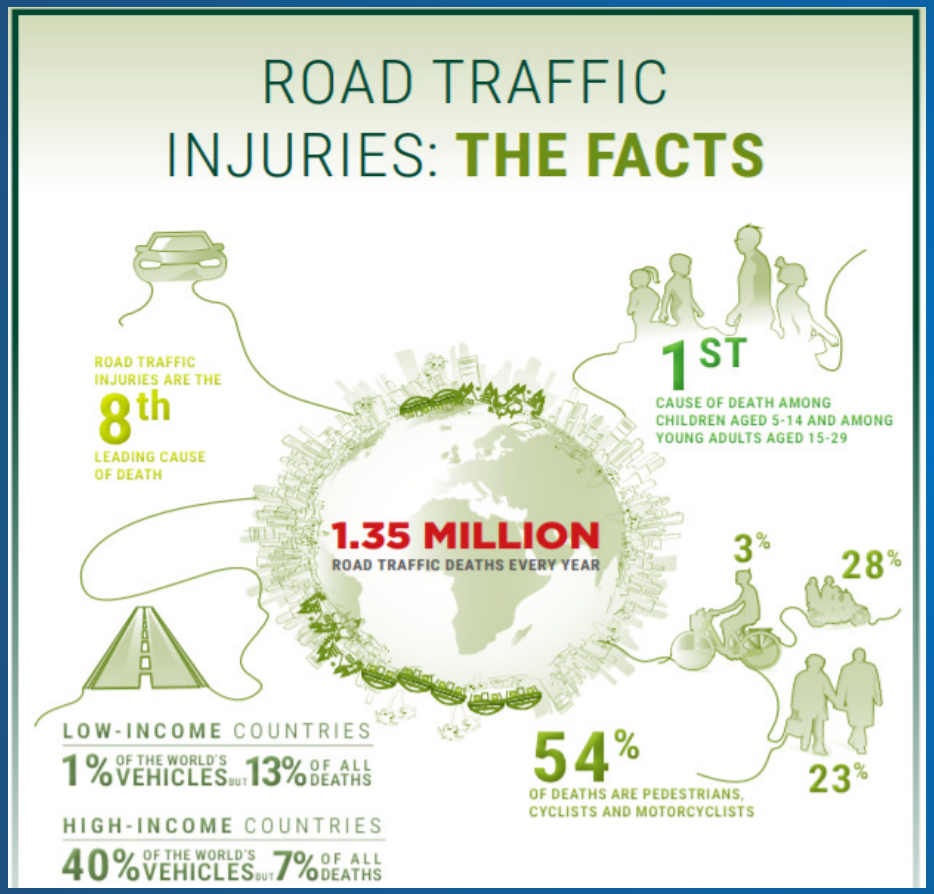
Modern Autonomous car (level 4)

Typical price at least $100,000. 300 HP, Electronic contents ~40% of car price

Key Drivers for Modern Cars

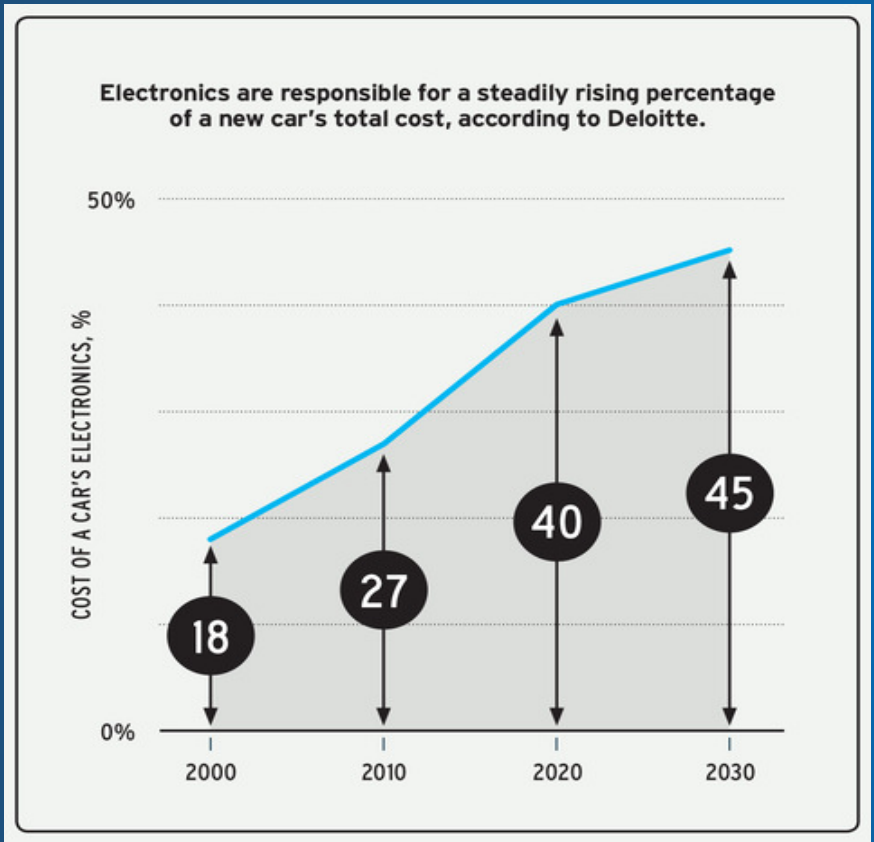
1. Electrification (energy conservation, efficient mileage, less pollution)
2. Autonomous car (self driving, less human error)
3. Safety (less accident, less damage)
4. User interactivity (GPS, Media, V2V,,)
5. Comfort (no noise, less stressful journey,,)

Safety Concern

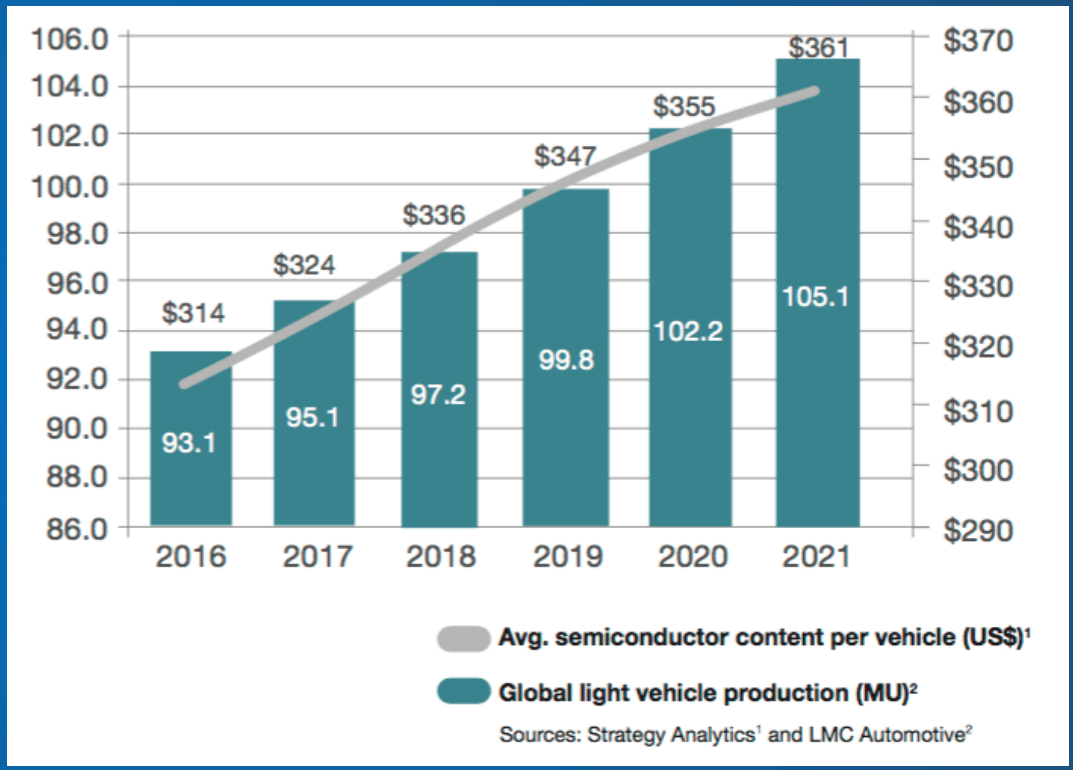


Courtesy: https://www.asirt.org/safe-travel/road-safety-facts/

Electronics Contents in the Car



https://www.caranddriver.com/features/a32034437/computer-chips-in-cars/



Automotive Semiconductor Market

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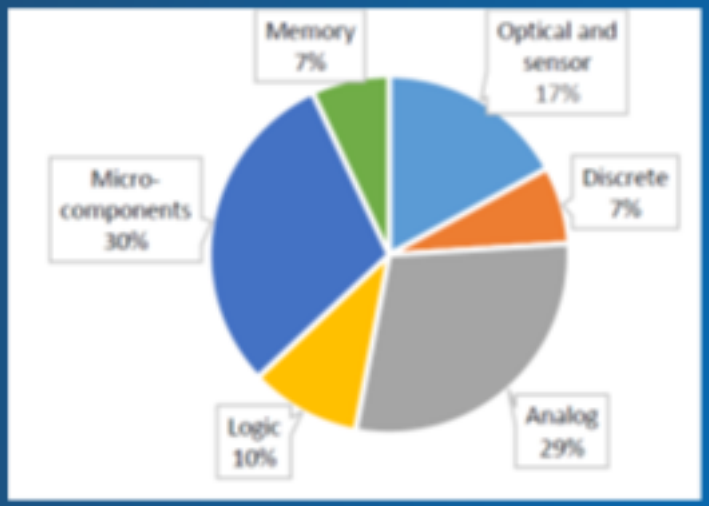

2020 automotive semiconductor device segment (USITC)

Device Type	US Firm(s)
Analog	Texas Instruments; ON Semiconductor; Maxim
Discrete	Vishay Intertechnology, ON Semiconductor
Logic	Marvell; Texas Instruments; Qualcomm
Memory	Micron; Western Digital
Micro-components	Microchip/Microsemi
Optical and Sensor	ON Semiconductor; Vishay Intertechnology

US automotive semiconductor firms (USITC)

Semiconductor Feature	Consumer Electronics	Automobile Electronics
Process Technology	28 → 7 nanometers	180 → 7 nanometers
Temperature Range	32 – 100 Degrees Fahrenheit	-40 – 300 Degrees Fahrenheit
Operating Lifetime	3 – 5 Years	15 Years
Tolerated Failure Rate	<1,000 parts per million	Zero parts per billion
Long Term Supply Needed?	No	Yes, up to 30 years' worth

Courtesy: USITC

Automotive Market Size by Segment

- Global car sales CAGR ~3% per year
- Electronic content is about to double by 2025
- More features in the car
- Autonomous driving car

Automotive Segment	2017	2022	CAGR
ADAS	$3.6B	$9.2B	19.0%
Body & Convenience	6.9	9.1	5.4%
Chassis & Safety	6.1	6.9	2.5%
Infotainment	6.6	8.7	5.1%
Powertrain	8.9	12.5	6.4%
Others	3.6	4.6	4.8%
Total	**$35.8B**	**$50.9B**	**6.9%**

Source: IHS

Product Lifecycle Smartphone vs Car

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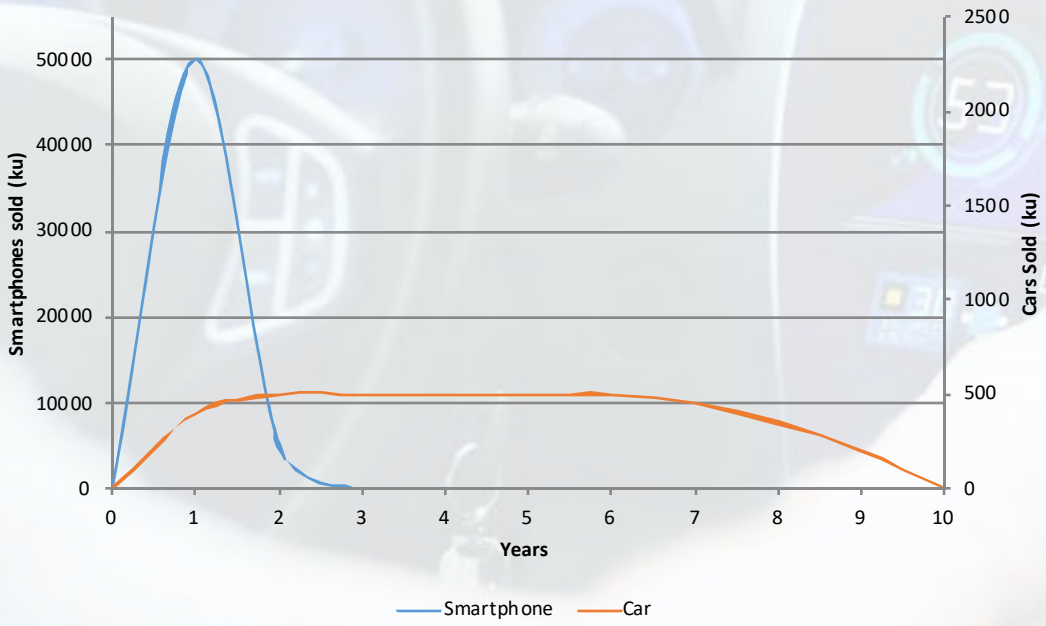


Life >10 years

Requires Robust Devices & Systems

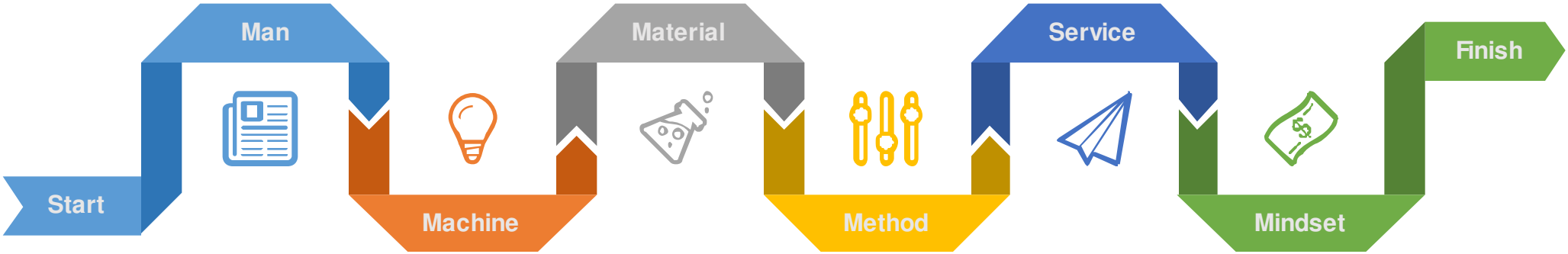
High Quality << 1ppm

Automotive Process and Quality Control

- Min.6 Months Working Experience
- Automotive Training & Certification
- Badge & MES Register Control
- Special Initiatives

- IATF 16949 Certified Supplier List
- Supplier Quarterly Assessment
- No Life Time Extension
- No Rework

- In-house Reliability Lab
- In-house FA Lab
- 24H Response
- Top Management Involvement



- Specific Certificated Procedure
- Designated Machines
- CMK>1.67
- Automation Level Requirement

- VDA6.3 Process Audit
- AEC-Q100 compliance
- APQP, MSA, SPC, FMEA, PPAP
- Change Management
- Tighten pprocess ccontrol, No skip lot
- Record Retention – 15+ Years

- Automotive Committee Organization
- Zero Defect Mindset Training
- Continuous Improvement program

Automotive Reliability Grade Level Mapping

In the past automotive ICs used mostly mature package technologies

Current trend is to use more advanced packaging and advances Si nodes to enable advances such as autonomous driving

Grade	Field Temperature Range	Segment Guide Line
0	-40C to +150C	Powertrain if close or at engine
1	-40C to +125C	Under the hood or other depending on criticality
2	-40C to +105C	ADAS, Chassis & Safety, Powertrain
3	-40C to +85C	ADAS, Infotainment, Body electronics

JCET Automotive Engagements

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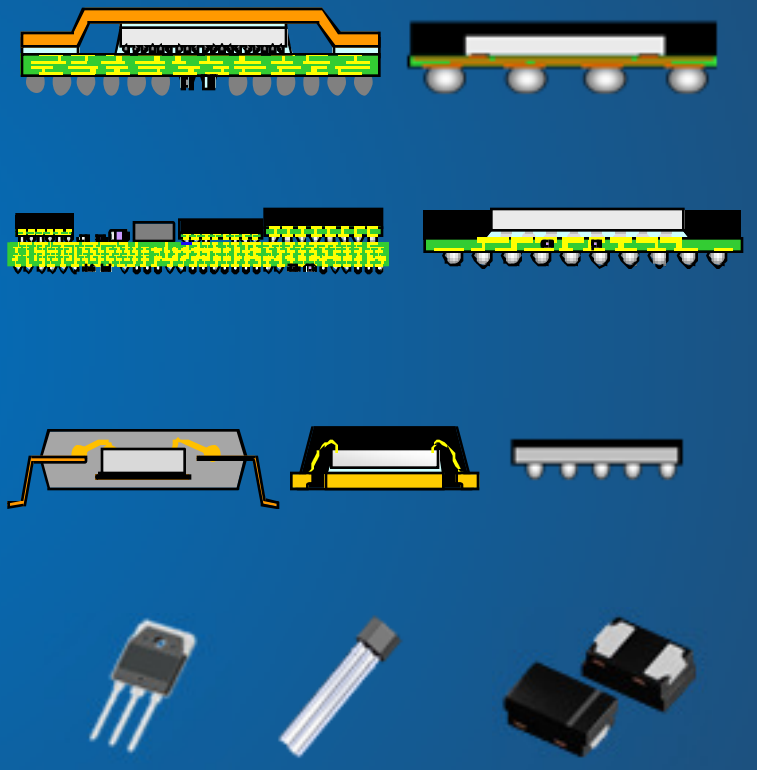
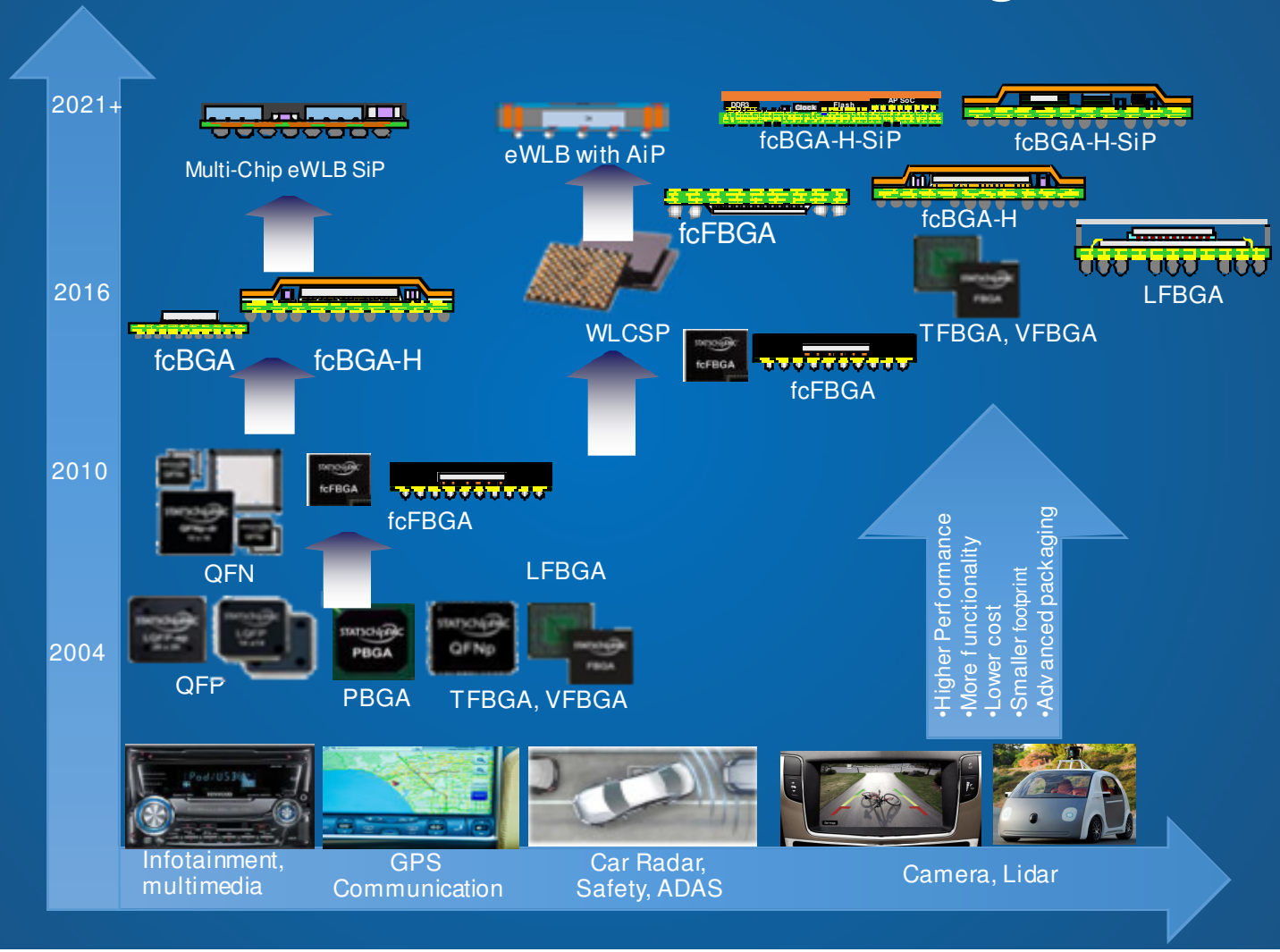


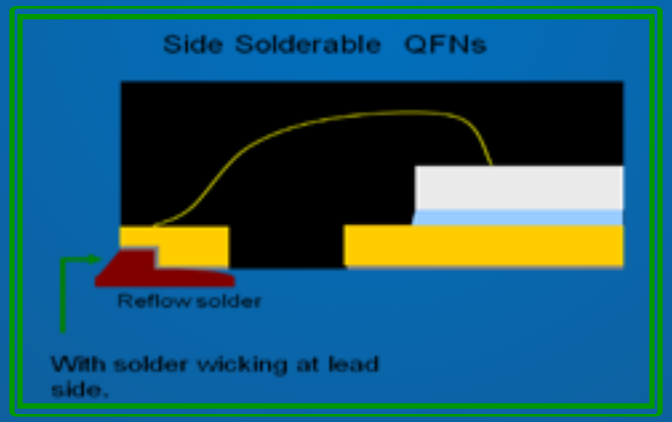
Typical Automotive Semiconductor Package Roadmap

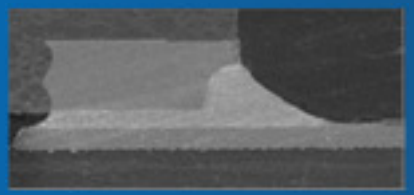


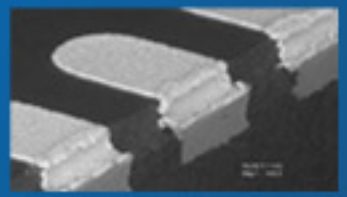
QFN-SS for automotive (Grade 2)

Infotainment and Body System

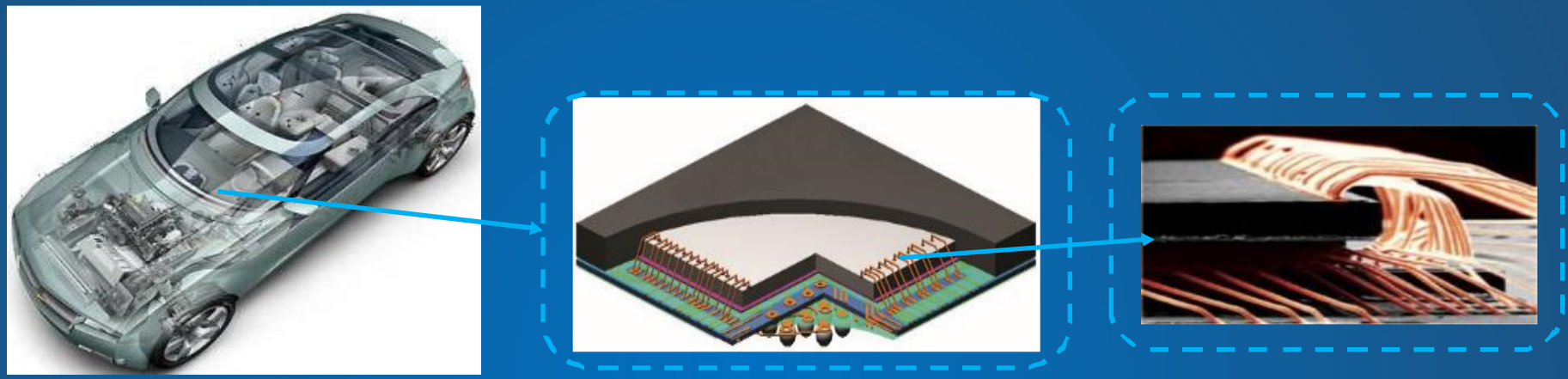
- Side Solderable QFN equivalent to wettable flank QFN
- Special Process Flow and Leadframe Design creates step-cut on package side wall with Sn plated on side of the leads
- Solder is able to wick to the side of the leads to create fillets that enhance Solder Joint Reliability
- Allows easy inspection of solder fillet from external leads
- Easily Meet Automotive device requirements







Cu Wire for Automotive (AEC Q006)



- Cu wire being used widely in non-automotive market for long time
- Cu wire adopted for automotive at least 5 years ago
- Very robust reliability data
- Typical Cu wire available packages : Discrete, Power PKGS, QFN, QFP, MQFP, TQFP, LQFP, PBGA, FBGA, etc. (with and without stacked die)

Flip Chip for Automotive Applications

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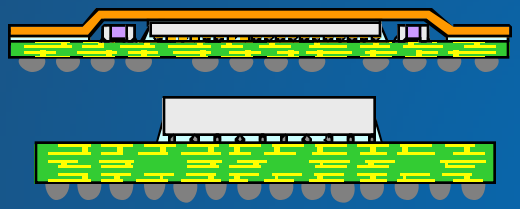
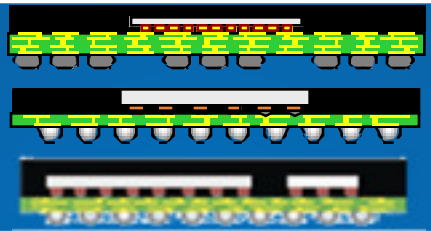
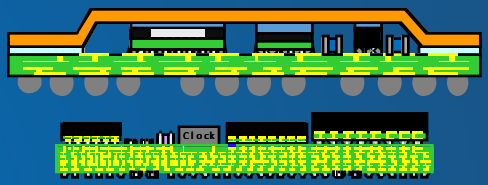
fcBGA/-H	fcCSP	SiP
		
fcBGA/-H package type for high pin count applications such as processors	fcCSP also been used for some radar and telematics applications	System in package for next gen ADAS, Autonomous car, etc.

Due to the increasing complexities and higher performance, higher power, and lower cost requirements of automotive applications, the packaging industry is moving towards high performance packages such as flip chip or wafer level fan-out packaging to SiP for automotive ADAS, Infotainment, Automotive network/connectivity, Autonomous driving, etc.

Automotive fcBGA-SiP Module (Grade 2)

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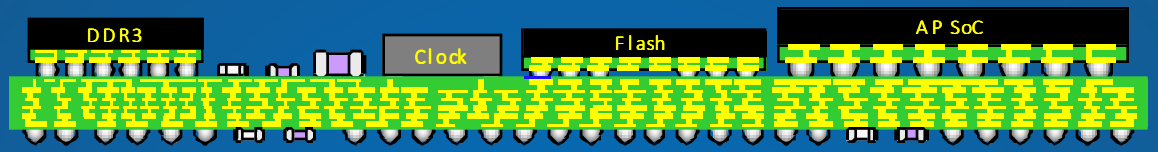
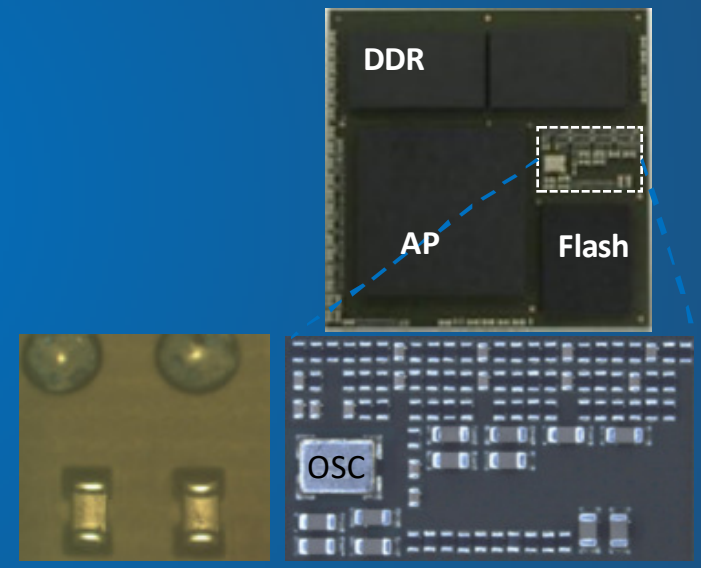


Target Application	Automotive SiP Module for ADAS
Package Configuration	SiP Module w/ Singulated BGA / UF
Active Components	AP, DDR, Flash, Oscillator, etc.
Passives	0402/0201; XXX pieces
Substrate	6-Layers
Ball Pitch/Solder Composition	1.0mm / SAC305
Reliability Test Conditions (AEC Q100)	uHAST (130C/85%) – 96 Hours TCB (-55C to +125C) – 1000X HTST (+150C) – 1000 Hours



Passives on BGA Side

Passives on Die Side

Automotive fcBGA-SiP Module (Grade 2)

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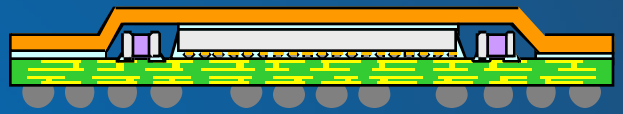
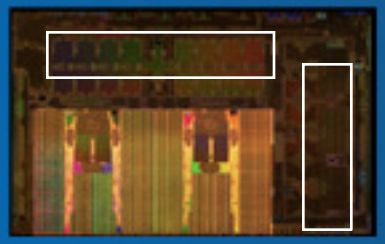
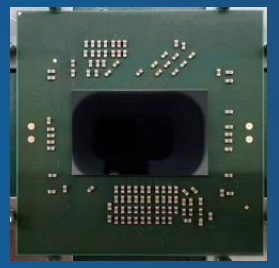
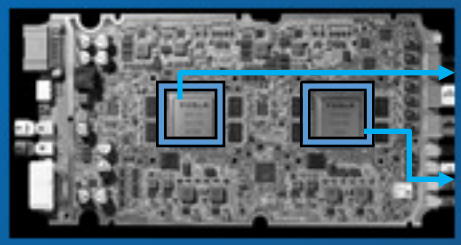
Package	*PKG Type*	**fcBGA-H**
	Body size	37.5 x 37.5mm
	Solder ball pitch/dia.	0.8mm / 0.5mm
	Total height	Max 3mm
Die	*Die size / Thickness*	260 mm^2 / 780umT
	Bump Type	LF Solder bump
	Bump Pitch	Min 140um
	Bump Height	70um
Substrate	*Substrate Layer/Thickness*	8L / 1.2mm
	Pad Finish : Bump Pad / BGA pad	SAC305 on ENEPIG / ENEPIG

AEC Q100 Grade 2, High power device (90W)



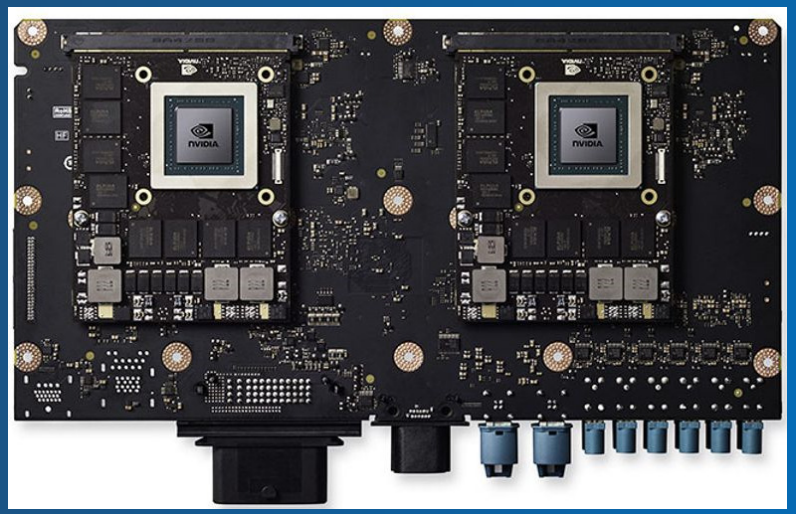




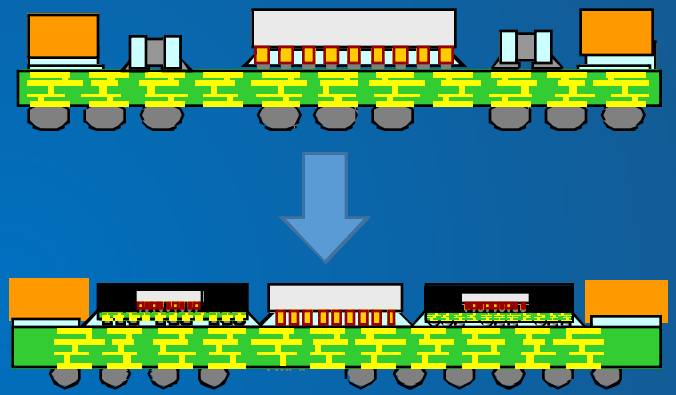


Source : THE VERGE

High End Processor for Autonomous Car



A GPU processor based hardware platform for autonomous driving (courtesy: nvidia)



Package level integration

AEC-Q100 G1 Validation for fcBGA-H

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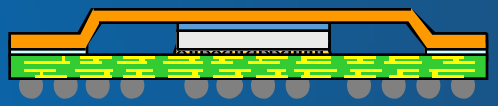
AEC-Q100 G1 validation for fcBGA-H and got promising results with passing TCC 3,000x, HTS 2000hrs and uHAST 192hrs which is comparable to AEC-Q100 G1/G0

Descriptions		Description
Package	Package size	530 mm^2
	Package Total Thickness	Max. 2.3mm (w/ HS)
	Ball pitch / size / solder ball composition	0.8 mm / 0.5mm / SAC305
Die	Wafer Node	28nm
	Die size / Thickness	70 mm^2 / 350um T mm
	Bump Height (um):	65(Cu 40+SnAg 25)
	Bump Pitch / UBM Size (um)	135 / 45x65
Substrate	Layers (stack-up) / Thickness	4L (1-2-1) / 0.572mm T (400um Core)
	Bump Pad & BGA pad metal finish	CuOSP

fcBGA-H



fcBGA

Leg	Package	UF	S/S	MSL3	uHAST		TC 'C' (-65-150C)						HTST (@ 150C)			
					96hrs	192hrs	500x	1,000x	1,500x	2,000x	2,500x	3,000x	500hrs	1,000hrs	1,500hrs	2,000hrs
1	fcBGA-H	A	231ea	0/154	0/77	0/77	0/77	0/77	0/75	0/73	0/71	0/69	0/77	0/77	0/75	0/73
2		B	231ea	0/154	0/77	0/77	0/77	0/77	0/75	0/73	0/71	3/69	0/77	0/77	0/75	0/73
3	fcBGA	A	231ea	0/154	0/77	0/77	0/77	0/77	0/75	0/73	0/71	0/69	0/77	0/77	0/75	0/73
AEC Q100 Grade					Gate	Extended	G1	G0	Extended					G1		G0

AEC-Q100 G1 CLR Validation for fcCSP

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AEC-Q100 G1 validation for fcCSP and got promising results with passing TCC 1,000 cycles, HTS 2000hrs and uHAST 96hrs which is comparable to AEC-Q100 G1

Package	
Package Type	fcCSP
Package Size	140mm ^2
Total Height (Max)	0.90 mm
Mold Cap Thickness	450 um
BGA Pitch/Dia	0.400 / 0.25mm
Passives	0201 on DSC only

Die	
Die Size / Thickness	70mm^2 / 150um T
Fab Technology	14N
UBM Stack	Ti/Cu/Ni
UBM Size	45 x 75 um
PIO	20 x 30 um (oblong)
Bump Pitch	100um

Substrate	
Solder Resist	SR1
Core Material	HL832NS
Core Thickness	60 um
Layer Count	4L SAP
Total Thickness	0.20mm

Leg	EMC	S/S	Output Response									
			MSL3 462ea	uHAST / 231ea		TC 'C' /231ea			HTST /45ea			
				48hrs	96hrs	500x	750x	1,000x	500hrs	1,000hrs	1,500hrs	2,000hrs
1	A	507ea	0/462	0/231	0/231	0/231	0/231	0/231	0/45	0/45	0/45	0/45
2	B	507ea	0/462	0/231	0/231	0/231	0/231	0/231	0/45	0/45	0/45	0/45

Typical FC Packaging Issues for Automotive

- Trace cracking sometimes noticed on FC-BGA packages
- Underfill cracking driven by
  - Package design induced stress
  - Type of underfill material used
  - Process induced defects such as voids
  - Risk of cracking is higher with extended TC requirements for automotive
- Underfill process considerations
  - Must optimize the bump pitch scaling between process and reliability
  - Underfill flow time must be optimized to prevent voiding
  - Fine filler and/or lower filler loading may be required, but must be balance against thermo-mechanical requirements of CTE, fracture toughness, etc. that drive higher filler loading
  - New underfill materials and processes may be required
- Improved substrate performance is required to meet automotive reliability (zero failure criteria)
  - Package design optimization required
- New thermal interface materials may be required to handle high heat dissipation

5G and mmWave in Automotive

Vehicle-to-Vehicle (V2V) Communication
Nearby cars will exchange their location, speed, acceleration, direction and steering data real-time

Vehicle-to-everything (V2X) communication
Cars will connect to everything on the roads like traffic lights, gantries and lampposts – as well as the roads themselves

Radar Sensors
ADAS
Autonomous driving
Human heath monitoring

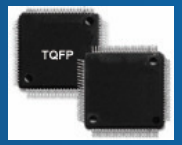
Advanced telematics
The car will become an extension of our digital selves

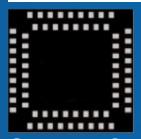
Surveillance
Data from cameras and sensors will be stored and used by governments and others for security and surveillance purposes

In-Vehicle communication
Low latency communications between sensor networks and MCUs for mission critical systems (e.g. crash detection)

ADAS Radar Package Overview

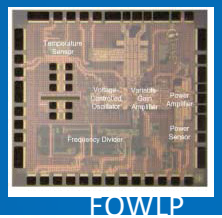
Present		Next few Years …(2021+)
Lower Freq	60-77GHz	>77~79GHz
Leaded	Fan-Out Molded Solutions	Next Gen Solutions



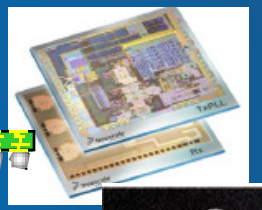


QFN MIS

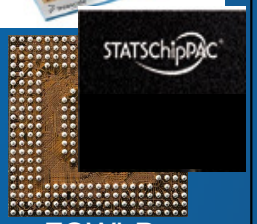
Flip Chip



FOWLP



FOWLP with AIP



FOWLP

- Low Cost
- Excellent RF isolation
- Proper ball array interconnect with the board
- Grade 1 reliability (per AEC-Q100-Rev H)

FOWLP SiP Evolution

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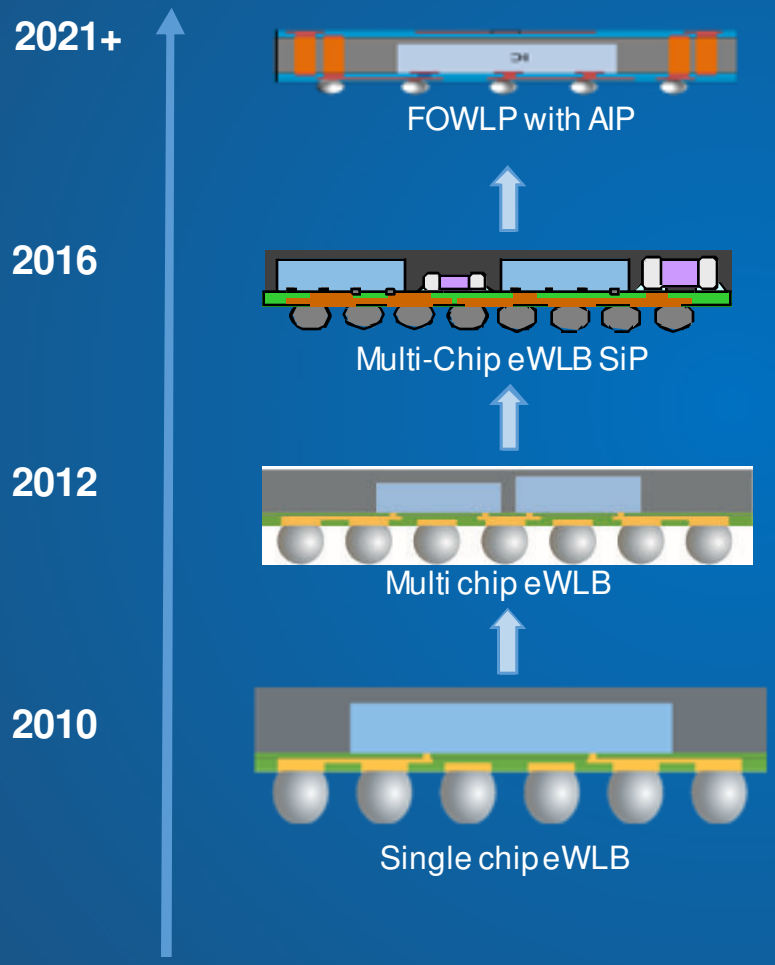
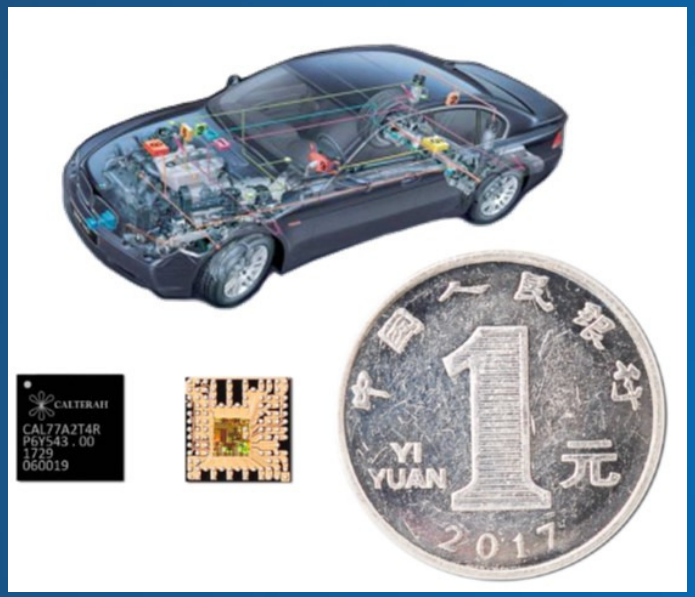
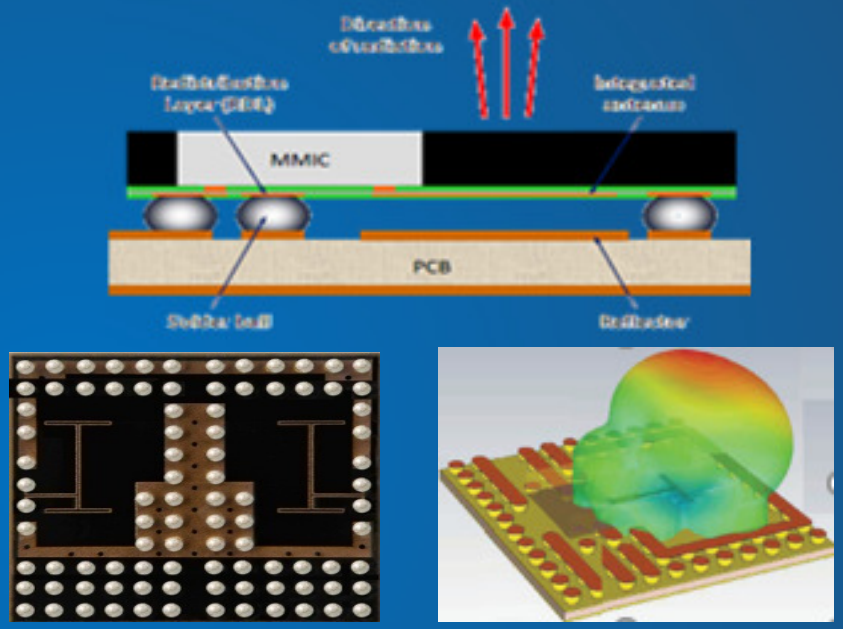


77GHz Automobile Radar Device (ADAS) in eWLB



77GHZ ADAS eWLB



AiP (Antenna-in-Package) antennas integrated in the Cu RDL

- Smaller form-factor and **much less interconnection parasitic** →critical for high-frequency applications
- Qualified for **AEC Q100 Grade 1** reliability up to 9x9mm
- Passed board level **TCoB >1500 cycles**

eWLB for Radar Passed AEC Q100 Grade -1

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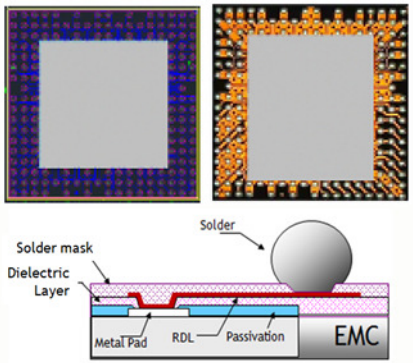
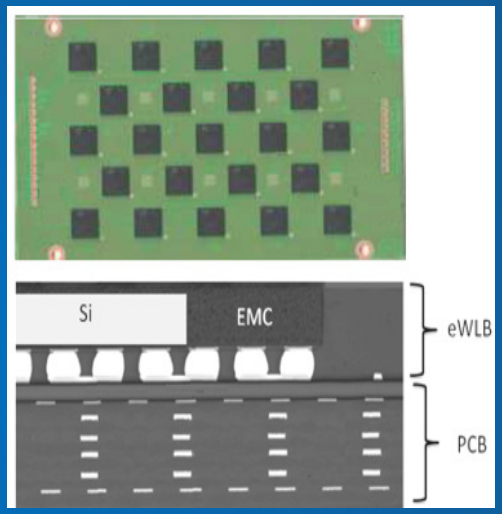
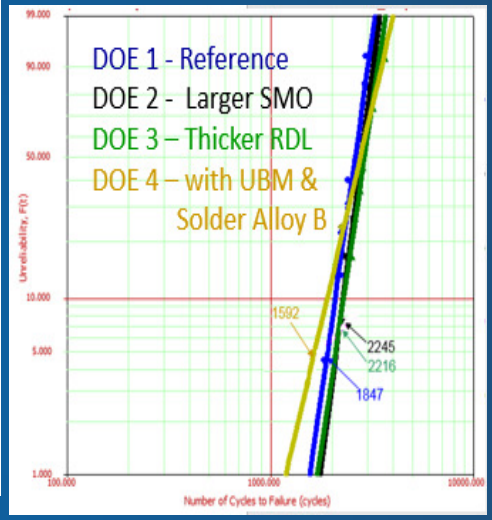
Items	Specification
PKG size	9x9mm
Die Size	36mm^2
Ball Pitch	0.5mm
Ball Dia	0.3mm
IO No.	230
UBM	No
Cu RDL No.	1 layer
Die Thickness	440mm
PKG Thickness	770 mm







Source : JCET Group Joint papers with ST Microelectronics, EPTC2016 & ECTC2017

- Passed AEC Q100 Grade-1 Reliability
- Passed TCoB 1500x (with customized low loss PCB)
- Further TCoB improvement with design optimization

Summary

- Automotive is one of the highest growth semiconductor market now (CAGR: ~7%)
- Adding more autonomous features in the car and increasing car sales are the main drivers for automotive semiconductor market
- Due to the increasing complexities and higher performance, pin count, power, and cost requirements automotive packaging landscape changes from traditional wire bond to fine pitch flip chip or wafer level fan out (eWLB) and SiP
- Low insertion, smaller footprint, thinner profile at competitive cost draws interest in advanced packaging such as FOWLP for the heterogeneous integration of multi-die and 2.5D/3D ICs.
- Extensive assembly and reliability data proved that both flip chip SiP and wafer level fan out (eWLB) are very robust to fulfill next gen automotive needs (Grade 1 or even 0)

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