Reliability Tests for Discriminating Between Technological Variants of QFN Packaging

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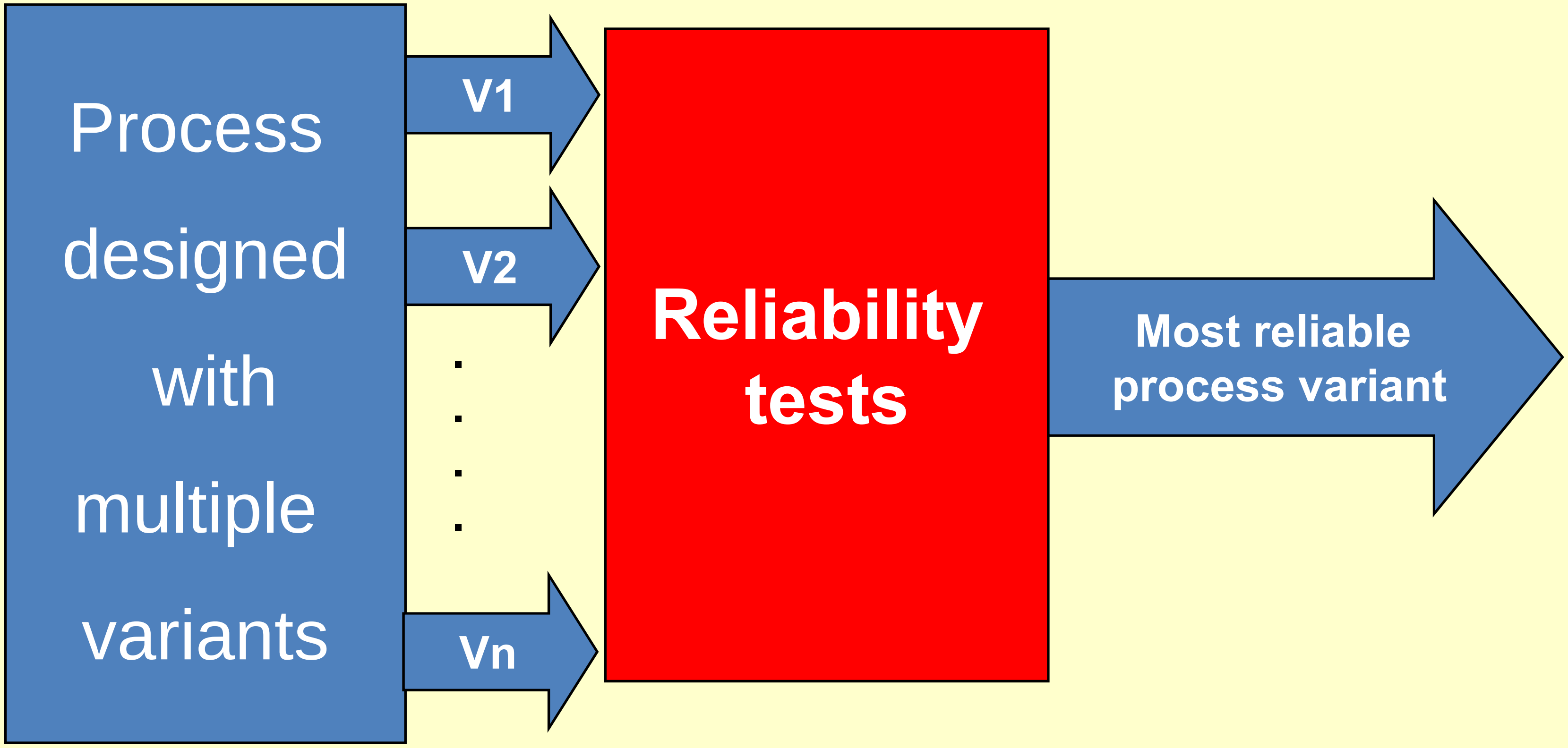
The challenge



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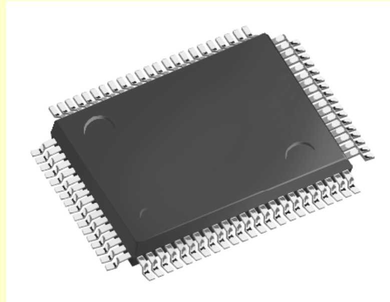
1. Introduction

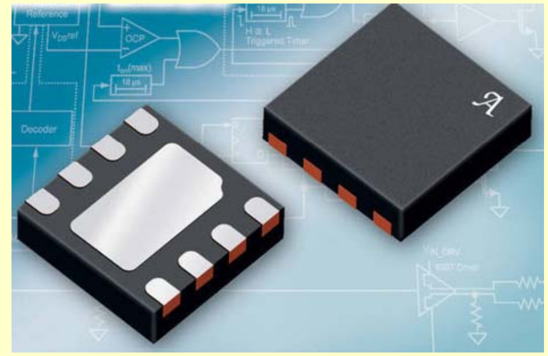
Packages for surface-mount technology

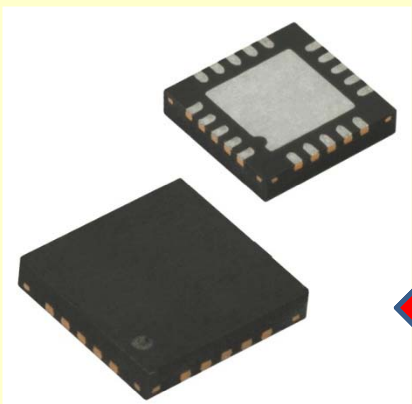
* Quad Flat Package



* Flat no-leads:

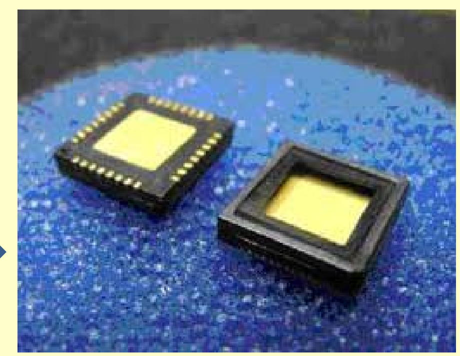
DFN (dual-flat no-leads)



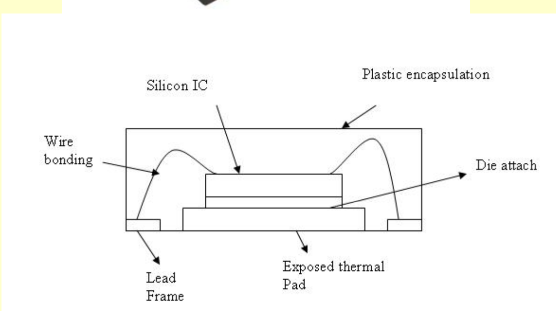


QFN (quad-flat no-leads)

- Air-cavity QFN



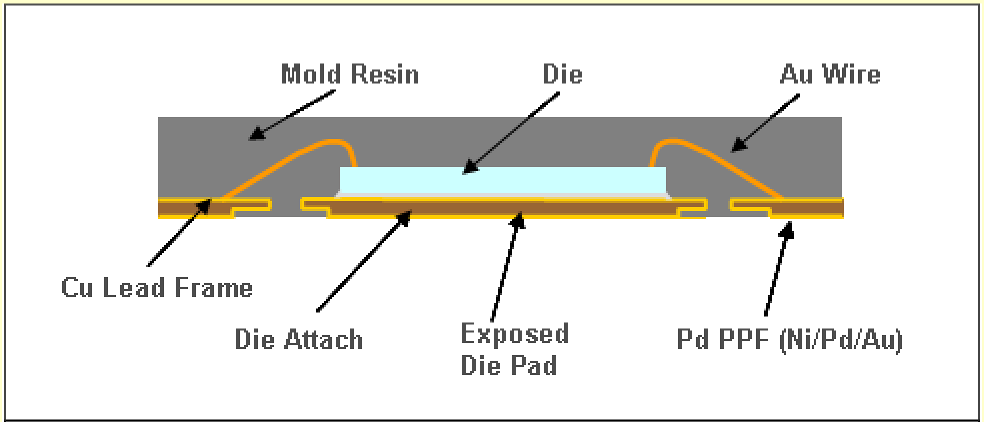
- Plastic-moulded QFN



Section View of a QFN package

1. Introduction

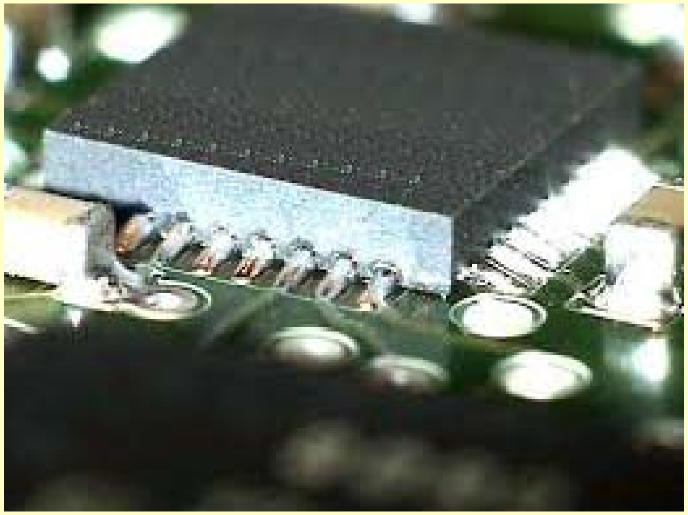
- Two types of reliability issues for QFN:



QFN Cross Section

(i) First level interconnection (i.e. die attaching, wire bonding, solder bump, encapsulation)

(ii) Second level interconnection (package attaching on PCB, solder joint)



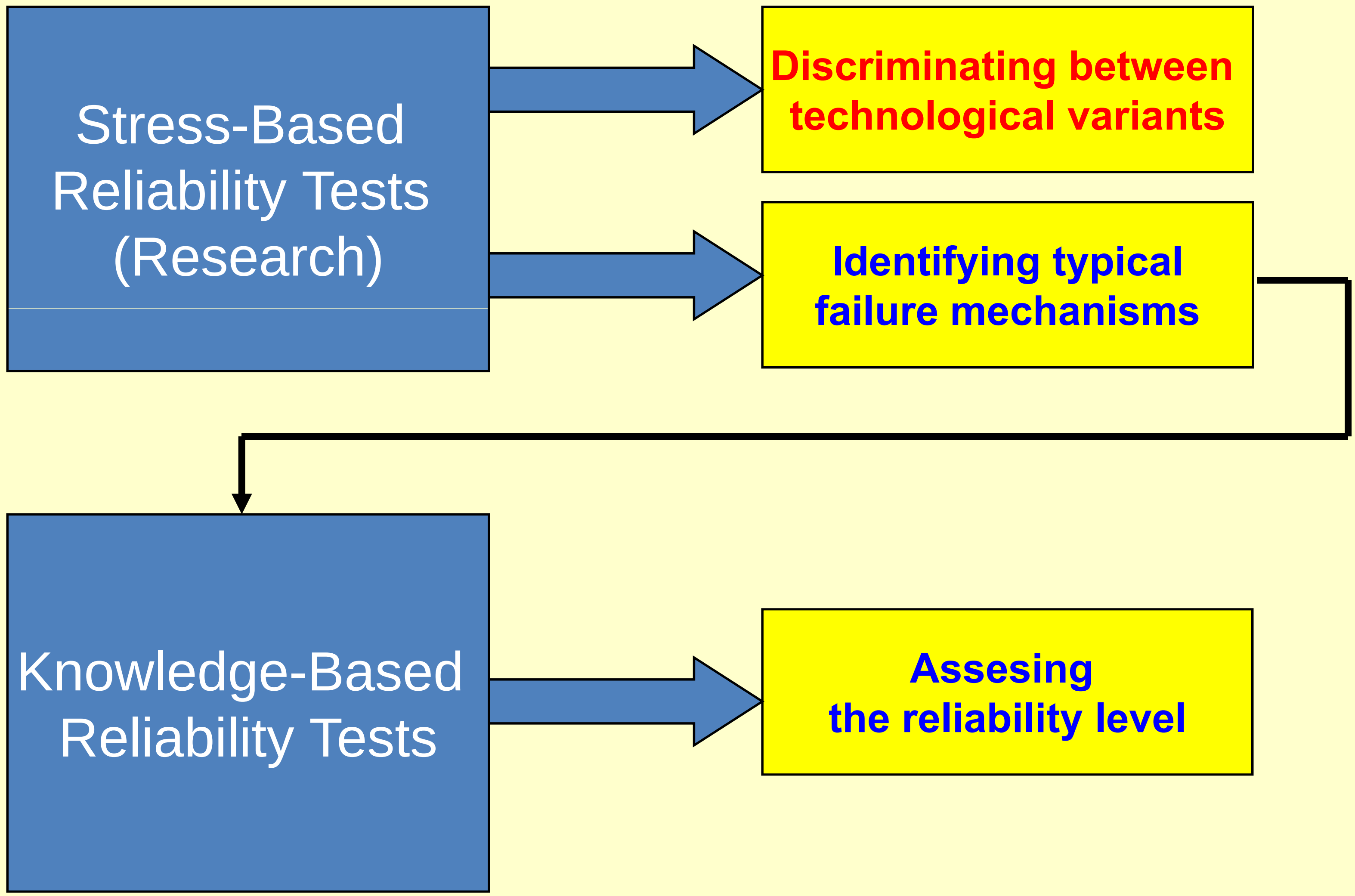
1. Introduction (2)

Stress-Based Reliability Tests (Research)

Discriminating between technological variants

Identifying typical failure mechanisms

1. Introduction (2)



Significant environmental factors:

- **Thermal stress** - Most detrimental in the form of *thermal cycling*, where QFNs have a much lower reliability than the QFP packages. So, the thermal cycling seems to be significant for QFN.

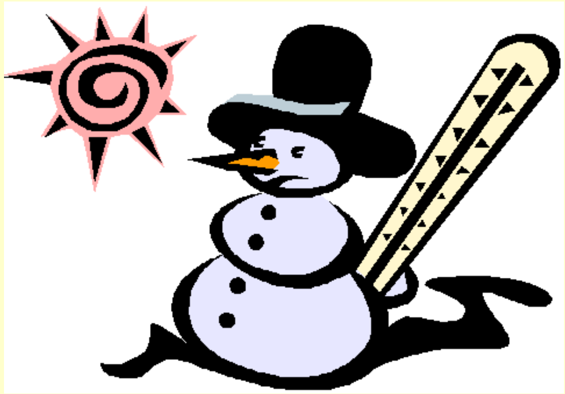
- **Mechanical stress** - Vibration could lead to the detection of possible reliability risks (but this effect is significant only for **second level interconnection**).

- **Humidity** - If arrived at die level (e.g. after a humidity test), could indicate a leaking plastic encapsulant.

2. Reliability tests (2)

JEDEC standards - the JESD22 A series:

- **Thermal cycling** - **test condition H**



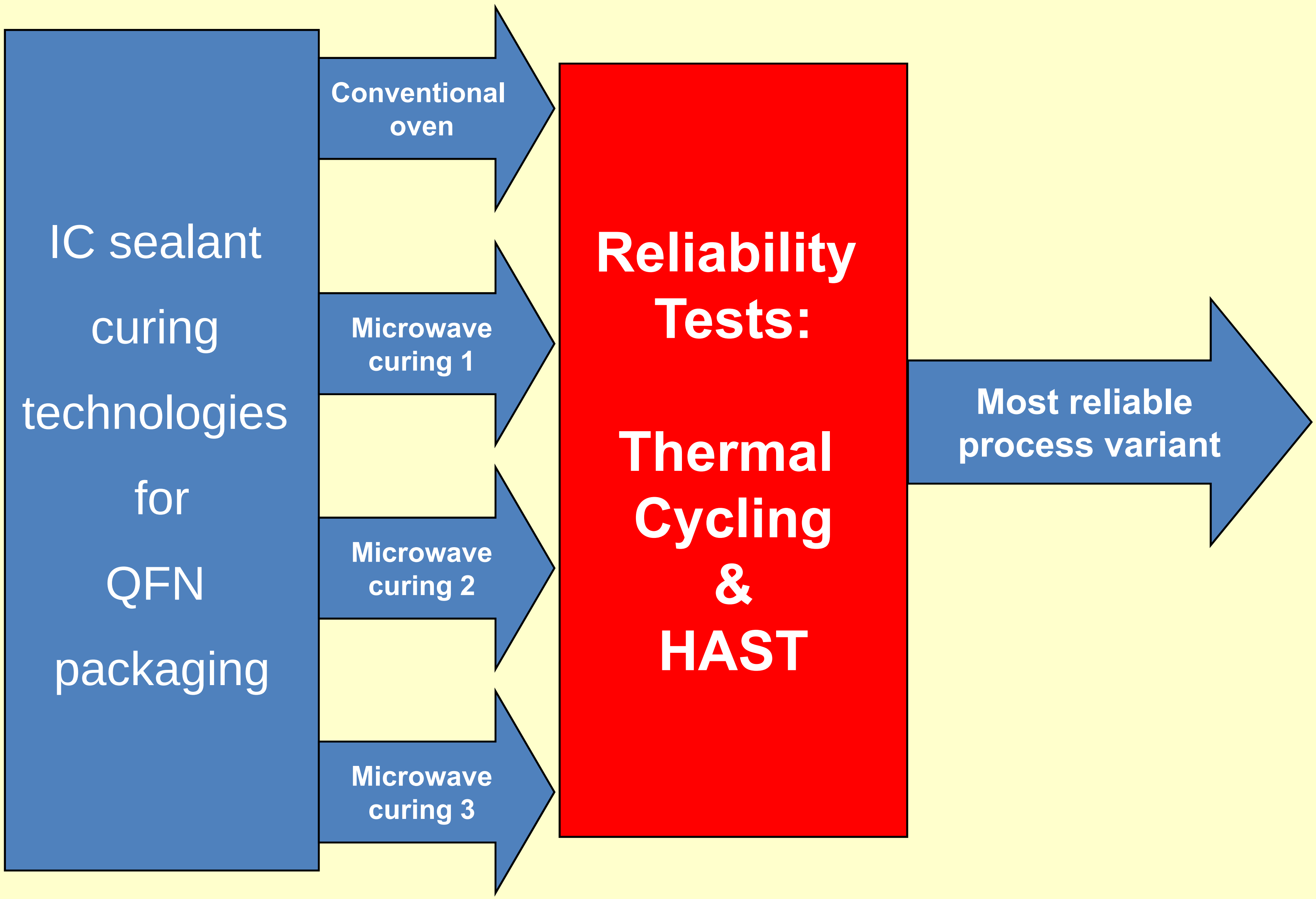
(JEDEC std. no. 22A104D): T_{min} = -55^{0}C,
T_{max} = +150^{0}C. Preliminary tests have shown that these temperatures are the adequate ones.

- **Humidity** (two possible accelerated tests):

- Highly Accelerated Stress Test (HAST)
(JEDEC std. no. 22A110D, i.e. 110 or 130^{0}C and 85% relative humidity, without electrical bias;

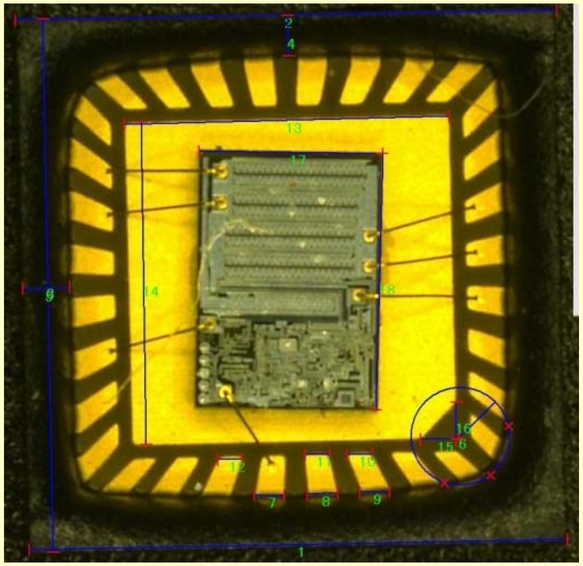
- 85/85 test - JEDEC std. no. 22-A101,
(85^{0}C and 85% relative humidity,
but with electrical bias on the test structure.

3. Experiment (1)



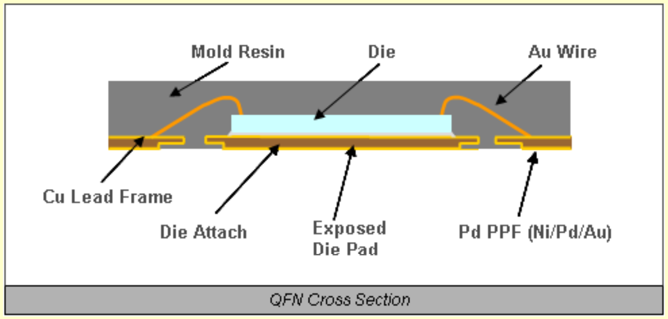
3. Experiment (2)

- Samples manufacturing by FP7 project “Frequency Agile Microwave Bonding System -**FAMOBS** (2009-2012, 14 European partners).
- Test vehicle: LM2940C-12, 12V voltage regulator (already used in earlier tests, so we had some preliminary information about microwave curing), placed into QFN32W.5 package that is 5mm x 5mm with 32 leads, lead pitch 0.5 mm.
- 80 silicon chips were assembled into QFN packages by Micross (UK) by standard industrial grade processes (in order to eliminate any reliability issues that would be caused from process variables either during die or wire bonding).
- Wire bonding of the 6 pads of the die to the package was done with 25 µm gold wire.
  A wall of epoxy-based encapsulant was also applied by the package manufacturer.



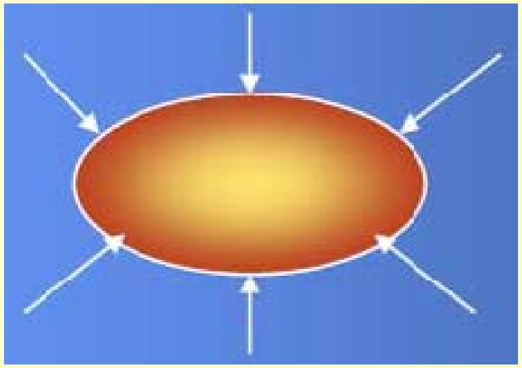
3. Experiment (3)

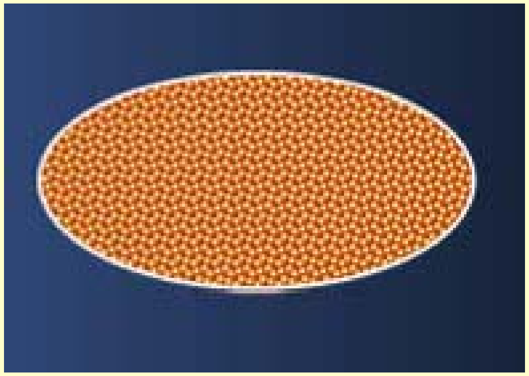
- At Fraunhofer IPA Stuttgart (Germany), all samples were functionally tested, then the QFN cavity was manually filled by dispensing Hysol EO1080



- After dispensing, 20 samples were randomly picked for oven curing, and the rest of the samples were randomly divided into three patches, to be cured on automated microwave curing machine using three different thermal profiles (P1, P2, P3).
- Microwave heating: Heating is volumetric, throughout the material, as compared to thermal transfer from convection heating.

Convection – heat penetrates from surface





Microwave – uniform heat generation

3. Experiment (4)

- **Two types of reliability tests** (performed at IMT-Bucharest, with the measurements system provided by Pera Technologies):

Thermal Cycling

Groups of devices	Test conditions
RT1-P1: 10 items	Thermal Cycling / -55^{o}C to 150^{o}C, 10 minute dwells; 1000 cycles; Initial, final and intermediate measurements at every 50 cycles.
RT1-P2: 10 items	
RT1-P3: 10 items	
RT1-W: 10 items	

HAST

Groups of devices	Test conditions
RT2-P1: 10 items	Highly Accelerated Stress Test (HAST) / 96h, at 130^{o}C and 85% relative humidity / Initial and final measurements.
RT2-P2: 10 items	
RT2-P3: 10 items	
RT2-W: 10 items	

3. Experiment (5)

Testing at: Thermal Cycling (left) and Highly Accelerated Stress Test - HAST (right).

- In both cases (Thermal cycling and HAST), the **failure criteria** are: (i) lack of functionality or (ii) exceeded parametric limits for the test structures that are encapsulated and tested.
- **Electrical measurements**: the parameters to be measured were chosen in the idea of identifying the device failure (output voltage, line and load regulation).

4. Results & Discussion (1)

Two sets of Reliability Tests (RT)

RT1 (4 x 10 items)

Thermal cycling (500 cycles)

A few failures

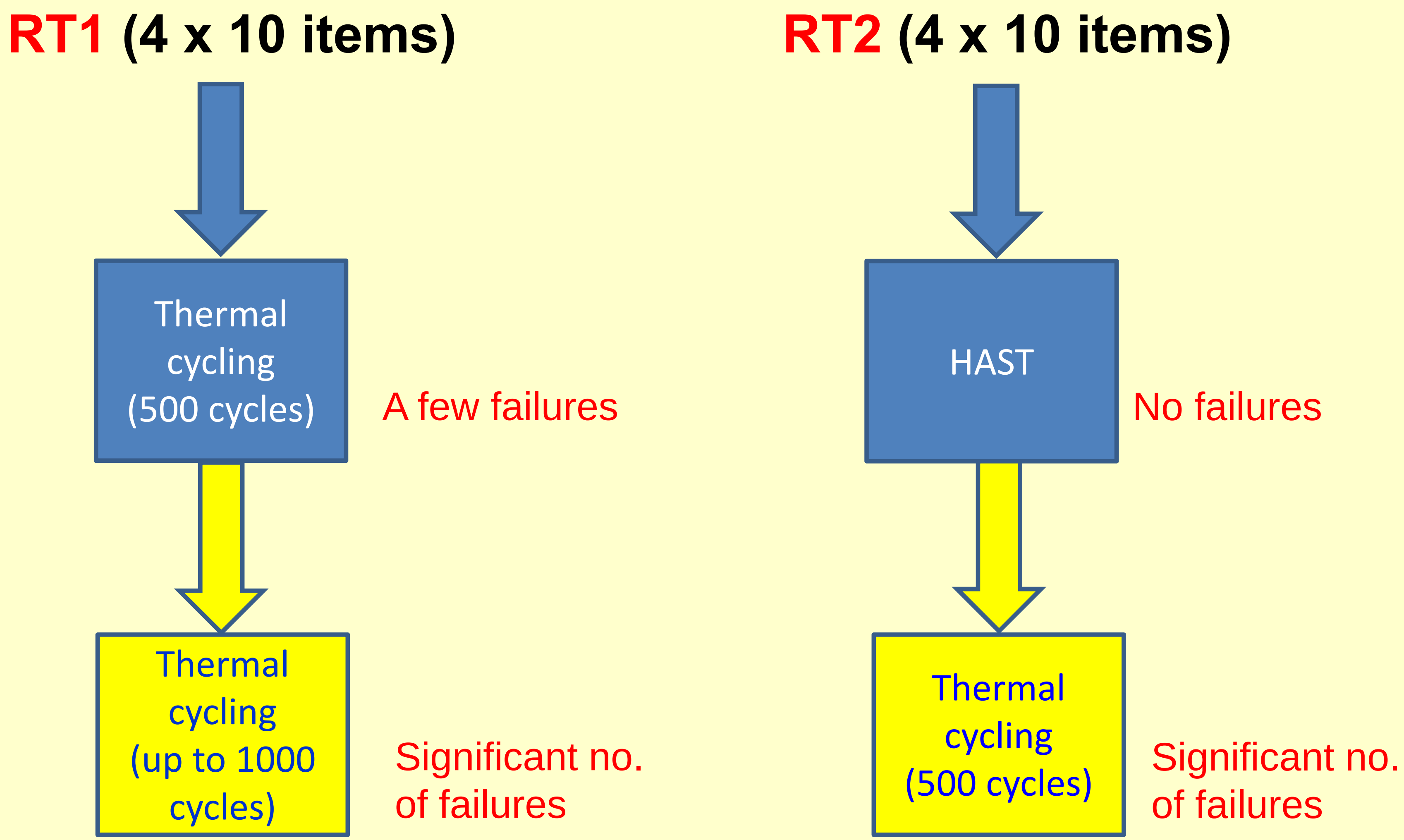
RT2 (4 x 10 items)

HAST

No failures

4. Results & Discussion (1)

Two sets of Reliability Tests (RT)



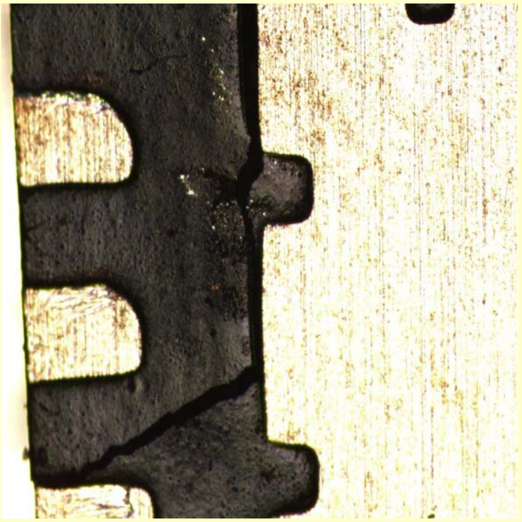
4. Results & Discussion (2)

Tests	Failure moment for the cumulative percentage of failures (cycles)						
	10%	20%	30%	40%	50%	60%	70%
RT1-P1		200	500	600	1000		
RT1-P2	150		350	950			
RT1-P3	150	200	600	900			
RT1-W				400	450	850	
RT2-P1	200	350	800				
RT2-P2	150	200	350	650	700		
RT2-P3	50	450	600	850	1000		
RT2-W	100	200	350	400	450	650	800

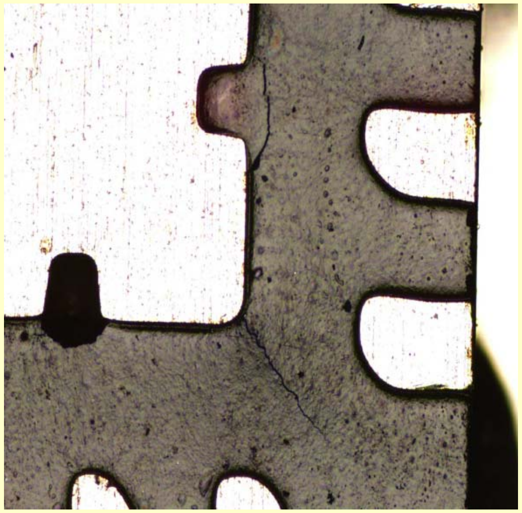
4. Results & Discussion (3)

Failure Analysis - 1

- **Electrical**: **open circuit**
- **Optical microscope**: **cracks initiated at plastic surface**



RT2/P1, failed after 200 cycles



RT2/P2, failed after 350 cycles

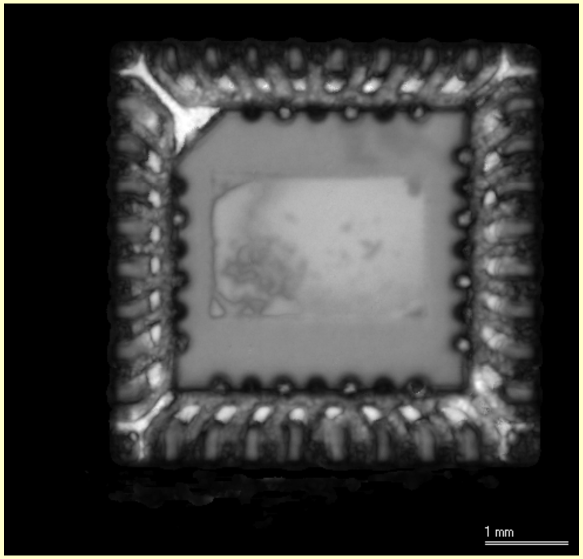
- Most probably, these cracks are initiated by a combination of temperature and humidity (originating from HAST), which was developed subsequently during thermal cycling.
- Question: **Are these cracks local ones only, without affecting the bonding between the die and the package?**

4. Results & Discussion (4)

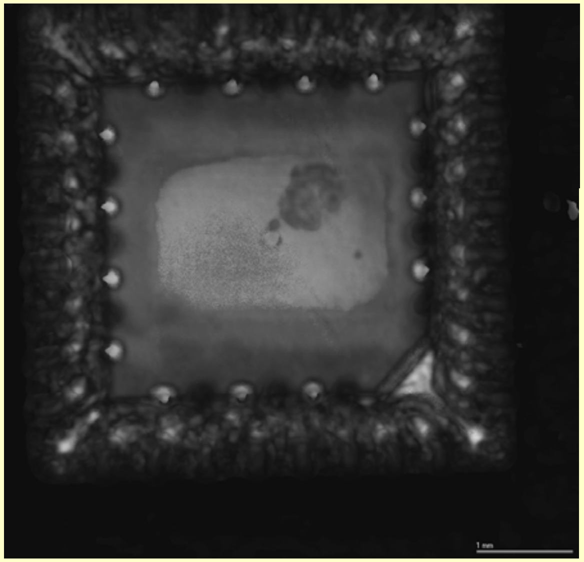
Failure Analysis – 2

- A PVA TePla SAM400 **Scanning Acoustic Microscope (SAM)** with 100 MHz transducer for the images was used by the Austrian Research Institute for Chemistry and Technology - OFI (Austria) for investigating **the interface between die and package**.
- the SAM analysis indicated a **poor contact between the die and the package** in the darker areas of the interface.

RT2/P1, failed after 200 cycles

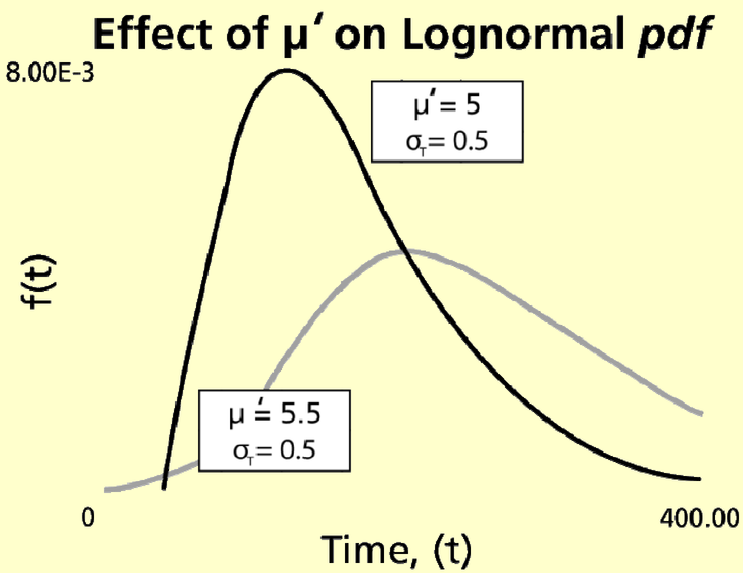


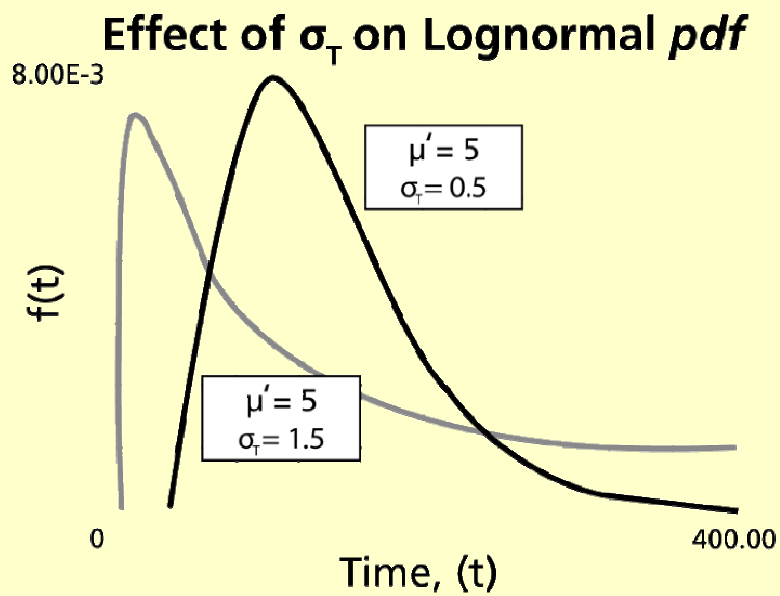
RT2/P2, failed after 350 cycles



Statistical Data Processing

- Based on previous results obtained for semiconductor devices, a **lognormal statistical law** (more flexible than the Weibull law) was chosen to describe the time dependence of the failures.
- The parameters are: **μ'** (**mean** of the natural logarithms of the times-to-failure) and **σ_T** (**standard deviation** of the lognormal distribution)





Better reliability = Higher μ'; Well-controlled process = Lower σ_T

Discussion - 1

Technological variants	Mean - μ’ (cycles)		Standard deviation - σ_T	
	RT1 (TC)	RT2 (HAST + TC)	RT1 (TC)	RT2 (HAST + TC)
P1	**1000**	1600	1.8	1.7
P2	**1400**	**700**	2.0	1.3
P3	**1500**	**1000**	2.1	1.0
W	**450**	450	1.5	1.2

- At thermal cycling, the mean for all 3 variants of microwaves process is much higher than for the classical variants of curing: 1000, 1400 and 1500, compared to 450 cycles. **Conclusion: better reliability for microwave curing!**
- For variants P2 and P3, HAST performed before thermal cycling determined a significant decrease of the reliability: see the decrease of the median time, t_m, from 1400 to 700 cycles (for P2) and from 1500 to 1000 cycles (for P3). This means: (i) **the microwave cured compound is permeable to humidity induced by HAST and the effect could be seen subsequently, at thermal cycling**; (ii) **P1 is the most reliable process (less permeable to humidity)**.

4. Results & Discussion (7)

Discussion – 2

Technological variants	Mean - μ' (cycles)		Standard deviation - σ_T	
	RT1 (TC)	RT2 (HAST + TC)	RT1 (TC)	RT2 (HAST + TC)
P1	**1000**	**1600**	**1.8**	**1.7**
P2	1400	700	**2.0**	**1.3**
P3	1500	1000	**2.1**	**1.0**
W	450	450	**1.5**	**1.2**

- For variant P1 (which seems to offer **the higher reliability level**), HAST is not detrimental for the reliability. Moreover, the mean increases (from 1000 to 1600 cycles!). This could mean that **the curing process is not yet stabilized, needing an optimized thermal treatment** (which is now performed by HAST).
- This role of HAST as stabilization treatment is also confirmed by the noticed **decrease of the standard deviation for all groups of tested devices**. As one can see, the standard deviation for RT2 is smaller than for RT1.

5. Conclusions

- **A procedure for discriminating between the reliability levels of various variants of technological process** was proposed and used for a real case.
- **The microwave curing of package compound improves the reliability of the device** compared to the conventional oven curing.
- Among the three profiles of process for microwave curing, **P1 seems to be the best one, succeeding in blocking the access of humidity inside the package**.
- However, the curing by microwaves seem to be not yet optimized, because HAST still plays a role of stabilization process for all samples. So, **a stabilization treatment has to be added to this process**.