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Back-End Manufacturing & Technology

Novel Pressure-less Adhesive Dispensing Strategy for Thin Die Applications

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Excellence is not a skill
it is an attitude

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Power Package Leadframe-based

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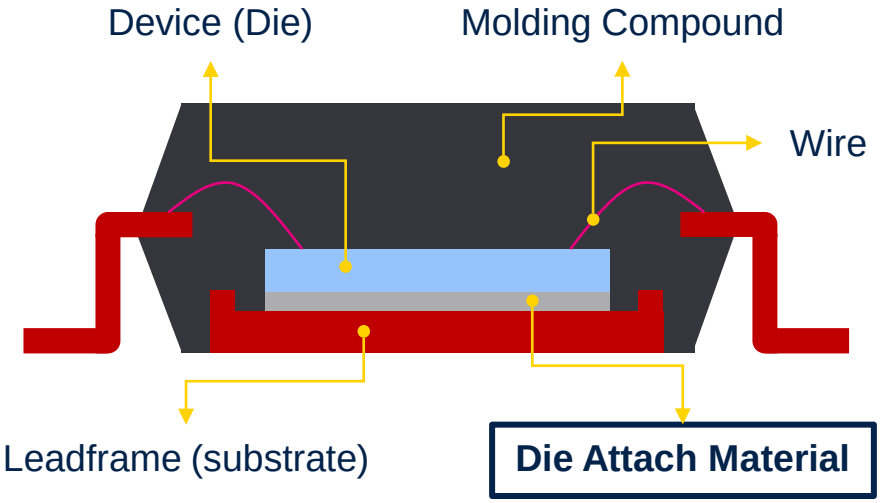
Power Package Leadframe-based

High lead containing solders: dangerous materials



High lead (Pb) containing Solders (also known as Soft Solder) are widely used as die attach material on power packages leadframe-based thanks to:

- High Thermal Conductivity: ~40W/mK
- Low Electrical Volume Resistivity: 10^{-5} Ω*cm
- High Melting Point: >260°C

European **End-of-Life Vehicle (ELV)** Directive (2000/53/EG)

European **Restriction of Hazardous Substances** Directive (2011/65/EU)

- **Lead (Pb) poses environmental and health risks**
- 2 European Directives (ELV and RoHS) restrict the use of Pb
- In the semiconductor field, Pb is still allowed by exceptions because no general Pb-free solution is currently available

Semiconductor IC makers are being called upon to find alternative lead-free solutions

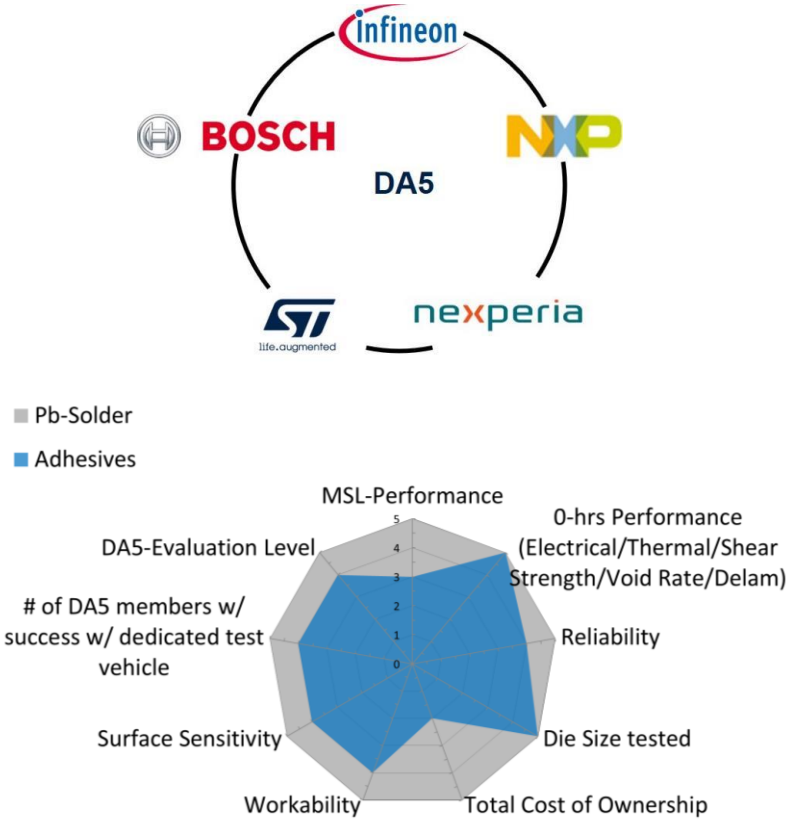
Power Package Leadframe-based

DA5 Consortium: towards lead-free solutions

DA5 Consortium

- Established in 2009
- DA5 = Die Attach 5
- 5 major European IC manufacture involved
- Joint development by semiconductor and material suppliers to address and mutually define the direction of Pb-free solder die- and clip-attach technology

→ **Pressure-less Ag-based Adhesives (Glues) are the most encouraging Pb-free alternative** to replace High Lead containing Solders.



Source: DA5 Customer Presentation (link)

Pressure-less Ag-based Adhesive

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Pressure-less Ag-based Adhesives

Lead-free solution

Properties of Pressure-less Ag-based Adhesives

Main Components

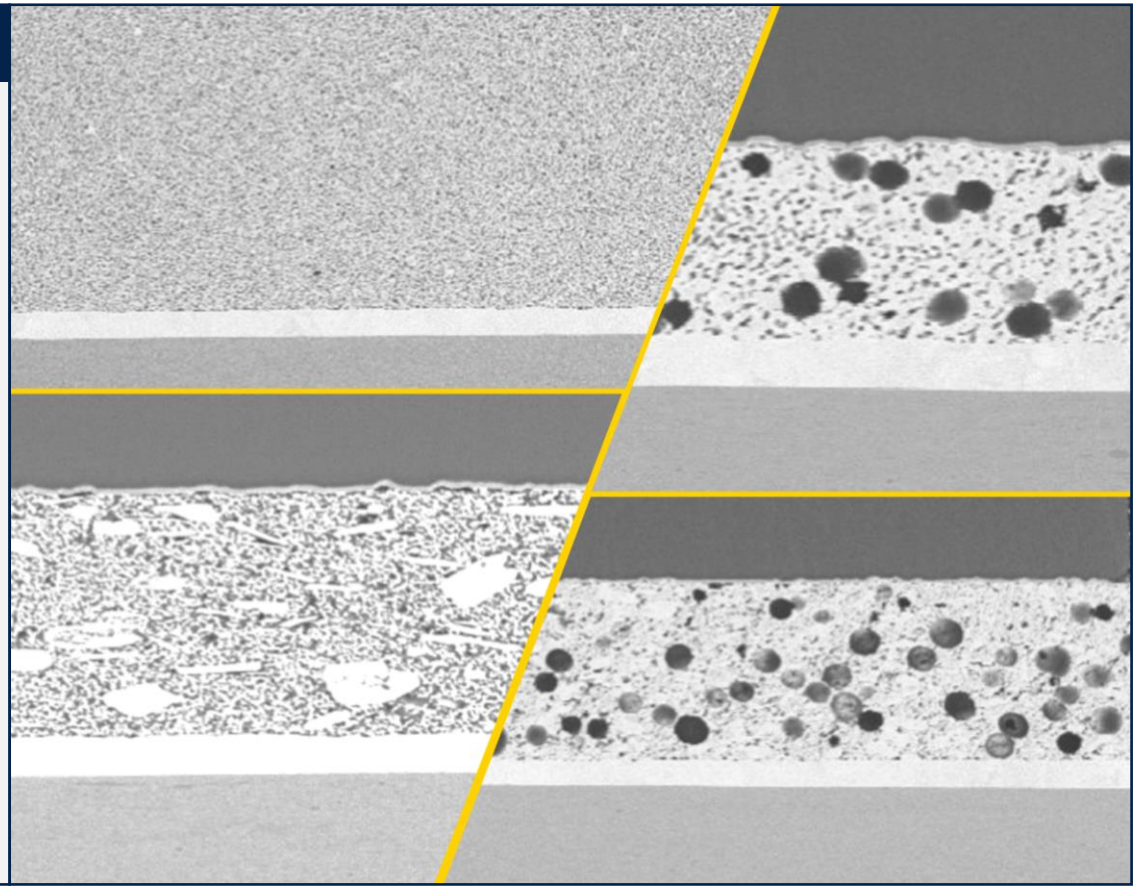
- **High load of micrometric and/or submicrometric silver particles with different geometric shape**
- **Thermoset organic resin**
- Small amount of solvent
- Additives (e.g. hardener, curing fastener)

Physical Properties

- **Electrical Volume Resistivity: 10^{-5} – 10^{-6} Ω*cm**
- **Thermal Conductivity: 40 – 210 W/mK**

Mechanical Properties

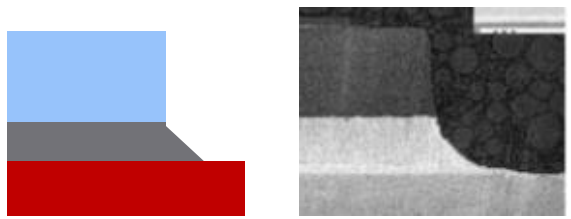
- Joint strength provided by **resin crosslinking, metal interdiffusion and semi-sintering phenomena**



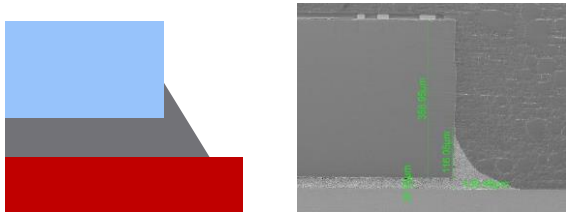
Pressure-less Ag-based Adhesives

Thin dice application challenge

- Semiconductor industry for automotive application is trending towards **thinner dice**, typically less than 200um, to meet higher electrical performances
- Unlike lead-based solder materials, pressure-less Ag-based glues have a natural tendency to climb-up the die vertical side (glue fillet-height phenomenon) → **risk of glue to flow over the die surface**



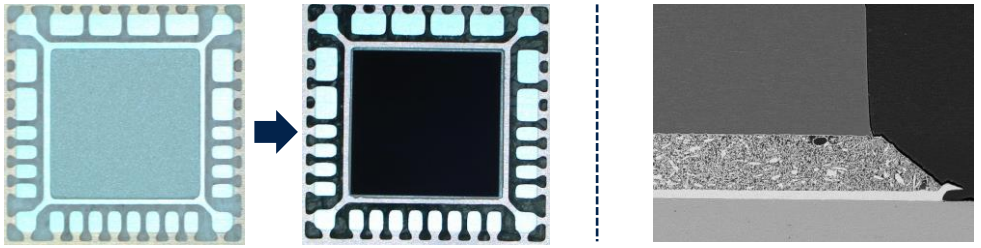
Lead-based Solders



Pressure-less Ag-based Glues

How to manage thin die with Pressure-less Ag-based glues?

2D Screen Printing (Stencil Printing) Technique



- Applicable to flat (2D) substrate only
- High material wastage

Advanced Time-Pressure Dispense Pattern Writing

- Applicable to both flat (2D) and non-flat (3D or downset) substrates
- Minimized material wastage

Advanced Dispense Pattern Writing

Advanced Dispense Pattern Writing

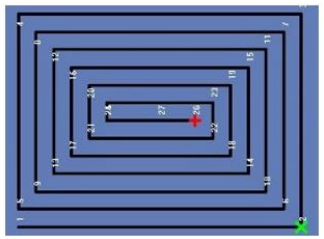
Rectangular spiral pattern concept

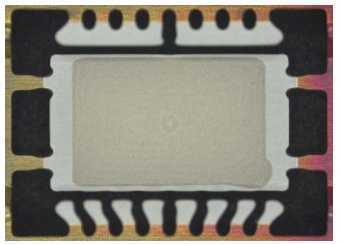
Die Attach Equipment

- Die Bonder DB2100 platform from Besi
- Glue in syringe format management
- Time-pressure dispensing system → **minimized material wastage**

Advanced Time-Pressure Dispense Pattern Writing

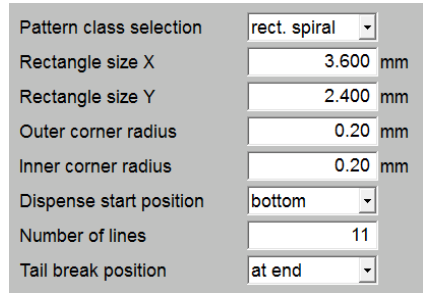
- Spiral movement at constant speed resulting in a **complete rectangular pattern**
- **Applicable to flat (2D) and non-flat (3D/downset) leadframe** types





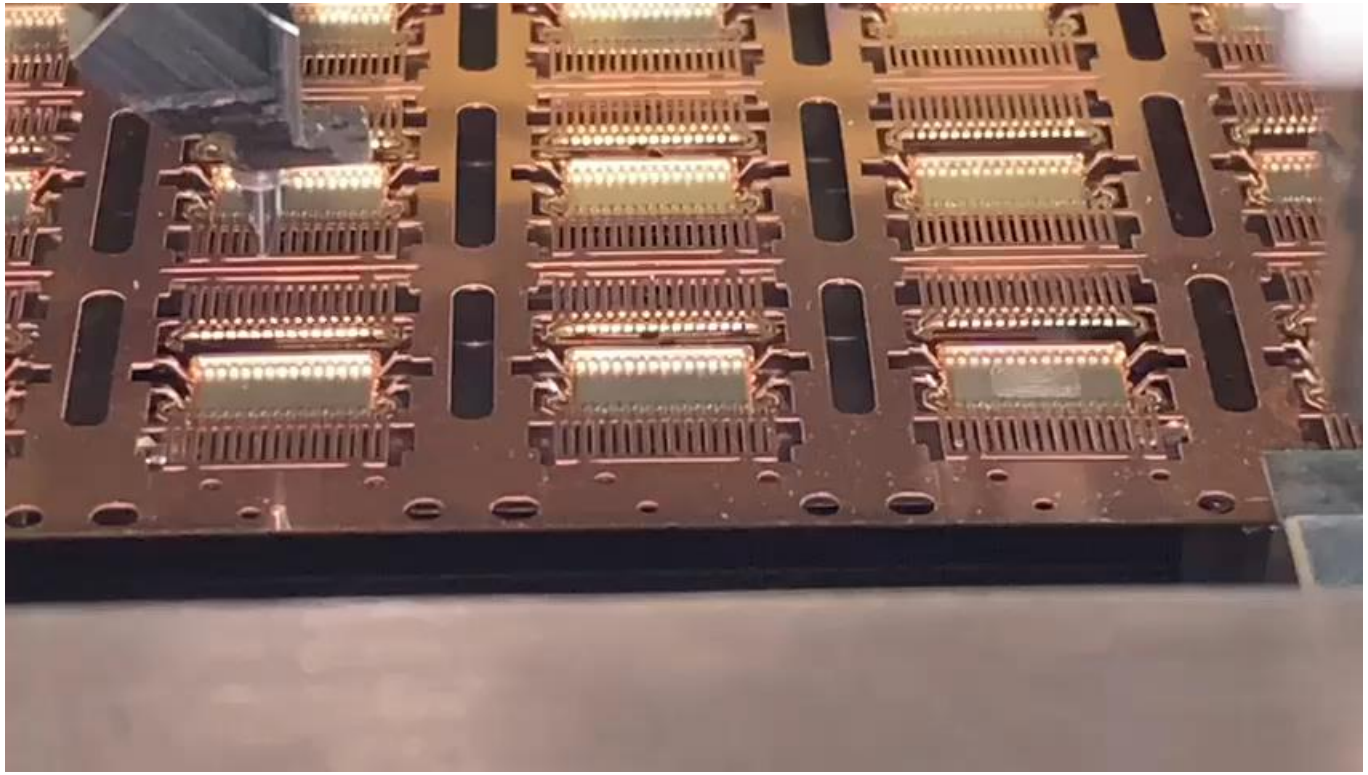
DB2100 Human Machine Interface (HMI)

- Rectangular size (X and Y)
- Dispense speed
- Dispense pressure
- Number of spiral lines



Advanced Dispense Pattern Writing

Rectangular spiral pattern concept

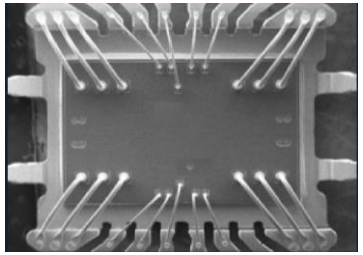


Study Case: Rectangular Spiral Pattern Implementation

Study case: Rectangular Spiral Pattern Implementation

Test Vehicle

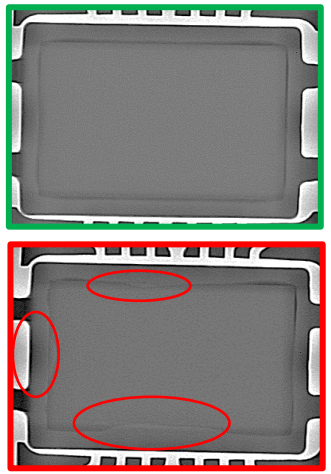
- SMT power package: PSSO16
- Substrate: PSSO16 - 3D/downset leadframe, Ag plated
- Device size: 3.45 x 2.25 x 0.110 mm
- Die Backside: Ag metallization
- Die Attach material: pressure-less Ag-based glue



Attempt with “standard” pattern shapes

- Different standard pattern shape evaluated: cross, snow star, double Y, asterisks
- Weak stability in controlling both die coverage and adhesive rise on vertical die side (fillet-height) simultaneously

→ **Unstable results resulting from long run exercise**



Rectangular Spiral Pattern Implementation

Dispense Screening DoE

↓

Dispensed Pattern Optimization

↓

Die Attach Process Optimization DoE

↓

Reliability Performances

Rectangular Spiral Pattern Implementation

Dispense screening DoE

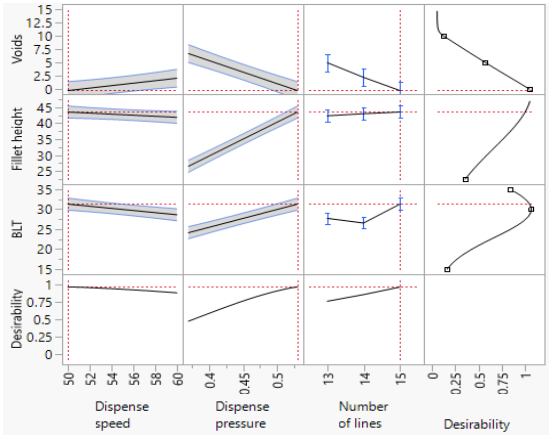
Input Parameters

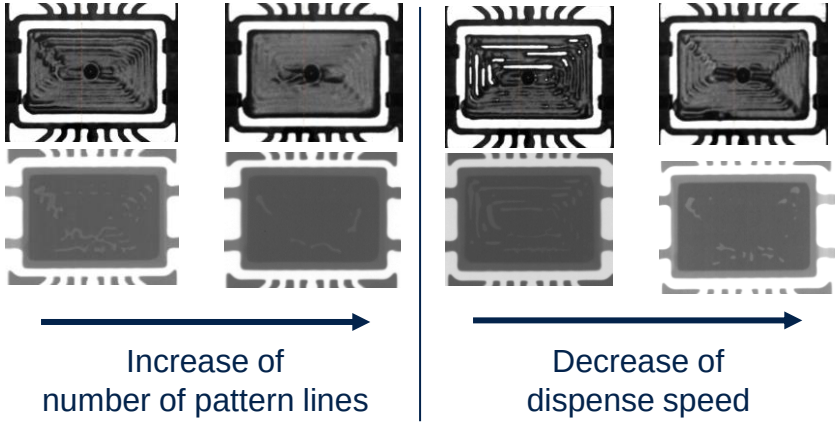
- Dispense Speed
- Dispense Pressure
- Number of Lines

Output Parameters

- Bond line Thickness (BLT)
- Die Tilt
- Voids Rate
- Glue Fillet Height

Output Factors	Input Factors	p-value
Bond Line Thickness (BLT)	Dispense Speed	**0.0017**
	Dispense Pressure	**<0.0001**
	Number of lines	**<0.0001**
Voids Rate	Dispense Speed	**0.0084**
	Dispense Pressure	**<0.0001**
	Number of lines	**<0.0001**
Glue Fillet Height	Dispense Speed	0.0677
	Dispense Pressure	**<0.0001**
	Number of lines	0.409
Die Tilt	Dispense Speed	0.2019
	Dispense Pressure	0.1379
	Number of lines	0.729





- No impact on Die Tilt by dispensing parameters
- Voids rate reflects pattern quality: pattern completeness and flatness
- All dispensing parameters significantly impact pattern quality
  - → **Number of Lines** and **Dispense Speed** to be consolidated during Pattern Optimization
  - → **Dispense Pressure** to be set up during Pattern Optimization, but further consolidated with Pick and Place parameters as it also impacts BLT and Glue fillet-height

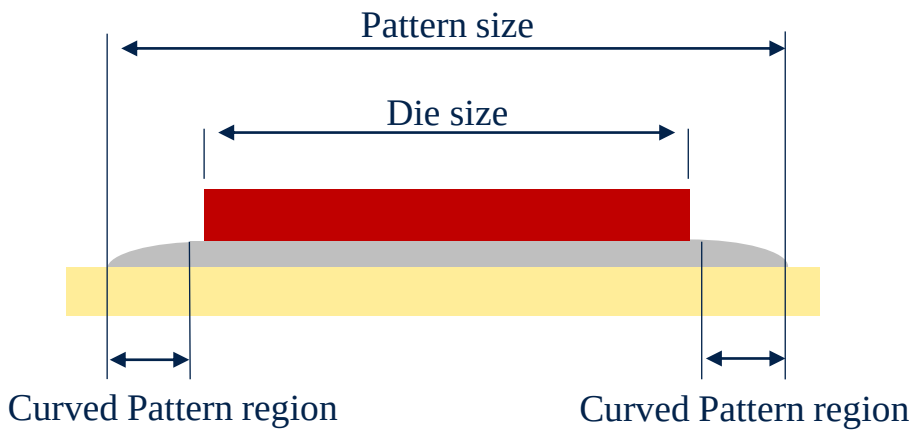
Rectangular Spiral Pattern Implementation

Dispensed pattern optimization

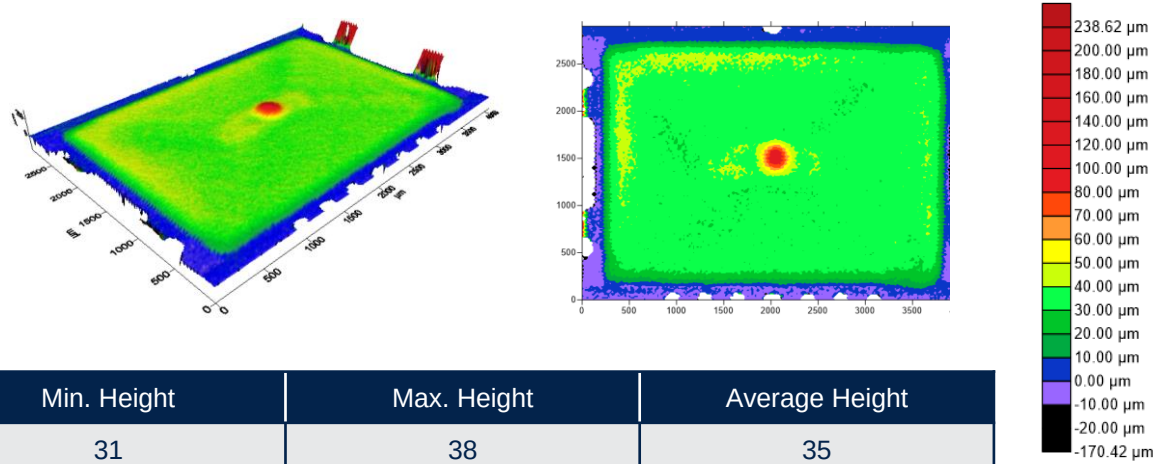
Objectives

1. Pattern Dimension
2. Pattern Quality
   - Completeness
   - Flatness
   - Thickness (close to the desired BLT)

1. Pattern dimension selection



2. Pattern Quality



Min. Height	Max. Height	Average Height
31	38	35

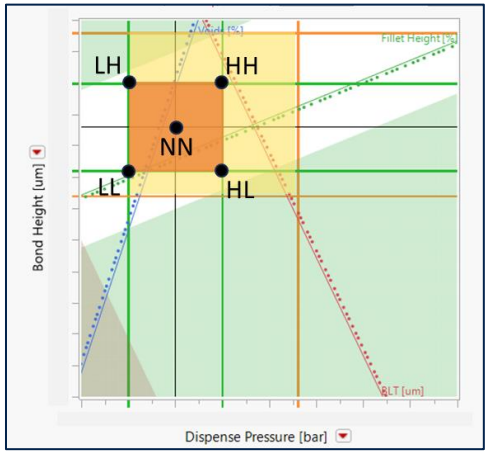
- **Pattern dimension** increased of 150um in both X and Y directions respect to the die size to achieve 100% coverage by design and to exclude the intrinsic curved patter regions along the pattern perimeter
- **Pattern quality** achieved selecting the maximum number of lines (for the selected pattern size) and reducing the dispense speed down to 55% of machine's capability. The dispense pressure was also set up for pattern quality, considering that it requires to be further consolidated in combination with P&P parameters

Rectangular Spiral Pattern Implementation

Die attach process optimization DoE

Input Parameters
Dispense Pressure
Bond Height (Distance to Bond Position)

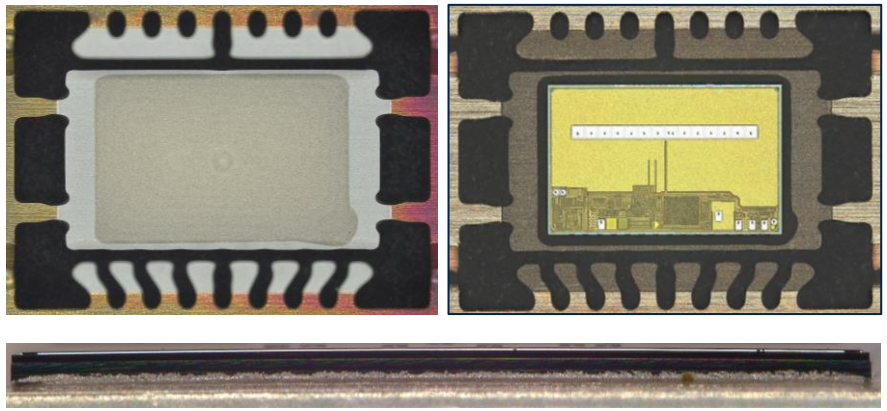
Output Parameters (responses)	Lower Limit	Upper Limit
Bond line thickness (BLT) [µm]	10	50
Fillet Height [% of die thickness]	-	80
Voids Rate [% of die area]	-	5
Coverage [% of die perimeter]	100	-



Process Window Validation

Input Factors		Output Factors (responses)			
Dispense Pressure	Bond Height	BLT [µm]	Fillet Height [%]	Voids [%]	Coverage [%]
N	N	27	27	1.3	100
H	H	32	28	1.1	100
L	L	20	30	2.2	100
L	H	21	20	3	100
H	L	23	62	0.5	100

Central Point (NN)



260°C HDS Strength [Kg/mm²]			
Min.	Max.	Av.	σ
1.53	1.9	1.7	0.13

Die Paddle Side

Die Backside

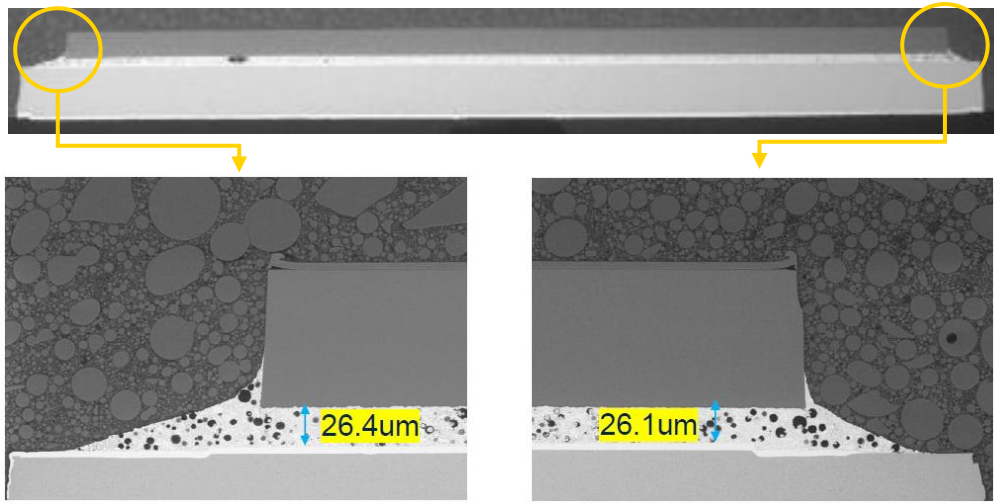
- **Surface Design DoE** adopted to identify the Process Window
- **Process Windows** successfully validated with all responses respecting considered limits
- Shear strength >1.5Kg/mm² and cohesive failure mode

Rectangular Spiral Pattern Implementation

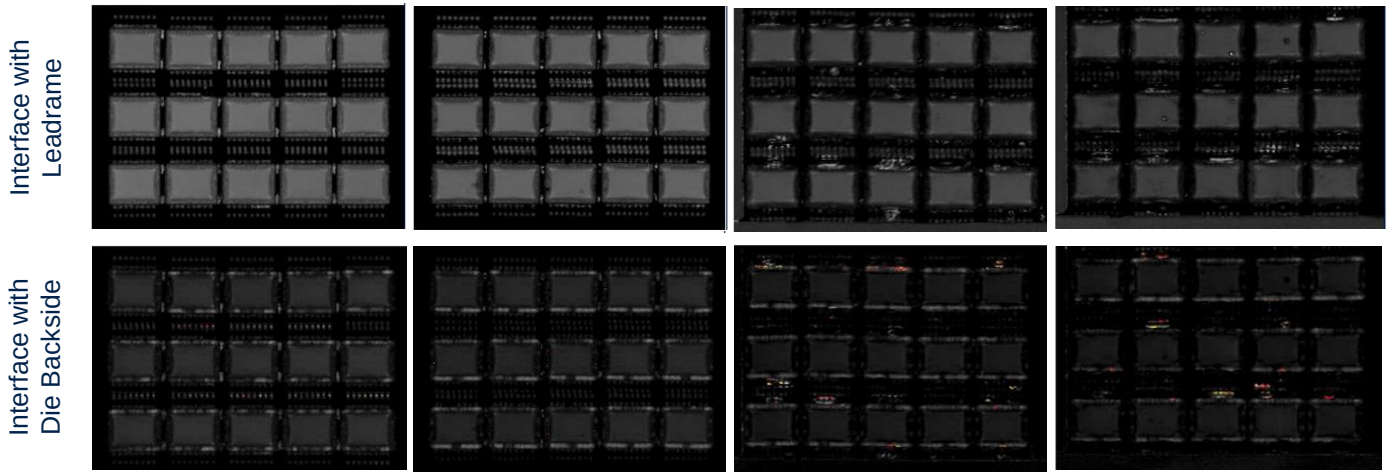
Reliability performances

Test	Method
PC (JSL3) STD	Bake 24 hrs@ 125°C Soak 192 hrs@ 30°C / 60% RH, Reflow Profile = J-STD-020D (T_{max}=260°C)
Thermal Cycling (TC)	TA = -55°C / +150°C 1000 thermal cycles

Ion Milling Cross Sectioning



Bottom C-SAM



- Reliability performances tested on closed units through pre-conditioning followed by 1000TC
- **No significant delamination detected at either the die backside or leadframe interfaces up to JSL3 + 1000TC**
- **Integrity of bond line as well as homogeneity of filler distribution confirmed** by ion milling cross sectioning

Summary and Outlook

Summary and Outlook

Summary

- High lead solders are widely used in power package leadframe-based, but they pose significant environmental and health risks.
- Ag-based pressure-less adhesives are a promising lead-free solution; however, these are challenged by thin die applications due to their tendency of climbing the die vertical sides.
- Rectangular spiral pattern represents an effective dispense strategy able to overcome the main limitations of 2D screen printing, as it is applicable to both 2D and 3D substrates and minimizes the material wastage.

Outlook

- UPH performances is the main limitation of rectangular pattern dispense strategy (process bottleneck).
- The 3.6 x 2.4mm pattern size of the study case results in a UPH value of ~1.6k, increasable up to 2.8k by implementing a second arm in the dispensing system.
- This can pose a limitation from mass production point of view, making the rectangular spiral pattern technique primarily suitable for small to medium die sizes.
- The outlook for Besi, as die attach equipment supplier, is to further improve the UPH when writing a rectangular spiral pattern or to derive a new pattern which can achieve comparable process performances at higher UPH.

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