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Material Characterization and Modeling for Microchip Encapsulation Simulation

STMicroelectronics
Daniela Spini

Moldex3D

. Introduction of STMicroelectronics
. IC Packaging
. Material Characterization
. Chip Encapsulation with Moldex3D
. Outcome

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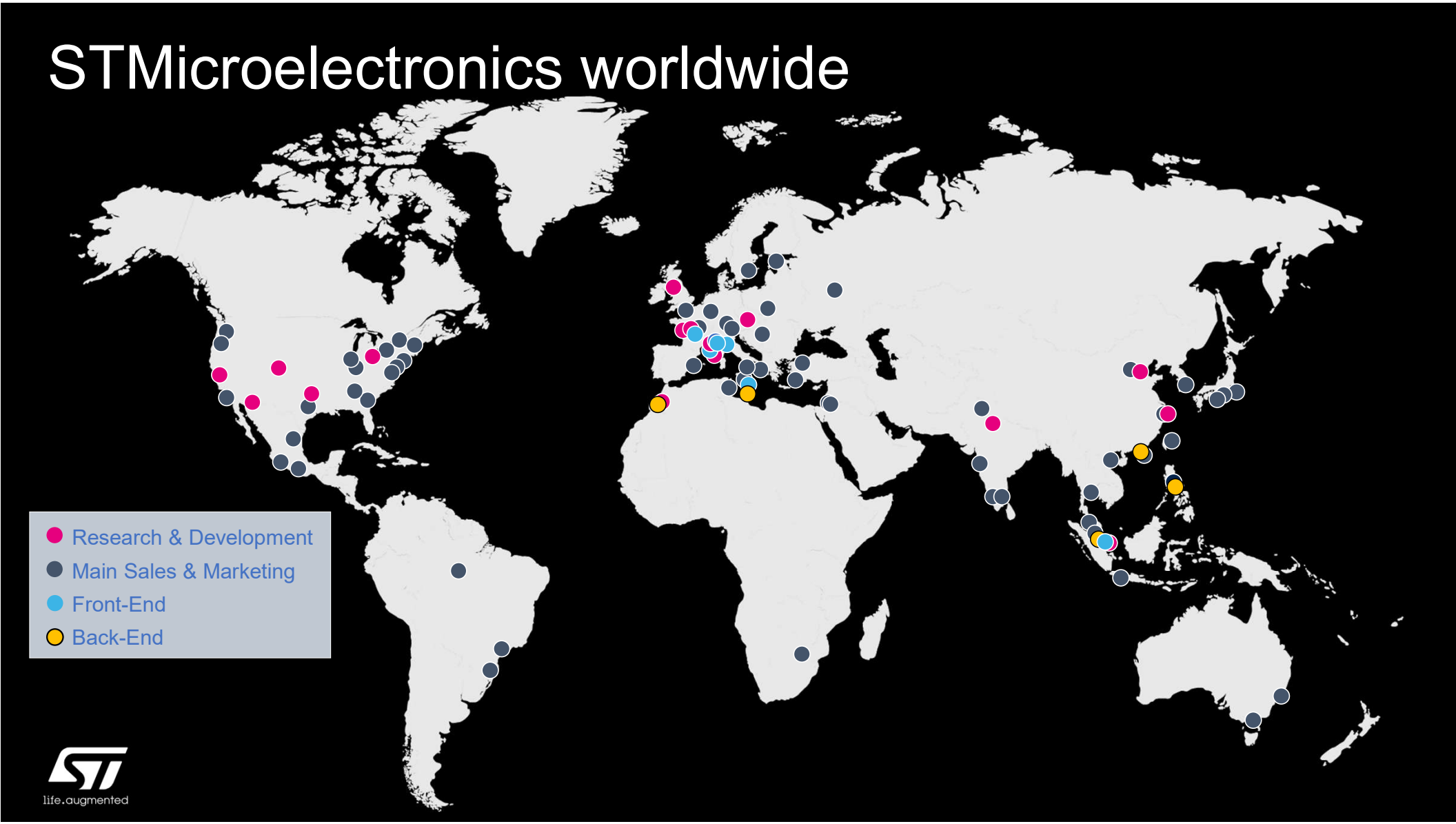
STMicroelectronics: Beyond Semiconductor

STMicroelectronics worldwide



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Our technology stems from long-term strategic enablers

Smart Mobility

ST provides innovative solutions to help our customers make driving **safer, greener and more connected** for everyone

Power & Energy

ST technology and solutions enable customers to increase **energy efficiency** everywhere and support the use of renewable energy sources

Internet of Things & 5G

ST provides **sensors**, **embedded processing solutions**, **connectivity**, **security and power management**, as well as **tools and ecosystems** to make development fast and easy for our customers

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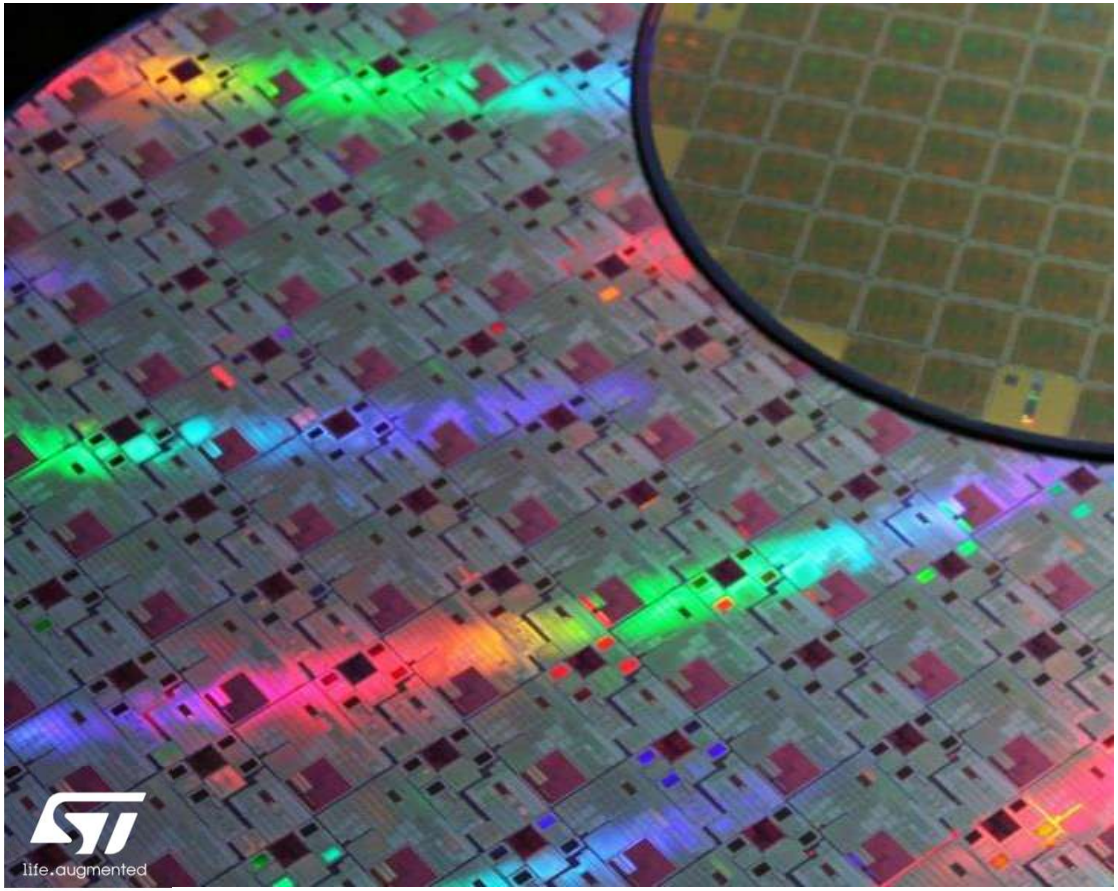
Semiconductor technologies are our foundation



Dedicated Automotive ICs

Discrete & Power Transistors

Analog, Industrial & Power Conversion ICs

MEMS & Optical sensing solutions

GP MCU & MPU, Secure MCUs

ASICs based on ST technologies

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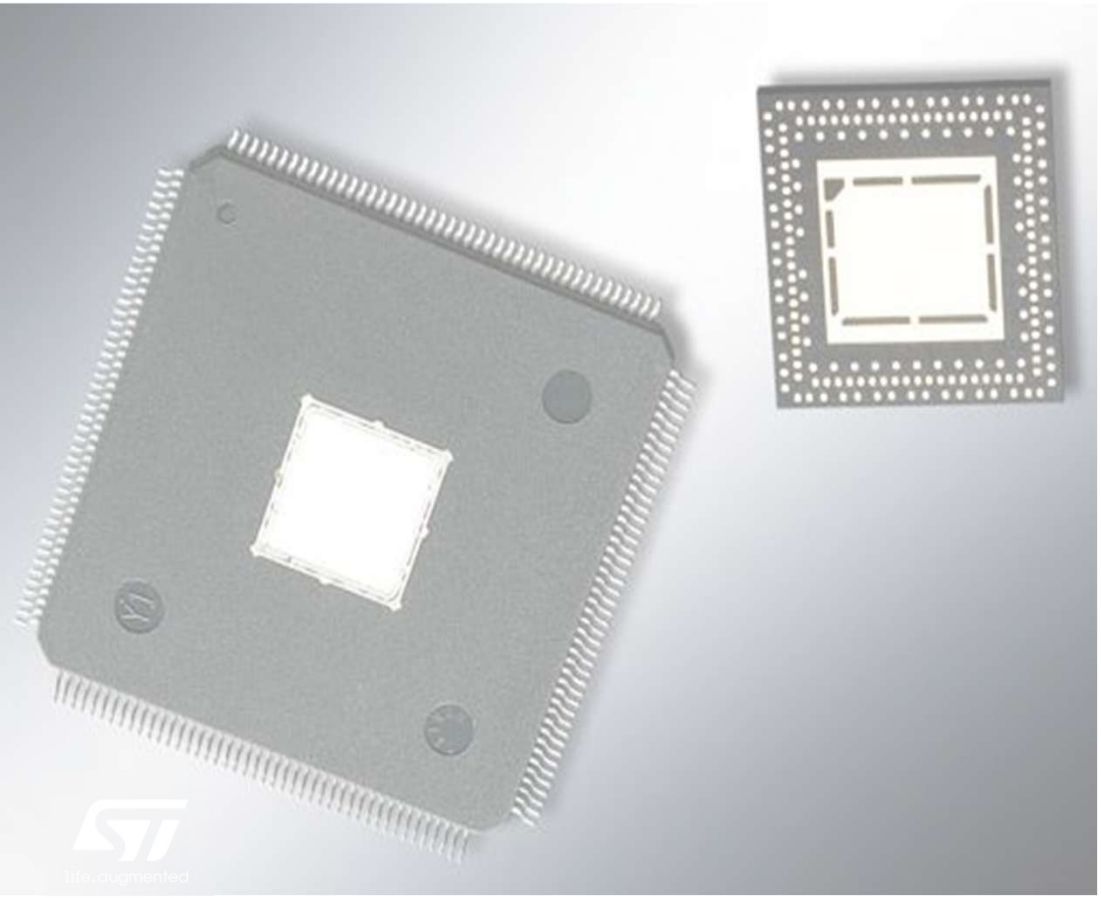
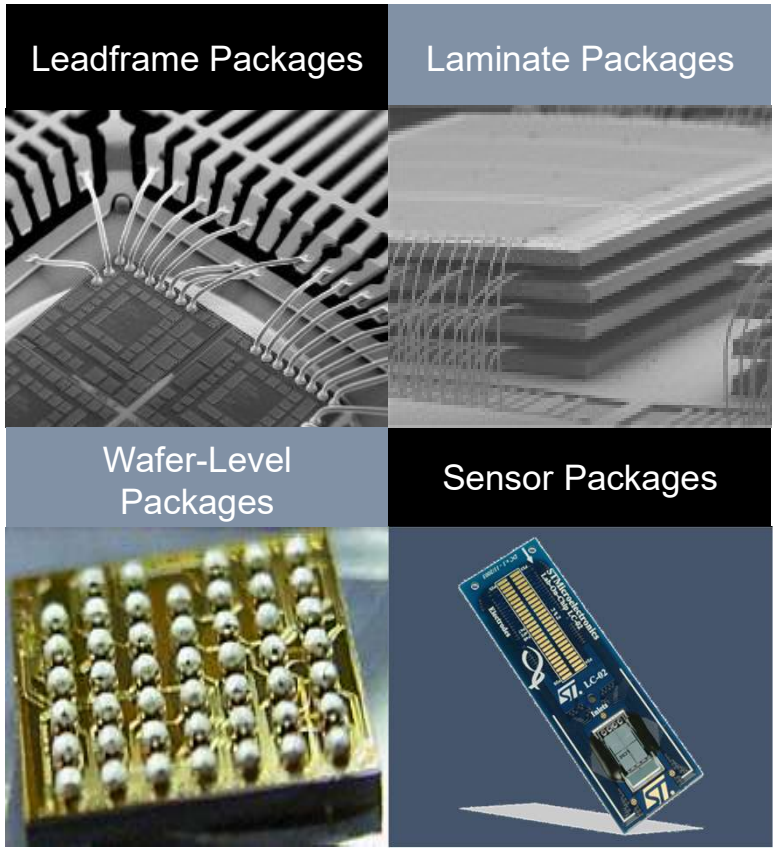
Packaging technologies are our future



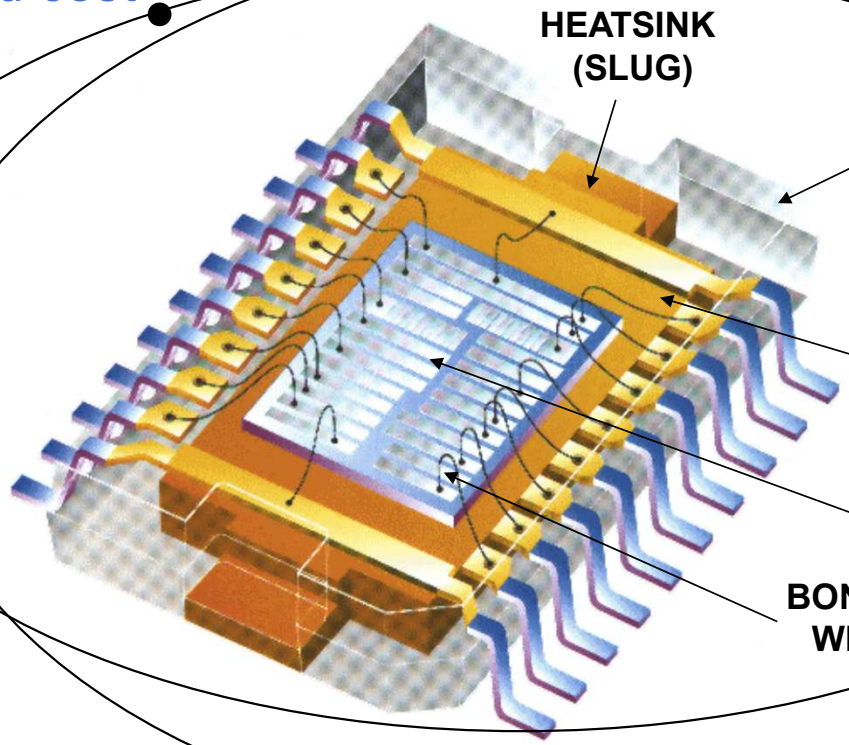


About myself

- Modeling and Characterization Engineer
  - Advanced laboratory experiments on materials for IC packaging
  - Molding process modeling for R&D activity
  - MSc in Material and Nanotechnology Engineering

IC Packaging

What's a package in microelectronics?



An added cost

A piece of plastic

A problem

A technology

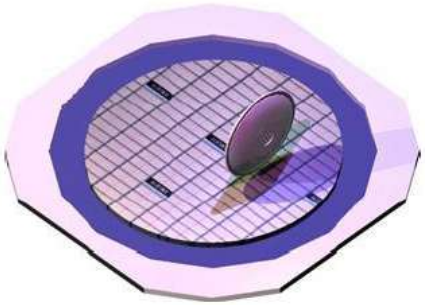
A system

A protection

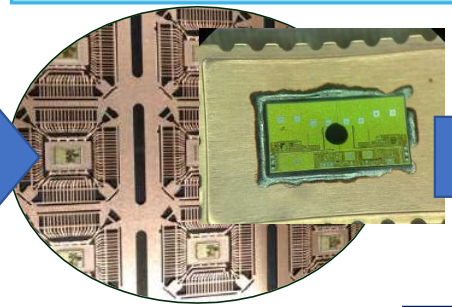
An electrical interconnection

Packaging assembly process flow

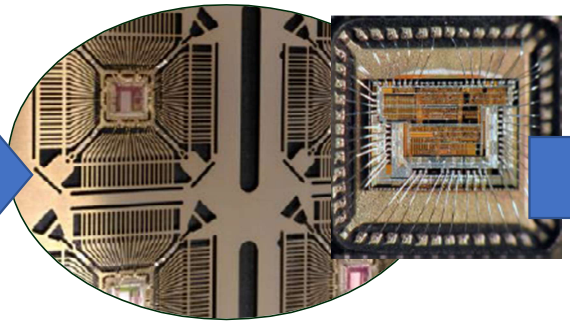
Wafer sawing



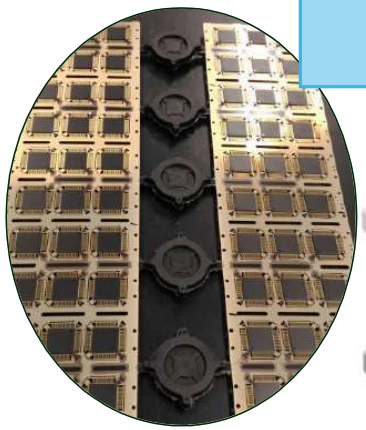
Die attach on leadframe

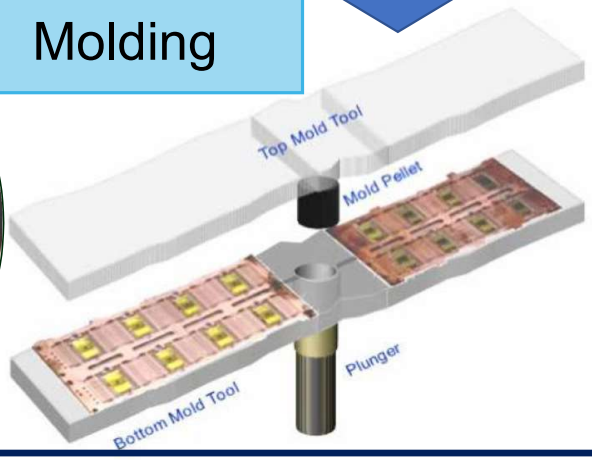


Wire bonding

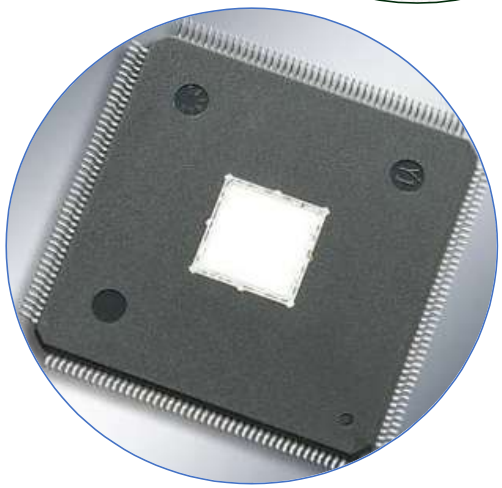


Molding

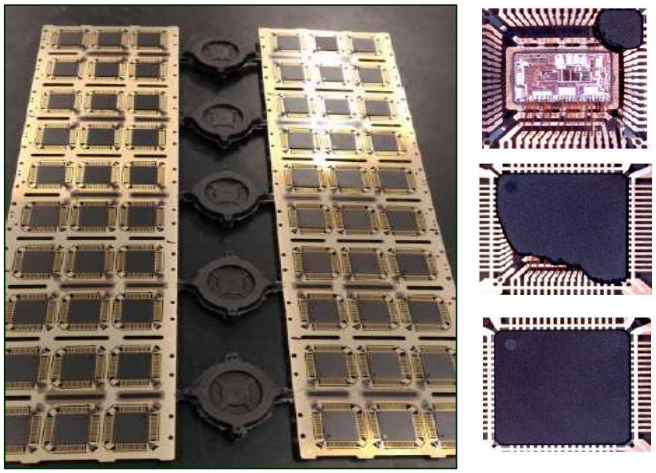


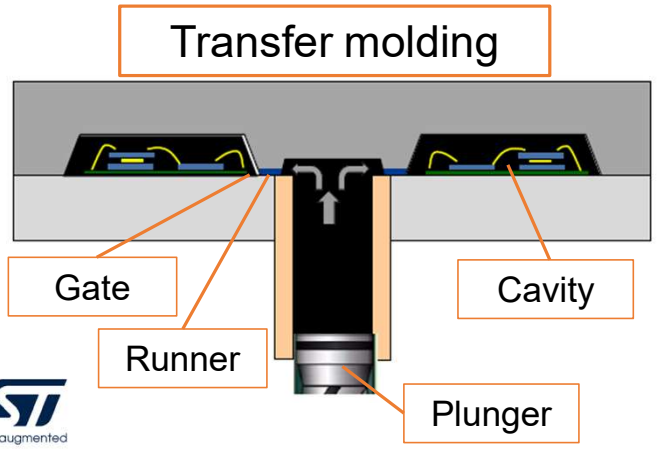


Final product



Molding process





- Molding is the process of microchip encapsulation within a mold cavity by epoxy molding compound (EMC) injection
- EMC is a combination of organic (thermoset polymer) and inorganic (silica filler)

What does EMC provide?

- Protection of the die from any damage and contamination
- Package structural and mechanical stability
- Create a barrier to limit the corrosion
- Low-cost manufacturing

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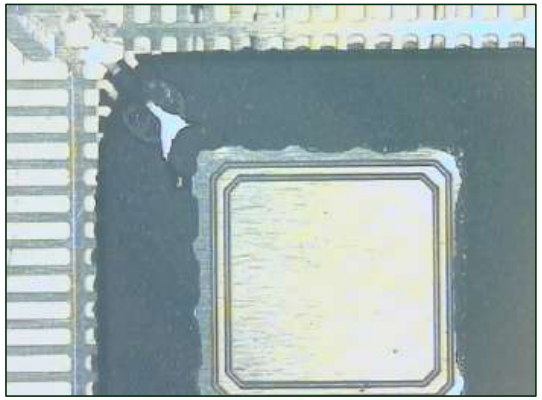
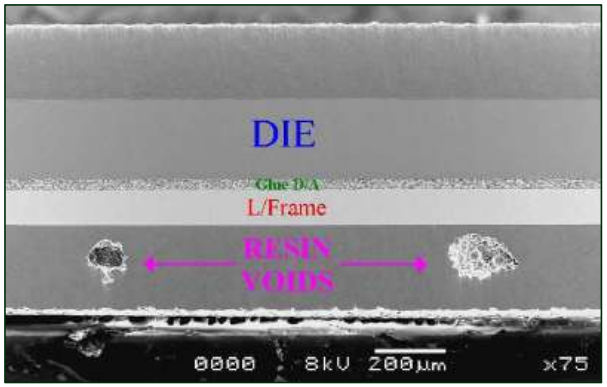
Molding process

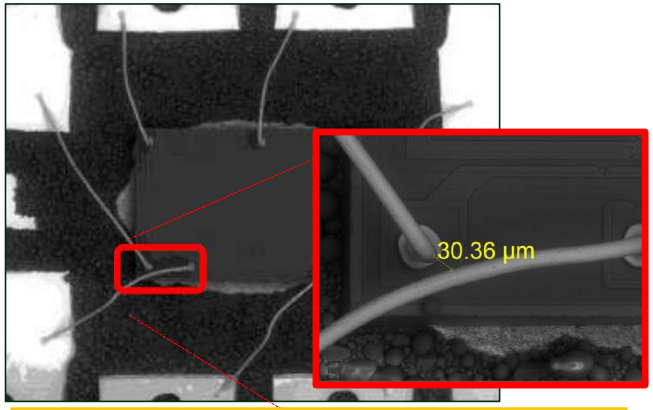
Typical reliability issues caused by molding process which led to production loss and/or customer complaint



Incomplete filling



Internal voids



Wire sweeping and crossing

It's time to predict molding defects by acting on:

- Process parameters
- Material properties
- Leadframe/cavity design

Modeling with **Moldex3D IC Packaging**

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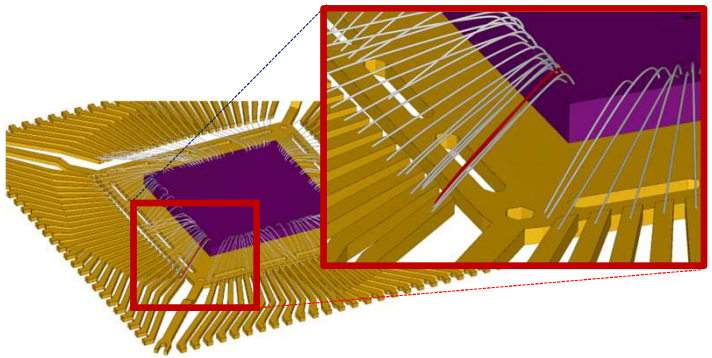
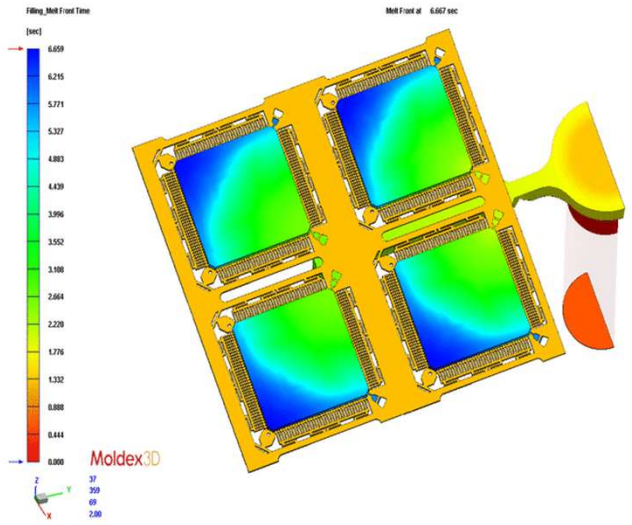
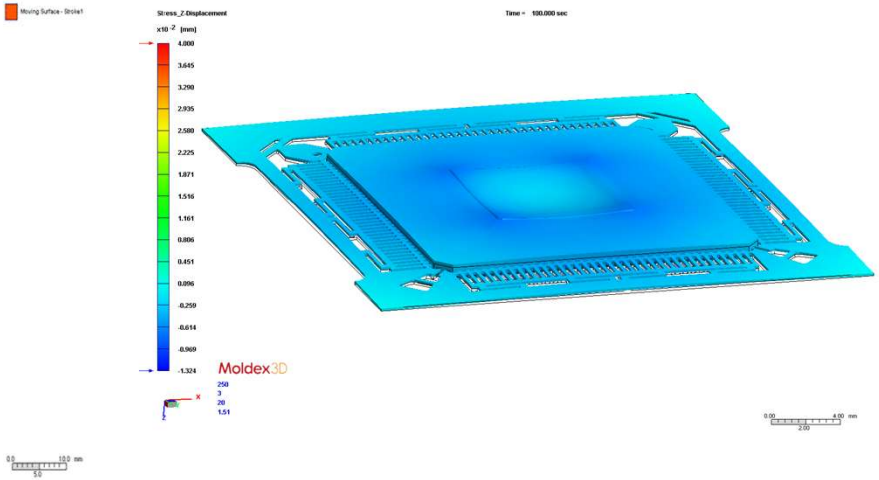
Moldex3D IC Packaging

- Simulation of the process of chip encapsulation with EMC from leadframe to chip, including wire bonding
- The process is relatively important for the advance variation of filling, curing phenomenon simulation, and further warpage



- Challenges:
  - Incomplete filling
  - Wire sweep
  - Paddle shift
  - Warpage





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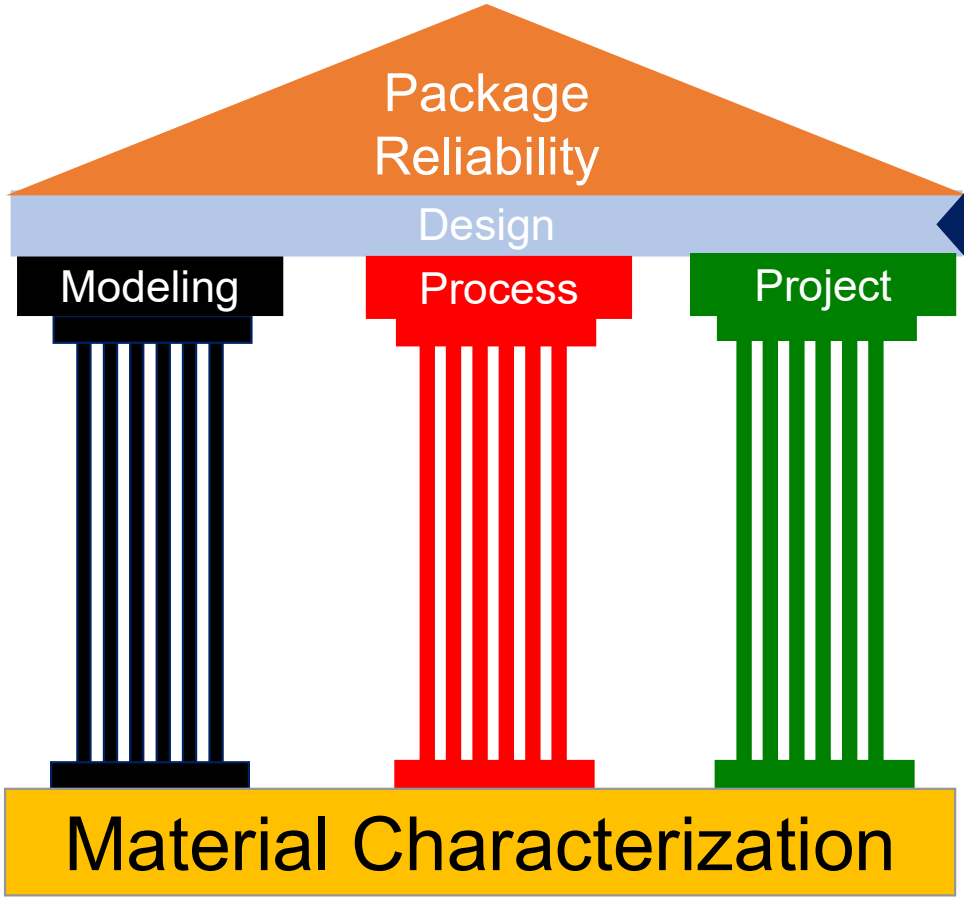
Material Characterization

Why investigate materials for IC packaging?



- Basis for package development
- Input for predictive models
- Understanding of failure mechanisms
- Equipment/methods “state-of-the-art”
- Control assembly processes
- Clearness in project management
- Design optimization

Key enabler for **anticipating** failures and **improve** reliability

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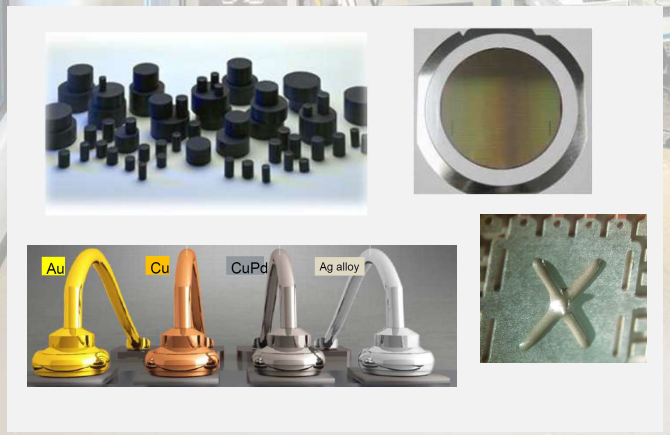
How we do material characterization?

- Characterization of packaging materials
  - Thermal
  - Thermo-mechanical
  - Rheological
  - Morphological

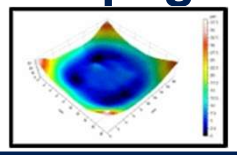


Material Laboratory

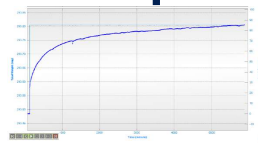
Mechanical Testing

Thermal Analysis

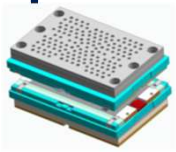
Dynamic Warpage



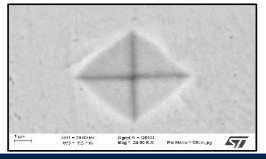
Humidity Absorption



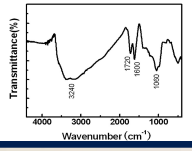
Sample Preparation



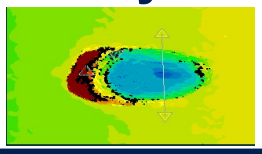
Material Hardness



Material Recognition

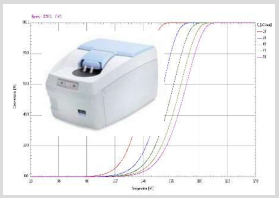


Surface Analysis

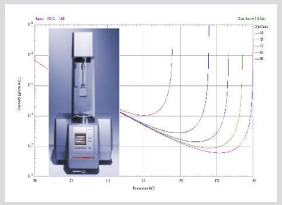


From resin characterization to Moldex3D

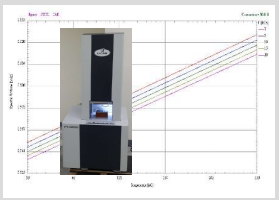
RHEOLOGY



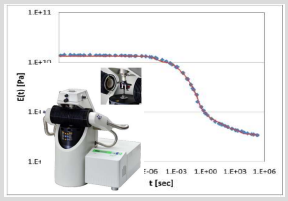
Curing kinetics (R)



Viscosity (τ, u)



P-V-T-C (V, T, p)



Visco-elasticity (E)

CONTINUUM

Thermal conductivity (k)

Heat capacity (C_p)

Thermal expansion (CTE, T_g)

MODELING

Mass balance

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

Momentum balance

$$\rho \frac{D\mathbf{u}}{Dt} = \nabla \cdot \boldsymbol{\tau} - \nabla p + \rho g$$

Energy balance

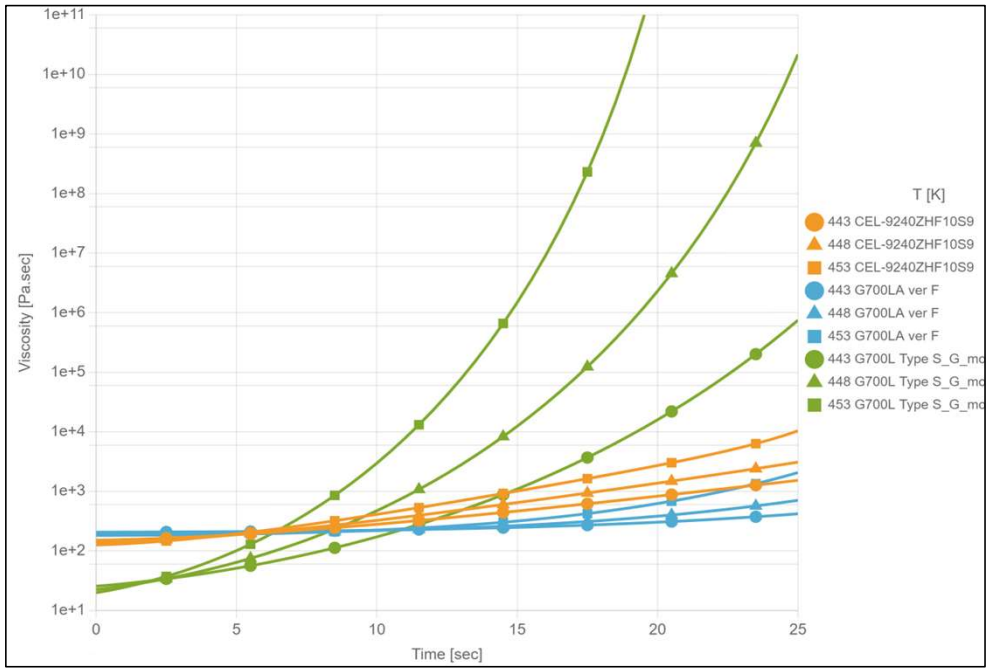
$$\rho C_p \left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \nabla \cdot k \nabla T - \tau : \dot{\gamma} + S$$

Thermoset conversion balance

$$\dot{X} + \nabla \cdot j + R = 0$$

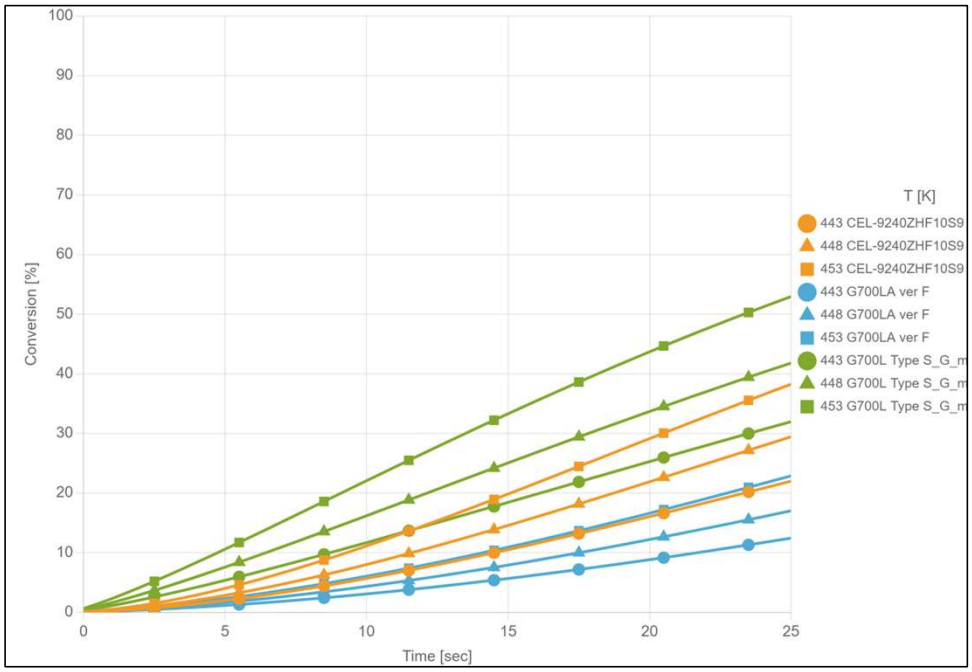
Moldex3D material models

Viscosity



Process window for EMC filling

Curing kinetics

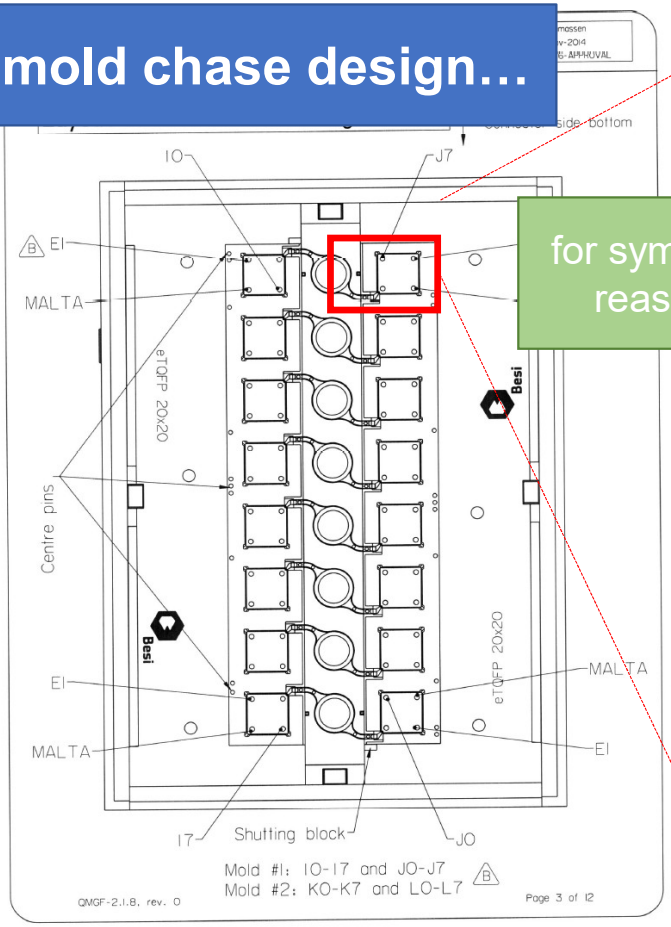


Degree of polymerization of EMC

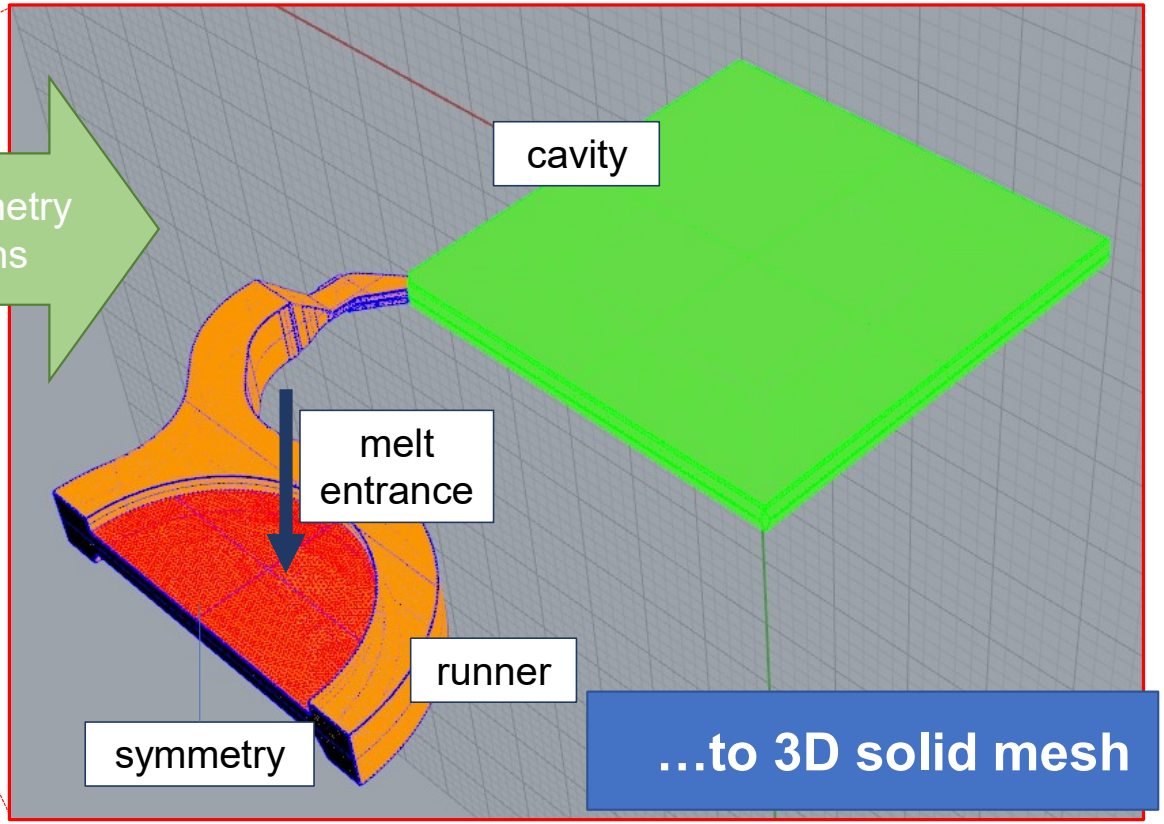
Chip Encapsulation with Moldex3D

Need for 3D model

From mold chase design…



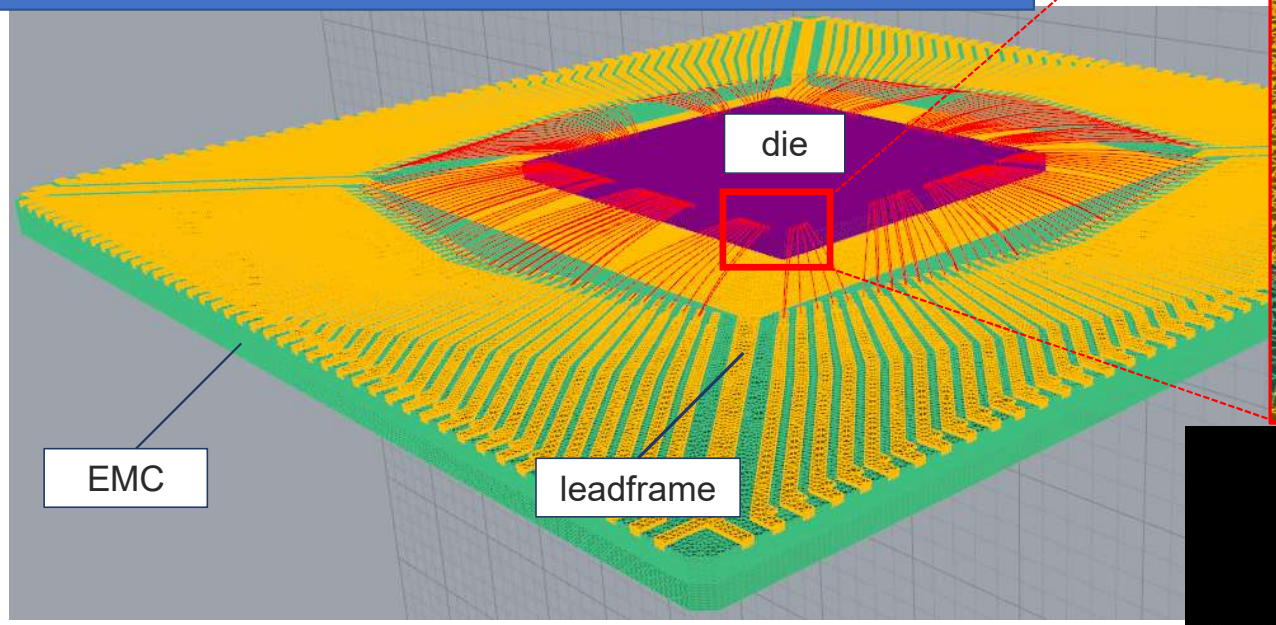
for symmetry reasons

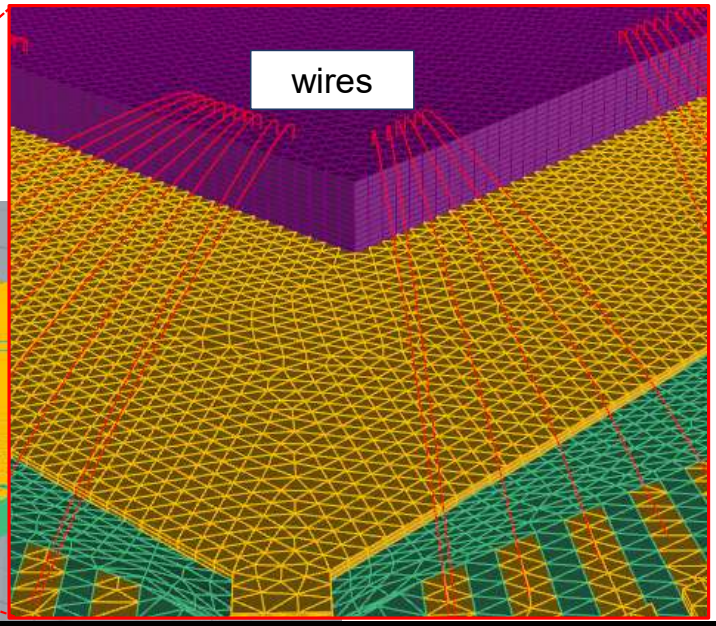


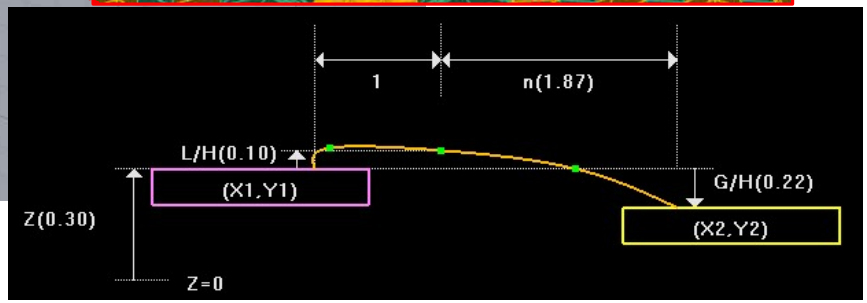
…to 3D solid mesh

Need for 3D model

Solid mesh details and wire bonding







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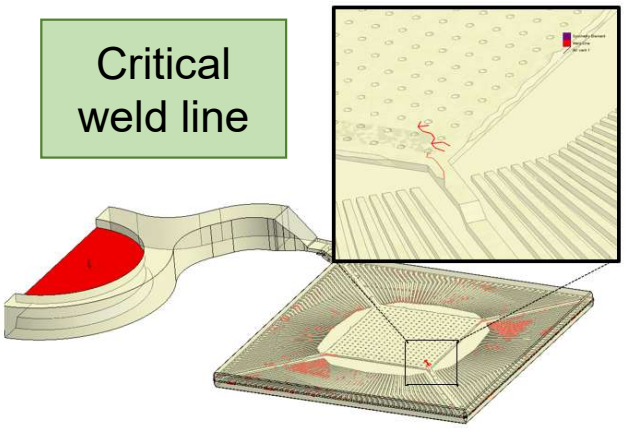
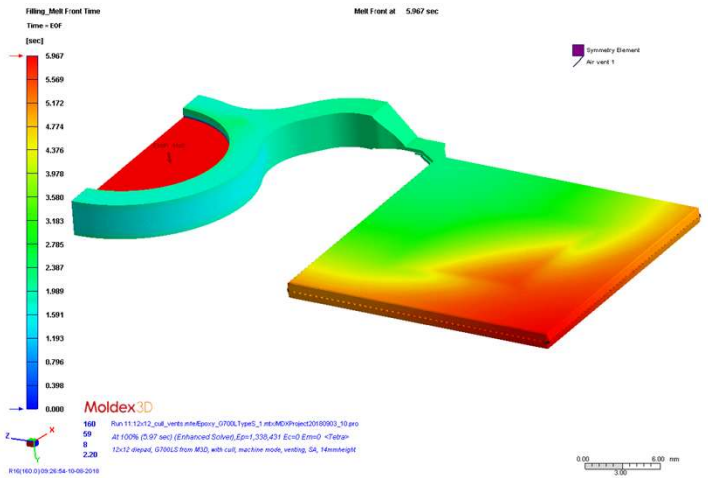
Filling process

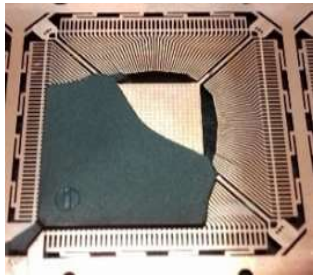
- EMC filling anticipation for
  - Improving packaging quality and optimizing molding process
  - Ensuring moldability and increasing package design reliability
  - Preventing potential defects (weld lines, voids)
  - Enabling venting analysis to solve air traps

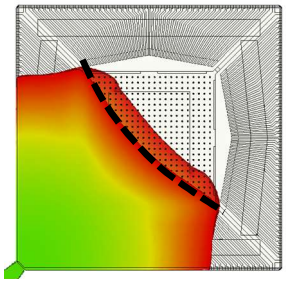
- Model validation by comparison with short shot experiments

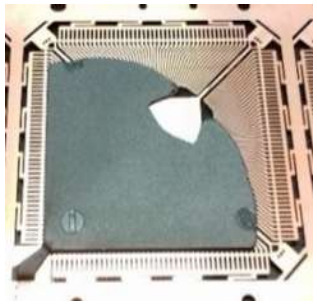
Critical weld line

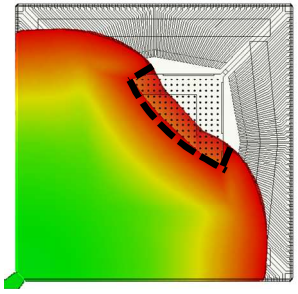




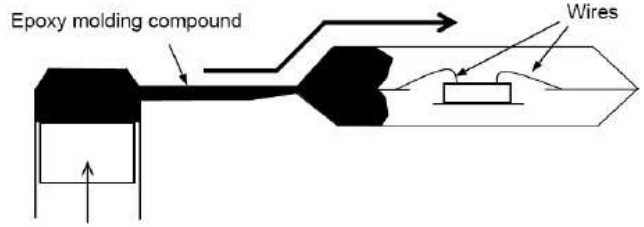


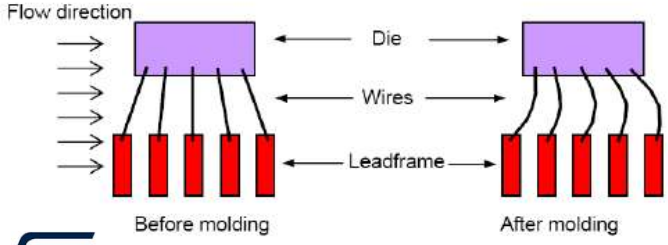






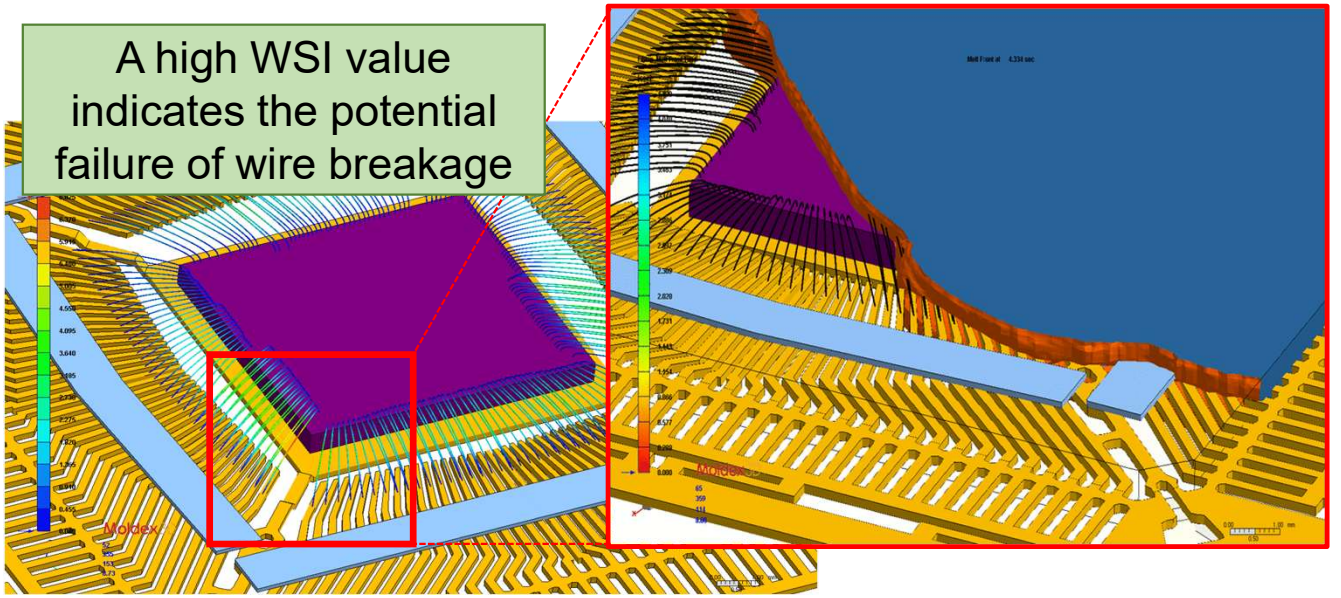
What's happening to wires?





- Efficient prediction of the excessive amount of wires deformation during EMC flow
- Significant indicator of wire structure optimization (wire sweeping index – WSI)

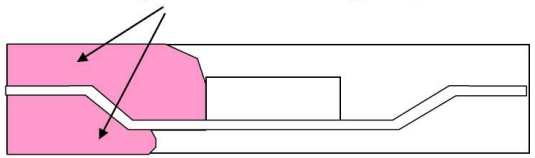
A high WSI value indicates the potential failure of wire breakage



Is die pad tilting?

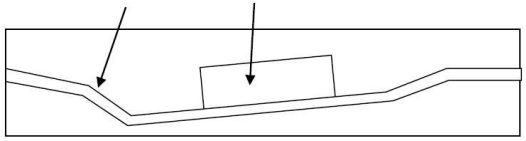
- Reproduction of die pad tilt effect due to unbalanced pressure loading from EMC flow during encapsulation
- Interaction between fluid and structure during EMC filling analysis

Unbalanced pressure loading from EMC flow



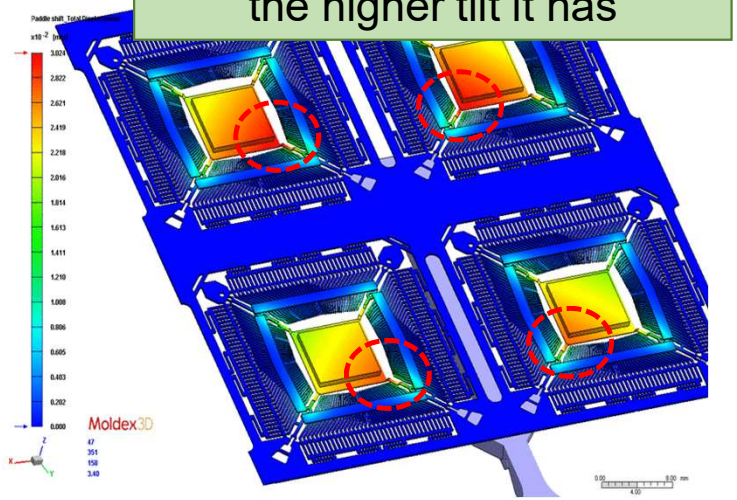
(a) Before deflection

Leadframe Chip

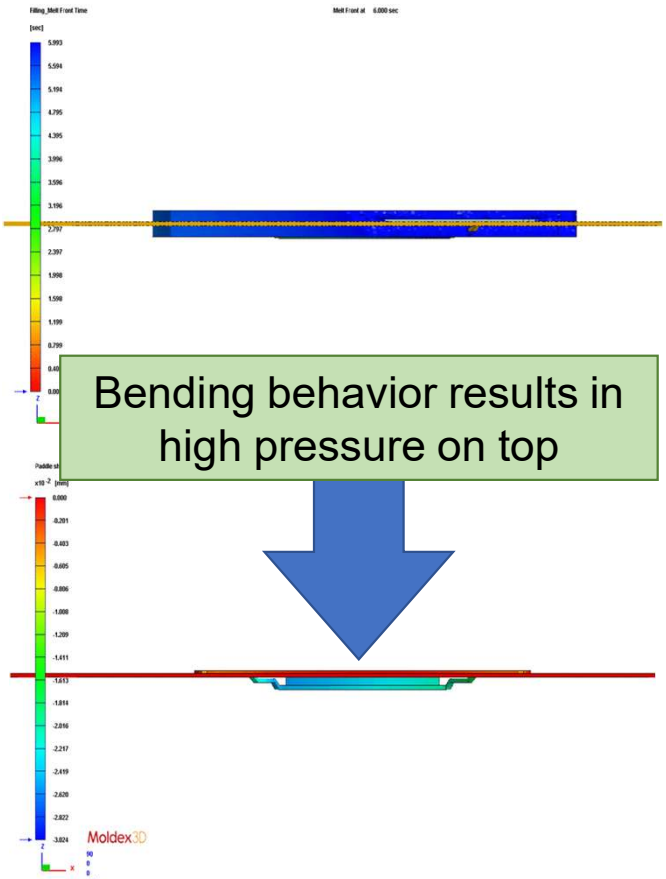


(b) After deflection

The closer to the gate area, the higher tilt it has

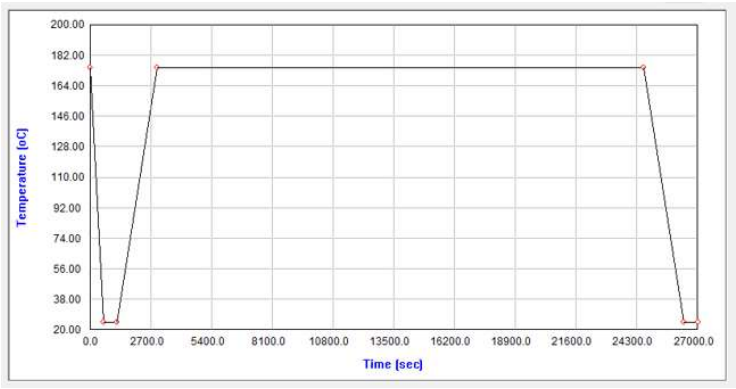


Bending behavior results in high pressure on top

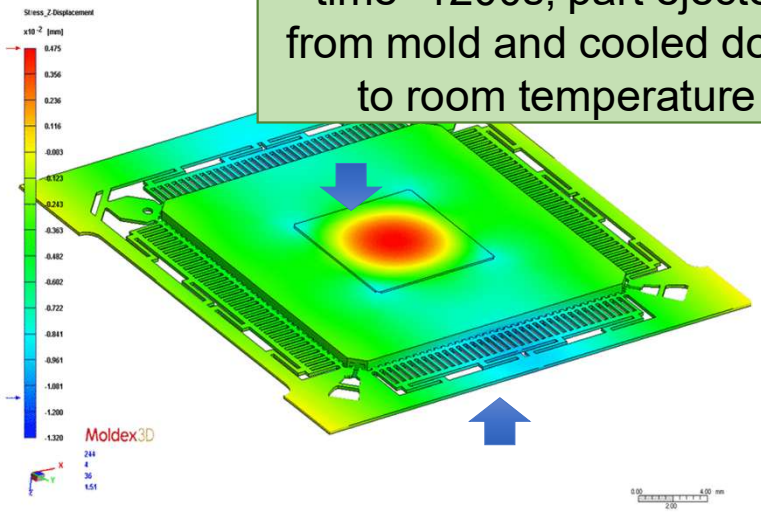


What about deformation?

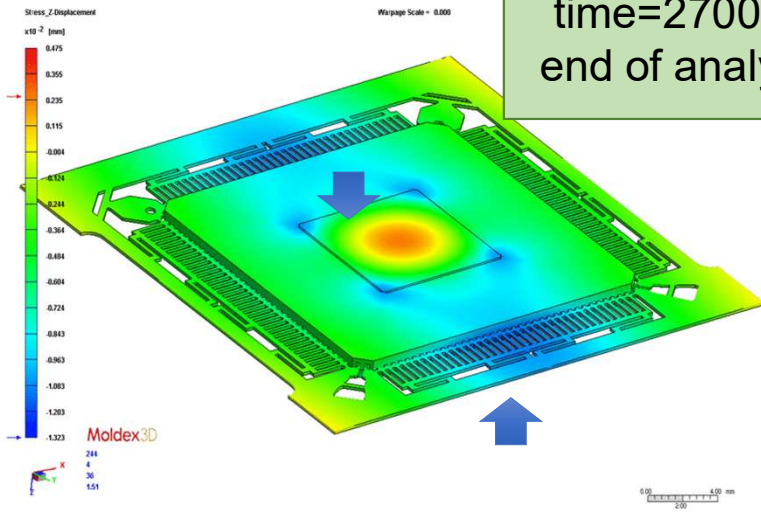
- Reproduction of warpage in different steps for package warpage validation in IC encapsulation process:
  - After in-mold curing
  - After post mold curing condition



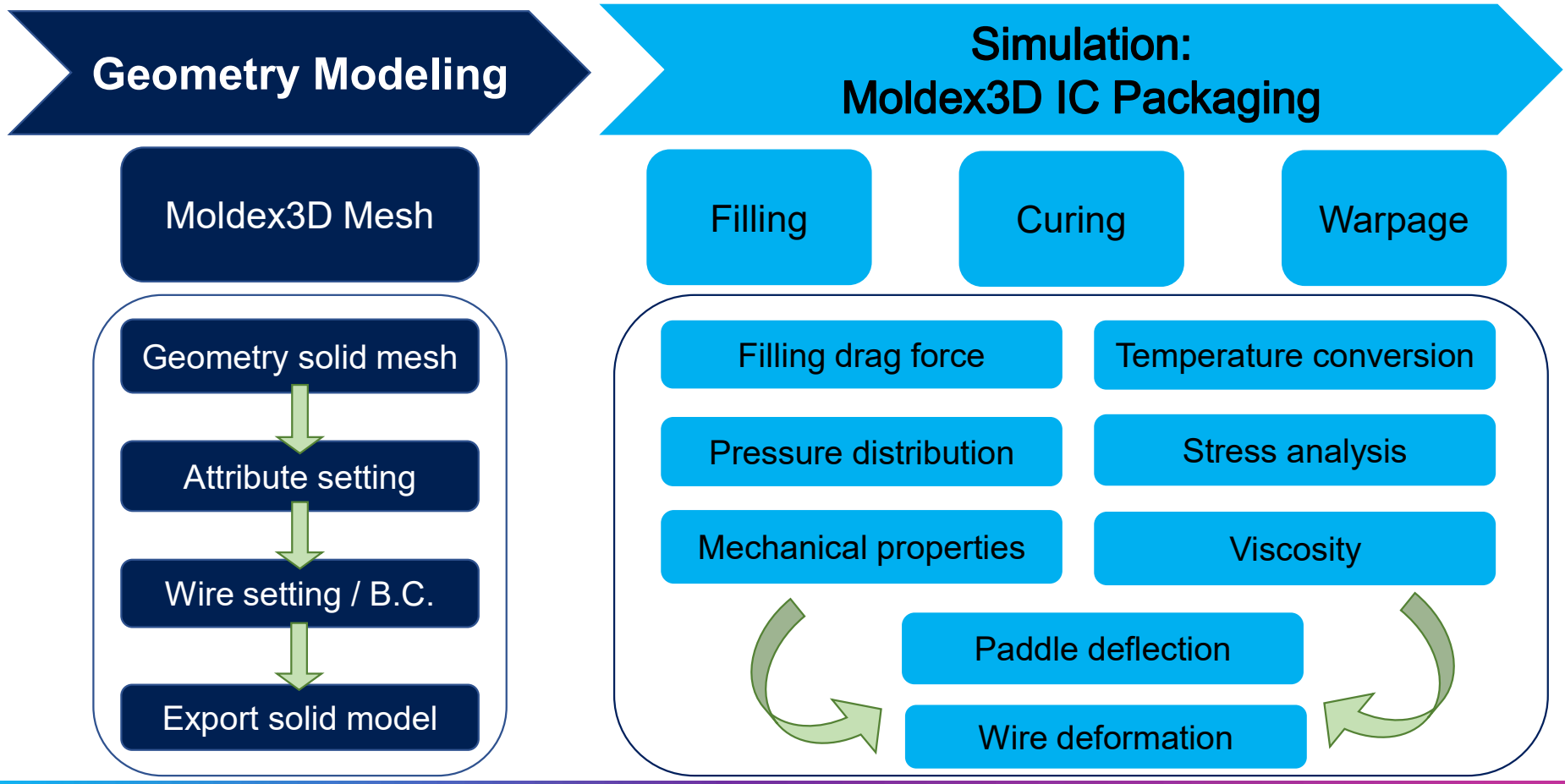
time=1200s, part ejected from mold and cooled down to room temperature



time=27000s, end of analysis



Workflow


Geometry Modeling
Simulation:
Moldex3D IC Packaging
Moldex3D Mesh
Filling
Curing
Warpage
Geometry solid mesh
Attribute setting
Wire setting / B.C.
Export solid model
Filling drag force
Temperature conversion
Pressure distribution
Stress analysis
Mechanical properties
Viscosity
Paddle deflection
Wire deformation

Outcome

mid Moulding Innovation Day 2025

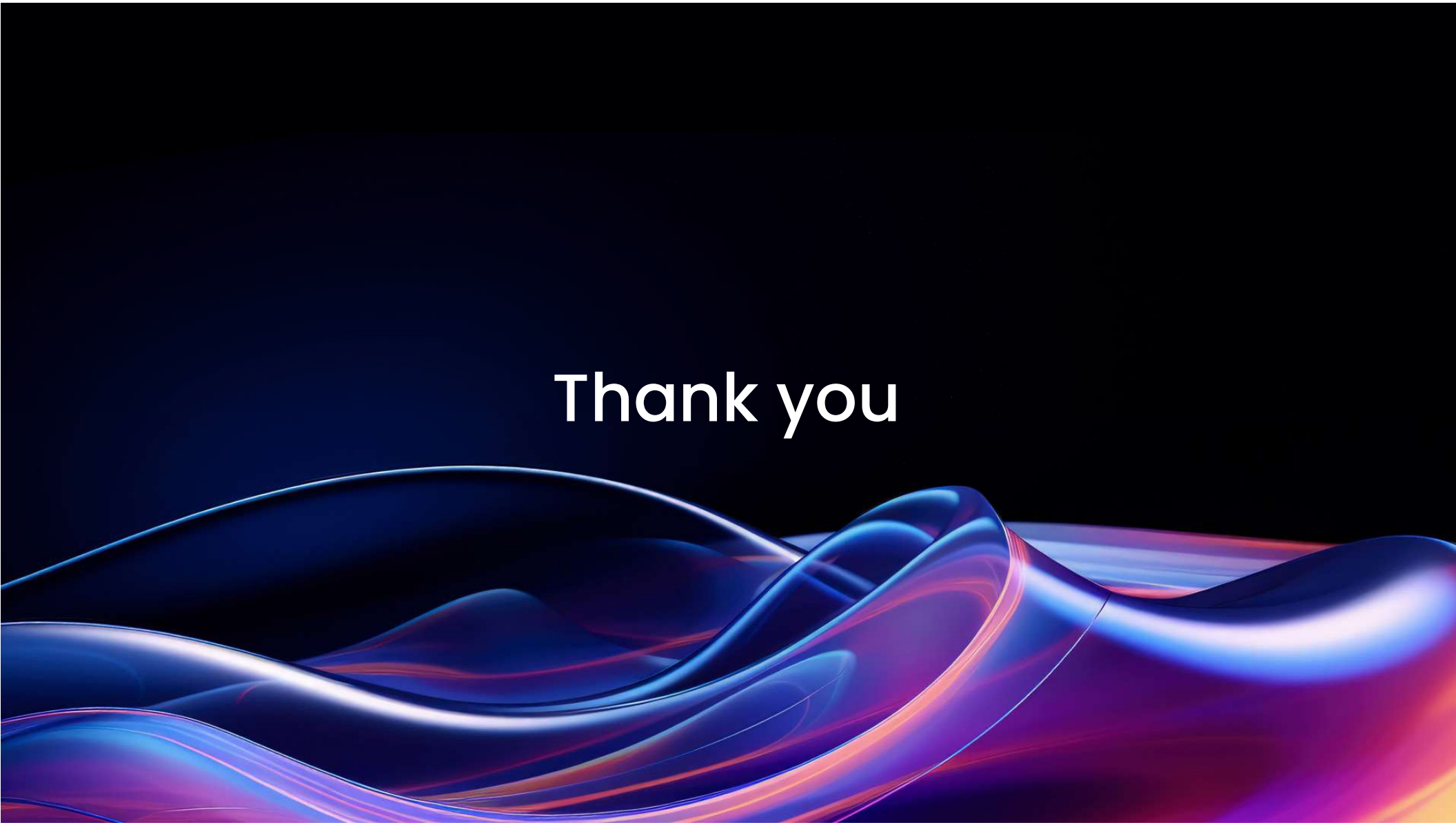
Outcome

- Material characterization has a key role in IC package development
- Experimental activity on package materials
- EMC characterization
  - ✓ Thermal
  - ✓ Thermo-mechanical
  - ✓ Rheological

- Chip encapsulation with Moldex3D
- Modeling activity requires strong knowledge of EMC properties in order to better reproduce:
  - ✓ EMC filling behavior
  - ✓ Wire deformation during encapsulation
  - ✓ Paddle shift cause by unbalanced flow
  - ✓ Warpage during post mold curing

Anticipation of process flow
Improvement of package reliability

life.augmented


Thank you