mid Moulding Innovation Day 2024

Warpage Issue in Chip Encapsulation

STMicroelectronics
Daniela Spini

Moldex3D

Agenda

1. Introduction of STMicroelectronics
2. IC packaging
3. Warpage issue
4. Methodology
5. Chip encapsulation simulations and results
6. Conclusion

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STMicroelectronics: Beyond Semiconductor

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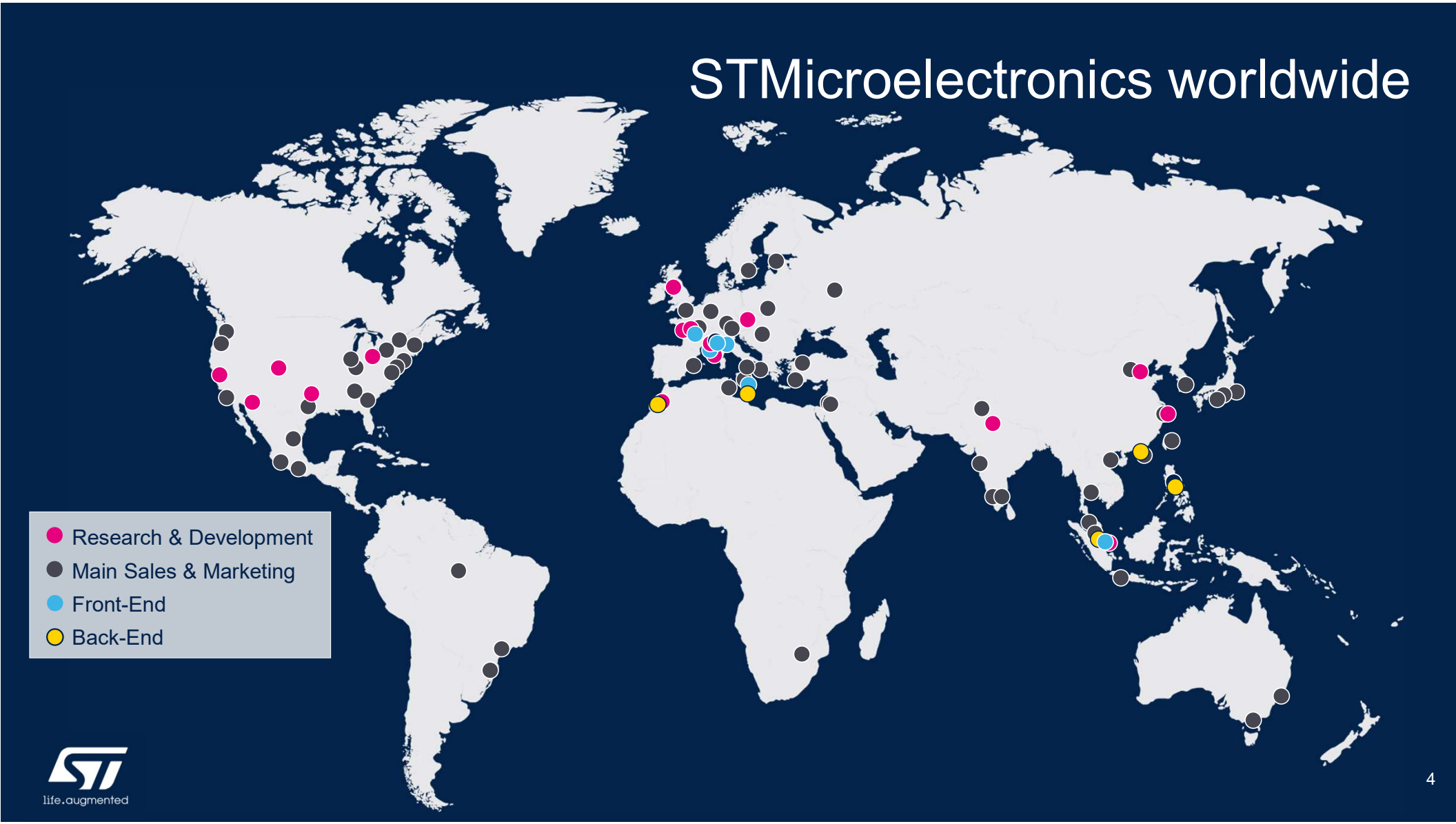
STMicroelectronics worldwide



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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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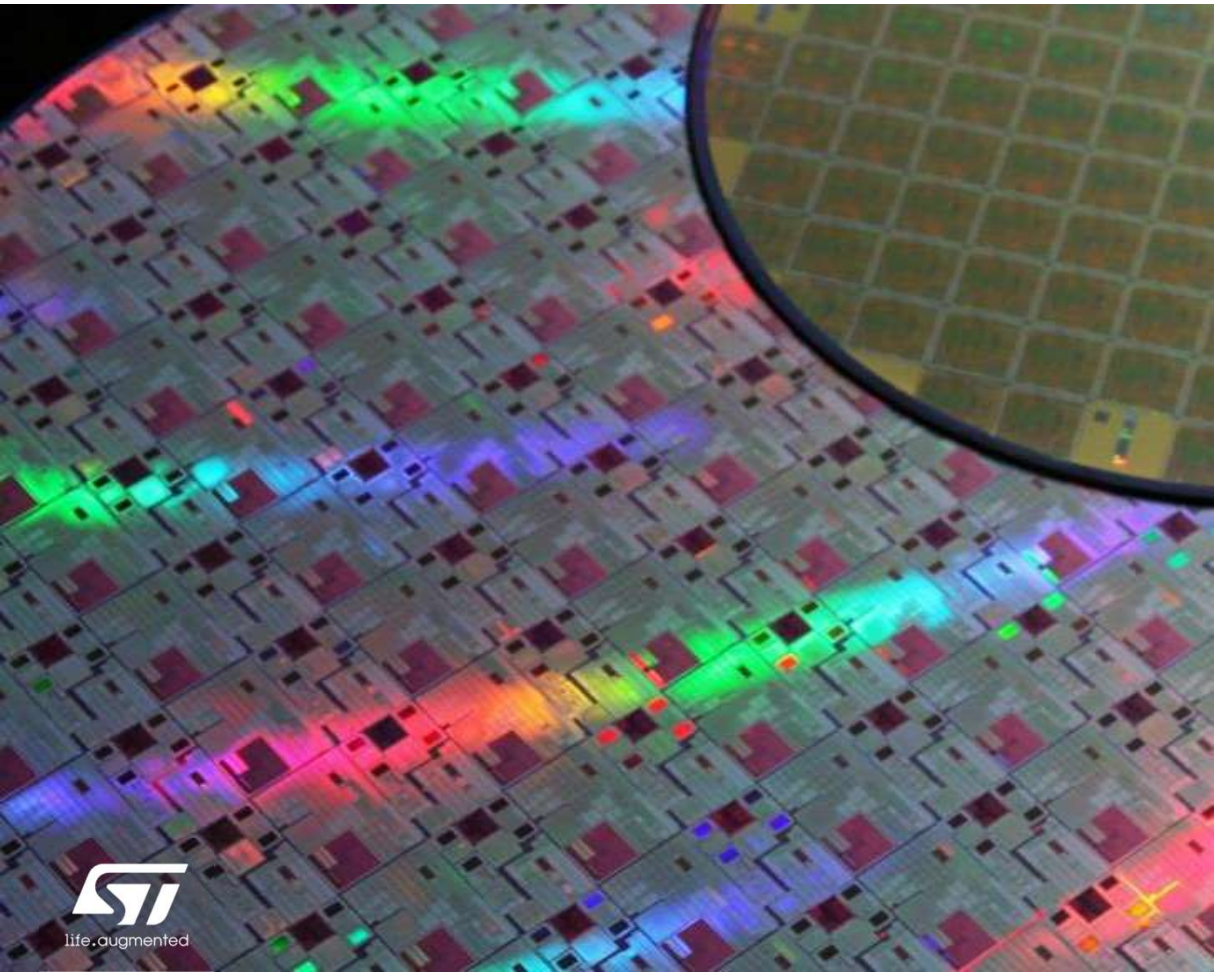
Semiconductor technologies are our foundation



Dedicated Automotive ICs

Discrete & Power Transistors

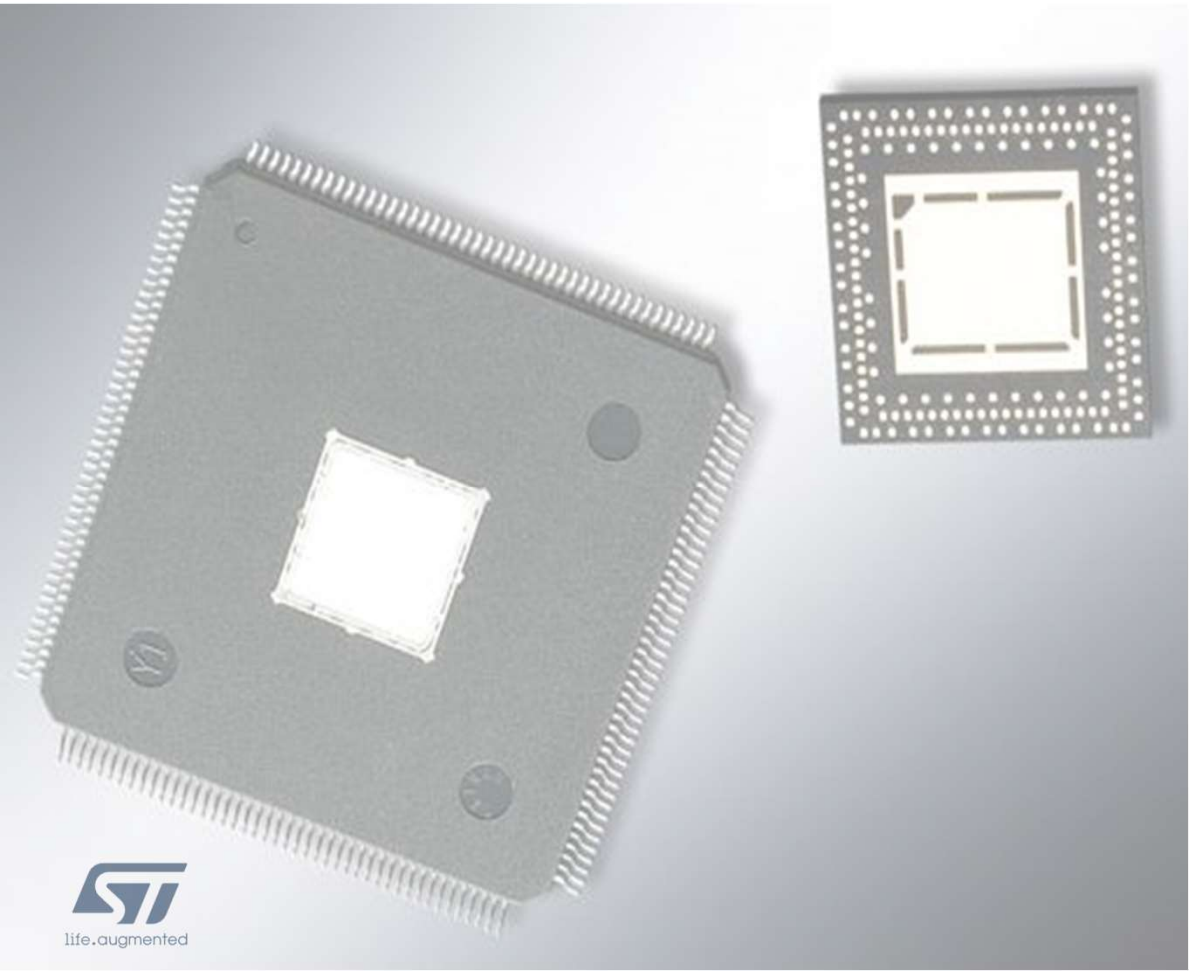
Analog, Industrial & Power Conversion ICs

MEMS & Optical sensing solutions

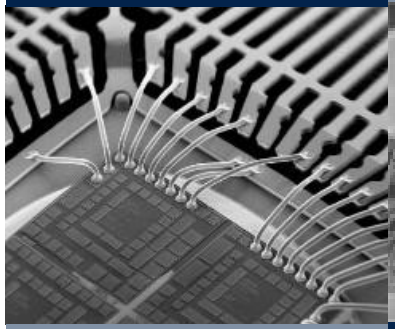
GP MCU & MPU, Secure MCUs

ASICs based on ST technologies

Packaging technologies are our future



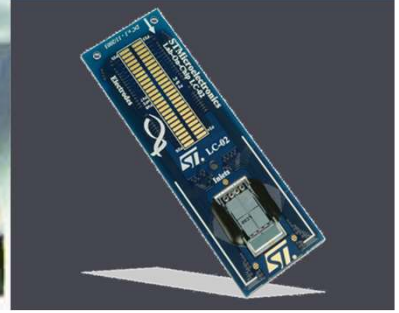
Leadframe Packages



Laminate Packages

Wafer-Level Packages

Sensor Packages



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

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IC Packaging

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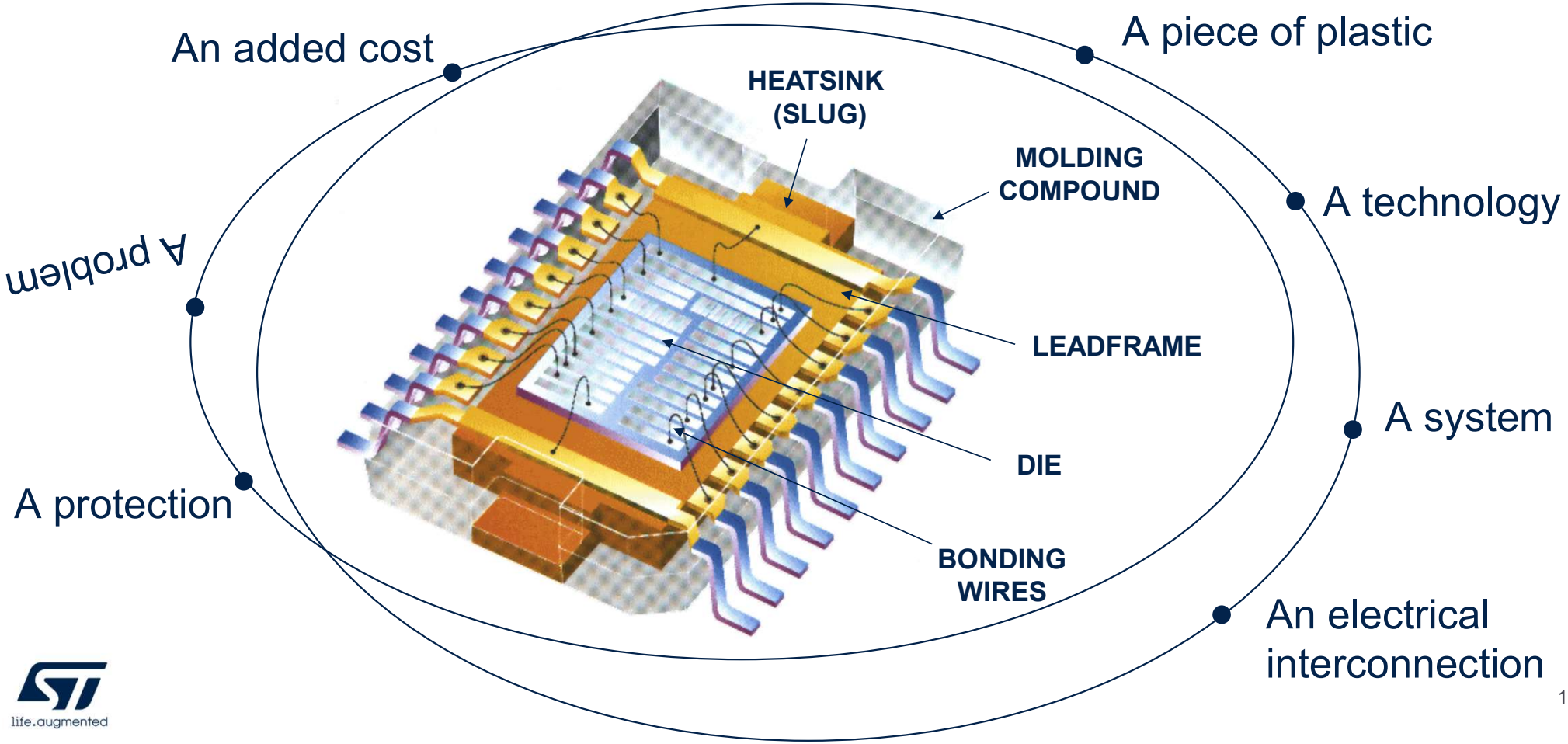
What's a package in microelectronics?



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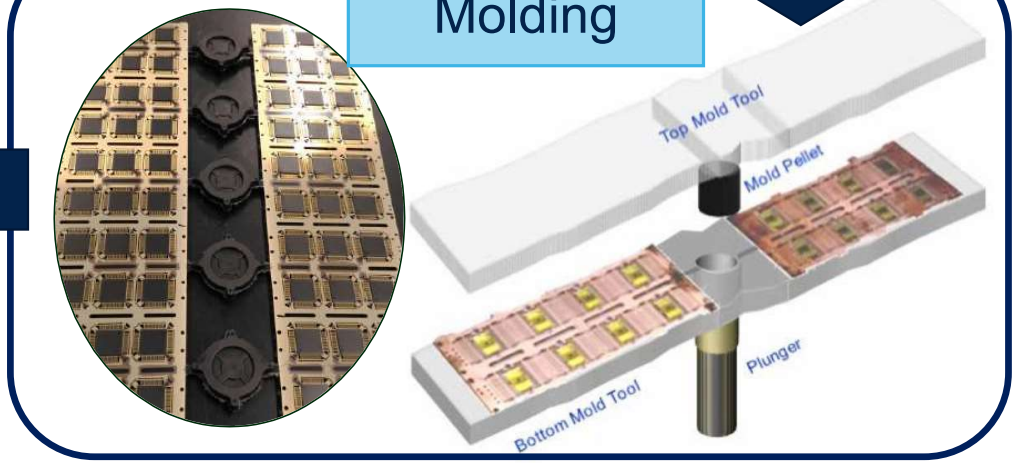
Packaging assembly process flow

Wafer sawing

Die attach on leadframe

Wire bonding

Molding



Final product

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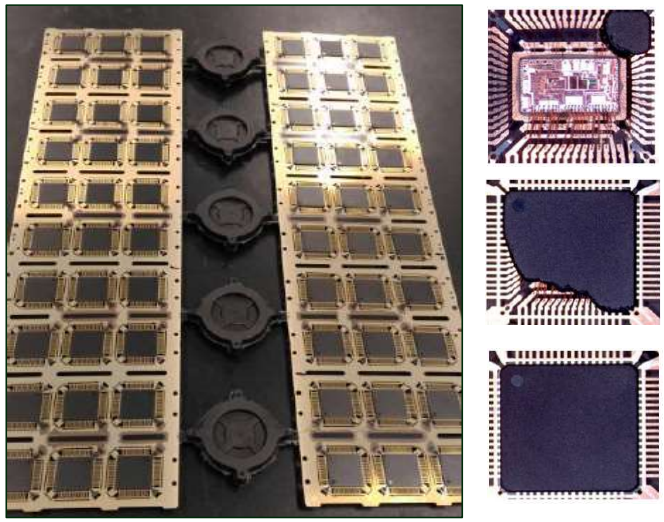
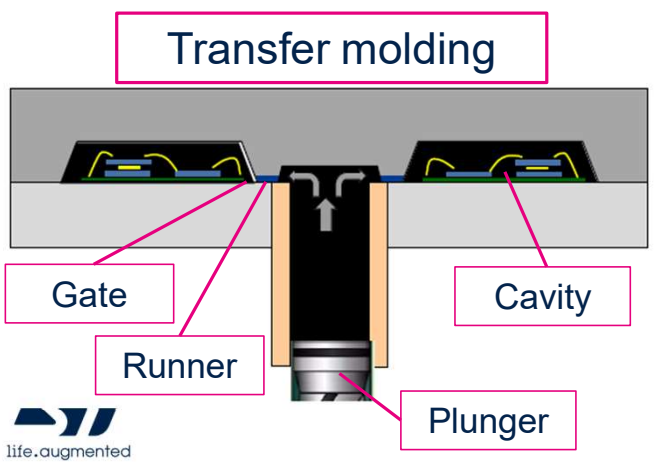
Molding process





- 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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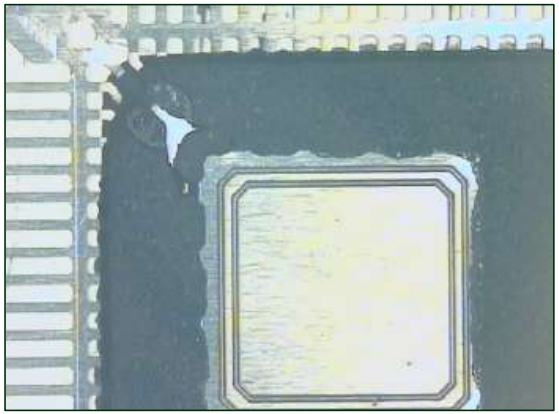
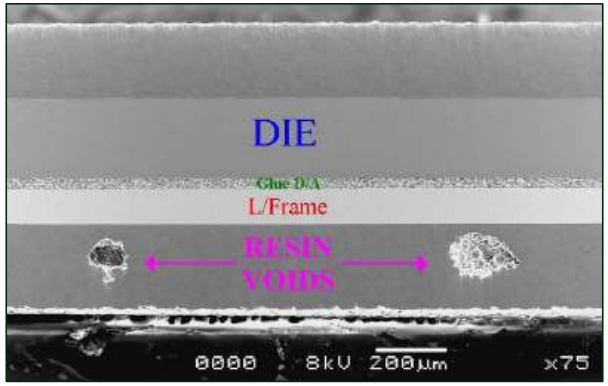
Molding process

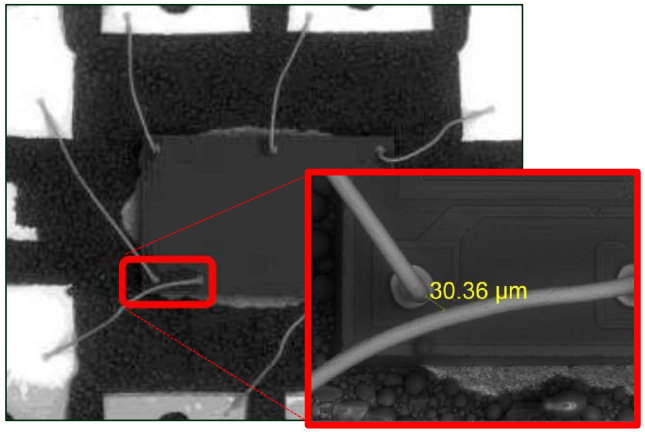
Typical reliability issues caused by molding process which led to production loss and/or customer complaint



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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Warpage issue

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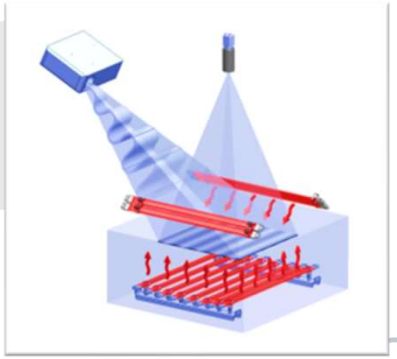
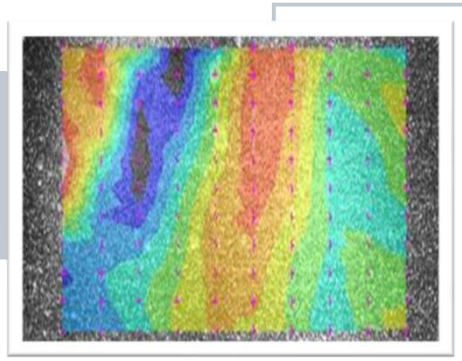
Warpage issue

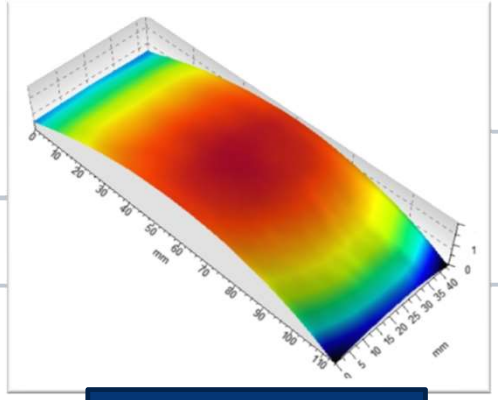
Causes

Thermal gradient



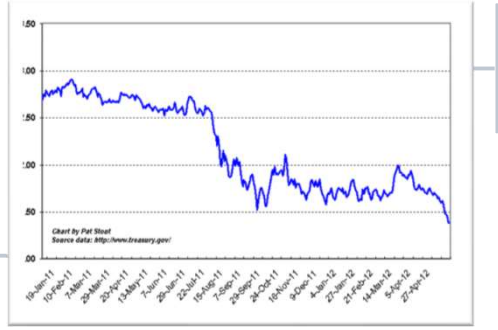
Thermal mismatch



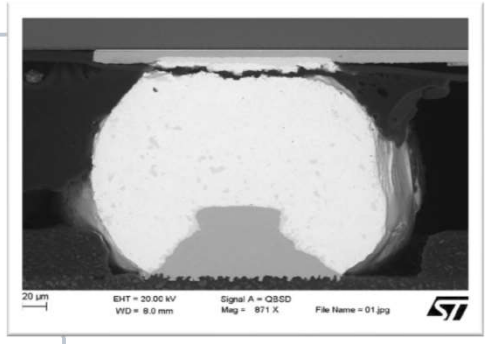


Warpage

Consequences



Yield loss



Reliability issue

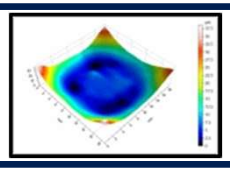
How do we face it?

Material characterization

Thermal Expansion

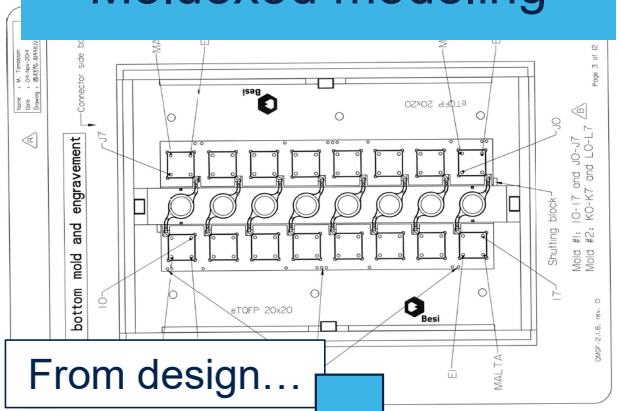
Mechanical testing

Dynamic Mechanics

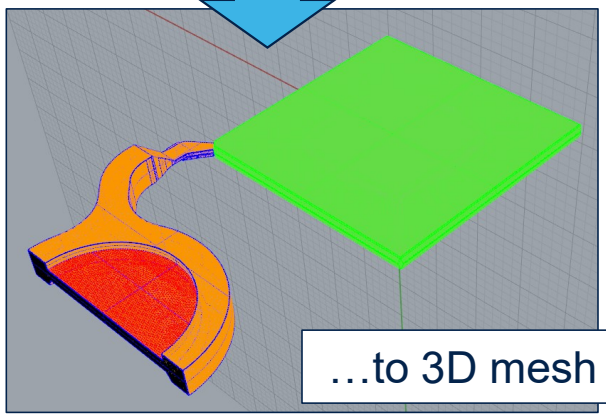


Dynamic Warpage

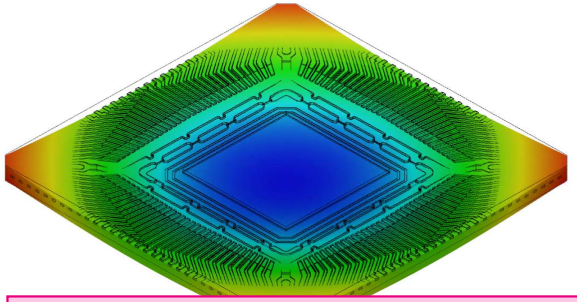
Moldex3d modeling



From design…

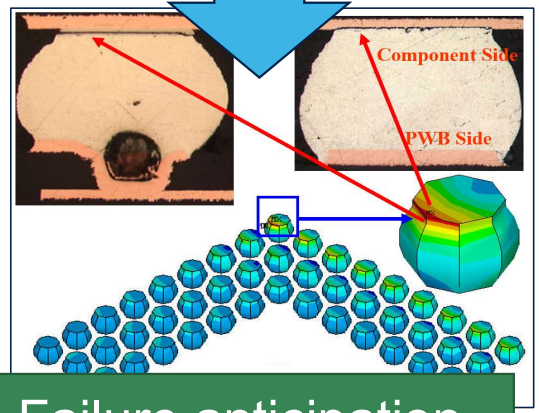


…to 3D mesh



Warpage prediction

for



Failure anticipation

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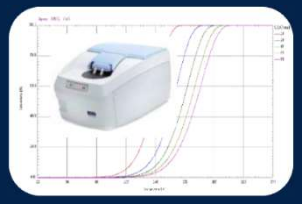
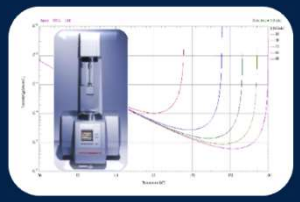
What we do for molding compounds?

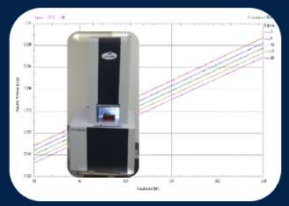
Rheology



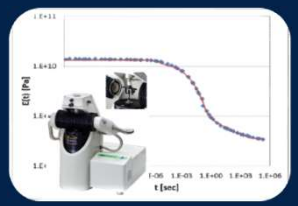
Curing kinetics



Viscosity

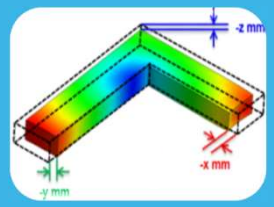


P-V-T-C



Viscoelasticity

Continuum

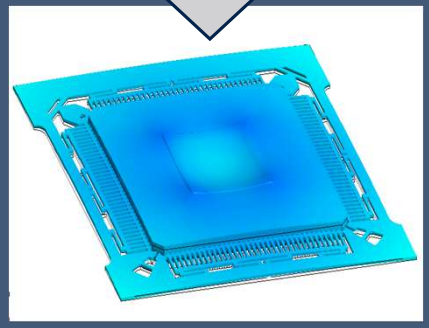


Shrinkage

Heat capacity

Thermal expansion

Molding compounds are **viscoelastic** materials!



Effect on warpage

Definition of MC model

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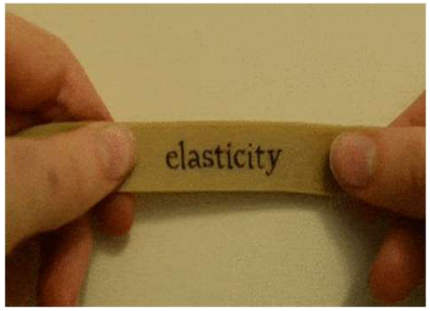
Methodology

Viscoelasticity in few words

Material exhibiting viscous and elastic characteristics when stressed

Viscous

Elastic



Visco-elastic materials

Elastic response changes with time

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How is viscoelasticity measured?

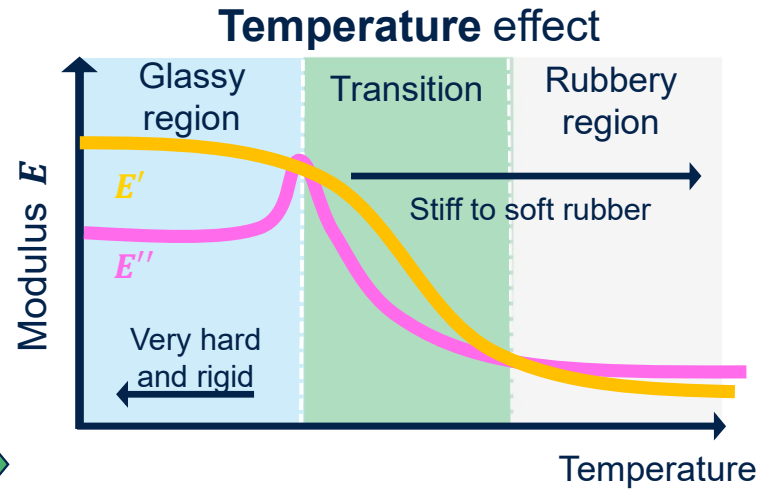
Dynamic Mechanical Analysis

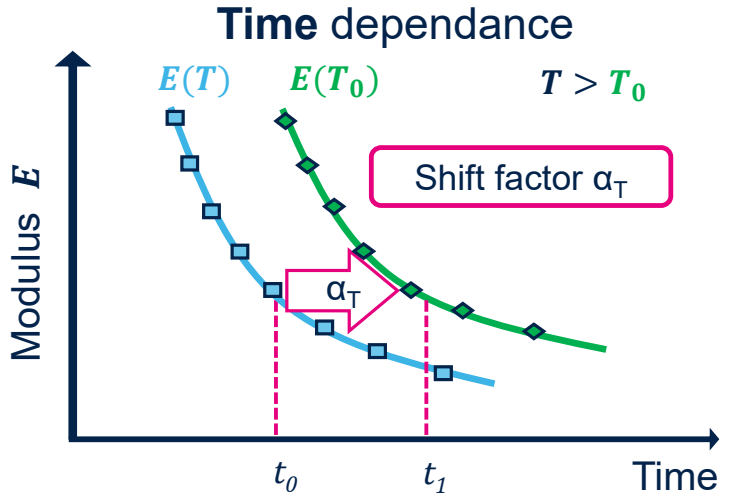
Experimental response:

$$E^* = \frac{\sigma}{\varepsilon} = E' + E''$$

E'' Loss modulus
viscous irreversible

E' Storage modulus
elastic reversible





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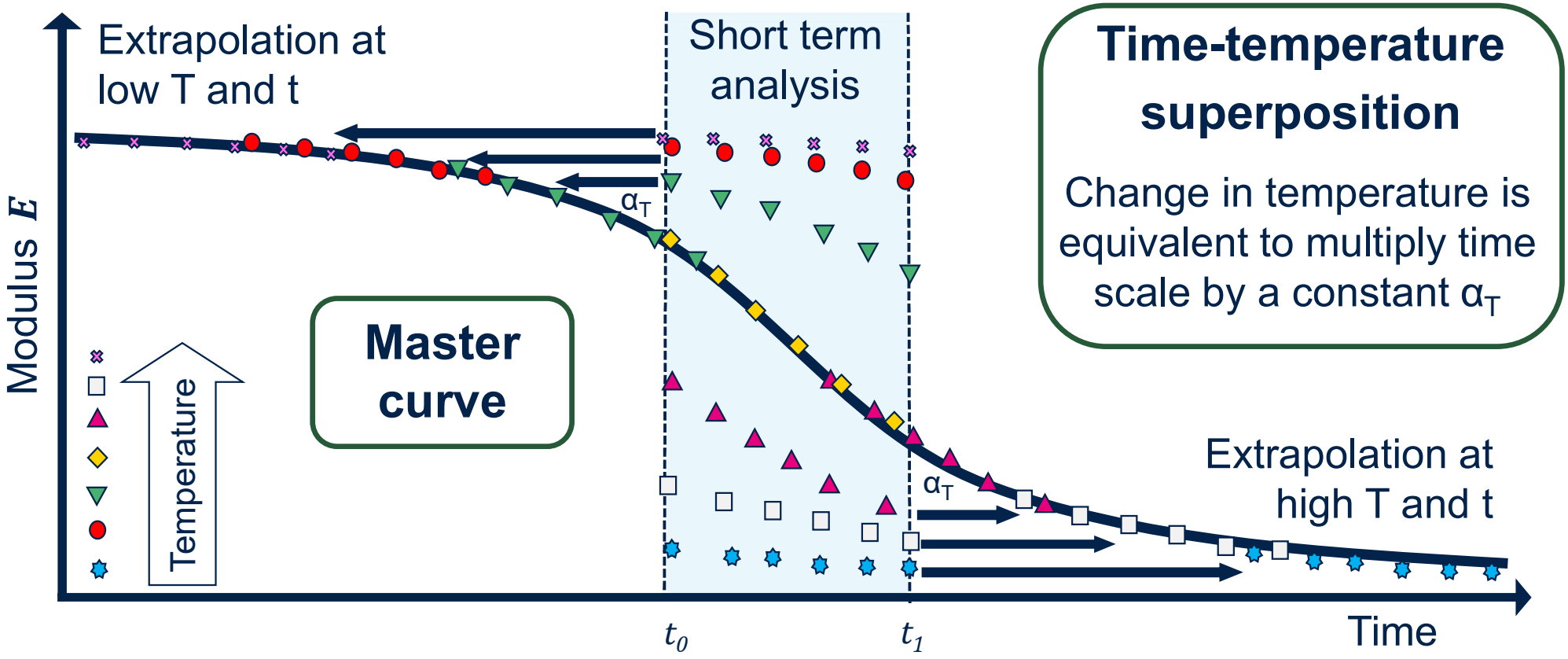
How is viscoelasticity measured?



Time-temperature superposition

Change in temperature is equivalent to multiply time scale by a constant α_T

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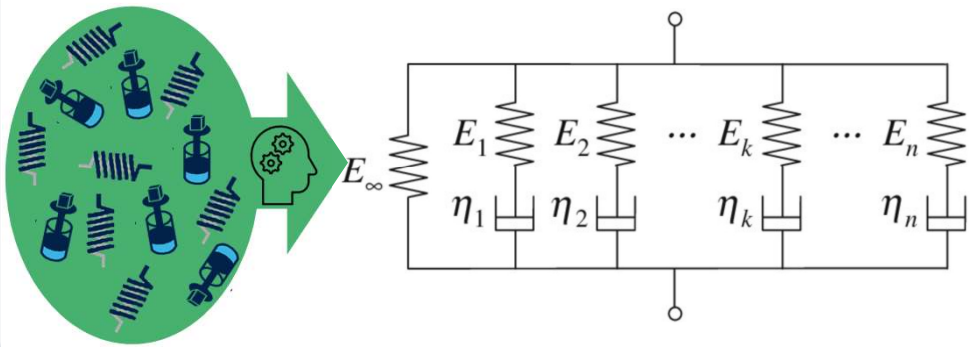
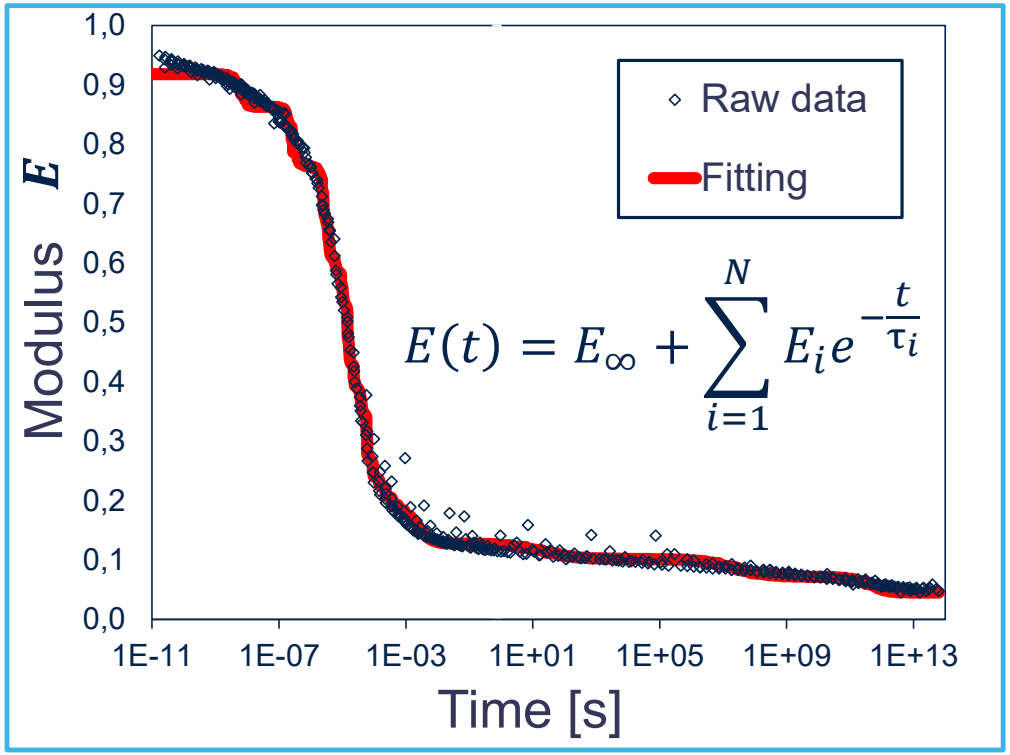
It’s now easy to model…

Material model

- From DMA tests to master curve
- Fitting raw data to Prony series
- Correlation with physical models





Material model is suitable for warpage analysis

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Chip encapsulation simulations and results

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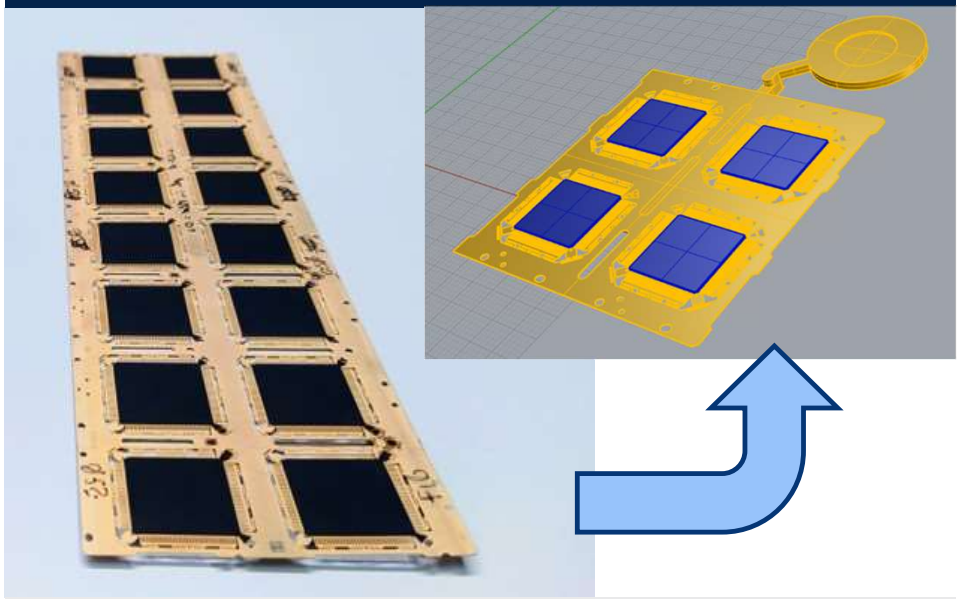
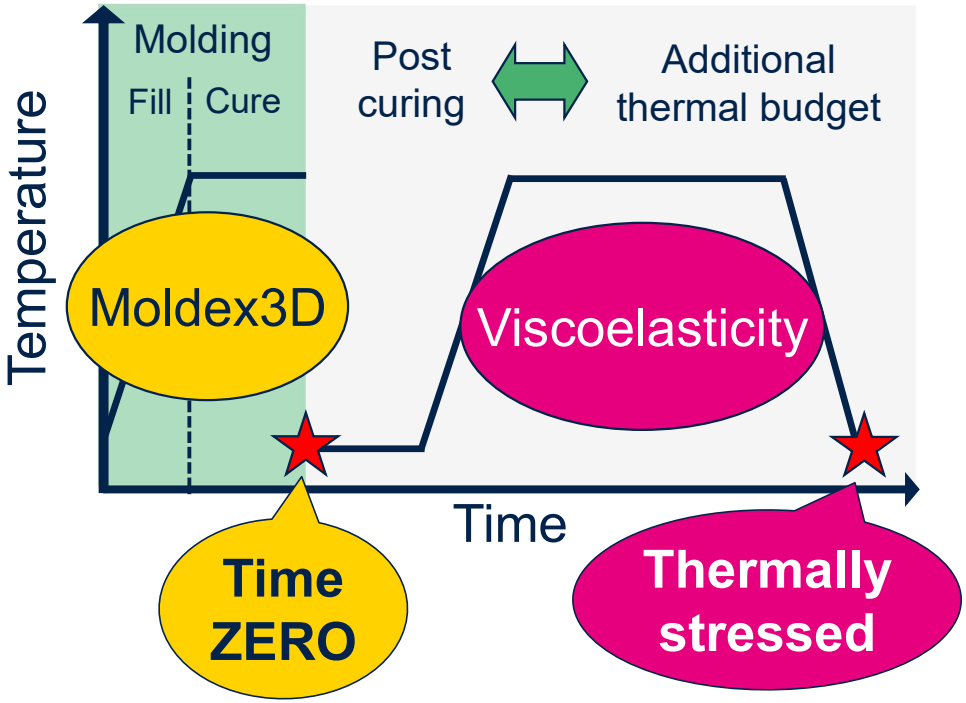
Case study for warpage investigation

Common plastic package



From real plastic package to a digital one

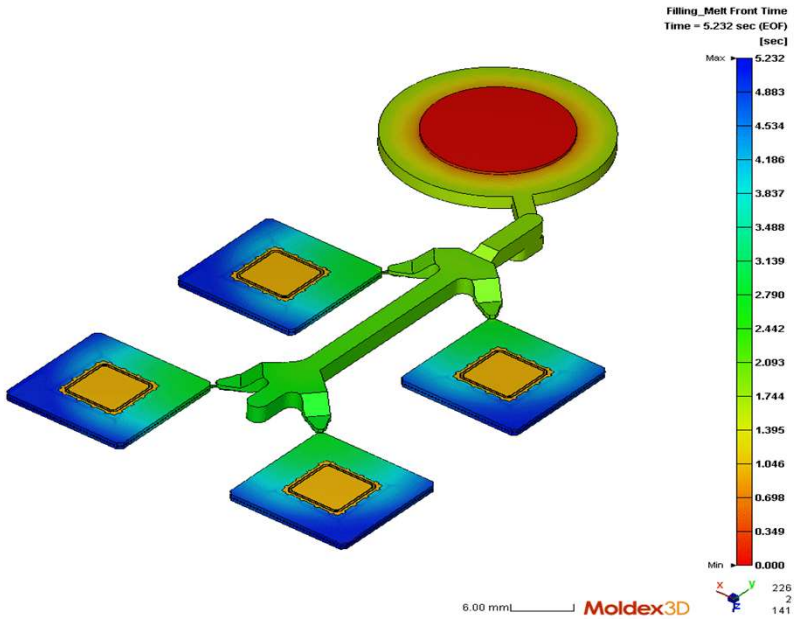
Moldex3D simulation



= experimental warpage check

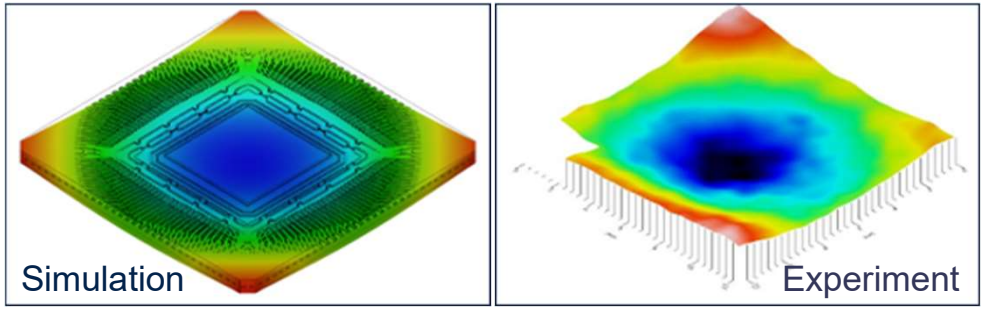
Simulation results

Molding process



Filling is complete and no voids are present

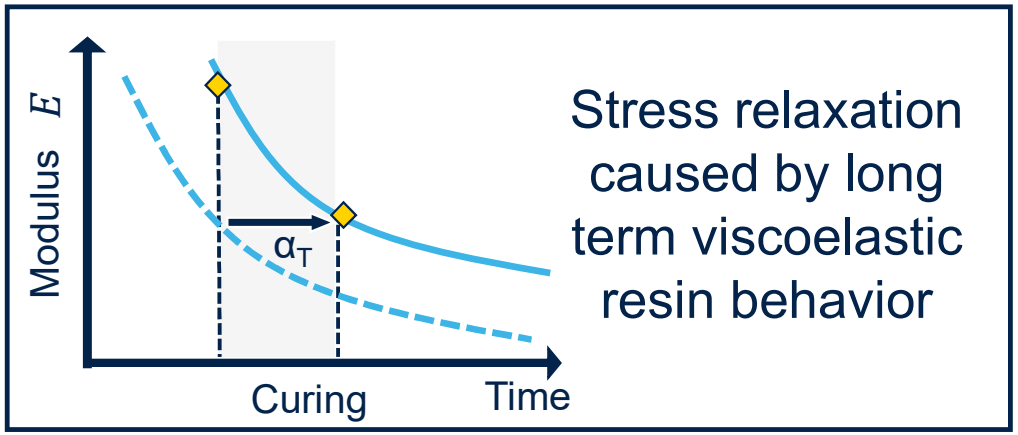
Warpage after mold



Warpage	Simulation	Experiment
Time ZERO	26.2um	24.7um

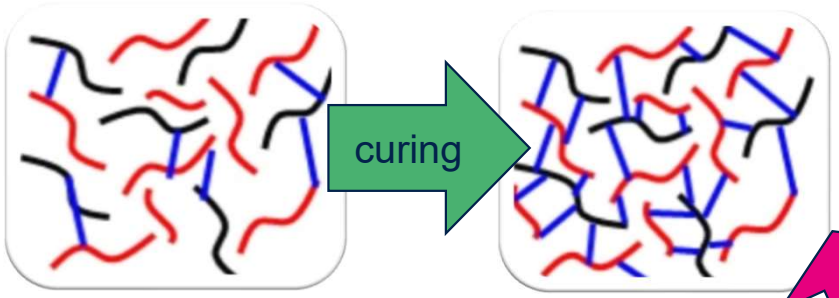
Good match, model validated!

Simulation results

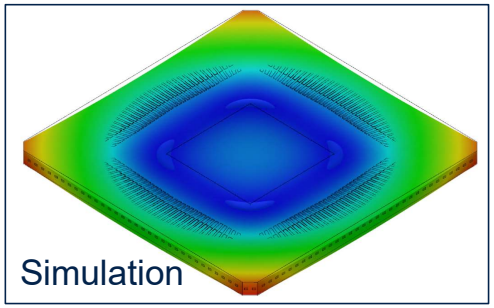


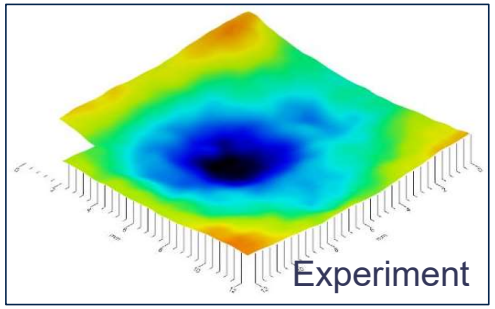
Stress relaxation caused by long term viscoelastic resin behavior

Impact of curing reducing MC shrinkage



Warpage post mold curing





Warpage	Simulation	Experiment
After mold	26.2um	24.7um
T Stress	19.4um	18.5um

Why?

Reduction of about 25%

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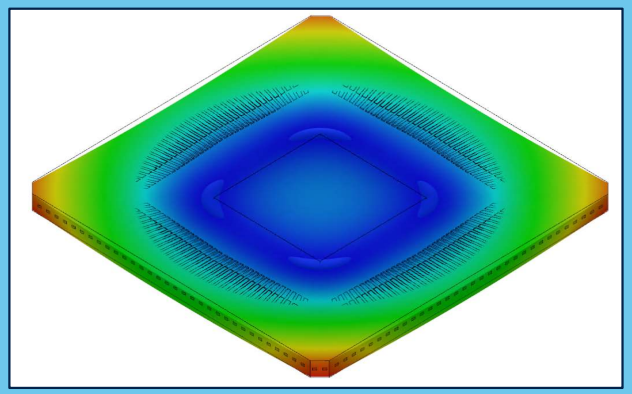
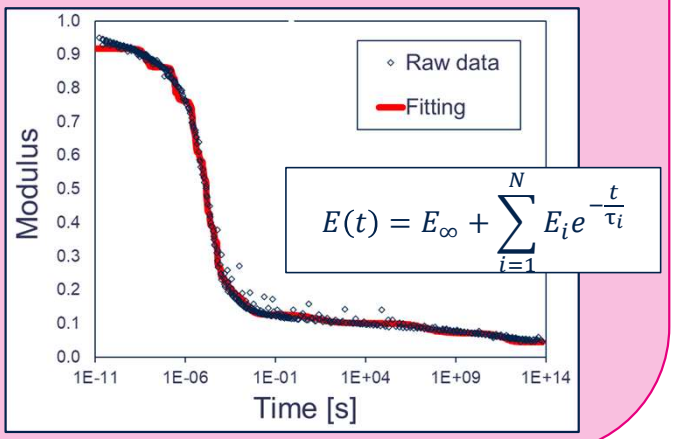
Conclusion

Thanks to Moldex3D simulation with chip encapsulation tool:

It is possible to reproduce warpage behavior of IC package in order to predict it.



It is possible to implement material properties with complex models:



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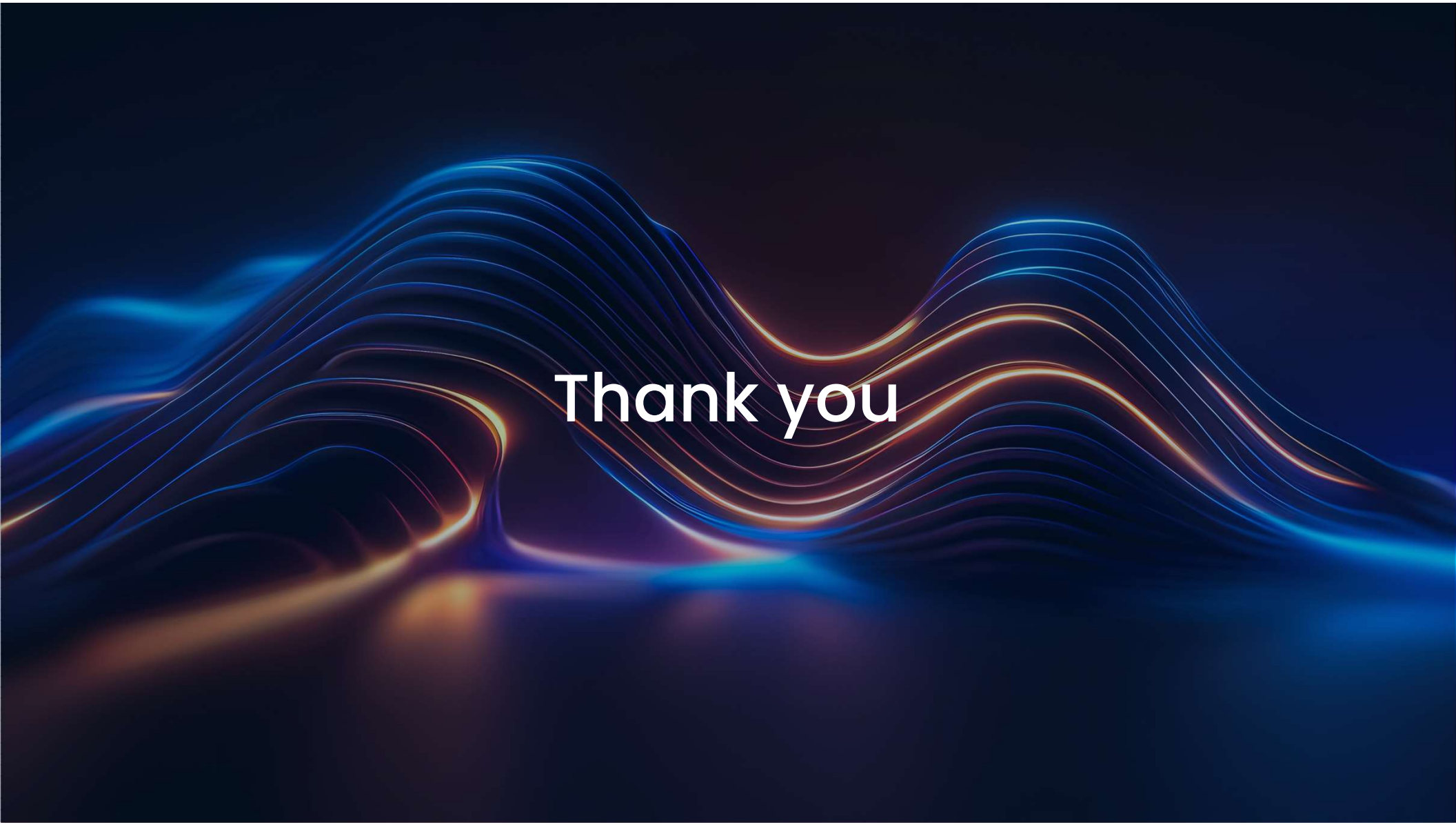
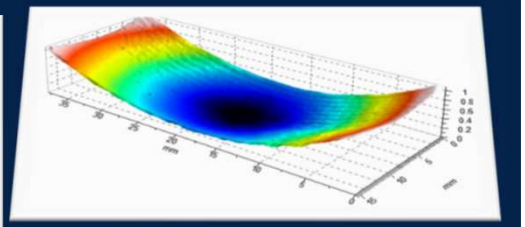

Thank you

Back-up slides

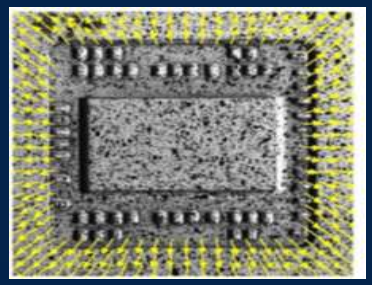
Warpage test

Topography and Deformation Measurement (TDM)

System



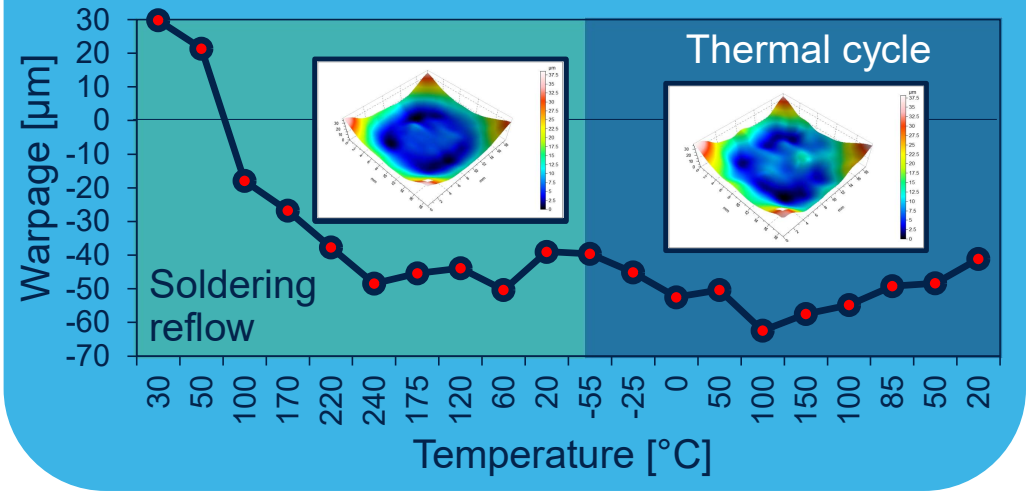
3D warpage



Thermal expansion

Application

- Real-time measurements
- Overall material expansion
- Temperature-dependence warpage



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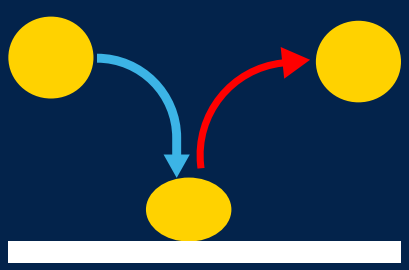
Physical interpretation

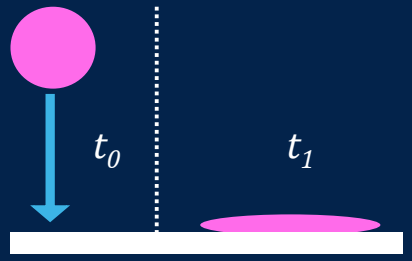
Elasticity described by a spring



$$\sigma = E\ \varepsilon$$

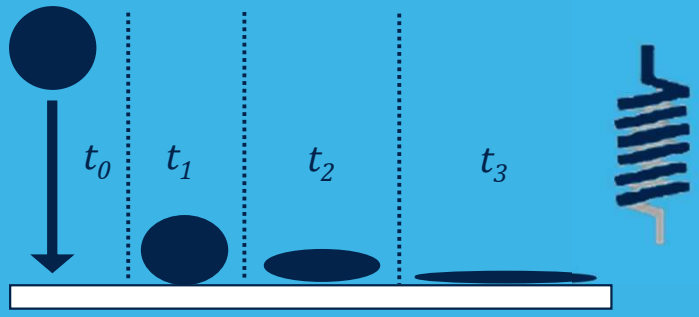
Elastic modulus

Dashpot for viscous response



$$\sigma = \eta \frac{\partial \varepsilon}{\partial t}$$

Viscosity



Viscoelasticity is a combination of springs and dashpots

Retarded elastic response

$$E(t) = \sum_{i=1}^{N} E_i e^{-\frac{t}{\tau_i}}$$

Need to quantify!

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