Strains and stresses control in microelectronic devices: how to optimize the steps from design to manufacturing?

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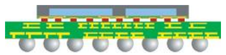
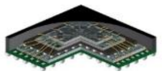
Background

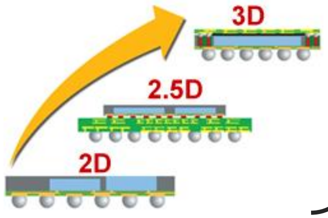
The control of strains is crucial to guarantee performance and reliability of devices

Integration = various types of stacking technologies

Silicon, Wafer, Package, level integration

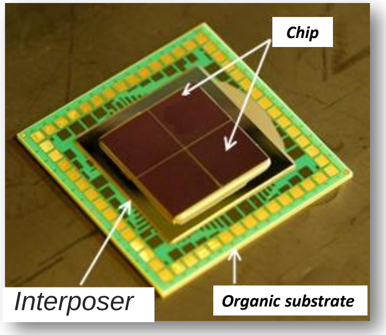






↗ electrical performance
↘ timing delays

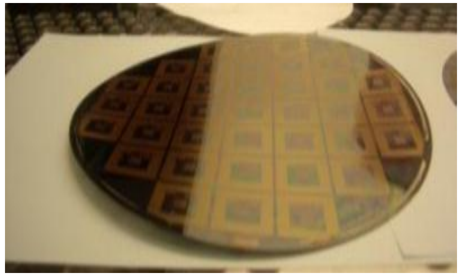
Multi-layer architecture



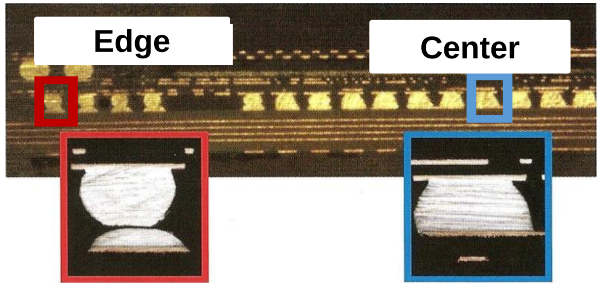
Potential problems during manufacturing steps :

1 – Size of wafers: optimize layers for automatic loading

2 – Size of devices: optimize layers to prevent connection problems and difficulties with alignment (high T°)



∅ = 300mm
t ≈ 775µm



$30 \times 30\,mm^2$
t ≈ 100µm

How to control the stress and strain generated during manufacturing?

Global method and not only case-by-case studies
(≈ 150 projects)

Mechanical models
+
Exp. measurements

Outline

Background

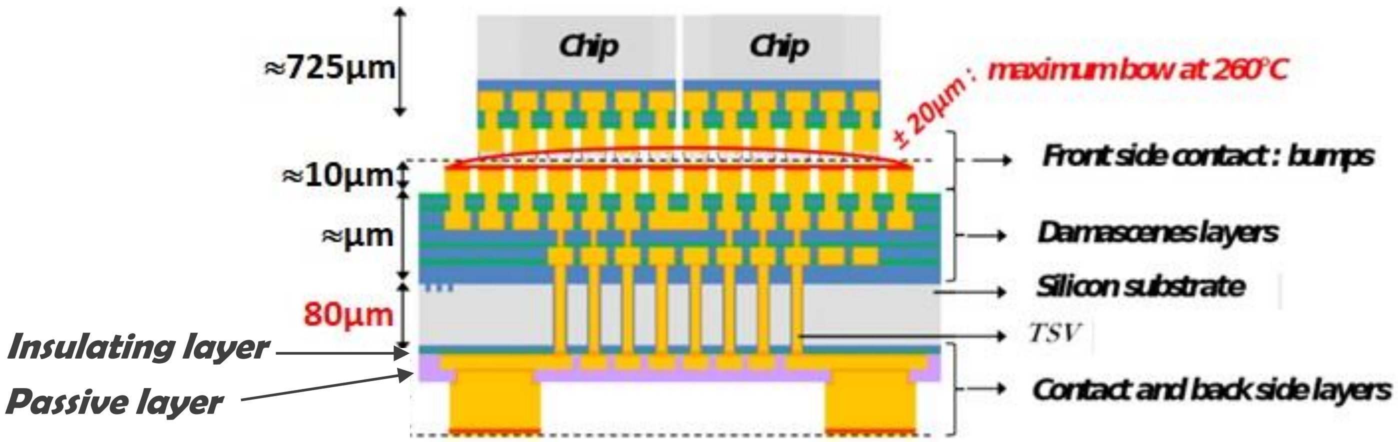
1. What about specifications?
2. Analytical model
3. What about materials behavior?
4. Experimental characterizations
5. Applications

Conclusion

1. What about specifications?

What about specifications ?

Example of an interposer device



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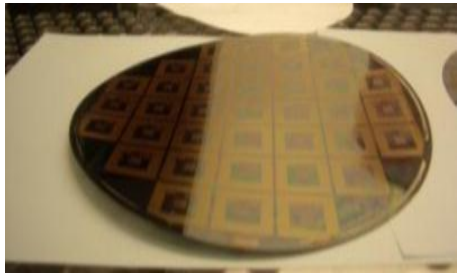
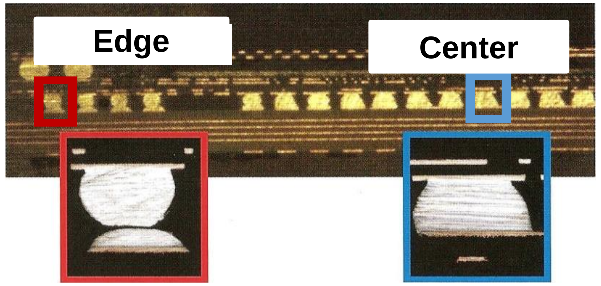


∅ = 300mm
t = 775µm

Maximum bow : ±100µm at RT



30x30mm^2
t = 80µm

Maximum bow : ±20µm at 260^{o}C

2. Analytical model

Analytical model

"Theory of elasticity" for the stress determination in multilayers [1][2]

$$\varepsilon_{Tot} = \varepsilon_{th} + \varepsilon_{int} + \varepsilon_{el} \quad (1)$$

a – Thermal strains: $\varepsilon_{th}(T) = \int_{T_{dep}}^{T} \alpha \, dT$ (2)

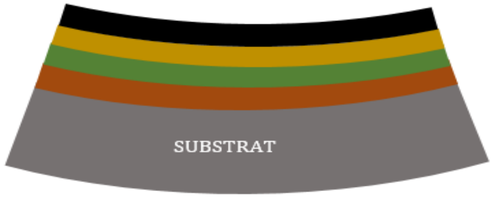
b – Elastic strains : $\varepsilon_{el} = \dfrac{(1-\nu)}{E} \sigma$ (3)

c – Total strains: $\varepsilon_{Tot} = \varepsilon_0 - \mathcal{Z}\mathcal{K}$ (4)

d – Stress in the layer i : (1-2-3-4 = 5)

$$\sigma_i(z) = \frac{E_i}{1-\nu_i}\left[(\varepsilon_0 - z\kappa) - \int_{T_{dep}^{i}}^{T} \alpha_i \, dT - \varepsilon_{int_i}\right] \quad (5)$$

Layer deposition process



$$\left.\begin{aligned}\sum_i F &= \int_0^{t_s} \sigma_s(z,T)\, dz + \int_{t_s}^{t_f+t_s} \sigma_f(z,T)\, dz = 0 \\ \sum_i M &= \int_0^{t_s} \sigma_s(z,T).z.dz + \int_{t_s}^{t_f+t_s} \sigma_f(z,T).z.dz = 0\end{aligned}\right\}$$

We obtain : $\varepsilon_0(T) = \mathrm{f}(E_f(T), \alpha_f(T), \varepsilon_{int\,f})$

$$\kappa^{Tot}(T) = \mathrm{f}(E_f(T), \alpha_f(T), \varepsilon_{int\,f}) = \kappa^{th}(T) + \kappa^{int}$$

$$\boxed{\sigma_i(z) = \mathrm{f}(E_i(T), \alpha_i(T), \varepsilon_{int_i})}$$

Sigmapεps

[1] J. W. Hutchinson, Stresses and failure modes in thin films and multilayers, 1996
[2] H. Issele "Mechanical characterization and modeling of thin films for processing of microelectronic devices - application to the field of 3D integration" PhD dissertation , 2014

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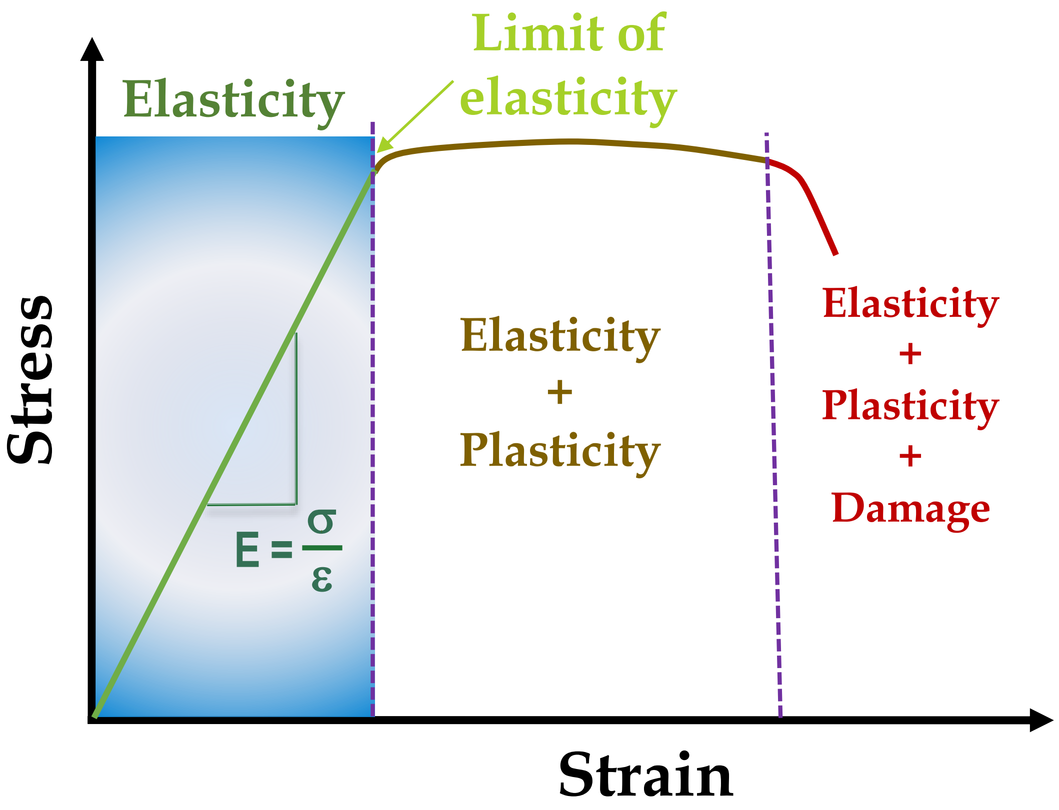
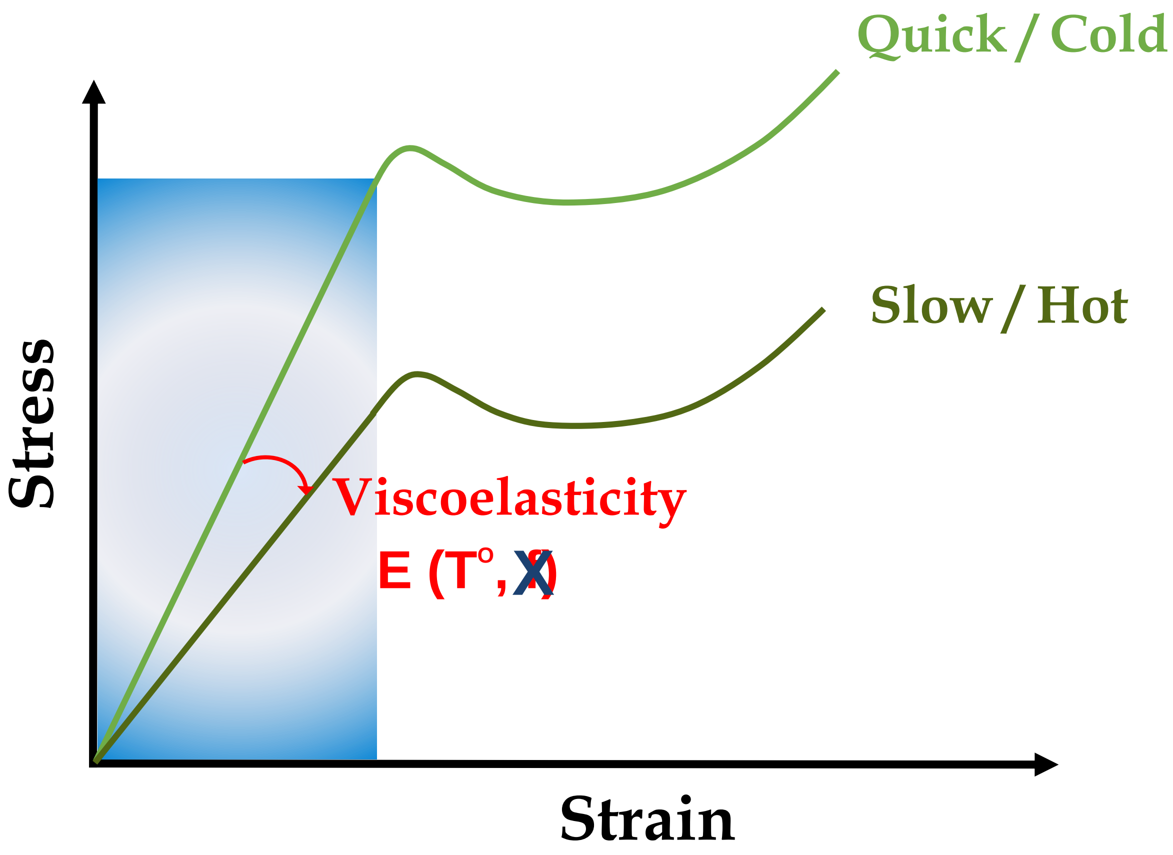
3. What about materials behavior?

What about materials behavior ?





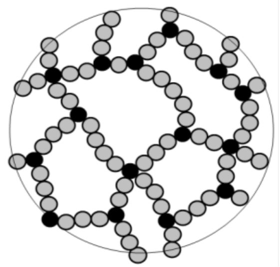
Elastic materials

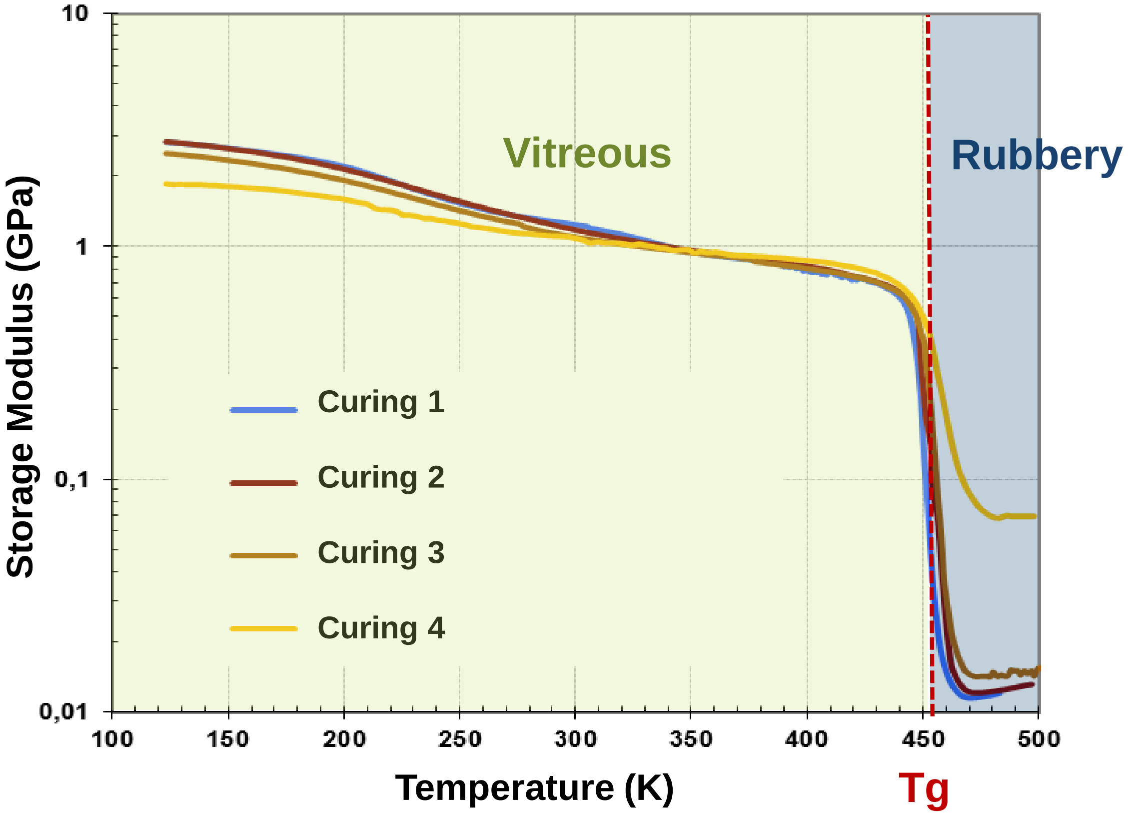
(Si, GaAs, Sapphire, Glass, SiO_2, SiN, …)

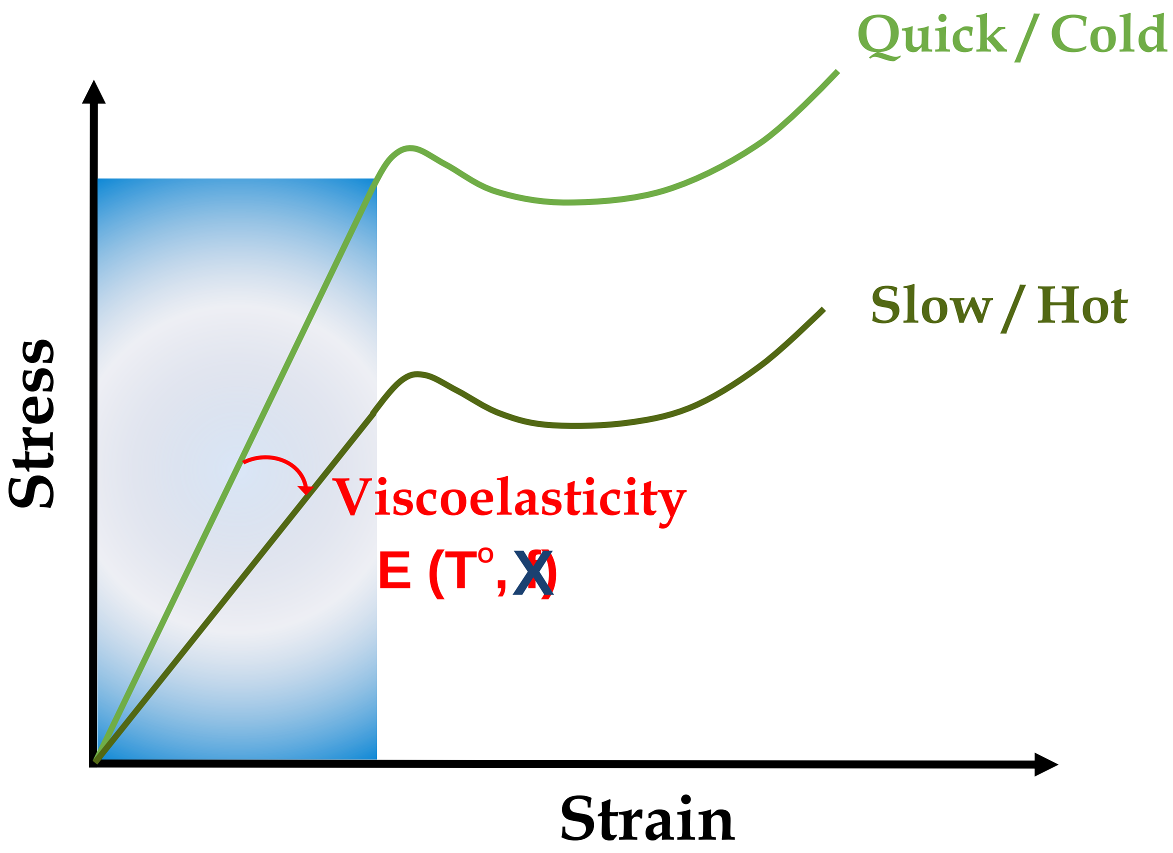
Viscoelastic materials

(Polymers : glues, passives layers, molding, packaging…)

What about materials behavior ?







Viscoelastic materials

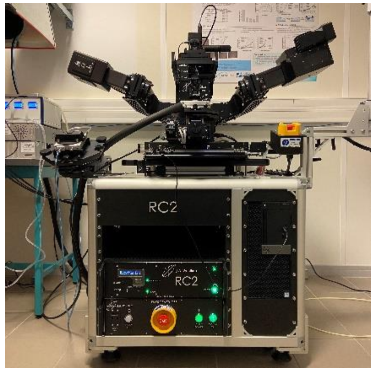
(Polymers : glues, passives layers, molding, packaging…)

4. Experimental characterizations

Experimental characterizations

Modulus E_i and coefficient of thermal expansion α_i of the film

Woollam RC2 Ellipsometer (T)



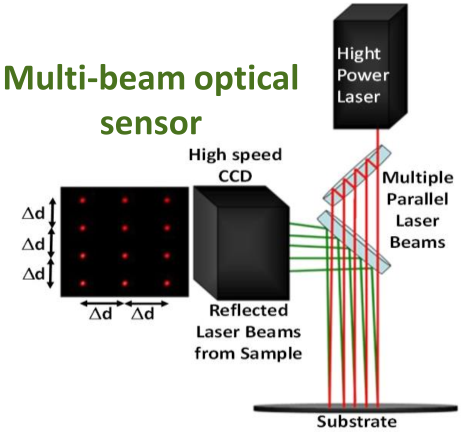
α_i +

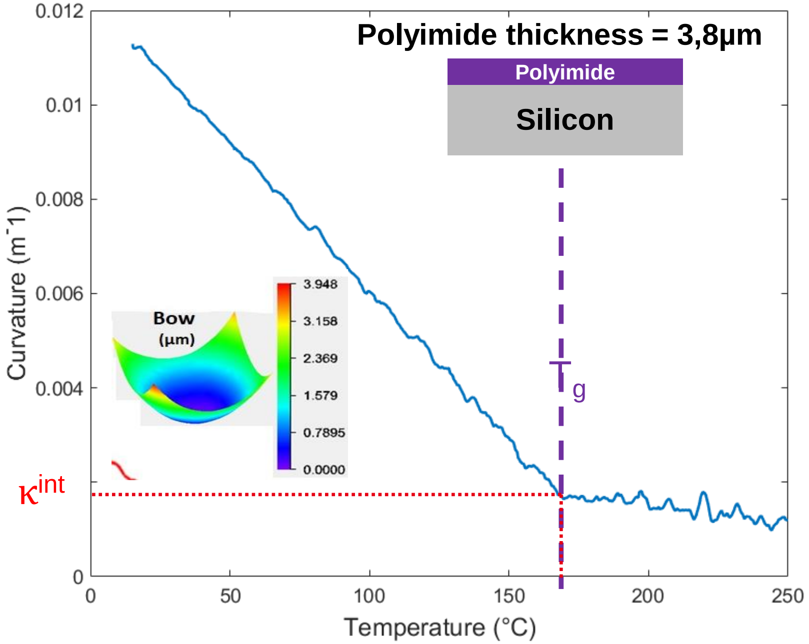
kSA MOS Thermal-scan

Nanoindentation, DMA, APiC (T)

E_i +

Multi-beam optical sensor





Curvature at every temperature

$$s_i = \frac{6m_i(\alpha_{s,i}-\alpha_f)}{h_{s,i}} \frac{h_i(1+h_i)}{1+2h_i m_i(2+3h_i+2h_i^2)+h_i^4 m_i^2} = \frac{a_i M_f(\alpha_{s,i}-\alpha_f)}{1+b_i M_f + c_i M_f^2}$$

$$a_i = \frac{6h_i(1+h_i)}{h_{s,i} M_{s,i}} \; ; b = \frac{2h_i(2+3h_i+2h_i^2)}{M_{s,i}} \; ; c = \frac{h_i^4}{M_{s,i}^2}.$$

→ E_i

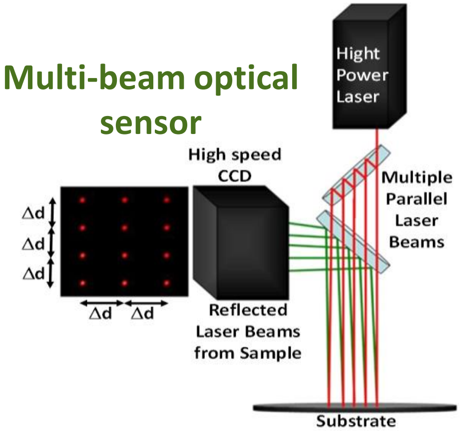
→ α_i

Experimental characterizations

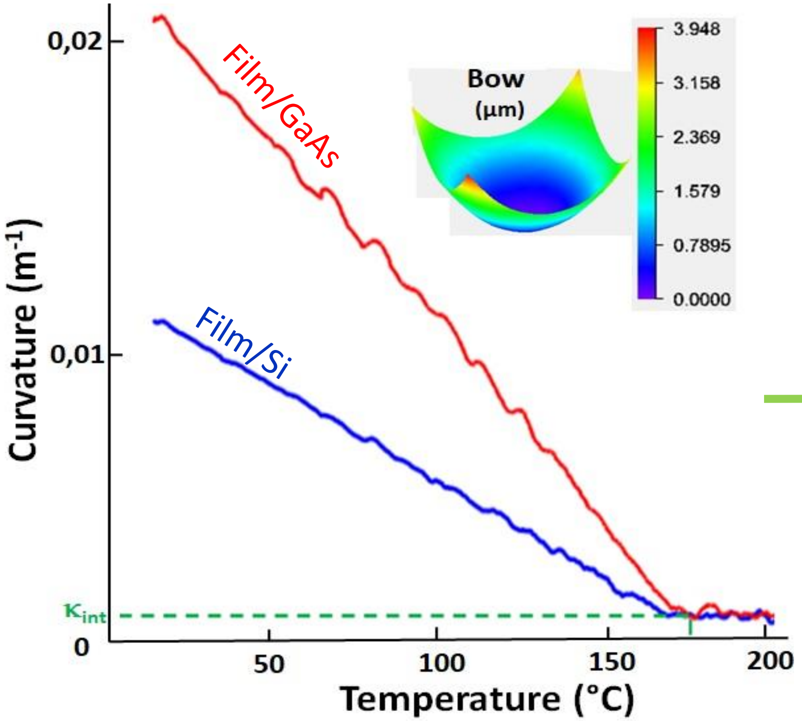
Modulus E_i and coefficient of thermal expansion α_i of the film

kSA MOS Thermal-scan

Multi-beam optical sensor



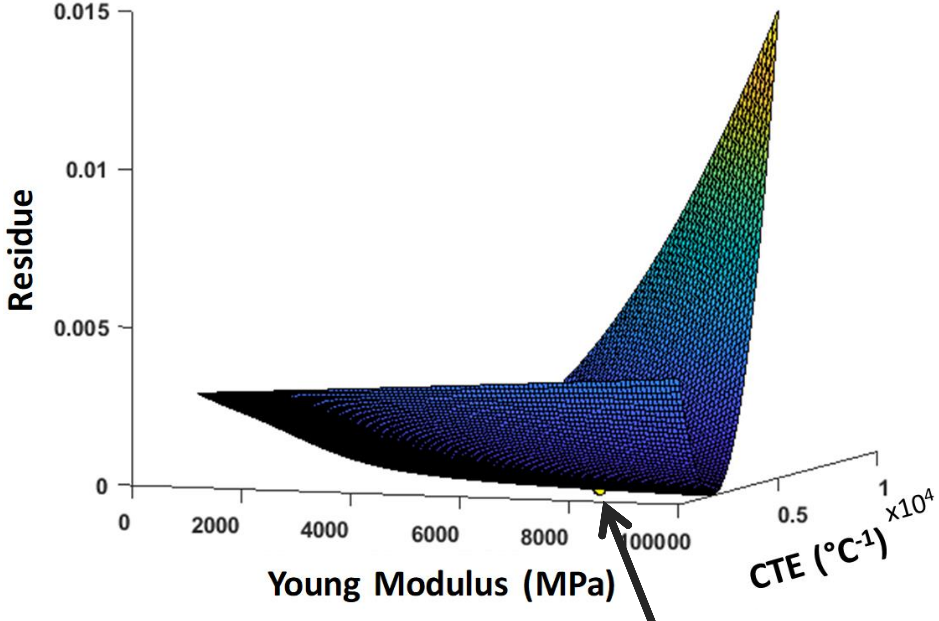
New method



Curvature at every temperature

Residue:

$$R_{ijk} = \sum_k \left(\kappa_k^{ij} - \kappa_k^{exp}\right)^2$$

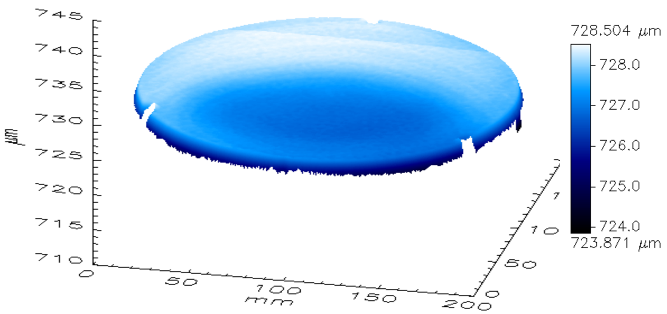


$(E_i\,,\,\alpha_i)$

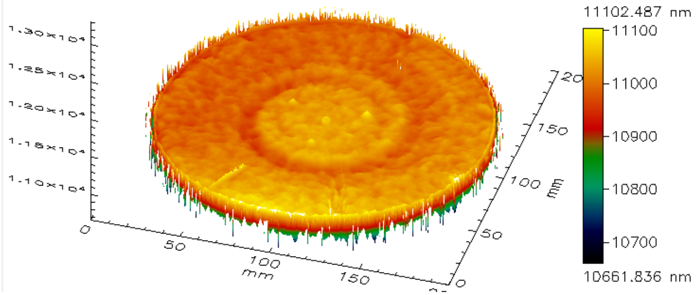
Experimental characterizations

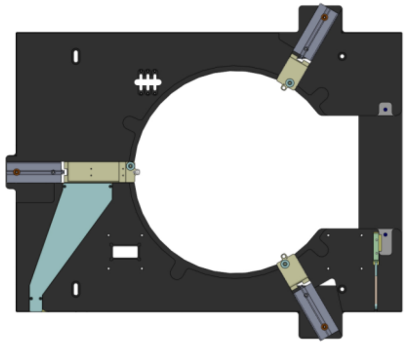
Intrinsic strain ε_i of the film

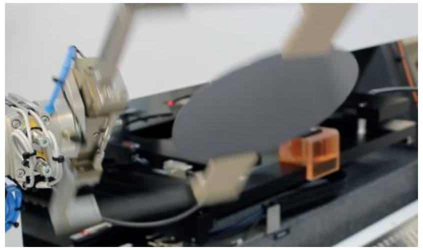
FRT Microprof MFE

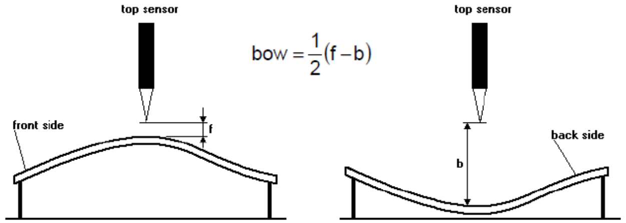


Thicknesses









Bow SEMI Standard

Stoney's model

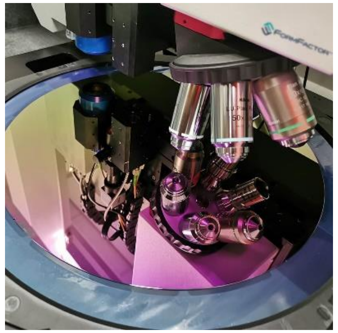
$$\sigma_f = -\frac{4E_s^* t_s^2}{3t_f D^2}\left(B_{after} - B_{before}\right)$$

$E_i \downarrow$

$$\varepsilon_{Tot_i}$$

$$\varepsilon_{th_i} = \int_{T_{dep}^i}^{T} \alpha_i \, dT$$

Dual chromatic confocal
+
IR interferometer sensors

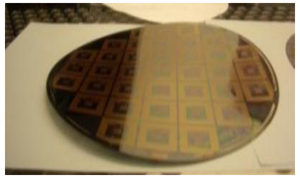


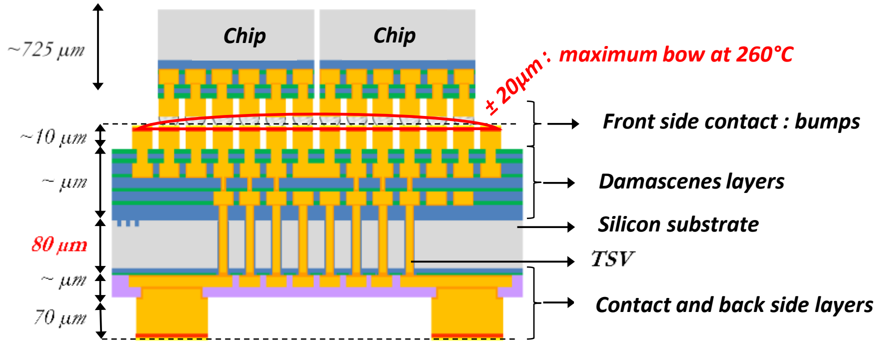
⇨ intrinsic strain : $\varepsilon_{int_i} = \varepsilon_{Tot_i} - \varepsilon_{th_i}$ of the film

5. Applications

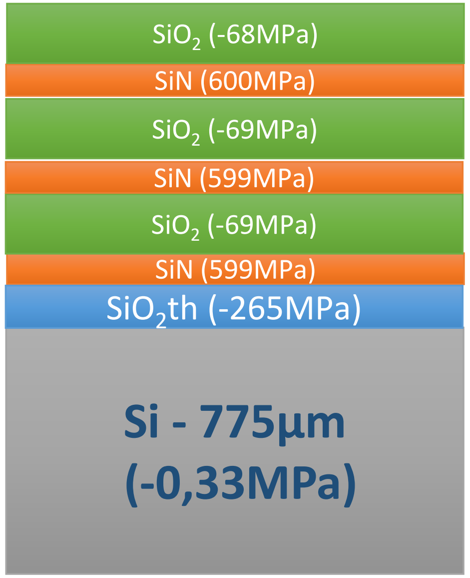
Application: the interposers

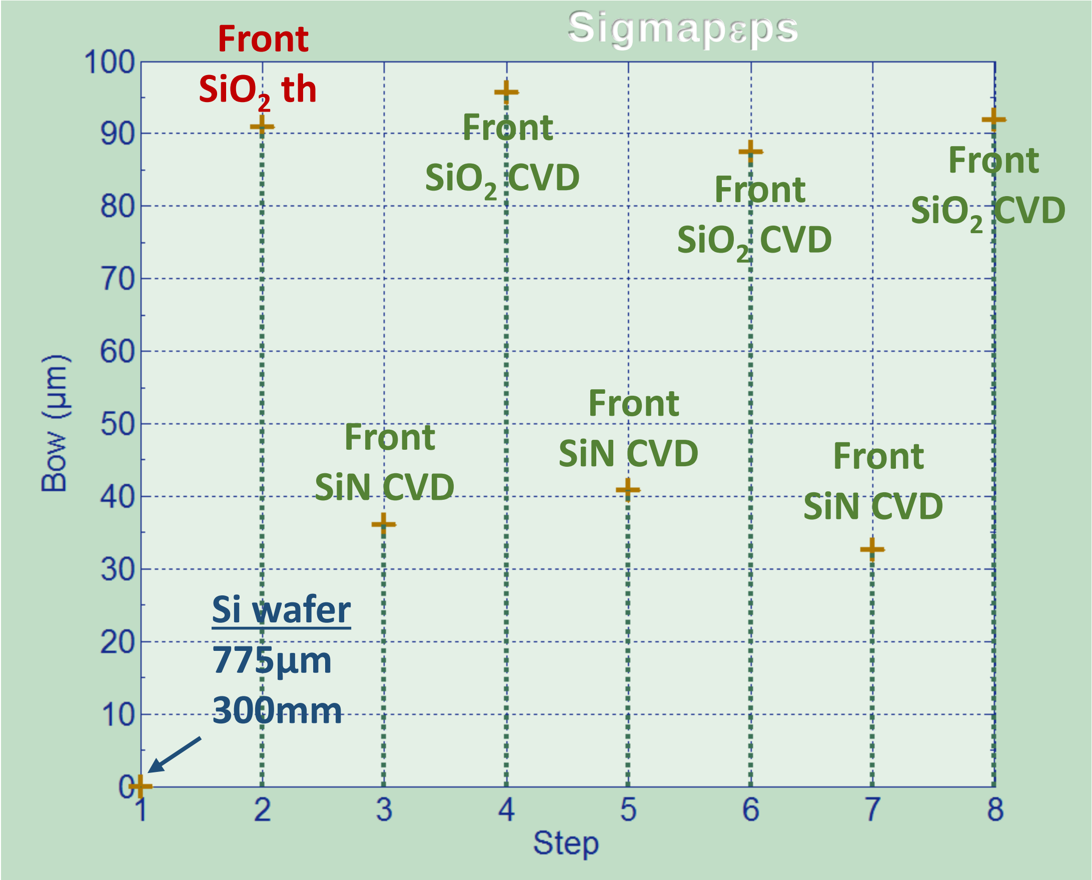
1 - Size of the wafer





Material	Intrinsic strain ε_{int} (.10^{-3} s.u.)	Young Modulus E (GPa) and Poisson's ratio ν : (E ; ν)	CTE α (10^{-6} /°C)	Fonction
SiO_2 {1fav}	-0.59	(70 ; 0.17)	0.55	TSV Isolating
SiN {1fav}	-4.8	(100 ; 0.25)	2.17	Dielectriques damascenes and passivation
SiO_2 {2fav}	-0.39	(72 ; 0.17)	0.55	

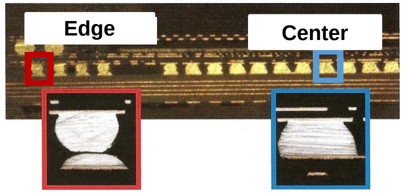




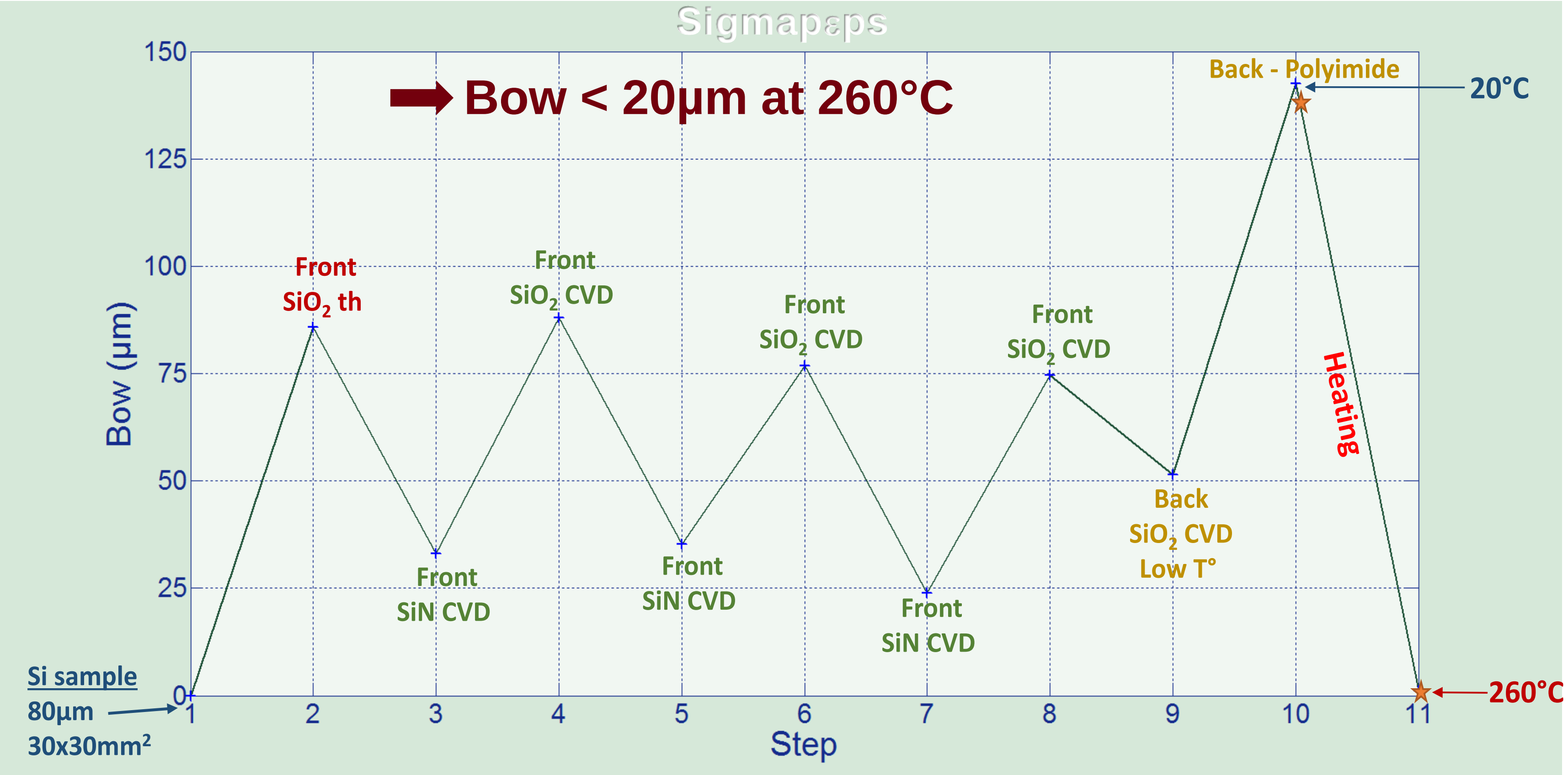
➡ **Bow < 100µm at RT**

Application: the interposers

2 - Size of the devise

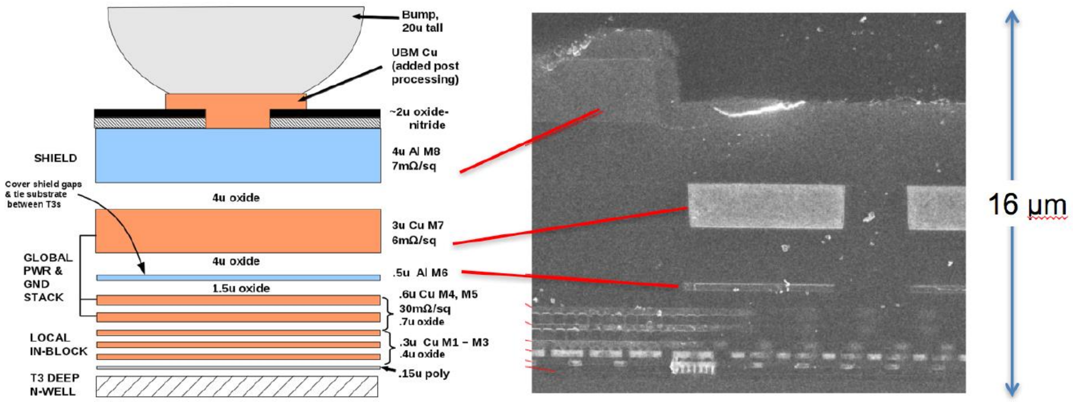


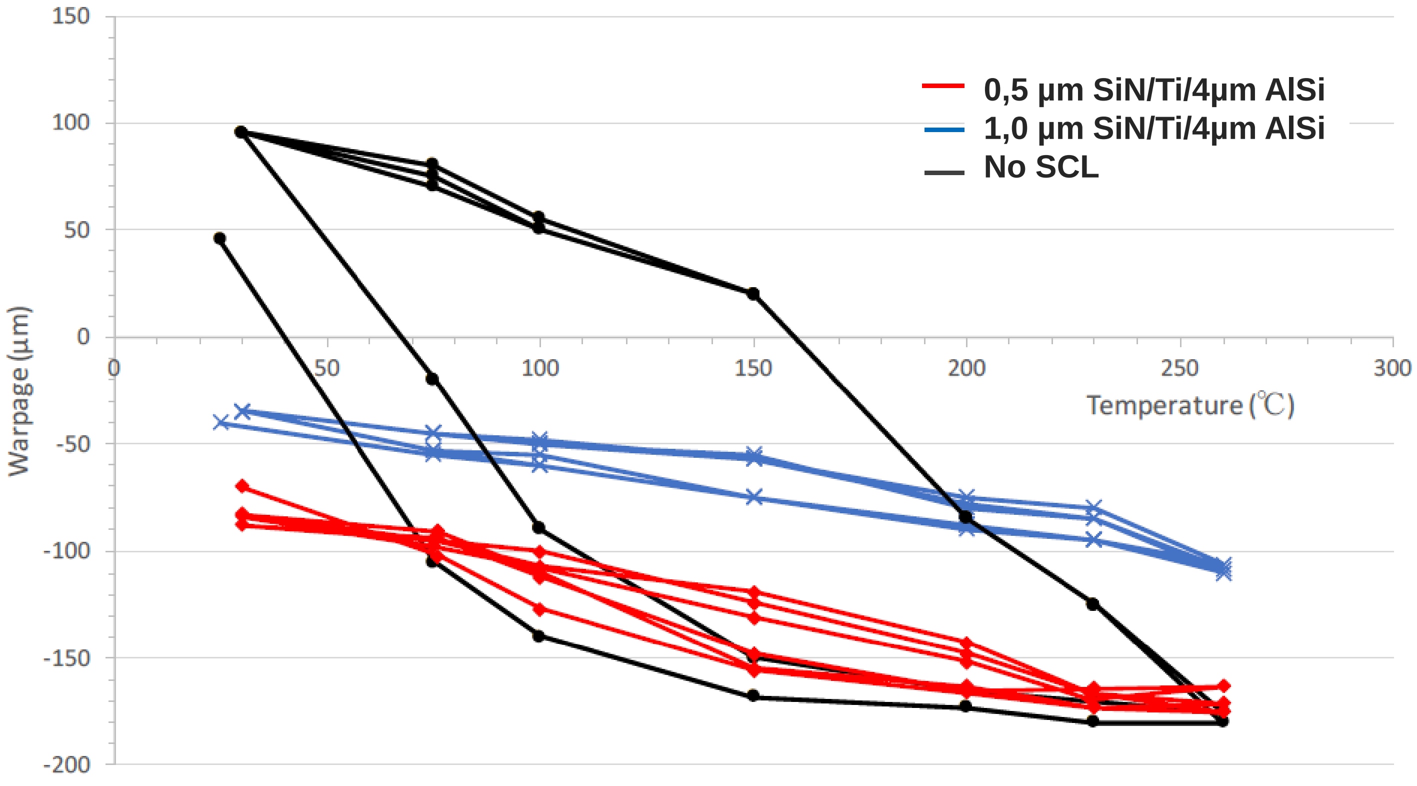
Material	Intrinsic strain ε_{int} (.10^{-3} s.u.)	Young Modulus E (GPa) and Poisson's ratio ν : (E ; ν)		CTE α (10^{-6} /°C)	Fonction
SiO_2 {2far}	-0.59	(70 ; 0.17)		0.55	TSV Isolating
Polyimide	-0.023	Before Tg	(7,5 ; 0.4)	21	Passive layer
		After Tg	(0,14 ; 0.4)	102	



Application: for the University of Glasgow

Backside compensation layer for a FE-I4 ship telescope





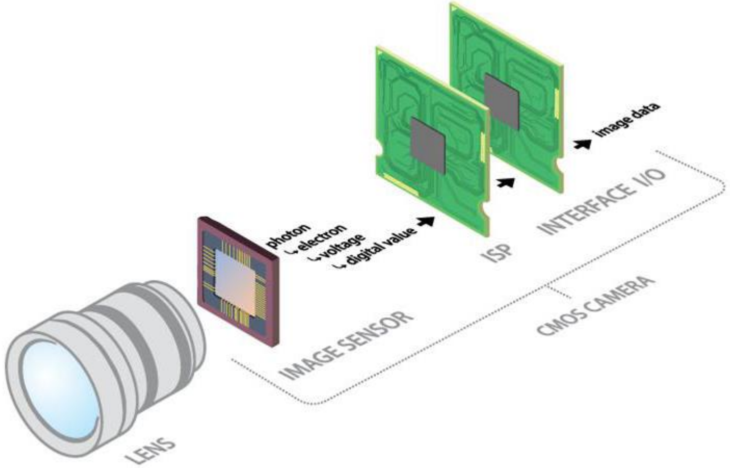
Bow in 100 µm thick FEI4 die as a function of temperature for two SCL recipes

[4] R. Bates and al. "Thin hybrid pixel assembly with backside compensation layer on ROIC, *JINST 12, C01018 (2017)*

Application: for ST Microelectronics

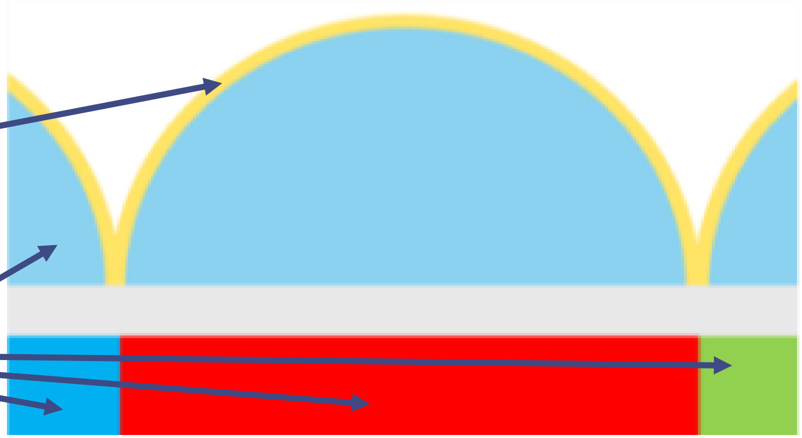
Imager devices : characterization of resins with our double curvature methods

Objective: prevent potential cracks of the protective layer



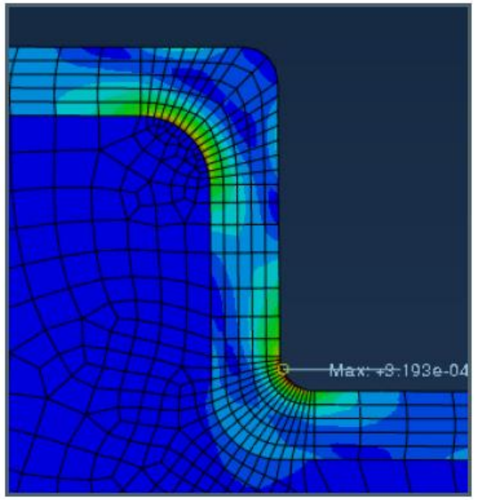
Protective layer

11 different resins



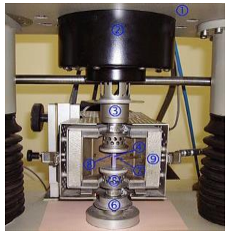
A microlens

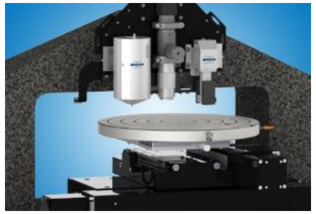
FEM



Conclusion

Conclusion





Experimental measurement
(FRT, kSpace, nDMA)

Thermo mechanical properties E, α, ε_{int}

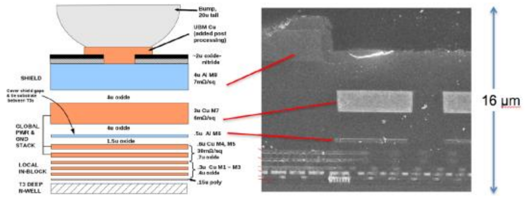
$$\sigma_i(z) = \frac{E_i}{1-\nu_i}\left[(\varepsilon_0 - z\kappa) - \int_{T_{dep}^i}^{T} \alpha_i \, dT - \varepsilon_{int_i}\right]$$

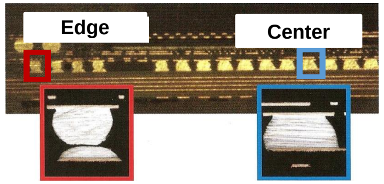
$$\varepsilon_0(T) = f(E_f(T), \alpha_f(T), \varepsilon_{int\,f})$$

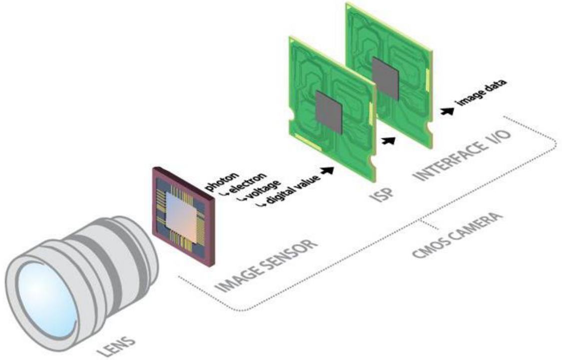
$$\kappa^{Tot}(T) = f(E_f(T), \alpha_f(T), \varepsilon_{int\,f}) = \kappa^{th}(T) + \kappa^{int}$$

Analytical simulation
Sigmapεps

Manufacturing







Thanks for your attention !

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