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Thermal FEM Simulation of a Multilevel Lab on Chip Device for Genetic Analysis

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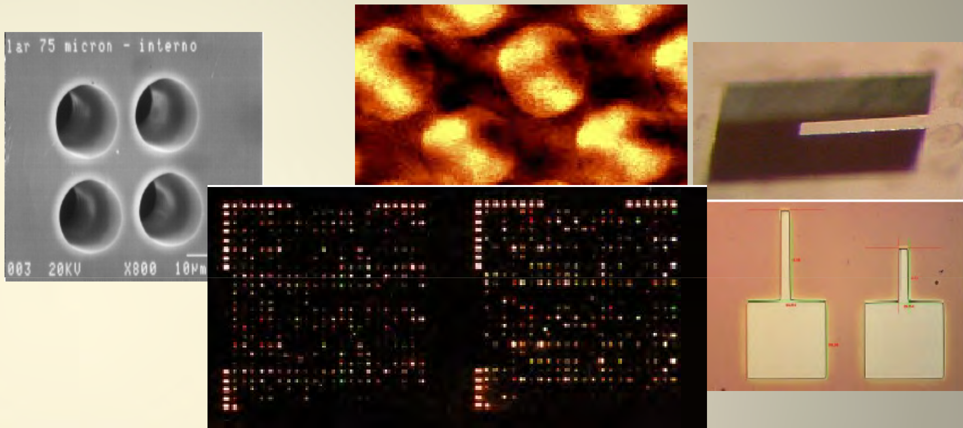
Introduction - χ_{Lab} Materials and Microsystems Laboratory

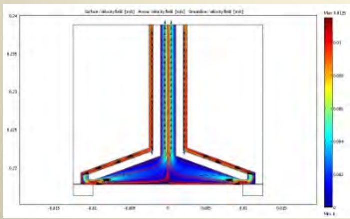
Materials and Microsystems Laboratory, is managed by Politecnico di Torino and works on the design and realization of micro and nano systems prototypes with a specific focus on technological transfer.

http://www.polito.it/micronanotech

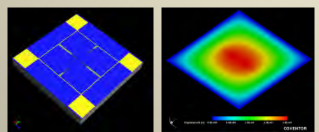


Multiphysics Modeling

COMSOL



CoventorWare®



MEMS simulation activity is transversal to most of χ_{Lab} research projects and required for the design of microstructures or for their performance prevision. F.E.M. Simulations of microstructures behaviour is carried out by Comsol™ thanks to its great multiphysics capabilities and Coventorware™.

Introduction – LOC Devices

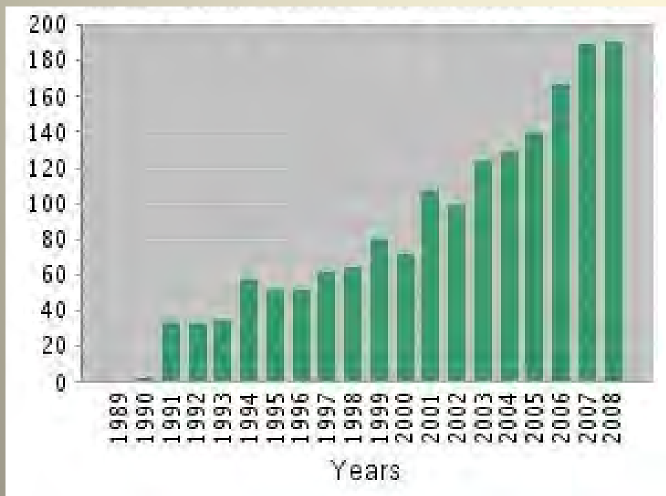
What is a Lab On a Chip ?

- *It is a device that integrates one or several laboratory functions into a miniaturized platform.*

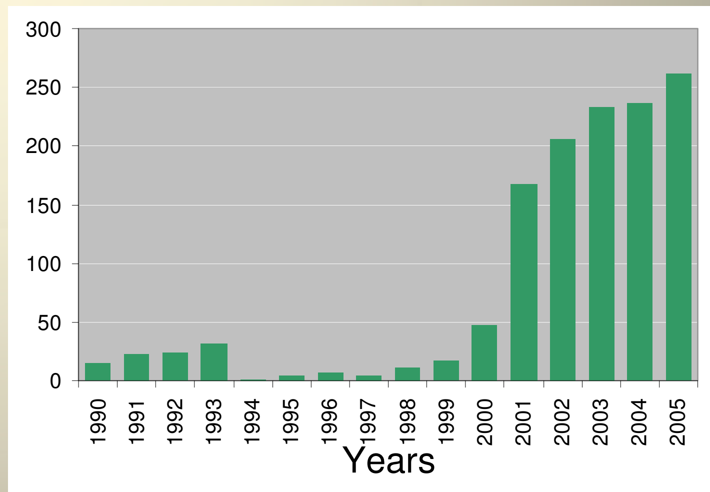
International Interest on LOC

- *A big boost in research and commercial interest came in the mid 1990's, when it turned out to provide interesting tools for genomics applications, like capillary electrophoresis and DNA microarrays.*

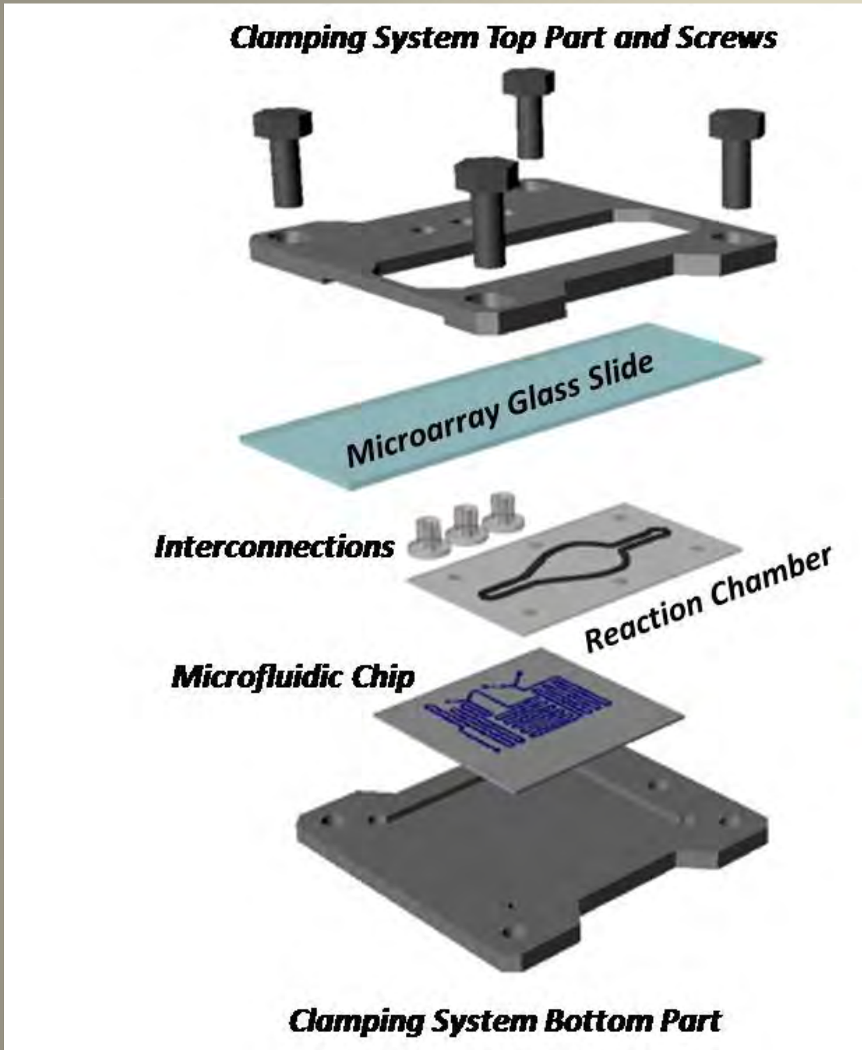
Published Items in Each Year



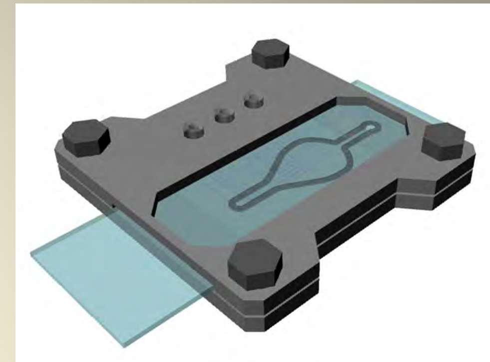
Patents in Each Year



LOC Design and Fabrication



Exploded view of the multilevel LOC platform

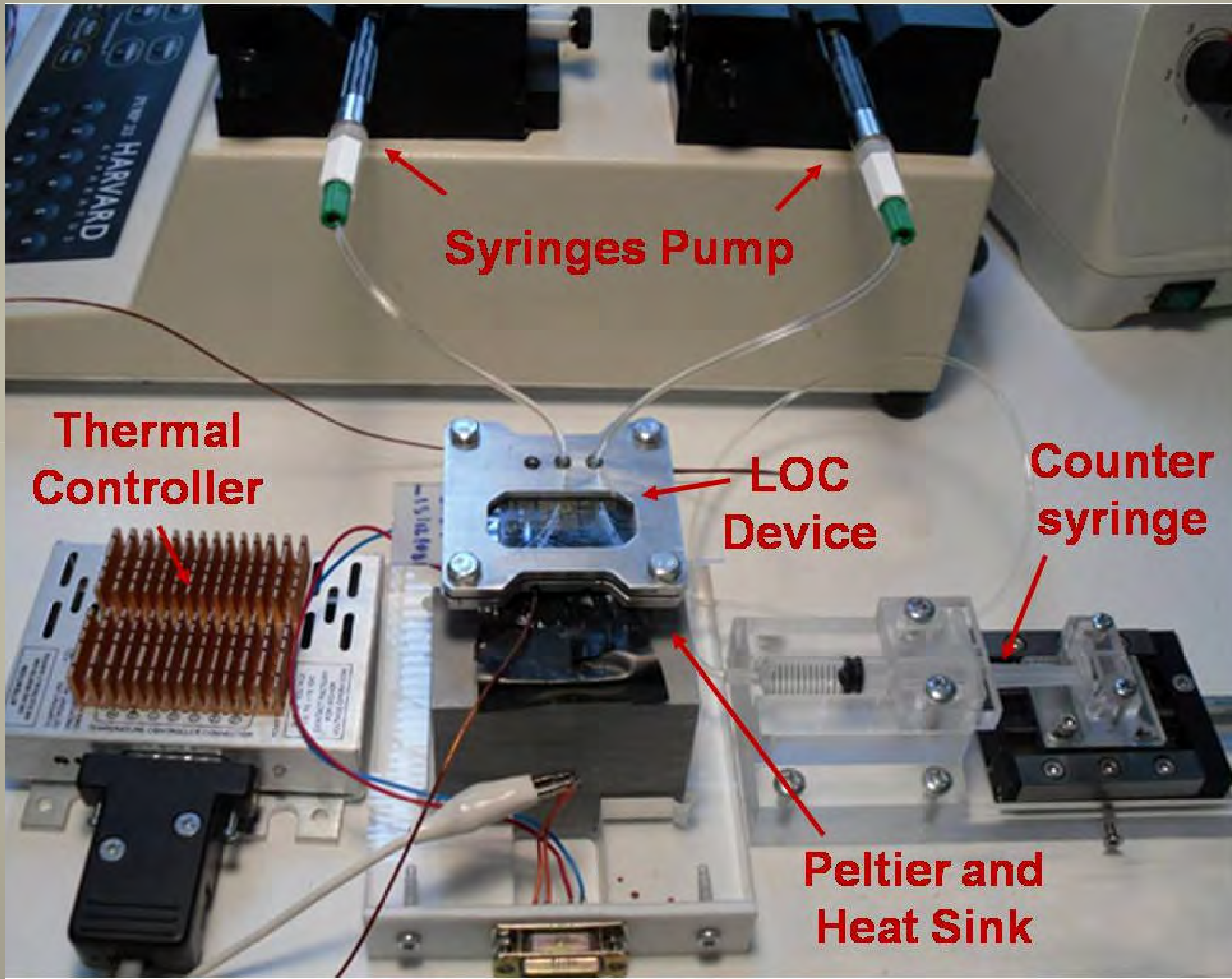


Assembly of the LOC platform

LOC features:

- *Multilevel platform;*
- *Multi inlets microfluidics with passive mixers;*
- *Microstructured reaction chamber with O-ring like retention system;*
- *Microarray reversibly interfaced with reaction chamber;*
- *Clamping system;*
- *Ad hoc interconnections for inlets and outlets tubes;*

Experimental Set-up



Genetic Protocol Thermal Needs

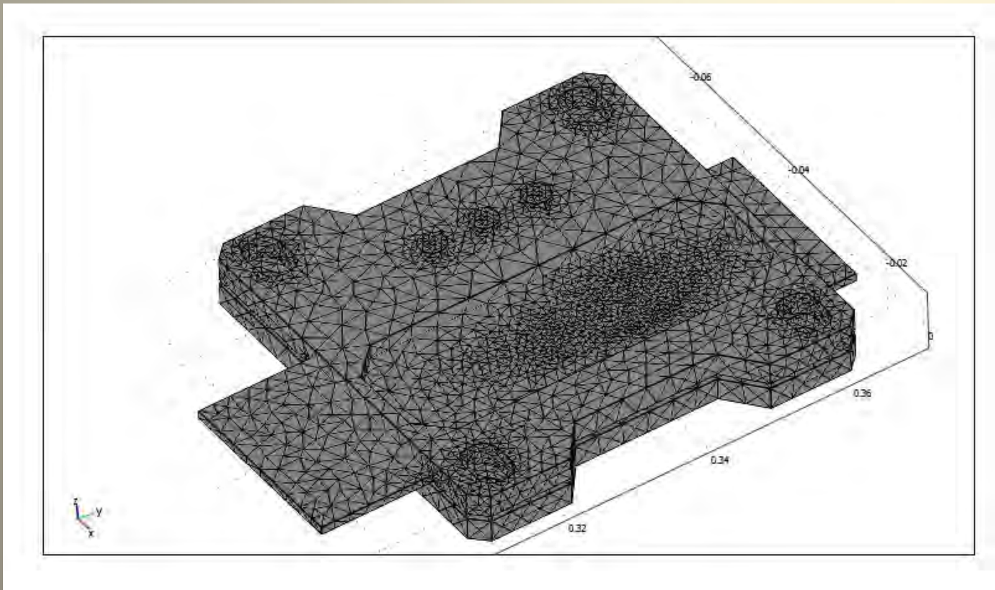
…for example

I) Initial Condition at RT → *II) DNA Denaturation at 95° C* → *III) Hybridization Performed at 60° C.*

Into reaction chamber

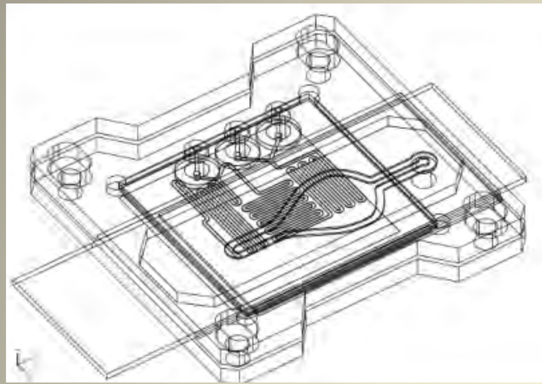
A proper Thermal FEM Model

can be used in order to estimate the Temperature Values

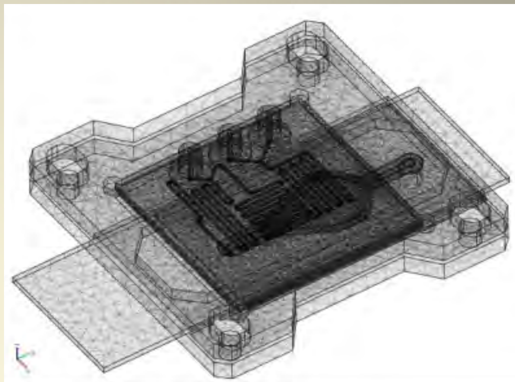


It is difficult to measure experimentally this temperature value being the reaction chamber inaccessible

Comsol FEM Model Details



<u>CAD Model</u>: *the import CAD module permits to import the 3D geometry of the whole device directly into the pre-processor of Comsol*



<u>FEM Model:</u>

- *Number of DOF = 29808*
- *Number of Tetrahedral Elements = 85939*
- *Elements Type = Lagrange – Linear*
- *Time Dependent Analysis*
- *Solver = Linear System Solver (Direct UMFPACK)*

Material Properties

Model Part	Clamping System	Glass Slide	Interconnections and Reaction Chamber	Chip (top layer)	Chip (bottom layer)	Reagents Volume
Material	**Aluminum**	**Corning 7740 (Pyrex)**	**PDMS**	**Corning 7740 (Pyrex)**	**Silicon**	**Water**
Thermal Conductivity k [W/(m*K)]	160	k(T)	k(T)	k(T)	163	k(T)
Density ρ [kg/m³]	2700	ρ(T)	ρ(T)	ρ(T)	2330	ρ(T)
Heat Capacity at constant pressure C_p [J/(kg*K)]	900	$C_p(T)$	$C_p(T)$	$C_p(T)$	703	$C_p(T)$

Comsol FEM Model Details – Internal Boundary Conditions

The LOC was composed of different parts and materials. Comsol **ASSEMBLY MODE** was used in order to activate some settings for those ***internal boundaries*** that are particularly important for the heat transfer through different layers

$$-\mathbf{n}_{down} \cdot \left(-k\nabla T\right)_{down} = \frac{k_{res}}{d_{res}}\left(T_{up} - T_{down}\right)$$

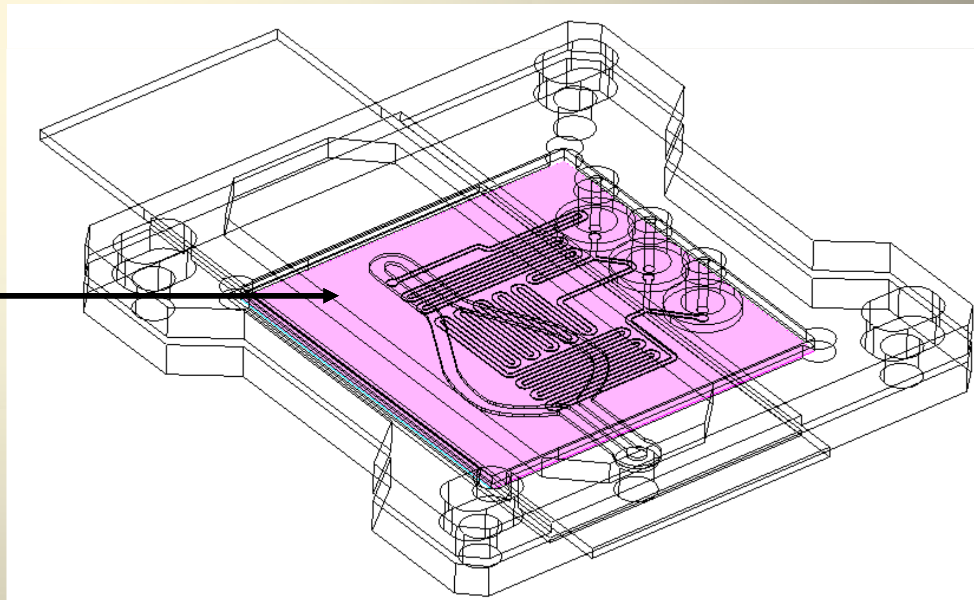
$$-\mathbf{n}_{up} \cdot \left(-k\nabla T\right)_{up} = \frac{k_{res}}{d_{res}}\left(T_{down} - T_{up}\right)$$

k_{res} is the thermal conductivity [W/(m·K)]

d_{res} the thickness (m) of the ***thin thermally resistive layer***

thin thermally resistive layer

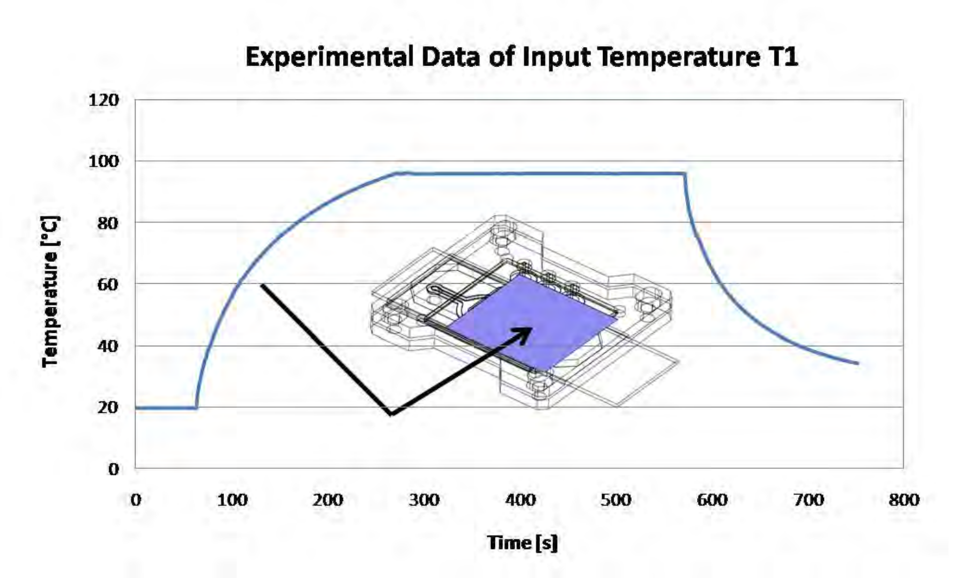
contact surface between the chip and the bottom part of the clamping



k_{res} and d_{res} are referred to the thermal grease

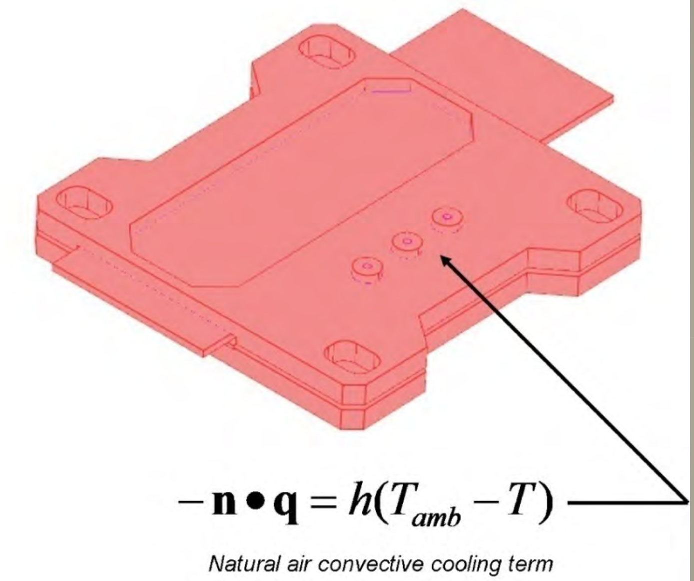
Comsol FEM Model Details - External Boundary Conditions

• *Dirichlet Condition that prescribes a specified temperature on a boundary Ω [eq. 1]*



$$T = T1(t) \quad on \ \ \partial\Omega \qquad [eq.1]$$

• *Neumann Condition that specifies the heat flux [eq. 2]*



$$-\mathbf{n} \bullet \mathbf{q} = h(T_{amb} - T) \quad on \ \ \partial\Omega \qquad [eq.2]$$

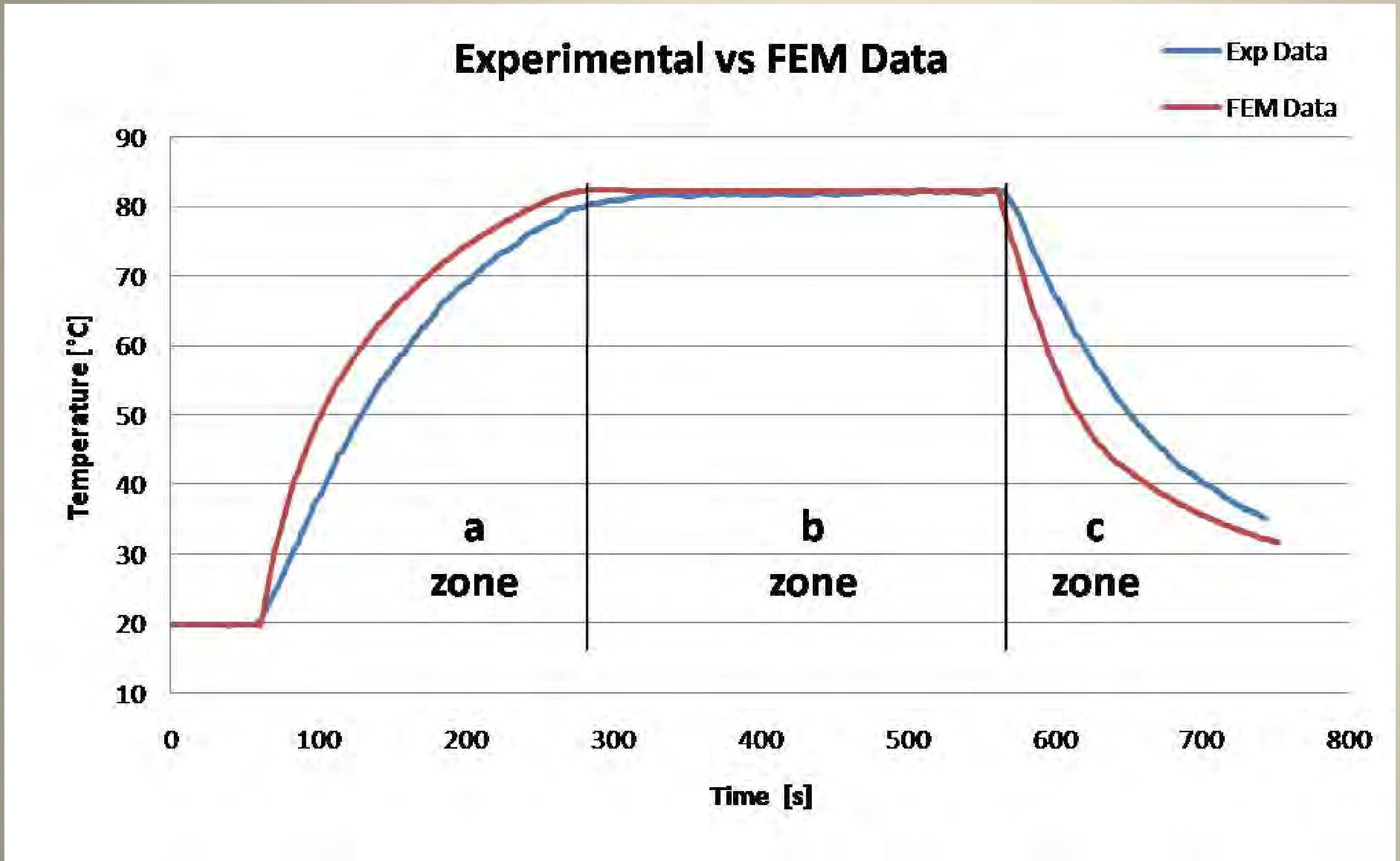
q= $-k\nabla T$ *is the conductive flux vector [W/m²]*

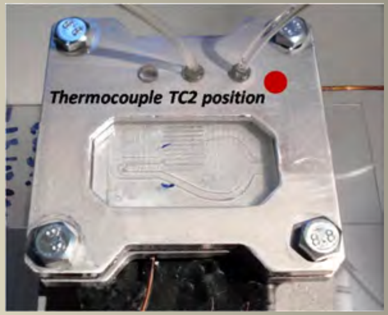
n *is the normal vector of the boundary, pointing out from the domain*

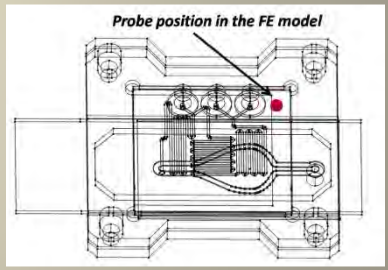
h is a heat transfer coefficient [(W/(m²·K)]

T_{amb} is the room temperature

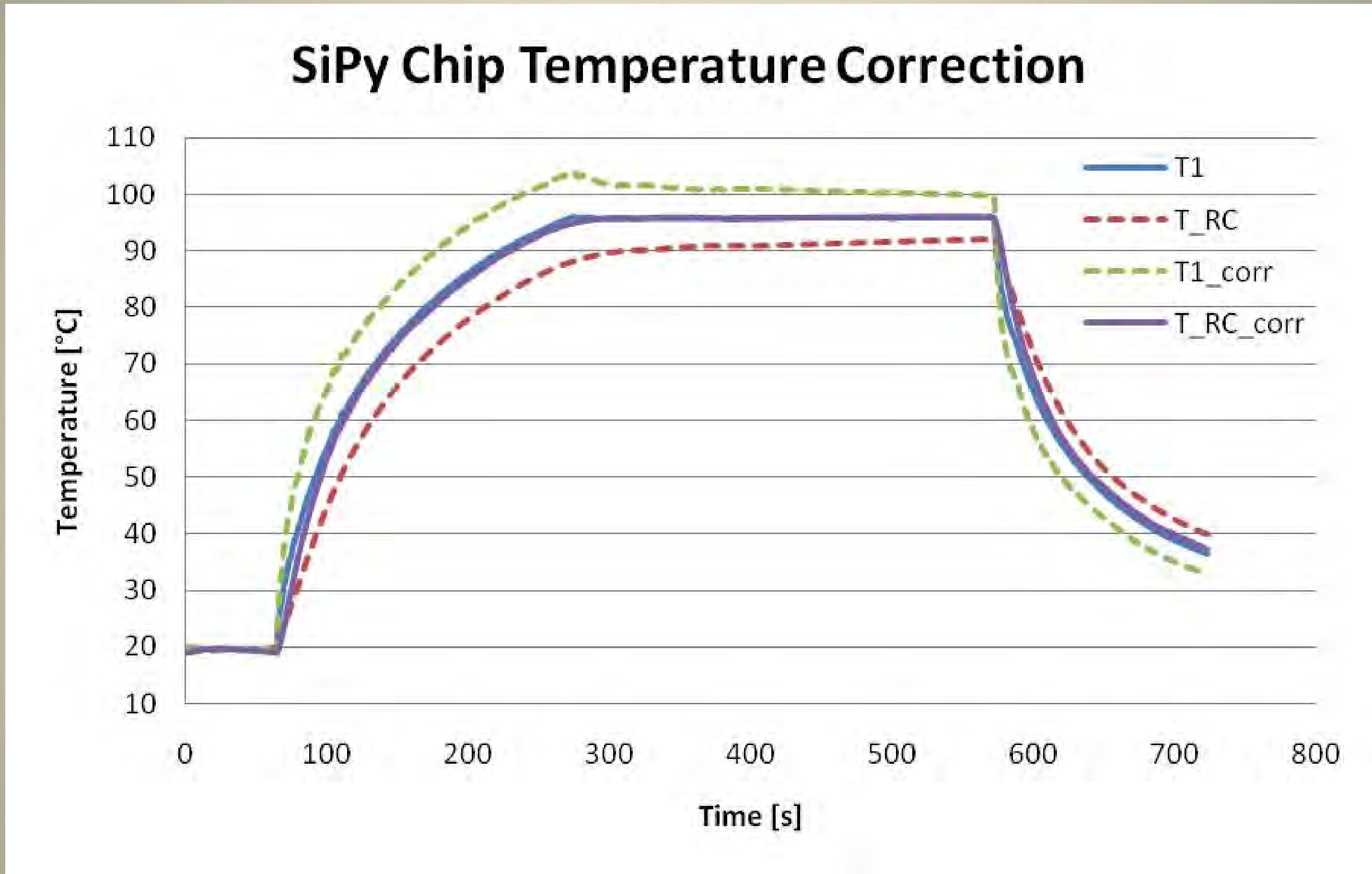
FE Model Validation: Experimental Measurement vs Fem Results





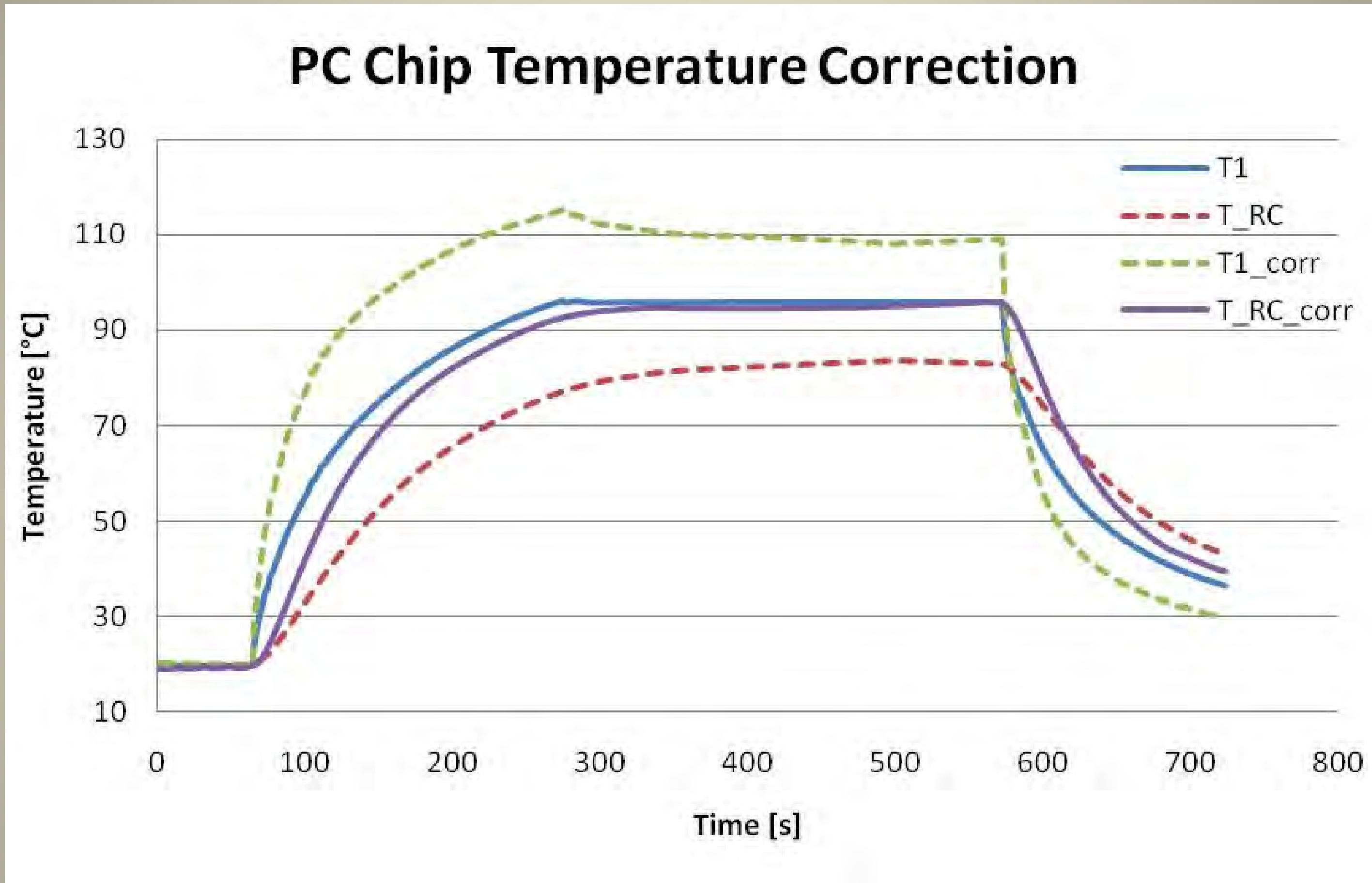


FEM Results



- *T1 = Temperature input curve*
- *T_RC = Temperature into the RC before the correction*
- *T1_corr = T1+ΔT   (ΔT is the correction factor)*
- *T_RC_corr = Temperature into the RC after the correction*

FEM Results



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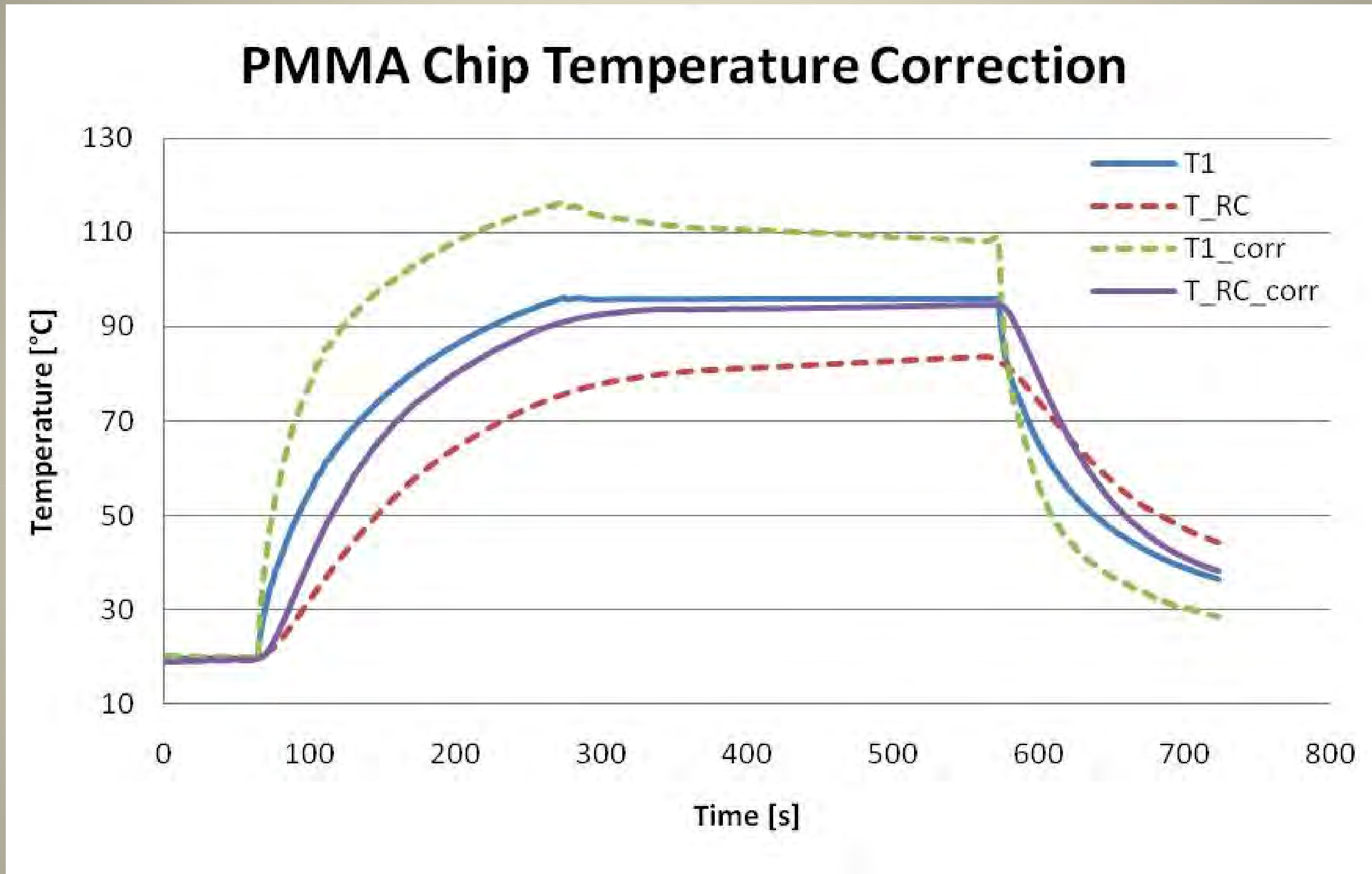

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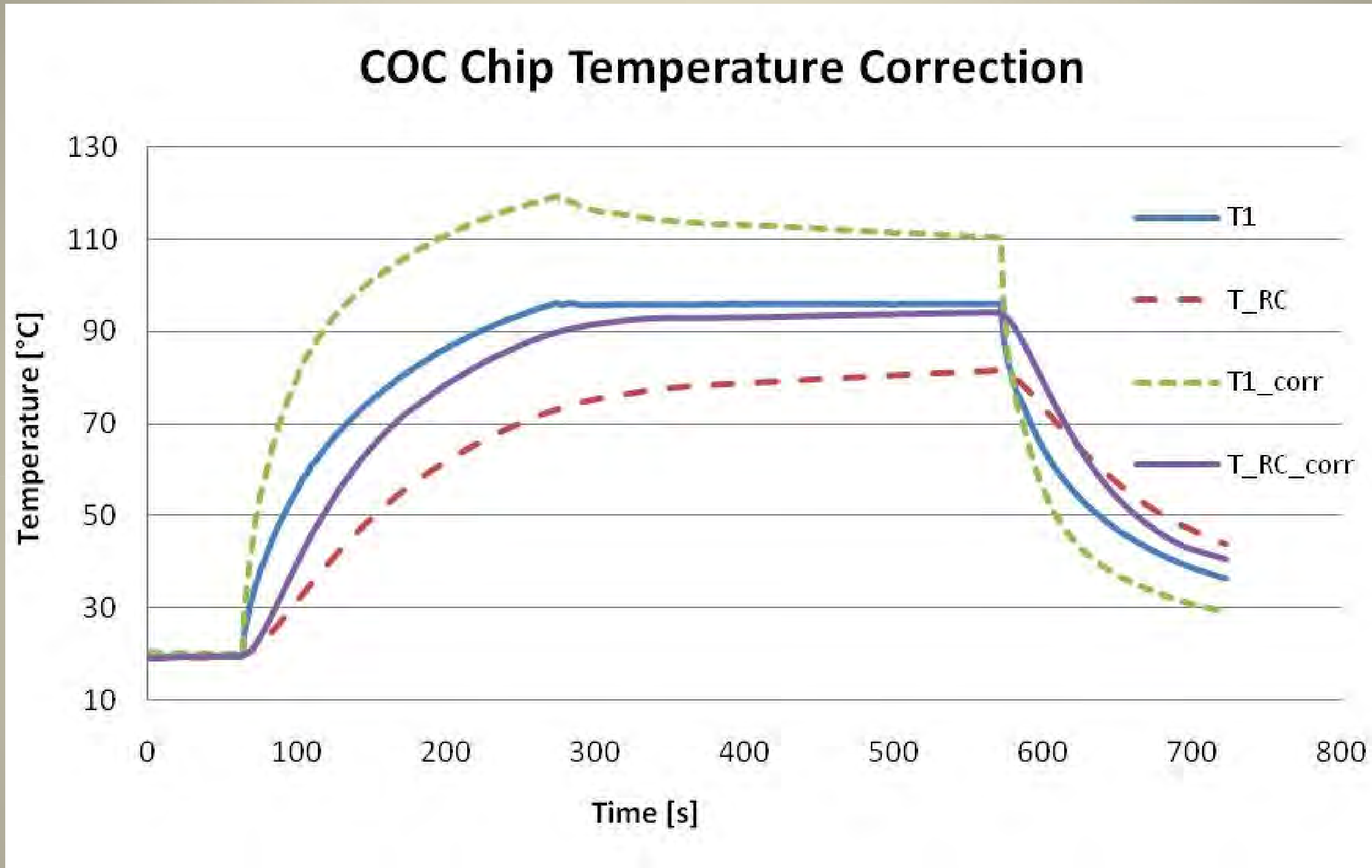

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Conclusion and Future Work

Conclusion

- *In this work, a FE model to monitor the temperature values into the reaction chamber of a LOC device is illustrated*

- *Among all the polymers analyzed, the PolyCarbonate (PC) performs better, from a thermal point of view*

- *This FE model allows to correct the temperature profile to be applied to the bottom part of the clamping system, to obtain the temperature profile into the reaction chamber according with the genetic protocols that have to be implemented in (DNA denaturation temperature in this case)*

Future work

- *Implement the FE model on the Comsol 4.0a to perform parametric time dependent analyses. In this way it will be possible to determine, through a "one-step" calculation, the minimum thickness of the chip that both maximizes the heat transfer and also allows to obtain the required temperature into the reaction chamber*

- *Add the Structural Mechanics module to explore the mechanical stress and strain of the whole device. In this way it will be possible to further optimize the geometry of the device in the region of the contact area between the reaction chamber and the microarray glass slide, where a reversible sealing is necessary*

Thanks for your

Attention