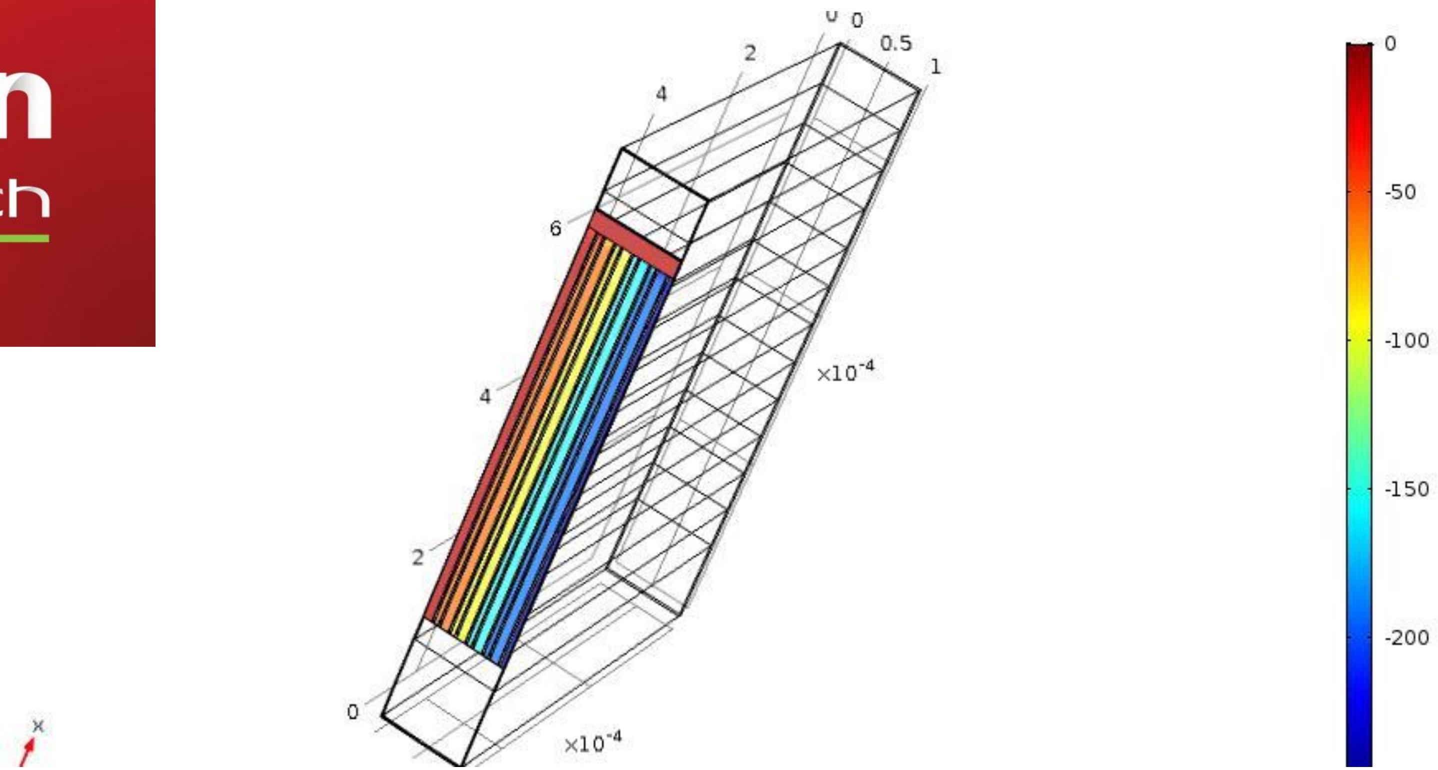


THERMAL MODELING FOR ON-INTERPOSER THERMOELECTRIC SENSORS

COMSOL Conference Rotterdam | Morel Christophe & Savelli Guillaume

OBJECTIVES

- **Our aim is to design micro ThermoElectric Sensors (μTES) to detect hot spots in microelectronic devices.**
- **Use of the Seebeck effect which produces a voltage signal when the μTES is placed in a thermal gradient.**
- **A μTES is made of a large number of positive Seebeck coefficient lines (p-lines) connected to the same number of negative Seebeck coefficient lines (n-lines) to form p-n junctions.**
- **μTES are placed in-between a thermal test chip (TTC acting as a hot source) and a Si-based wafer which may be etched (or not) to integrate micro-channels for cooling by air or water**
- **The goal is to attain a sensitivity Se = 100 mV/°C with a short response time (< 400 ms).**

THERMOELECTRICITY GOVERNING EQUATIONS (JAEGLE, 2007)

- **Equation for the temperature T:**

$$\rho C \frac{\partial T}{\partial t} + \nabla . \underline{q} = Q$$

$$\underline{q} = -k\nabla T + \underbrace{S}_{\text{Seebeck coefficient}} T \underbrace{\underline{J}}_{\text{electric current density}}$$

$$\underbrace{Q}_{\text{Joule heat source}} = \underline{J}.\underline{E} \qquad \underbrace{\underline{E}}_{\text{electric field}} = -\nabla U$$

- **Electric current density (A/m2):**

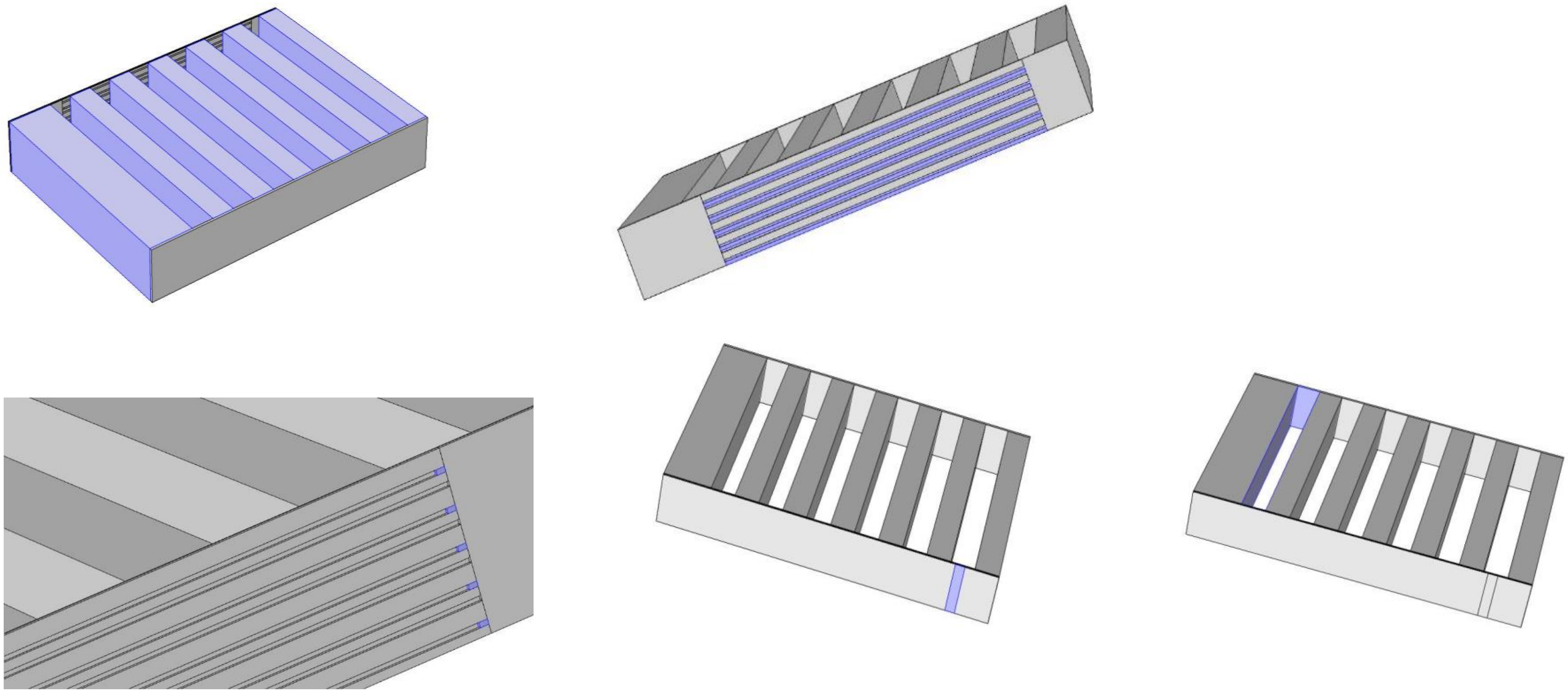
$$\underline{J} = -\underbrace{\sigma}_{\text{electrical conductivity}} \left(\nabla U + S\nabla T\right)$$

- **Equation for the electric potential U (V):**

$$\underbrace{\varepsilon}_{\text{permittivity}} \left[\frac{\partial^2 U}{\partial x \partial t} + \frac{\partial^2 U}{\partial y \partial t} + \frac{\partial^2 U}{\partial z \partial t} \right] = -\nabla . \underline{J}$$

GEOMETRICAL MODEL OF μTES AND MICRO-CHANNELS

- Only 5 junctions (10 lines) of the μTES are simulated (the complete μTES has 315 junctions which is not manageable by the simulation because of small details like silicides)
- Six micro-channels are simulated when they are present.



MATERIAL PROPERTIES OF THE P-N LINES

- **Two different thermoelectric materials are tested: SiGe (Silicium Germanium alloy) and QDSL (Quantum Dot SuperLattices).**

- **Definition of parameters used**

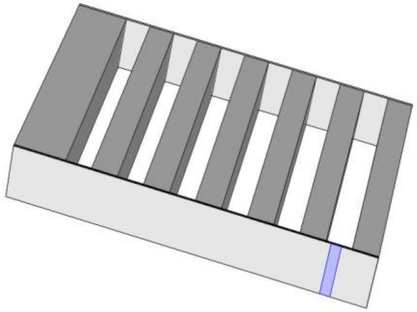
Materials	SiGe		QDSL	
Line type	p	n	p	n
R = 1/σ (Ω.m)	3.10^{-5}	$3,4.10^{-5}$	$1,6.10^{-4}$	$2,5.10^{-4}$
S (mV/K)	142	-185	253	-267
k (W/mK)	4.7	4.1	5.3	6.3
ρ (kg/m^3)	2330	2330	2330	2330
C (J/kgK)	710	710	710	710

SIMULATION CASES

- **We investigate two types of heat transfer boundary conditions:**

  -> Imposed temperature = 120 °C

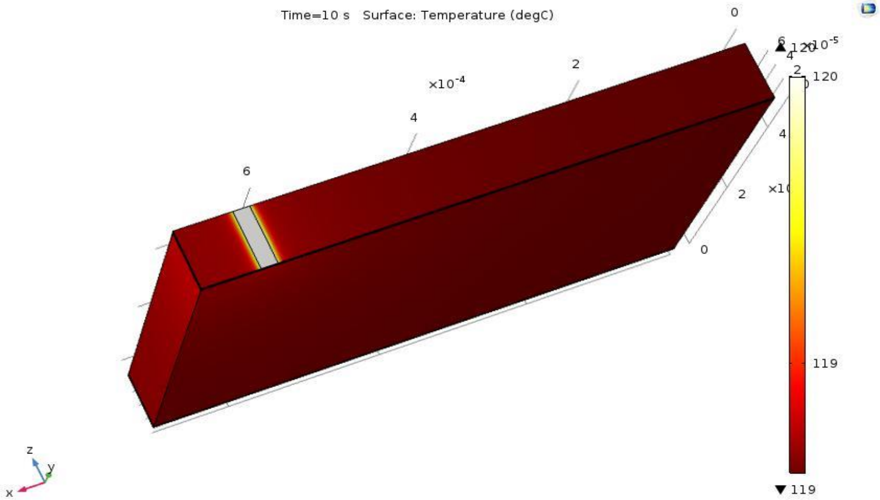
  -> Imposed flux density = P/S = 99469 W/m²

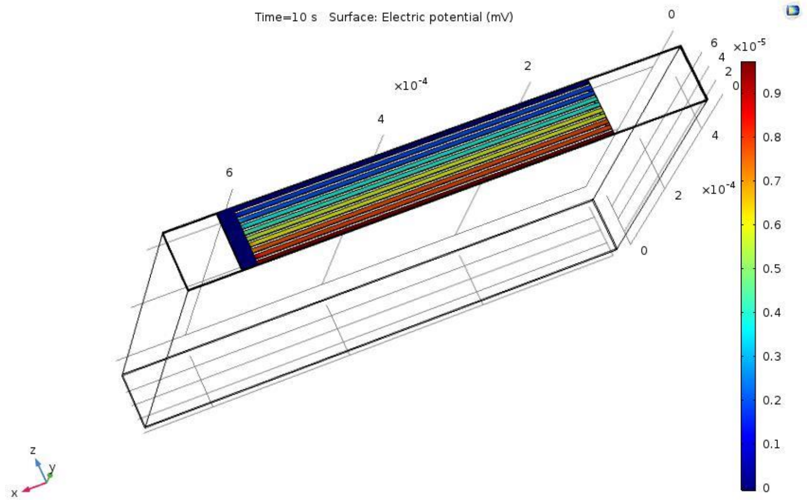


- **Calculations with and without micro-channels are made in order to investigate the cooling effect.**

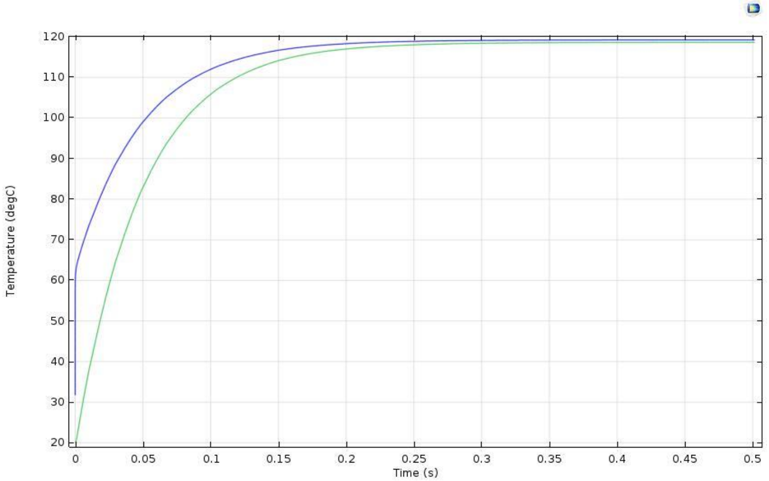
IMPOSED TEMPERATURE WITHOUT MICRO-CHANNELS
SIGE MATERIAL

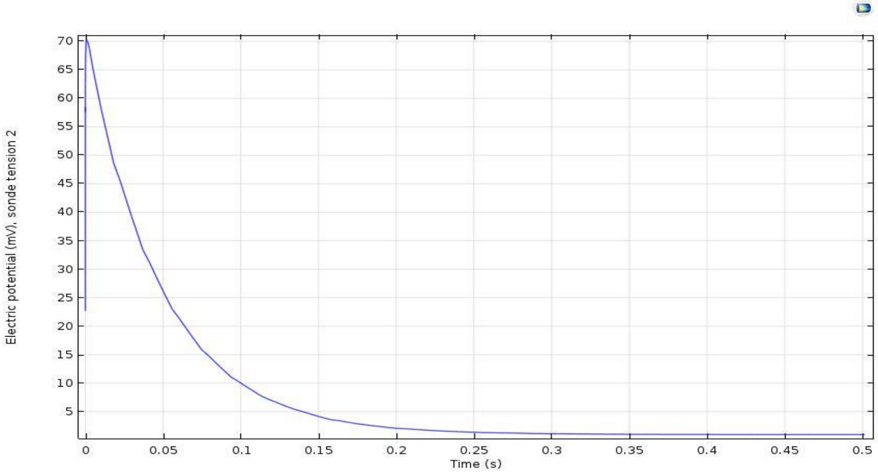
- **Temperature and electric fields at the end of the calc. (t = 10 s)**



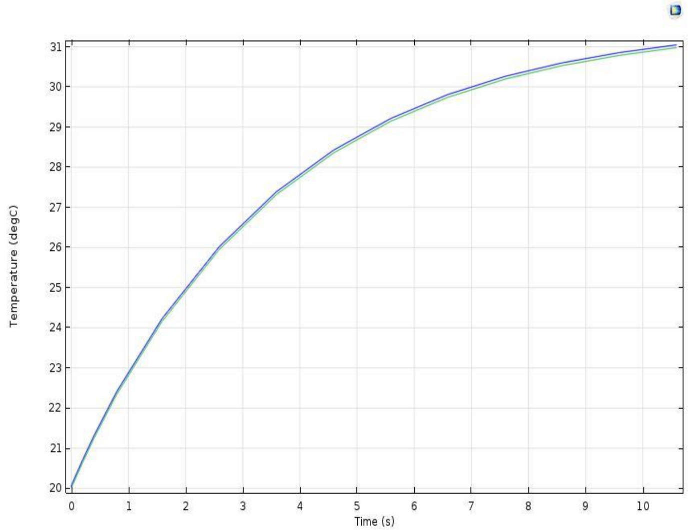


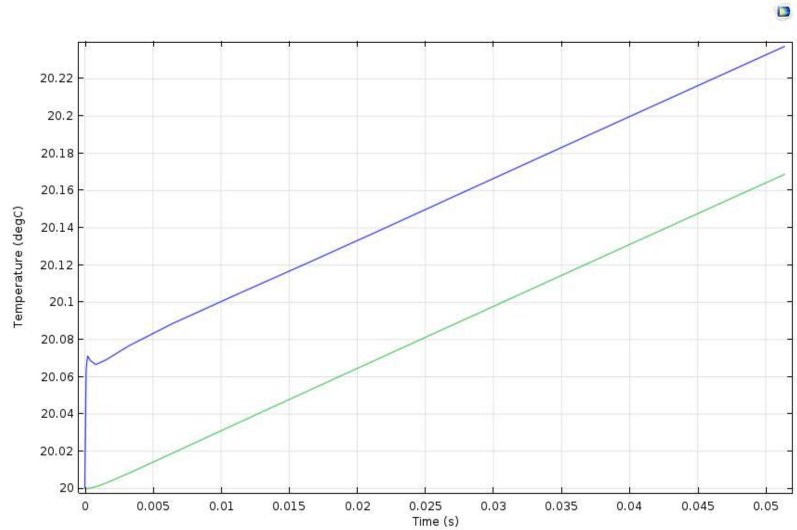
- **Time evolution of the hot and cold sides temperatures and the U**





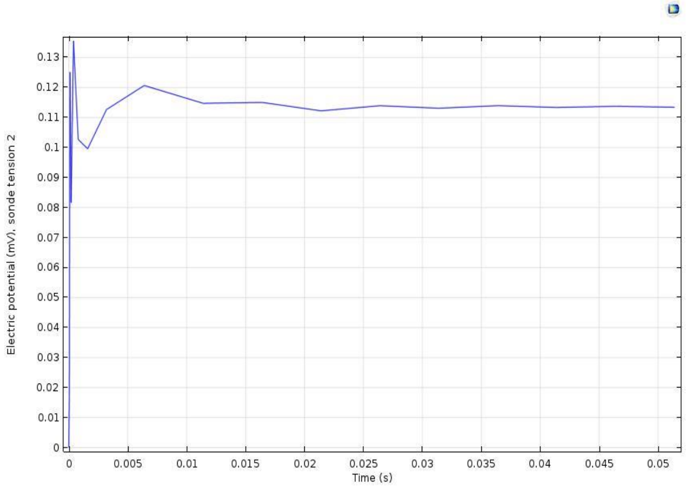
IMPOSED FLUX WITHOUT MICRO-CHANNELS
SIGE AND QDSL MATERIALS

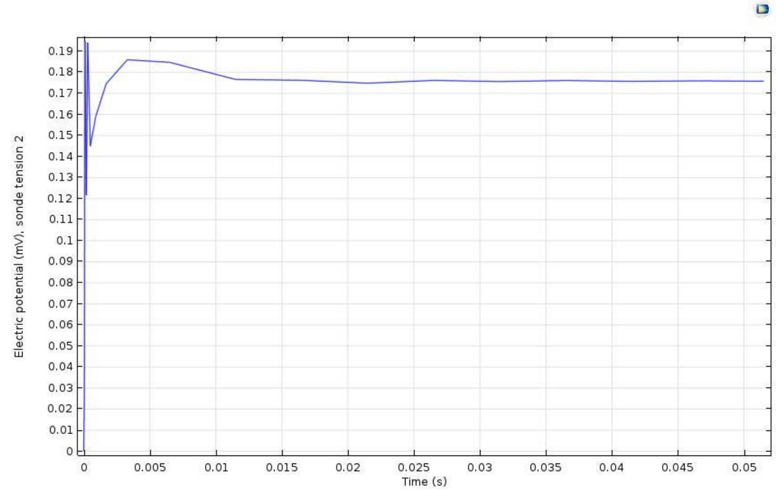




- Left: SiGe

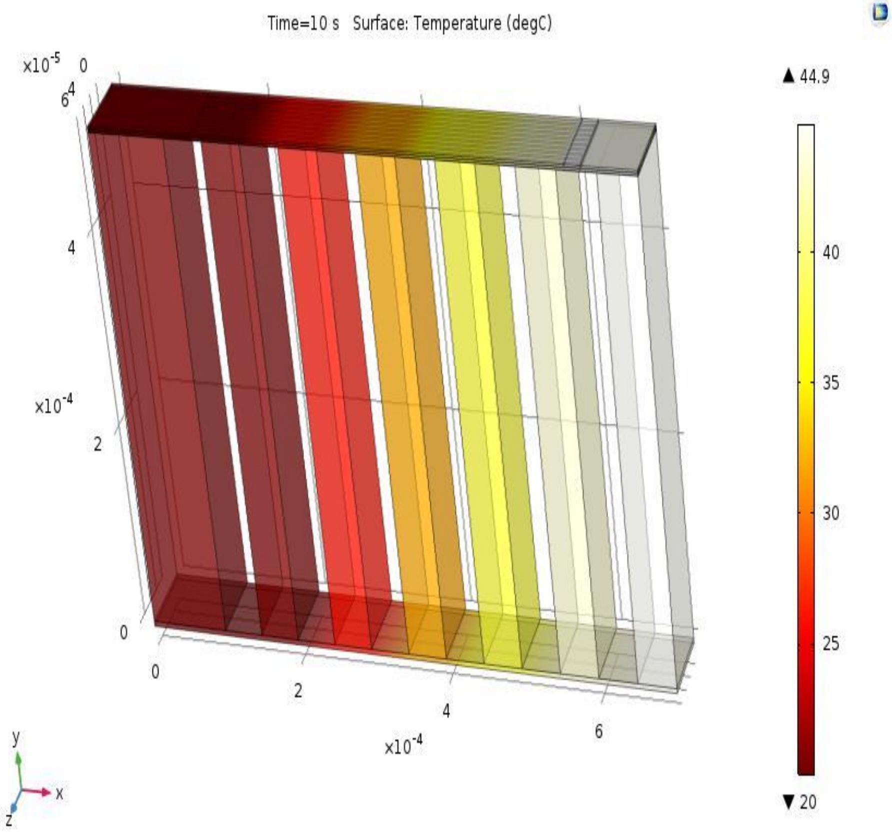
Right: QDSL

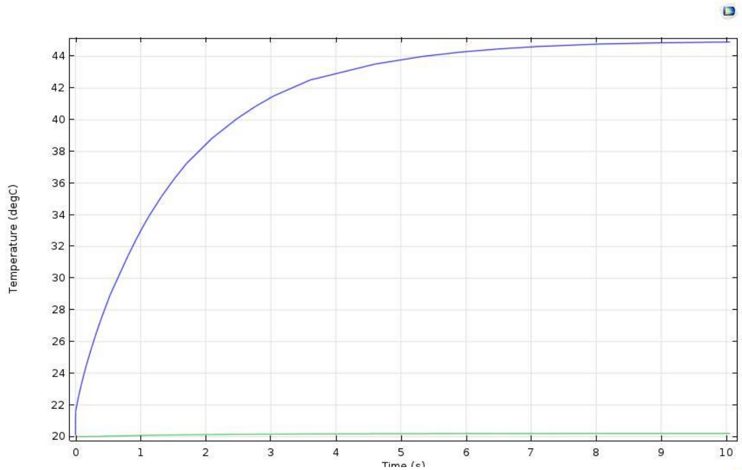


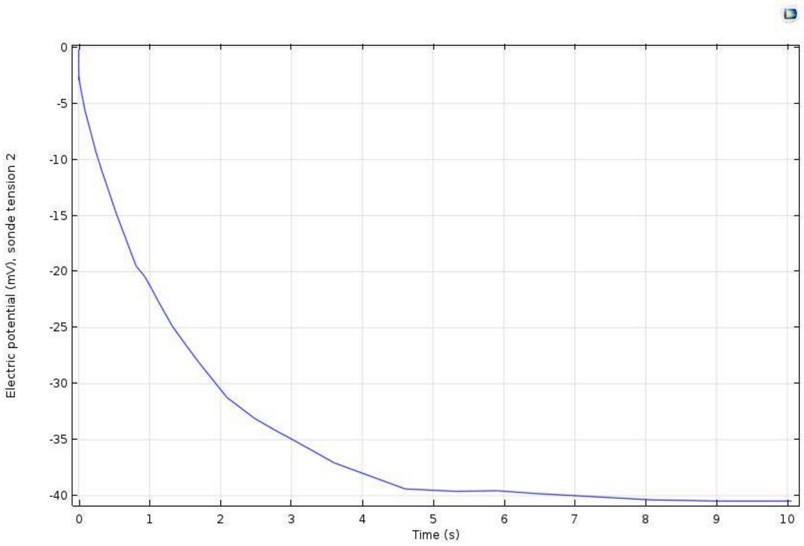


EFFECT OF THE CHANNELS
SIGE AND IMPOSED HEAT FLUX

- **5 micro-channels filled with air (h = 15 W/m²K) and 1 with water (h = 10000 W/m²K)**







CALCULATION OF THE SENSITIVITY IN THE DIFFERENT CASES

Materials	heat transfer boundary conditions	µchannels	Temperature difference $\Delta T = Th - Tc$ (K)	Voltage U (mV)	Time t (s)	Sensitivity Se (mV/K) 5 junctions	Sensitivity Se (mV/K) 315 junctions
SiGe	120 °C	no	43	70	0.01 s	1.63	103
QDSL	120 °C	no	43	112	0.01 s	2.6	164
SiGe	flux	no	0.072	0.12	0.001	1.66	105
QDSL	flux	no	0.072	0.19	0.001	2.64	166
SiGe	flux	yes	25	41	5	1.64	103

- **SiGe: 102.6 mV/K < Se < 105 mV/K for 315 junctions**
- **QDSL: 164 mV/K < Se < 166 mV/K for 315 junctions**
- **QDSL has a better performance due to its higher Seebeck coefficient**

CONCLUSIONS

- **The µTES sensitivities Se are always greater than the 100 mV/K required**

- **The response time varies with the temperature field predictions: a rapid temperature variation will give a quick response time**

ACKNOWLEDGEMENTS

- **EUROPEAN UNION**

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STREAMS

Smart Technologies for eneRgy Efficient Active cooling in Advanced Microelectronic Systems

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