Presented at the COMSOL Conference 2010 Paris

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Crystal growth set-up for Microelectronic process

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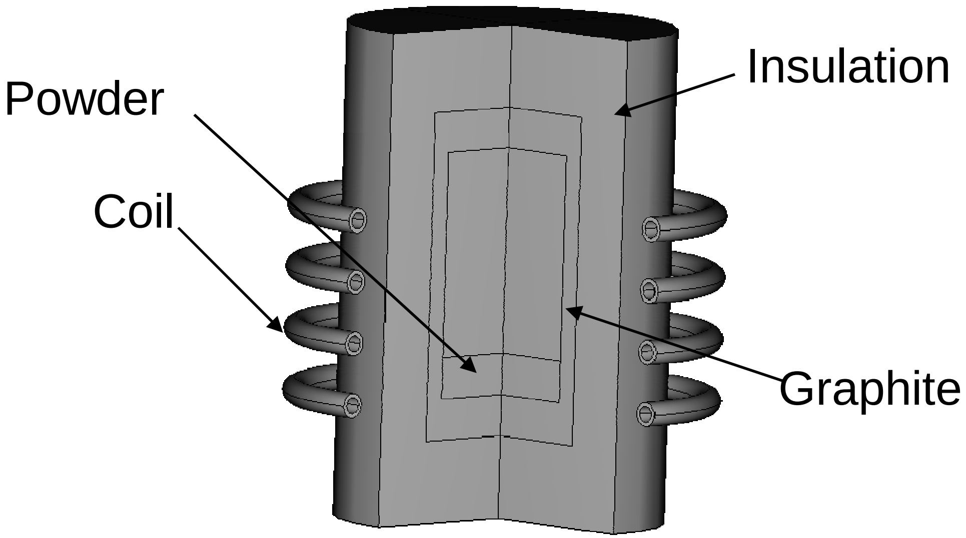
Control of geometry + control of power supply
= control of thermal gradient



Induction heating modeling
of crystal growth set-up

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Induction heating model with v4.0

Geometric Model : Hypothesis

- 2D cylindrical geometry to obtain optimize coil
- For induction heating model 2D axi

Physical Model : induction heating

- Electromagnetic
- Quasi-static approximation ($\sigma >> \varepsilon\omega$) in 2D axi
- Thermal radiation with ambient and in cavity in 2D axi

Numerical model : strong coupling

- Vector potential formulation – complex unknown
- Temperature formulation – non linear problem (T^4 ,$\sigma(T)$) in 3D
- Radiative flux with view factor

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Coil Design

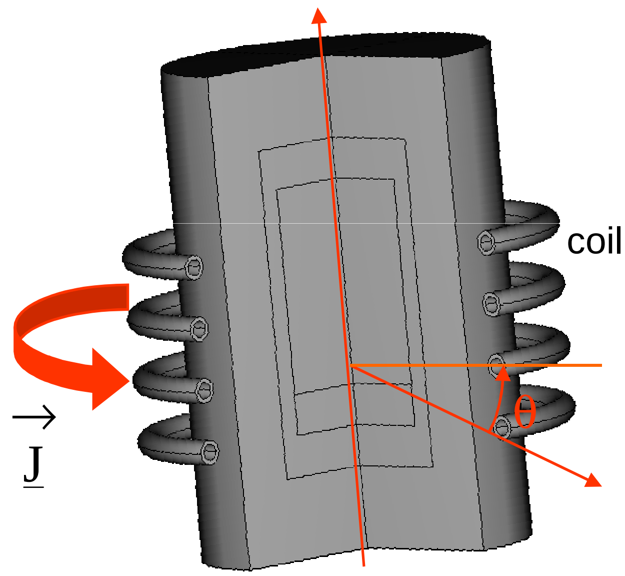
Mathematical model : Partial derivative equation

$$\vec{\underline{A}} \,/\, \vec{B} = \vec{rot}\, \vec{\underline{A}} \quad \left(\text{flux conservation : div } \vec{B} = 0 \right)$$

$$\vec{rot}\left(\vec{rot}\, \vec{\underline{A}} \right) + j\mu_0\sigma(T)\omega \vec{\underline{A}} = \mu_0\sigma(T)\, \vec{grad}\, \underline{V}$$

2D cylindrical geometry

$$\vec{\underline{J}} = \begin{pmatrix} 0 \\ \underline{J}_\theta(r,z) \\ 0 \end{pmatrix}$$



Coil Design

In order to design coil we needed losses in the copper
Voltage supply and computation of eddy currents in coil

$$\vec{J}_{total} = -j\sigma(T)\omega\underline{\vec{A}} + \sigma(T)\,\overrightarrow{grad}\,\underline{V}$$

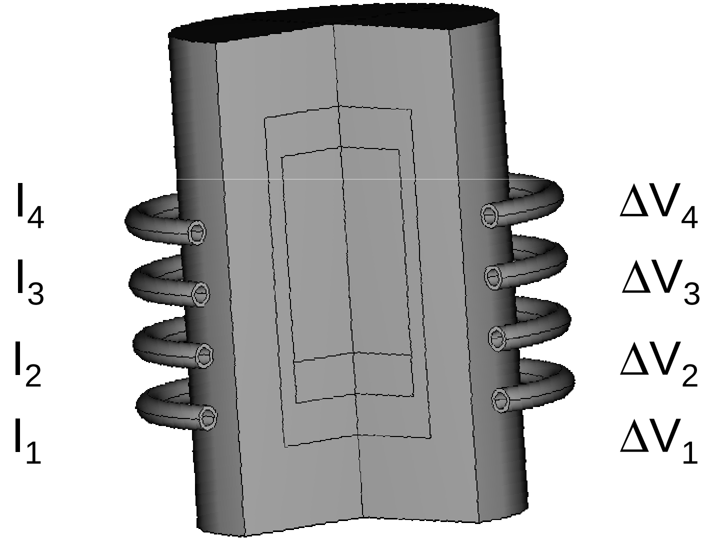
Turn coil are in a serial electric scheme :

$I_1 = I_2$ ...

ddp per turn coil imposed : **DV_i**

Constraint for an integral property :

$$I_i = \int_S \vec{J}_{total_i} . \vec{dS}_i$$



Adjustement of DV_i, in order to respect constraint

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Physical properties

Paramètres

Paramètres

Nom	Expression	Valeur	Description
sigma_isolation	2e3[S/m]	2000 S/m	
sigma_poudre	1e4[S/m]	10000.0 S/m	
I0	300[A]	300 A	
k_isolation	1	1	
k_graphite	10	10	
k_poudre	25	25	
FREQ	50000[Hz]	50000.0 Hz	

Frequency=50kHz

Propriétés de sortie

Propriété	Variable	Expression	Unité	T.
Conductivité électrique	{sig...a33}	sigma_graphite	S/m	3x
Perméabilité relative	{mu...33}	1	1	3x
Permittivité relative	{eps...33}	0	1	3x

Expression:

Entrées du modèle

Quantité physique	Variable
Température	T

Paramètres locaux

Paramètre	Expression	Unité
sigma_graphite	70000/(0.375+0.00035*T+144.7/T)	

$$\sigma_{graphite} = \frac{7\,10^{4}}{3.5\,10^{-4}\,T + 0.375 + \frac{144.7}{T}}\,\Omega^{-1}.m^{-1}$$

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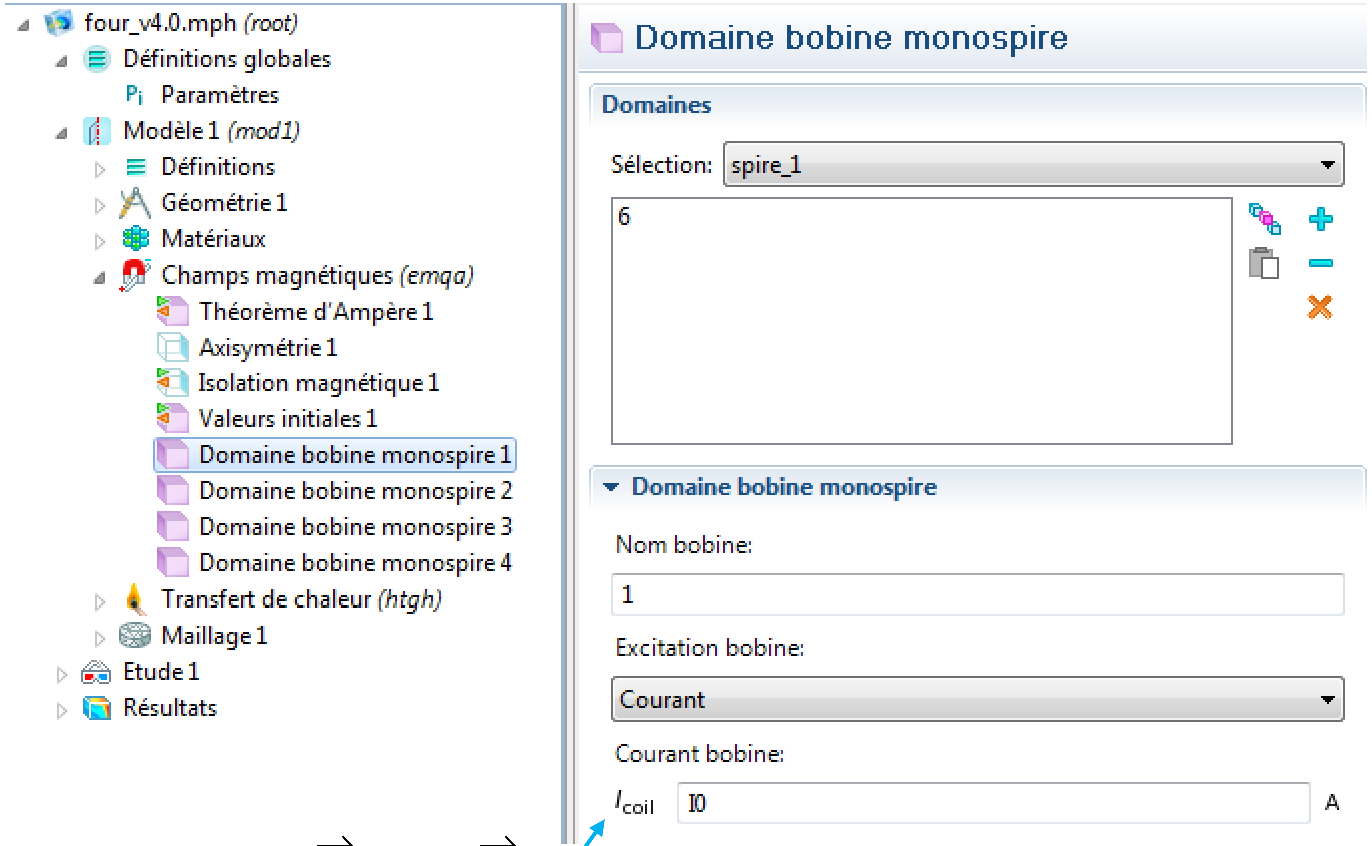
Constraint for an integral property

Single turn domain



$$I_i = \int_S \vec{J}_{total_i} \cdot d\vec{S}_i$$

$$\vec{J}_{total} = -j\sigma(T)\omega\vec{\underline{A}} + \sigma(T)\,\vec{\mathrm{grad}}\,\underline{V}$$

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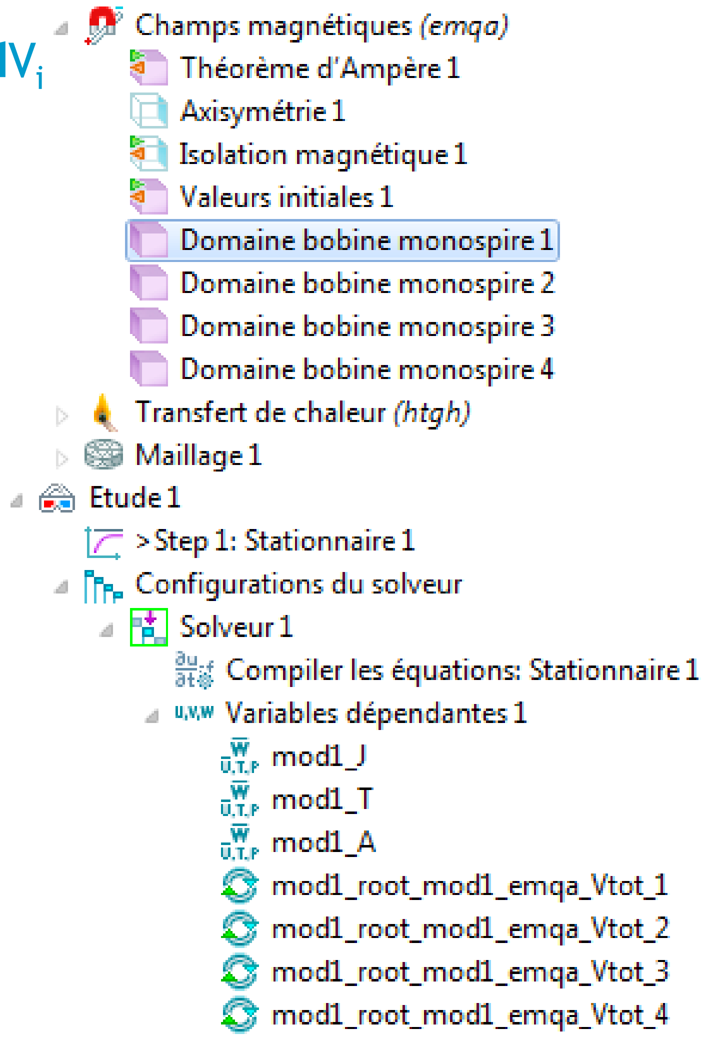
Single turn domain

ddp per turn coil computed automatically : **grad**V_i

Automatically add to dependent variables :
emqa.Vtot_1
emqa.Vtot_2
emqa.Vtot_3
emqa.Vtot_4

Adjustment of emqa.Vtot_i, in order to respect constraint I_0



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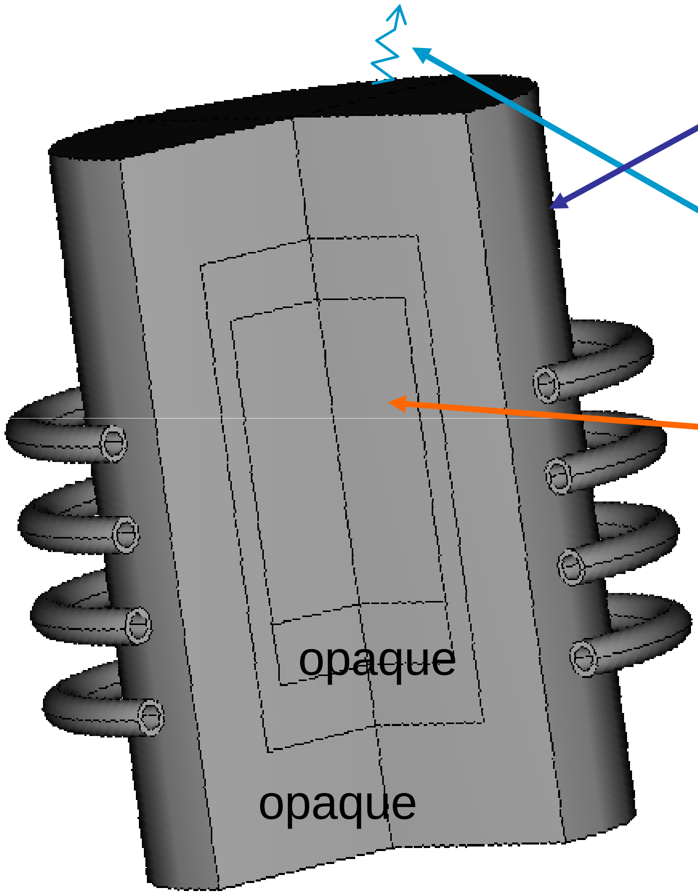
Radiation flux in cavity



Boundary conditions

T= 80°C

Boundary conditions

$$-k\,\overrightarrow{grad}\,T.\vec{n} = h\,(T-T_{amb}) + \sigma_s \varepsilon \left(T^4 - T_{amb}^4\right)$$

Radiation flux in cavity

$$-k\,\overrightarrow{grad}\,T.\vec{n} = h\,(T-T_{amb}) + \phi_{radiatif}$$

Non linear system to solve :

$$\sum_j \left[\frac{(\delta_{ij} - (1-\varepsilon_j).F_{ij})}{\varepsilon_j}\right]\phi_j = \sum_j (\delta_{ij} - F_{ij}).\sigma_s.T_j^4$$

View factor : $F_{ij} = \dfrac{1}{\pi S_i}\int_{Si}\int_{Sj} \dfrac{\cos\beta_i \cos\beta j}{d_{ij}^2} dS_i dS_j$

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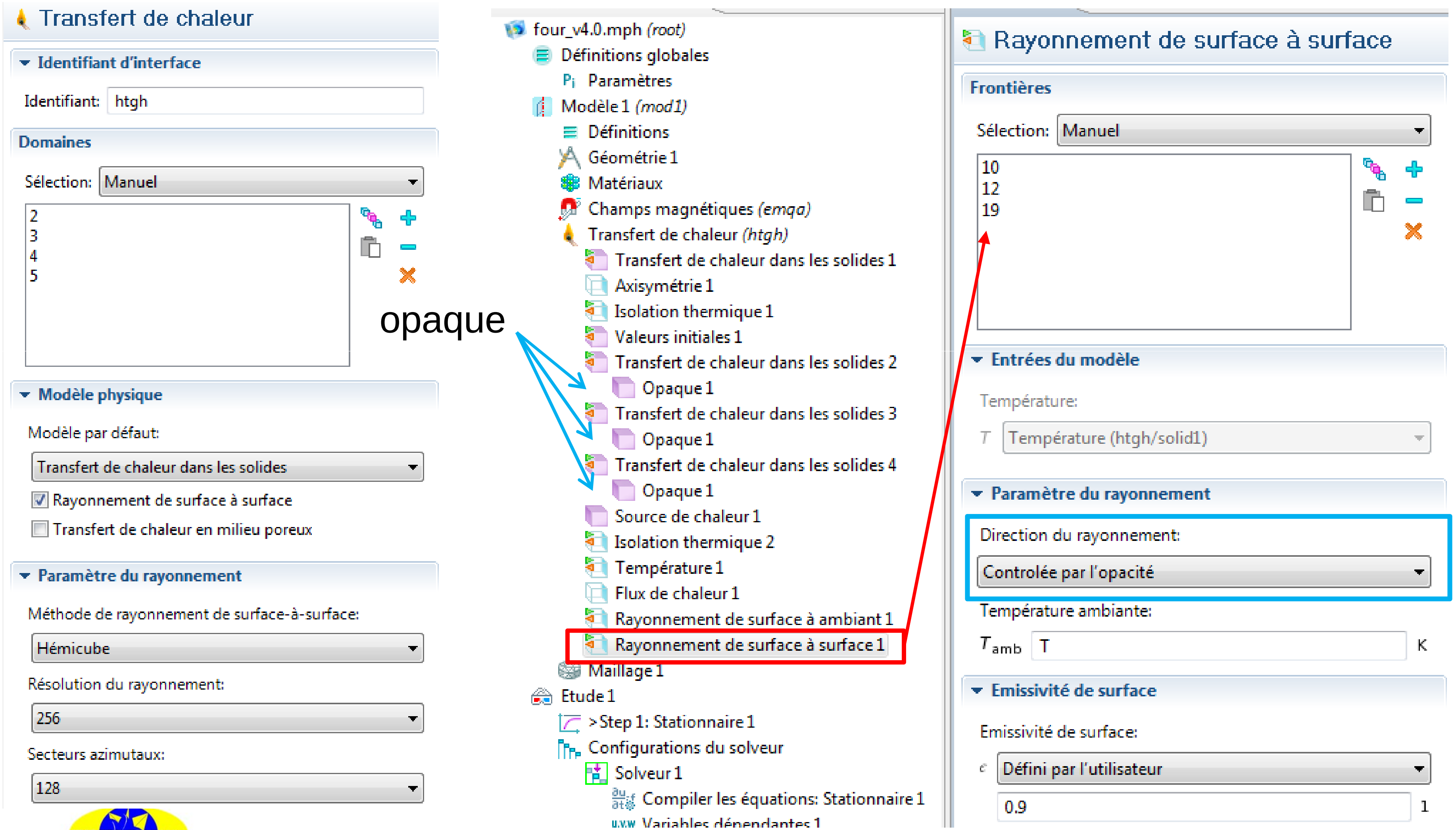
Radiation flux in cavity



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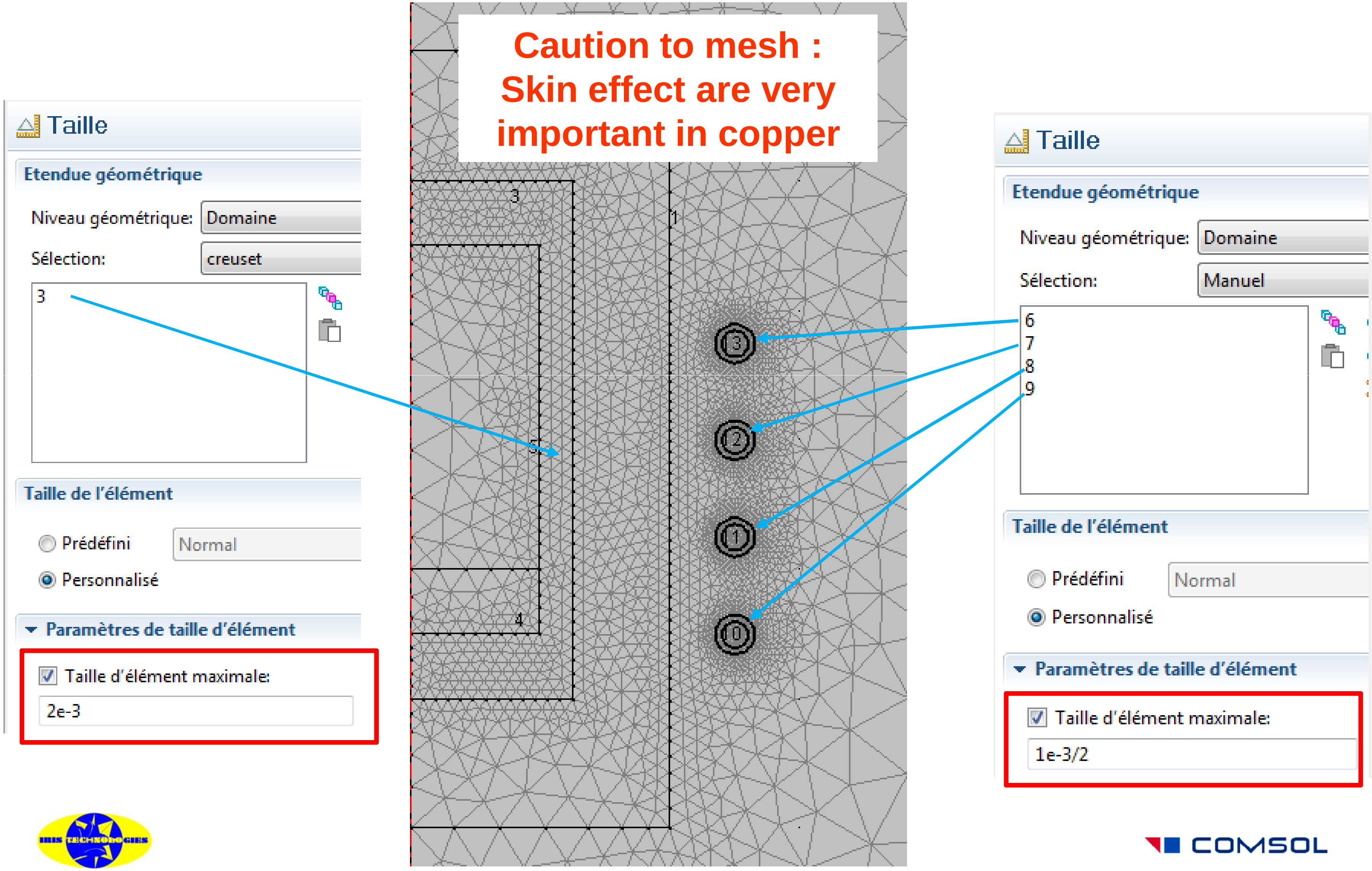
Mesh



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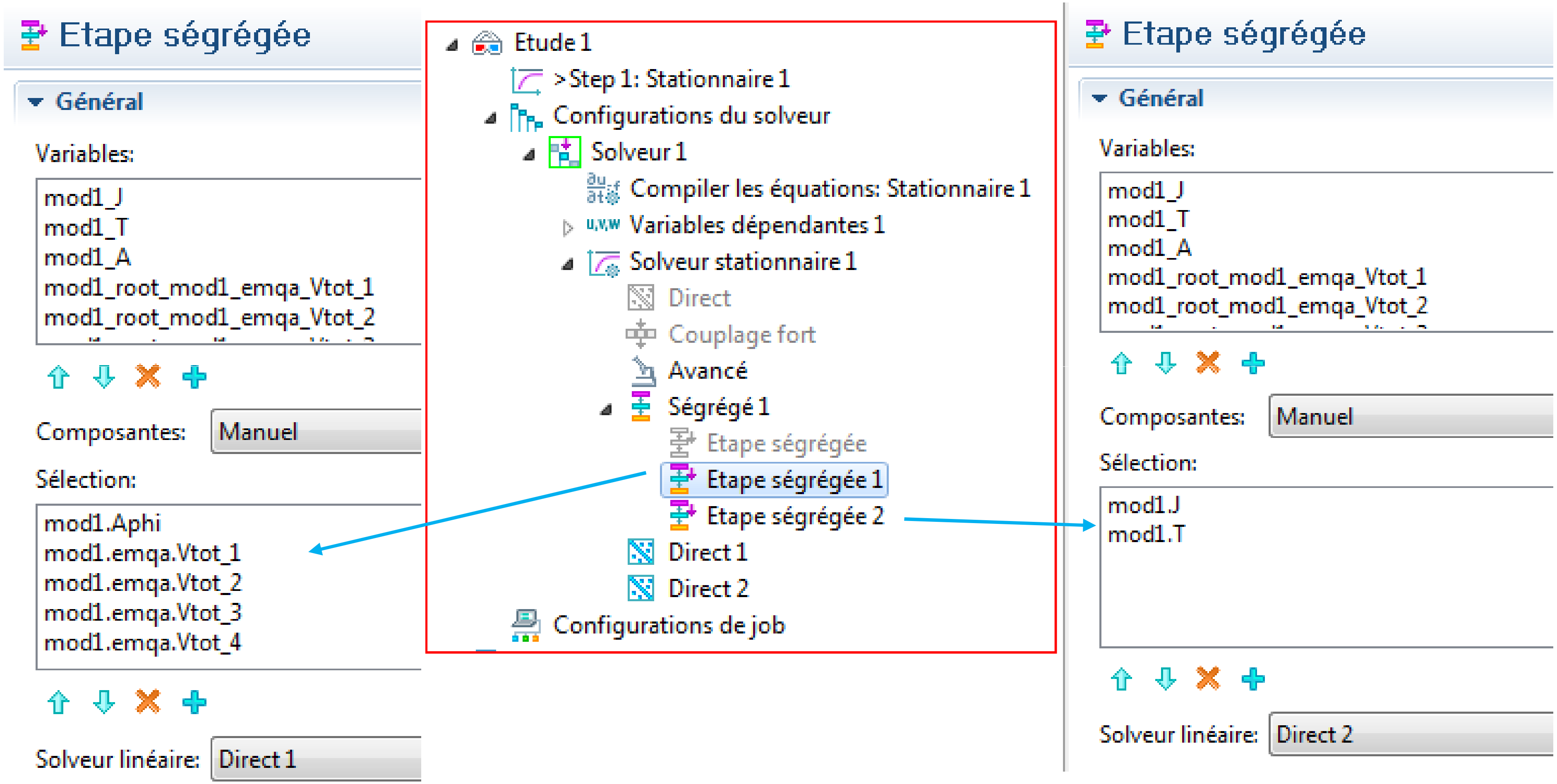
Solve



Electromagnetism

Heat transfer

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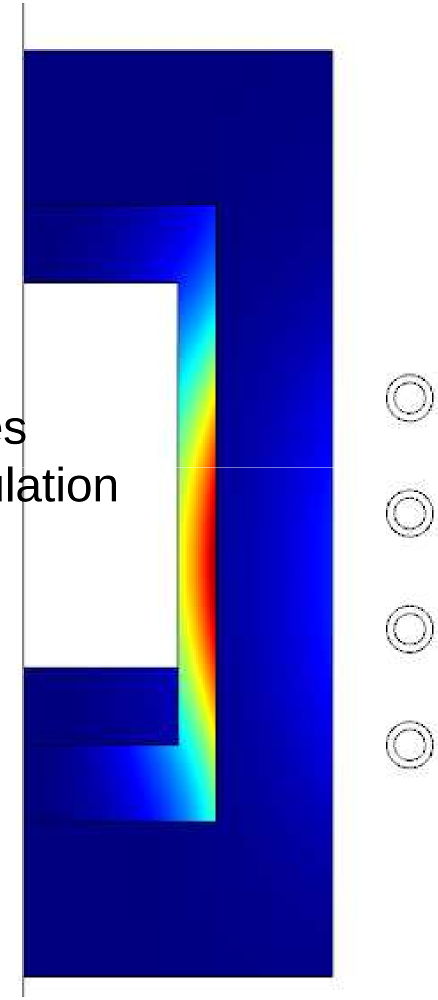
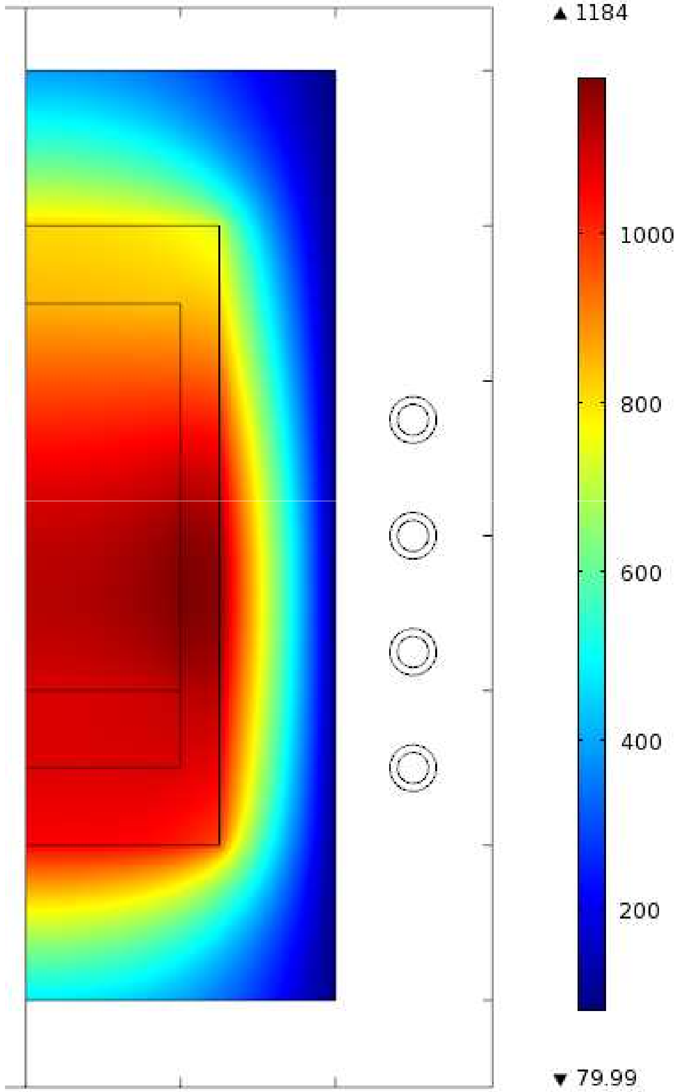
Post-processing

Joule losses
Graphite & Insulation



T in °C



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Exercise → Compute electrical parameters : R and L

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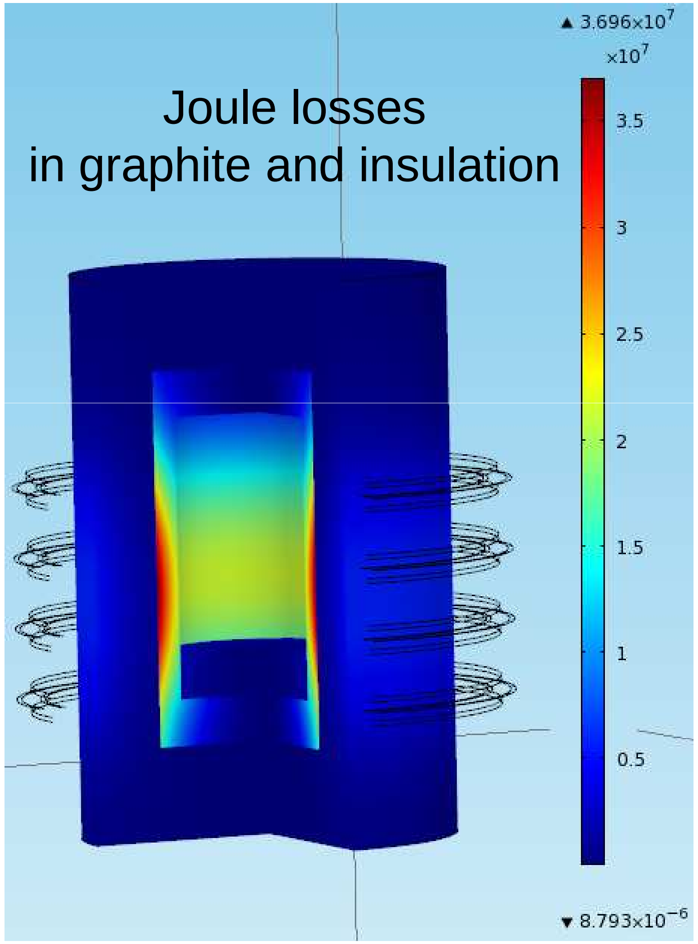
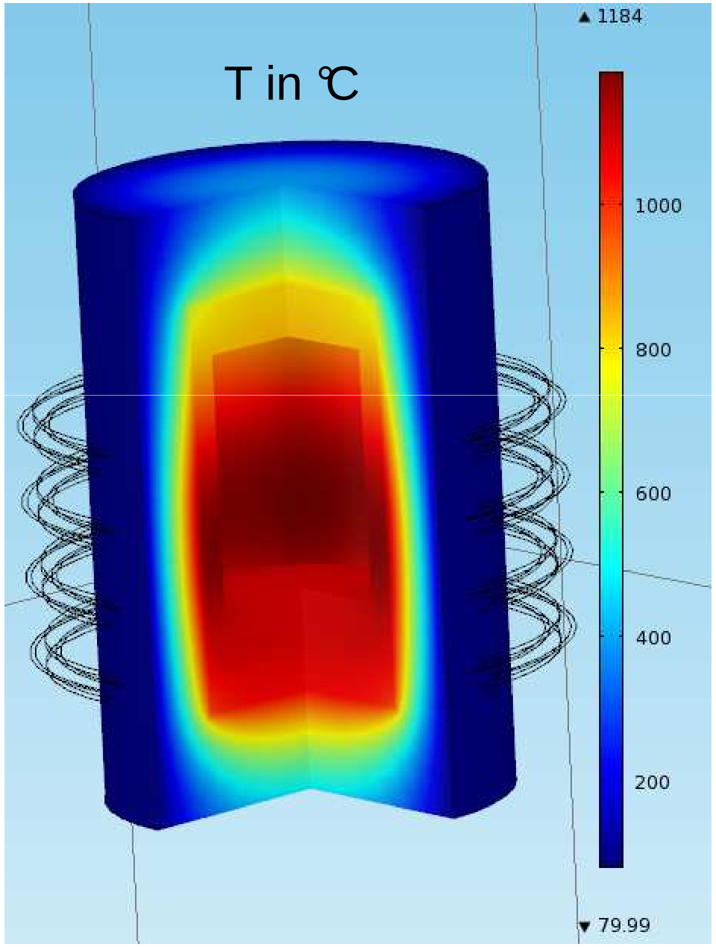
Post-processing 3D





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