Simulation of Dynamic Thermal Field Assisting DMLS Additive Manufacturing of Biocompatible Ti-Alloy

E.Lacatus [1*], G.C. Alecu [2], M. Sopronyi [3]

1. Polytechnic University of Bucharest (UPB), Assoc. Professor, Ph.D., Email: elena.lacatus@upb.ro
2. Groupe Renault, Romania
3. National Institute for Laser, Plasma & Radiation Physics (INFLPR), Romania

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Overview

- **Direct Metal Laser Sintering** (DMLS)
- **Use of COMSOL Multiphysics**
- **DMLS** *Laser thermal effect* ***- Model I***
- **DMLS** *Microwave assisted* - ***Model II*** (one microwave radiation source)
- **DMLS** *Microwave assisted*: ***Results –Model II***
- **DMLS** *Microwave assisted*: ***Results– Model III***
- **DMLS** *Microwave assisted* - ***Model IV*** (two microwave radiation sources)
- **DMLS** *Microwave assisted:* ***Results - Model IV*** (two microwave radiation sources)
- **Simulation**: *DMLS Dynamic Thermal Field-* ***Results (Model IV)***
- **Conclusions**

Direct Metal Laser Sintering (DMLS)

Use of Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) Additive Manufacturing (AM) technologies for:

- *complex 3D biocompatible metallic parts*
- *high level of customization, used in medical prosthesis / implants*

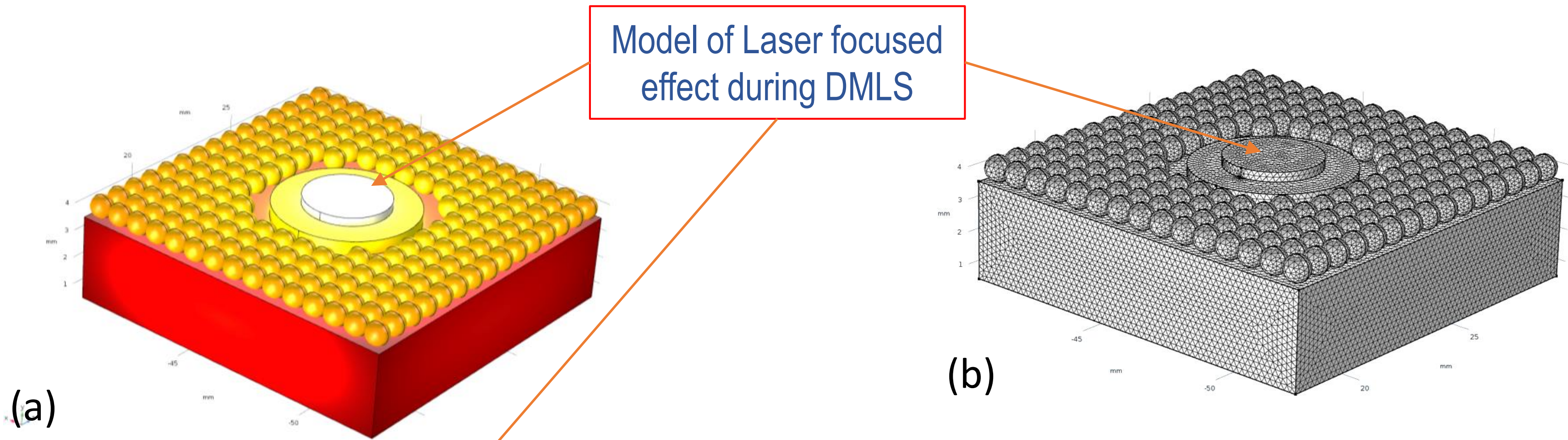
Limitations - DMLS and SLM technologies have:

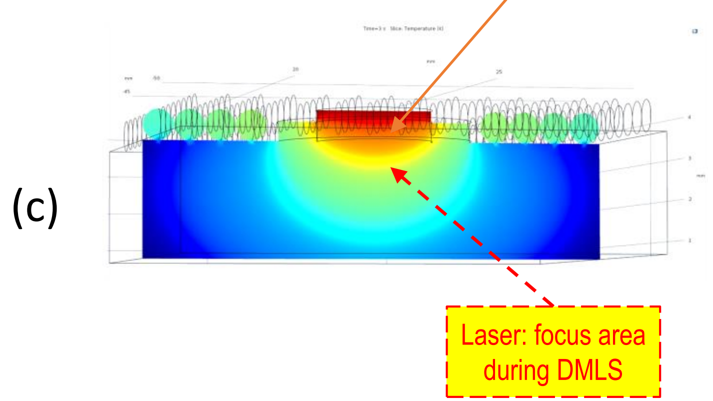
- *significant / costly post-processing (support removal ; hot isostatic pressing-HIP)*
- *quality and precision limitations*
- *frequent inconsistency and build failure (relative to traditional mfg. methods)*
- *restricted material choice*
- *macroscopic properties of AM parts not identical to traditionally manufactured parts*
- *restricted build volumes and speed limits application to low volume production*

Hypothesis *for DMLS metal powder printing:*

- *Readdressing the dynamics of Powder Bed Fusion thermal process could improve the quality of DMLS printed parts and reduce the post-processing operations time and costs*

Direct Metal Laser Sintering (DMLS) cont. I





Models: Direct Metal Laser Sintering (DMLS) fused powder bed

Ti6Al4V powder volume model

(a) SolidWorks imported CAD model
(b) Mesh of Ti6Al4V ELI Titanium Alloy Powder bed
(c) Laser thermal effect within the powder bed

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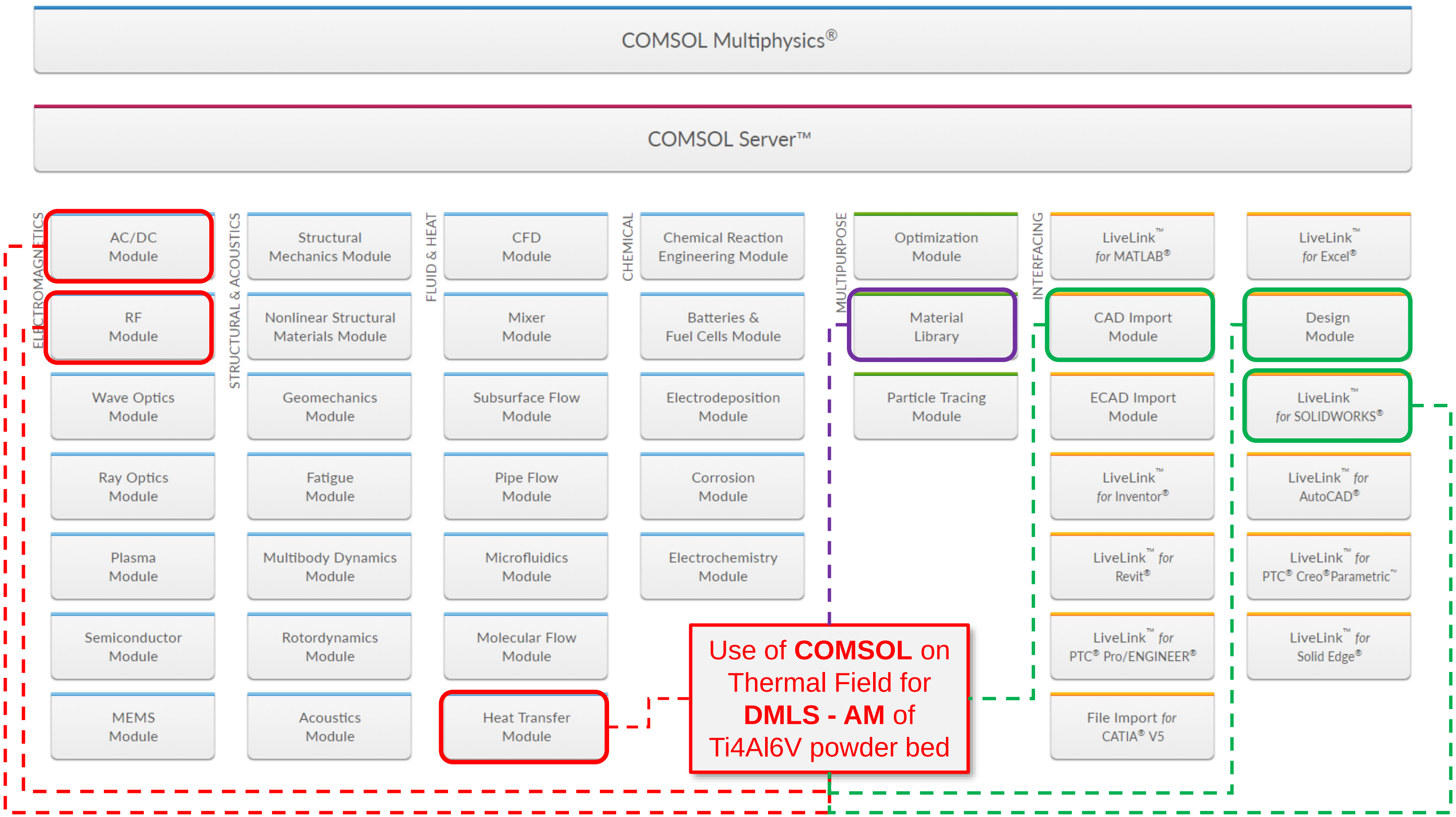
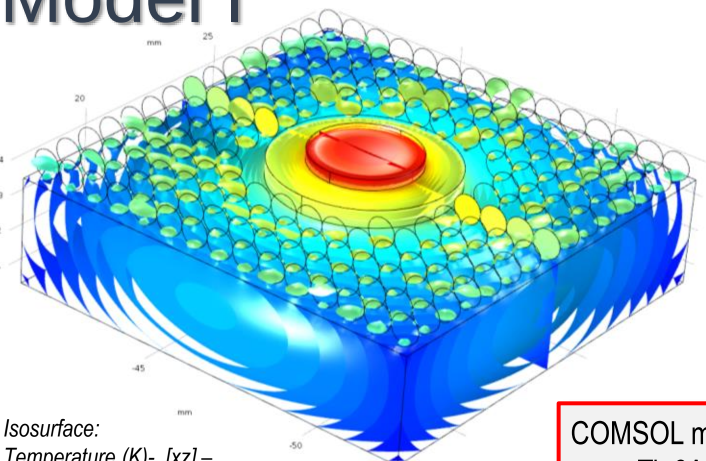
Use of COMSOL Multiphysics

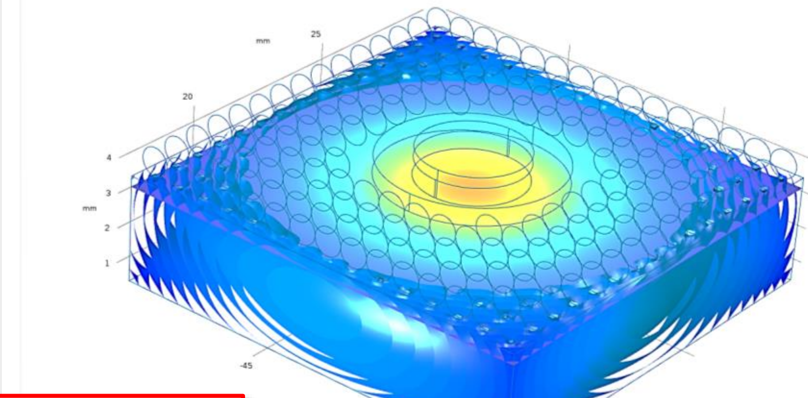


DMLS-Laser thermal effect

Model I

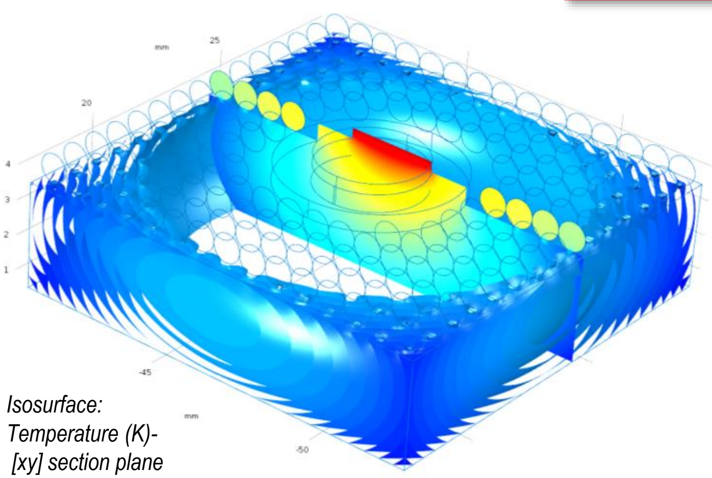


Isosurface:
Temperature (K)- [xz] –
beneath laser focus plane

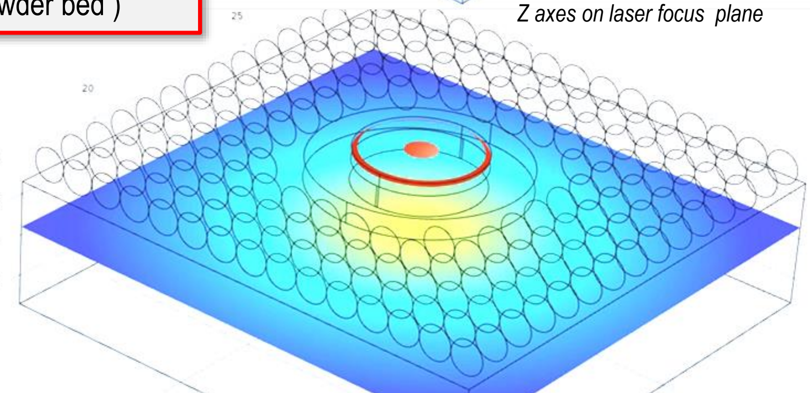


Isosurface:
Temperature (K)-
Z axes on laser focus plane

COMSOL model: DMLS of biocompatible Ti–6Al–4V ELI (powder bed)



Isosurface:
Temperature (K)-
[xy] section plane



Isosurface time related
Temperature (K)-
on Z axes during DMLS

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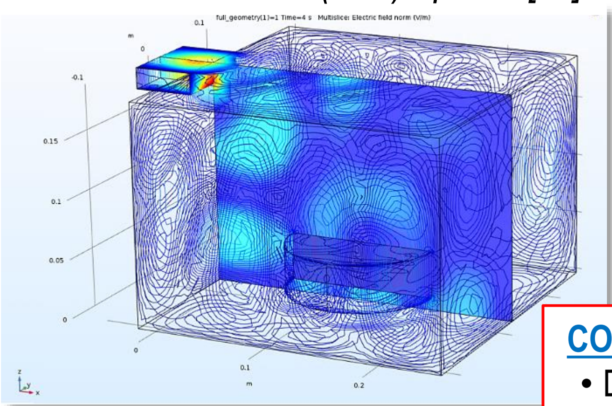
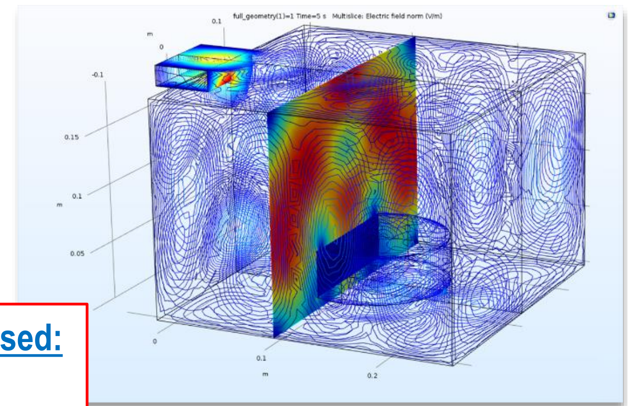
DMLS-Microwave assisted

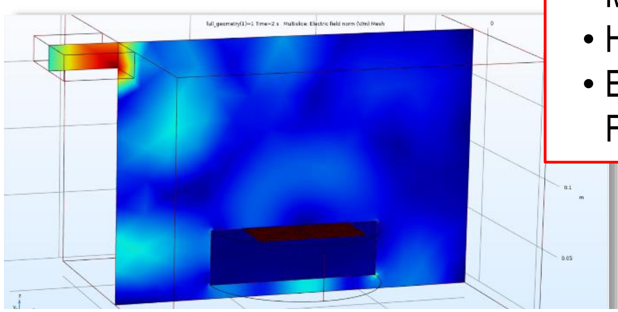
Model II (one radiation source)

Electric Field norm (V/m) –plane [xz]

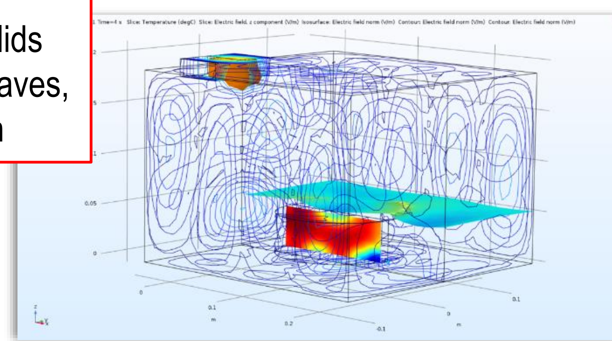


Electric Field norm (V/m) –plane [yz]





Electric Field norm (V/m) interacts with powder bed – selective resistive heating



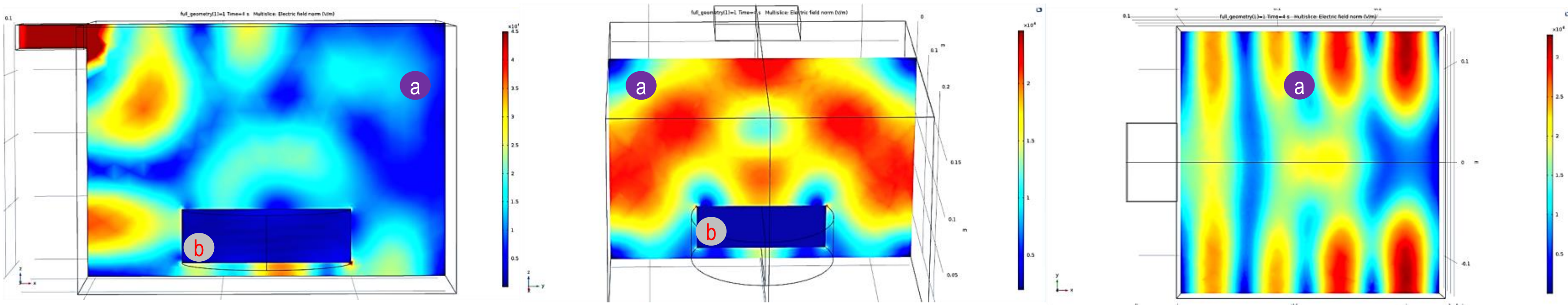
Electric Field norm (V/m) –plane [xy]

COMSOL Modules used:

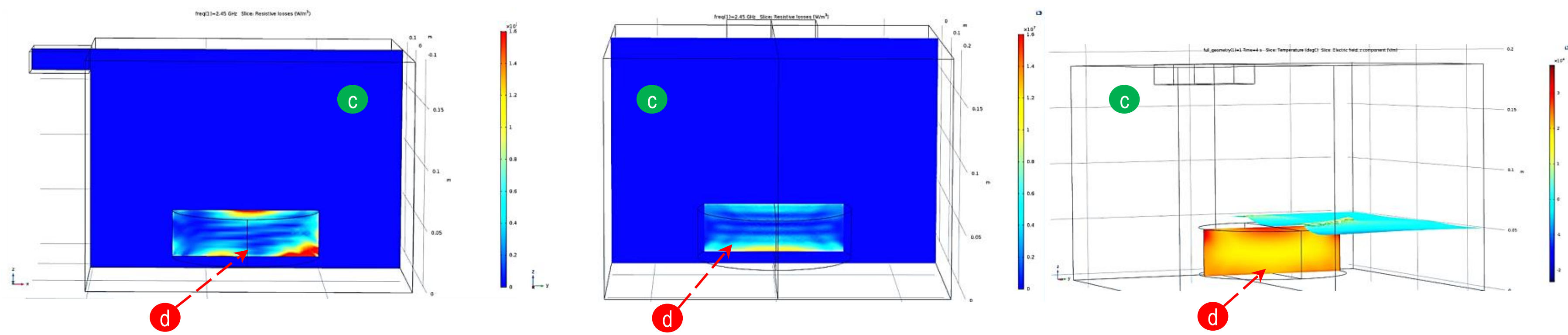
- Design Module
- Multiphysics
- Heat transfer in solids
- Electromagnetic waves, Frequency Domain

DMLS-Microwave assisted

Model II (cont. I)



Electric Field distribution within one radiation source Microwave Oven : inert gas flux (Argon) (a) ; Ti6Al4V ELI powder bed (b)



Resistive losses (W/m^2) on Ti-Alloy powder bed during Microwave Radiations *: inert gas flux (Argon) (c) ; Ti6Al4V ELI powder bed (d)*

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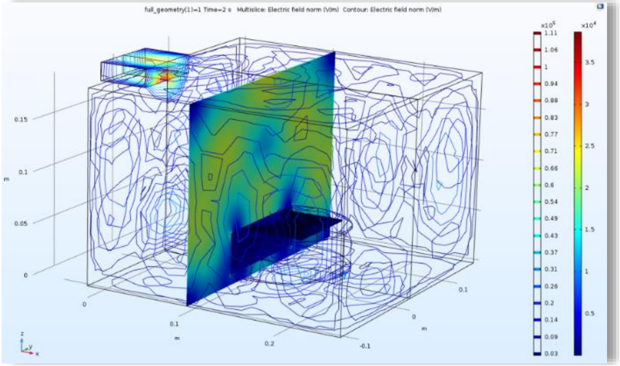
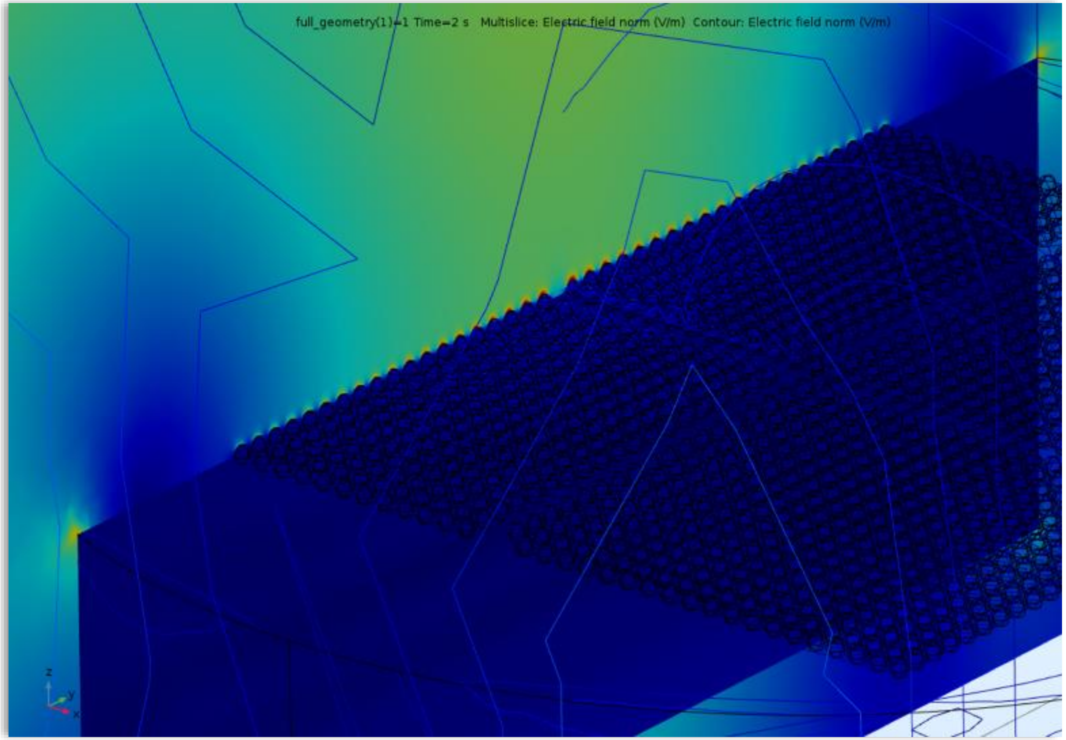
DMLS Microwave assisted

Results –Model II

Electric Field norm (V/m) –plane [yz]



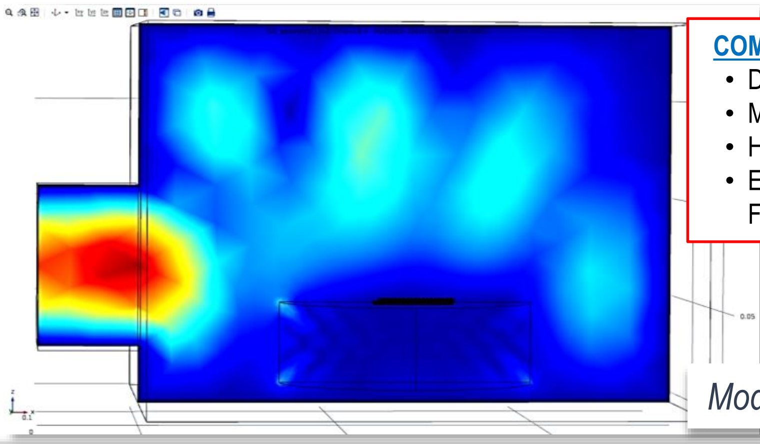
Detail: Response of powder bed layers to Electric Field



Biocompatible Ti-6Al-4V ELI powder layers selective response on Electric Field distribution

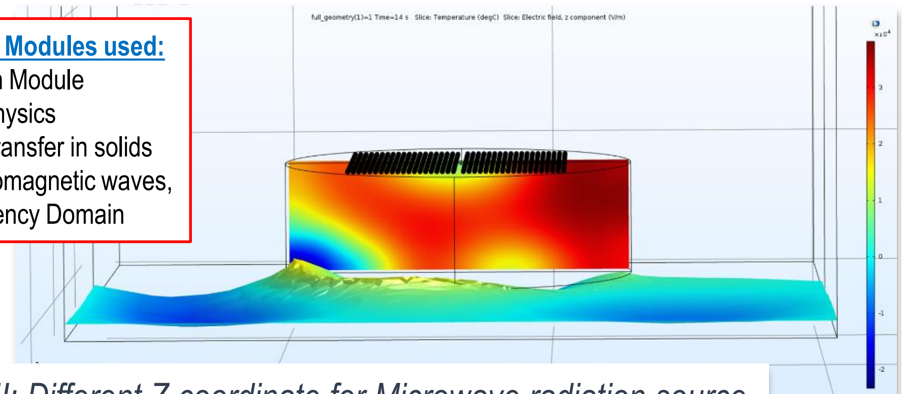
DMLS Microwave assisted

Results– Model III

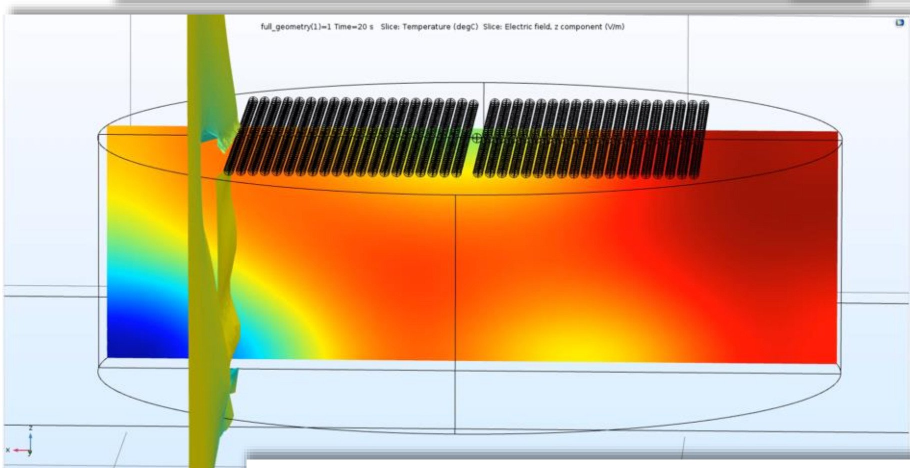


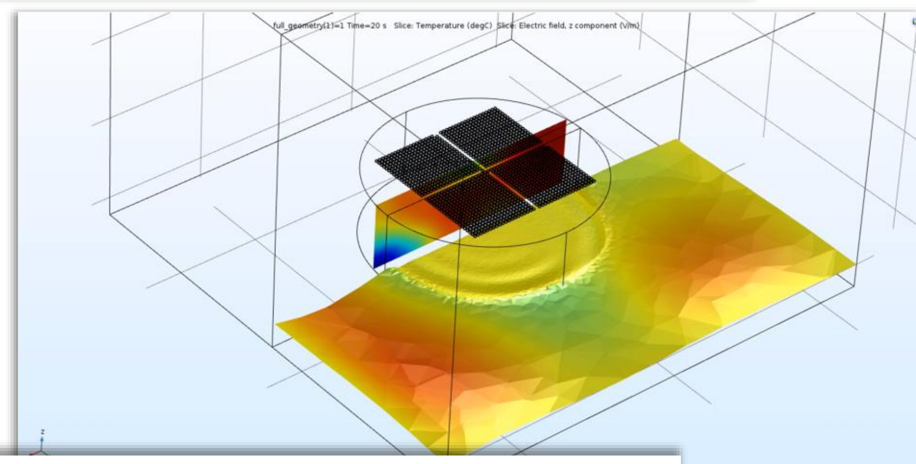
COMSOL Modules used:

- Design Module
- Multiphysics
- Heat transfer in solids
- Electromagnetic waves, Frequency Domain



Model III: Different Z coordinate for Microwave radiation source





Asymmetrical wave form response of the excited powder layers (electric field, resistive heating)

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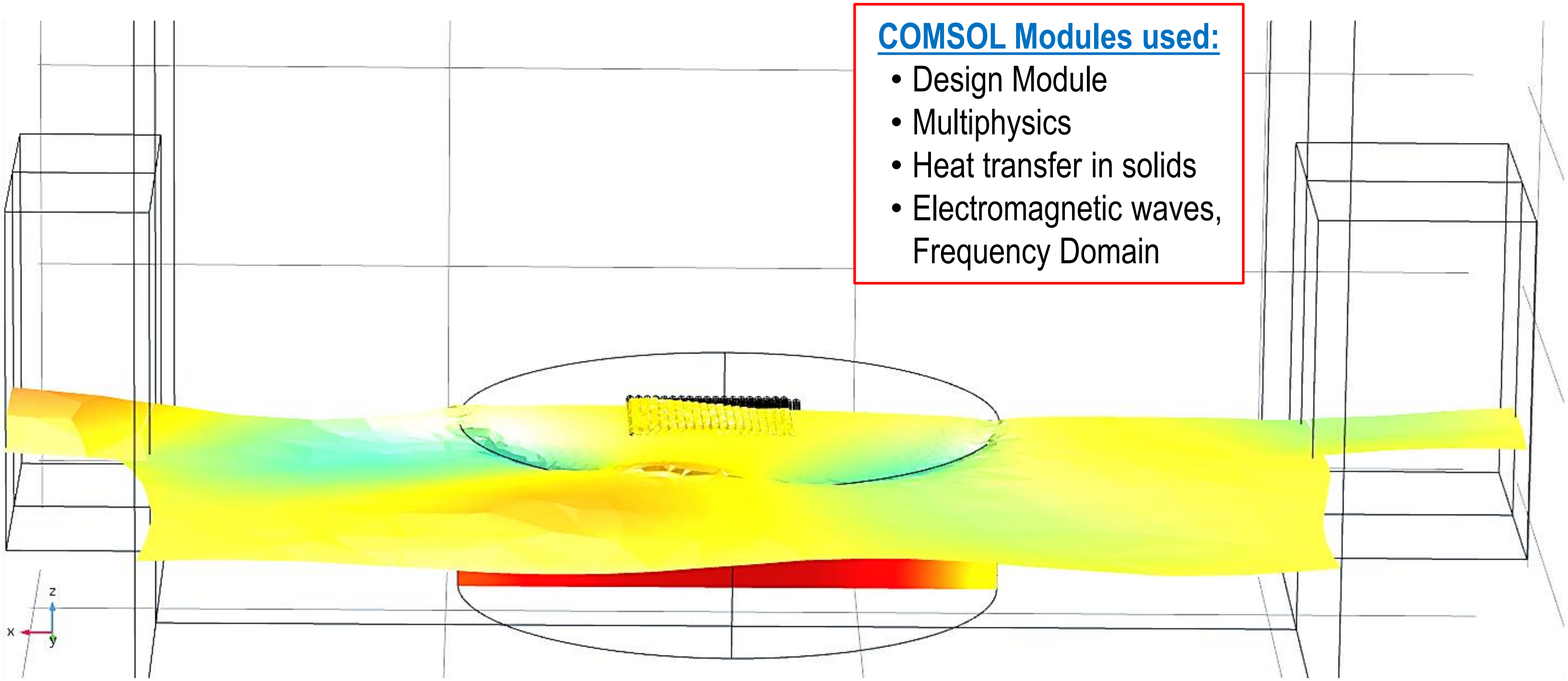
DMLS Microwave assisted

Model IV (two microwave radiation sources)



COMSOL Modules used:
- Design Module
- Multiphysics
- Heat transfer in solids
- Electromagnetic waves, Frequency Domain

Hypothesis *for DMLS assisted by two Microwave radiation sources:*
- *Predictable front-wave position during DMLS –AM of Ti-6Al-4V ELI powder*
- *Progressive symmetrical electromagnetic waves propagate within the powder bed*

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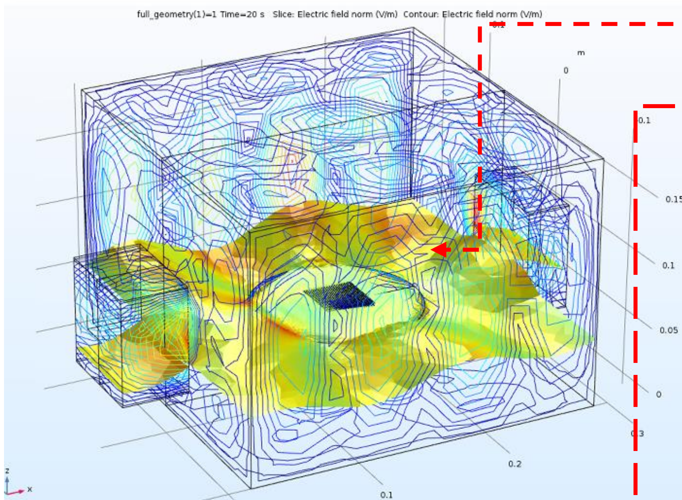
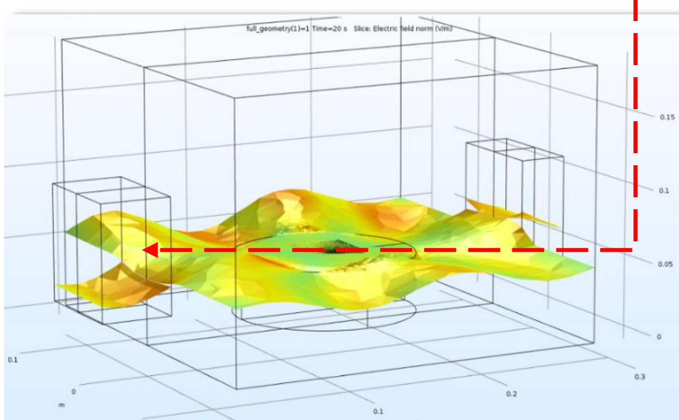
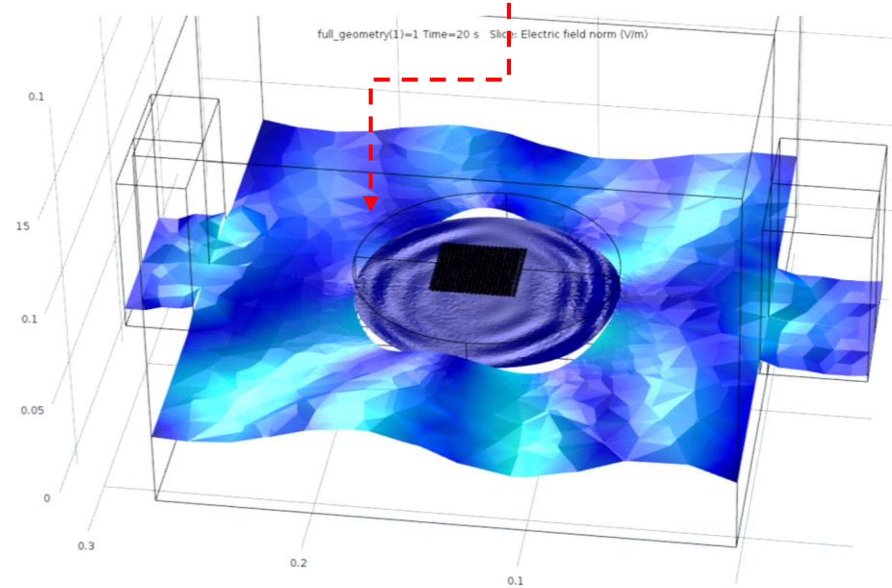
DMLS Microwave assisted

Results - Model IV (two microwave radiation sources)





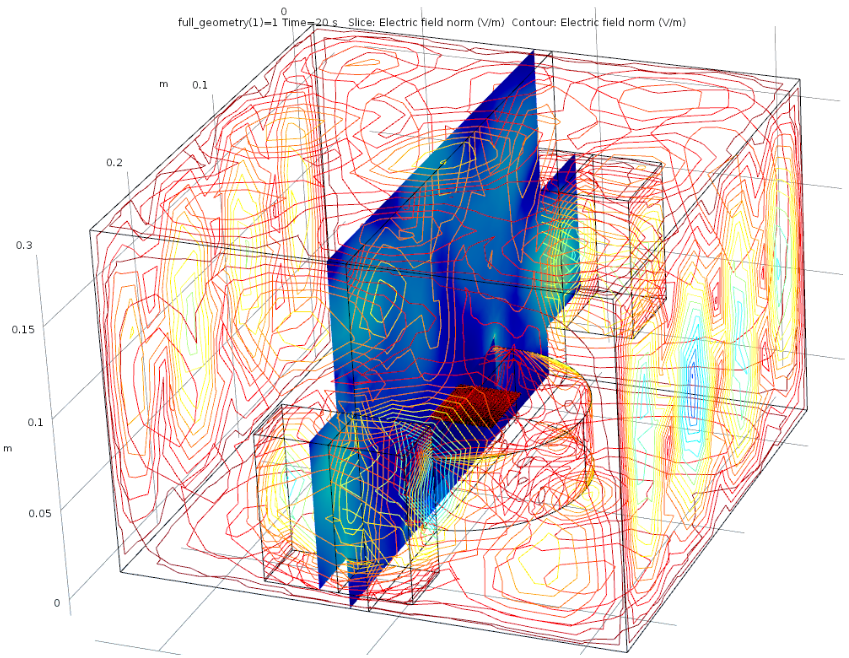
Electric Field norm (V/m) –plane [xy]



Model IV: symmetrical wave form response of electromagnetic microwave excited layers

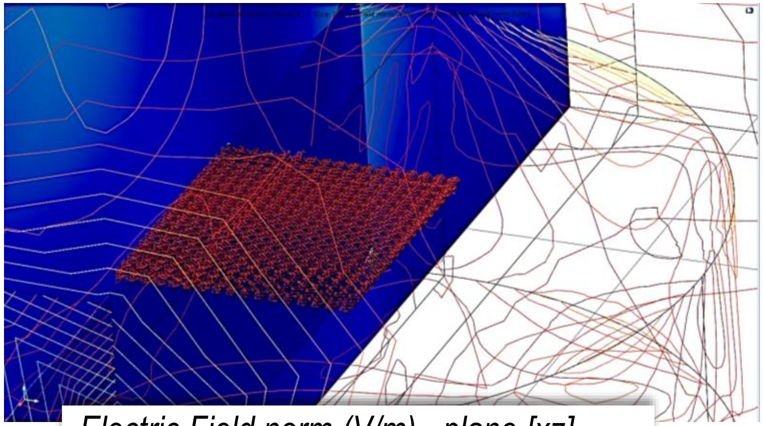
DMLS Microwave assisted

Results –Model IV (cont. I)



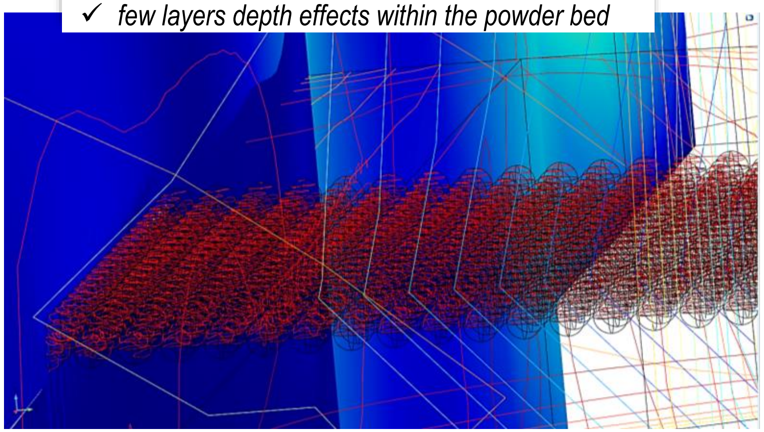
Electric Field norm (V/m) –plane [xz]

✓ - *Size-related effects within the powder bed*



Electric Field norm (V/m) –plane [xz]

✓ *few layers depth effects within the powder bed*



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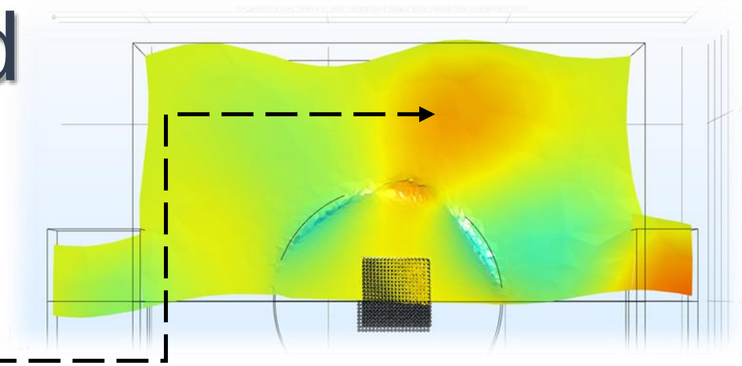
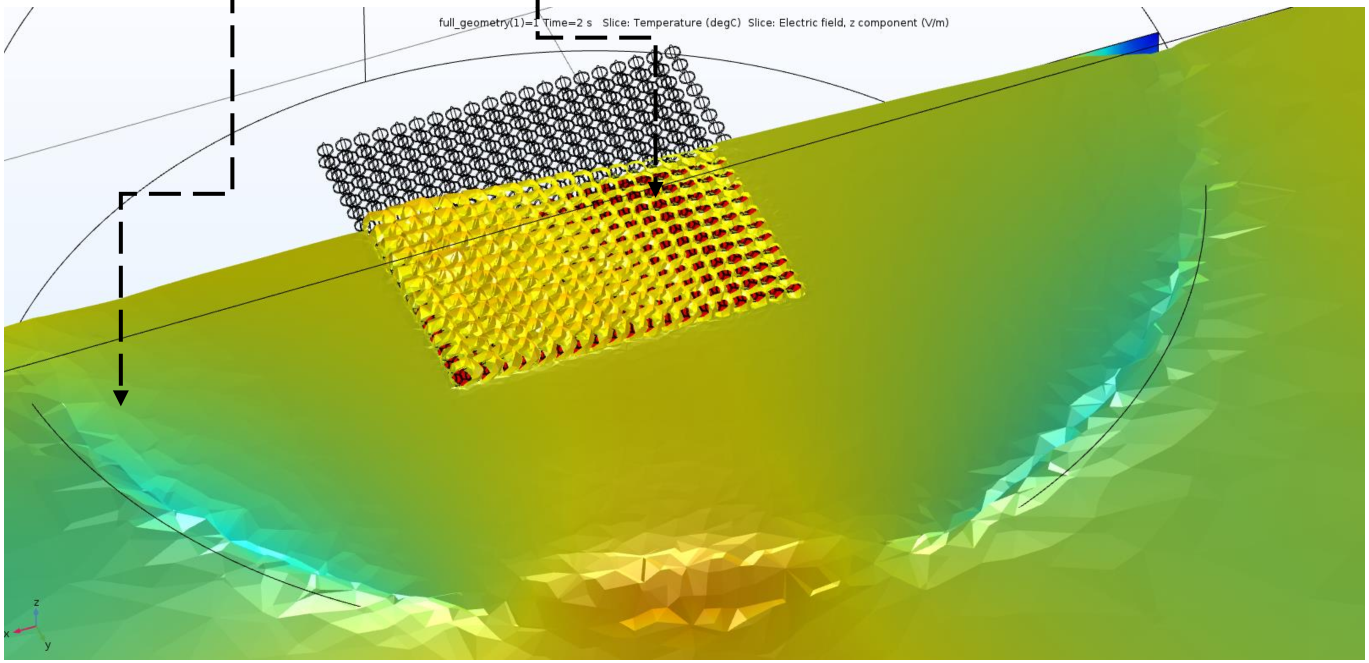
Simulation: DMLS Dynamic Thermal Field

Results –Model IV

Temperature	Process
Temperature (ht)	DMLS
Resistive heating (deg C)	Electric field (3D dynamic array





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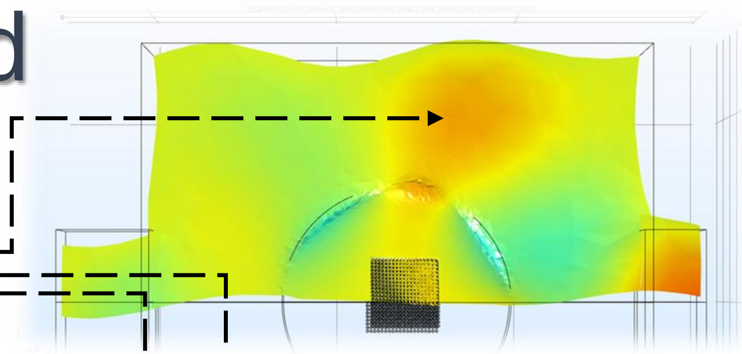
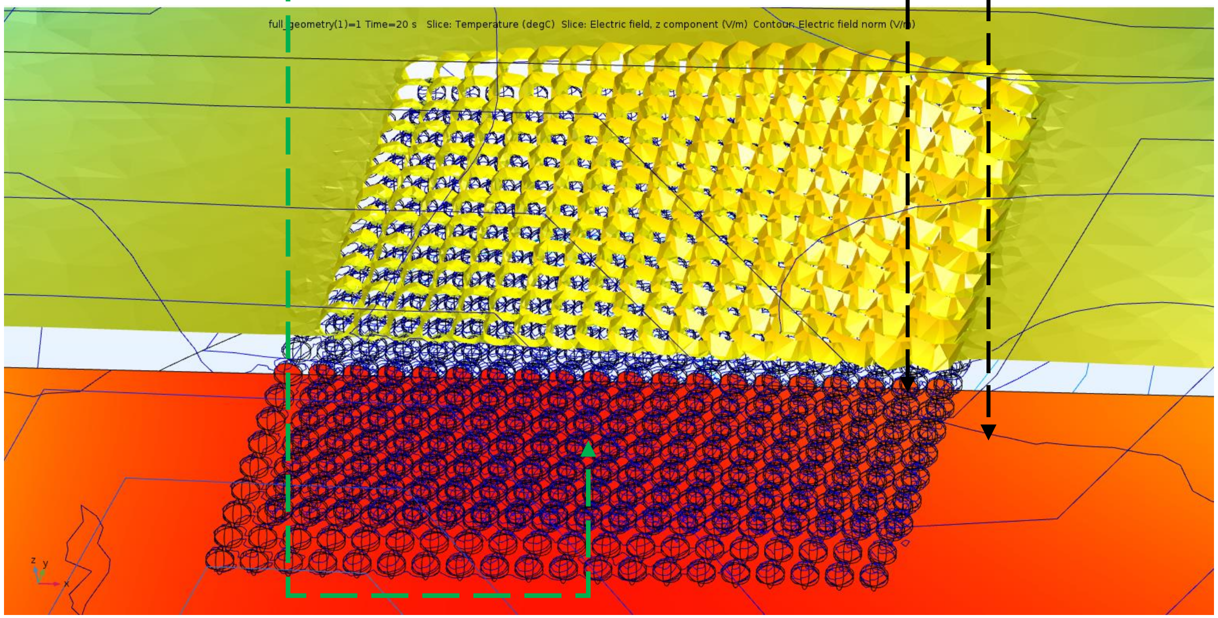
Simulation: DMLS Dynamic Thermal Field

Results –Model IV (cont. I)

Temperature	Process
Resistive heating (deg C)	Electric field (3D dynamic array
Temperature (ht))	**DMLS**





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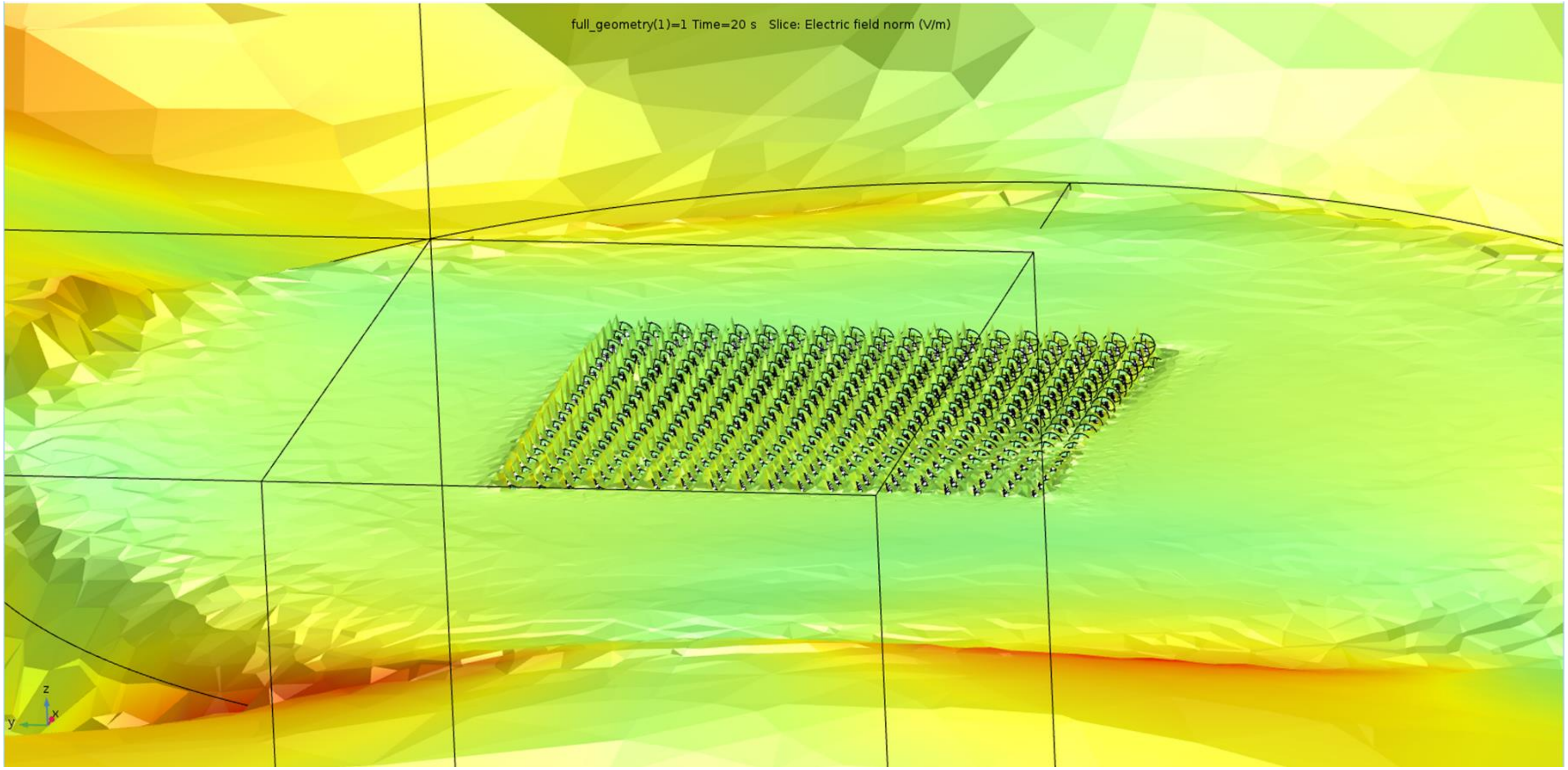
Simulation: DMLS Dynamic Thermal Field

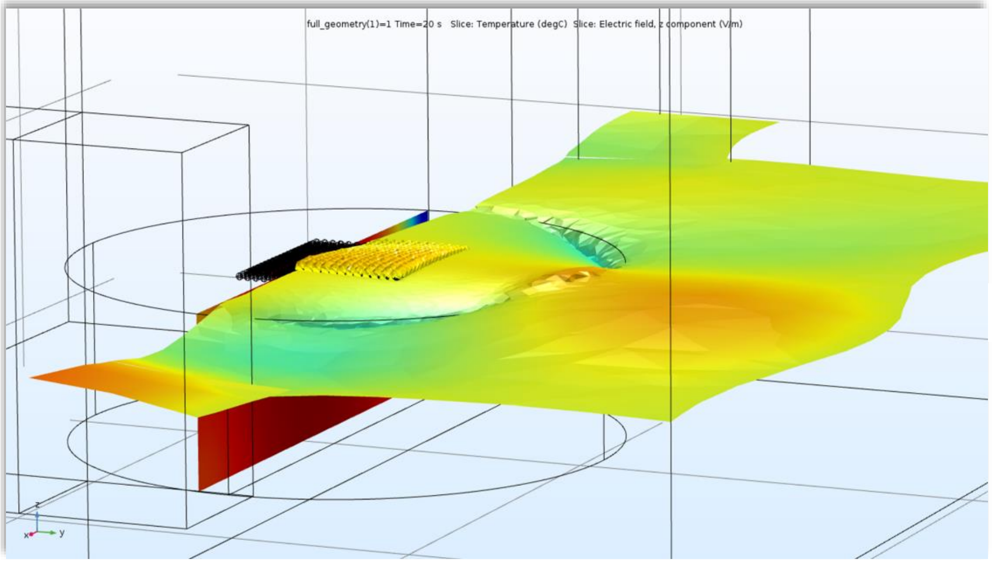
Results –Model IV (cont. II)



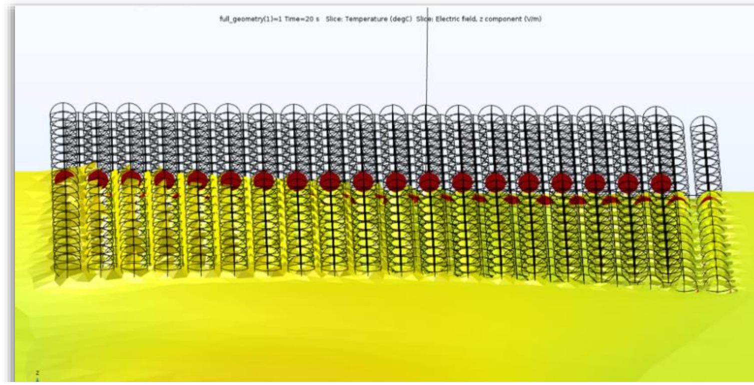
Electric field waves acting beneath the surface layer of Ti-6Al-4V ELI Powder bed

Simulation: DMLS Dynamic Thermal Field

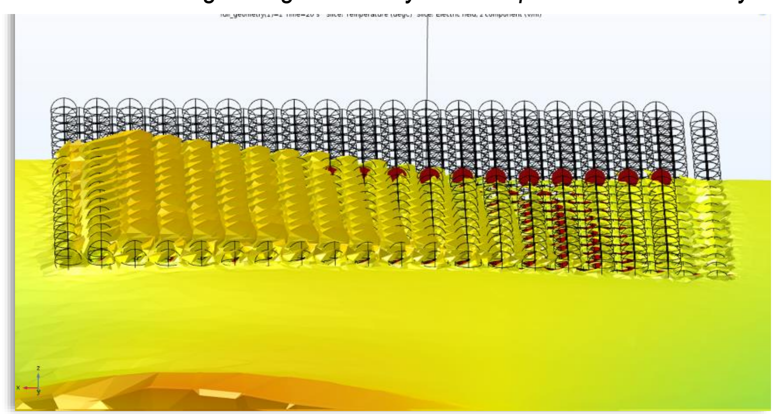
Results –Model IV (cont. III)



DMLS (laser heating) and Electric field (Resistive Heating) acting simultaneously on Ti-6Al-4V ELI Powder bed

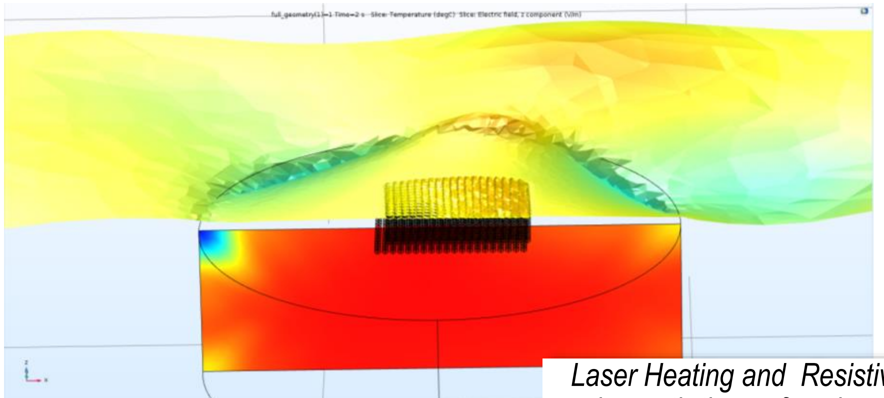


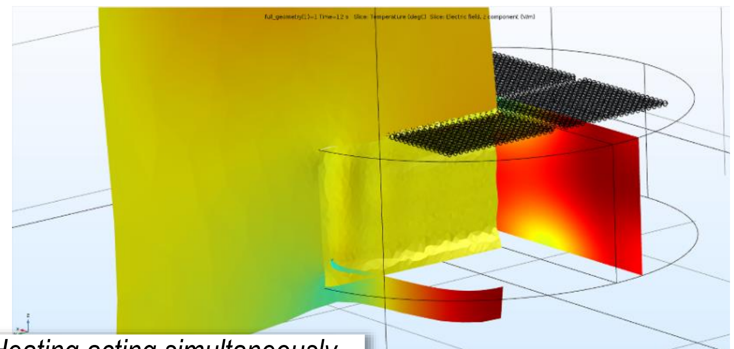
Resistive Heating acting effectively on in depth consolidated layer



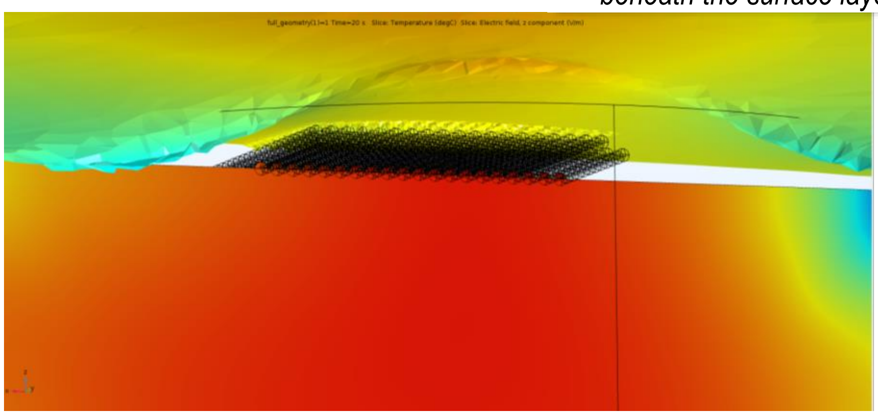
Simulation: DMLS Dynamic Thermal Field

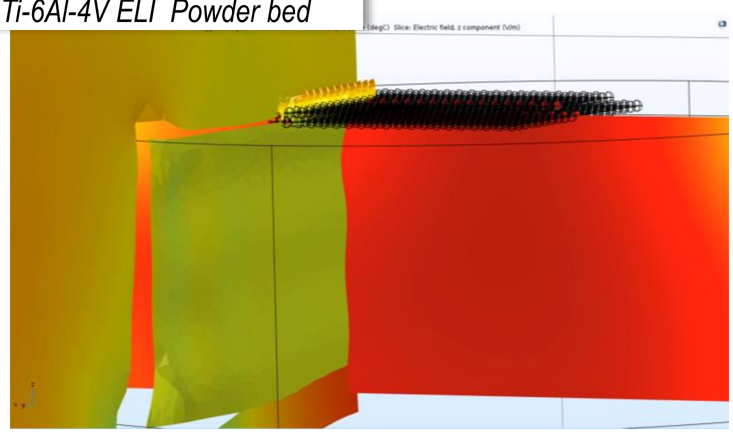
Results –Model IV (cont. IV)





Laser Heating and Resistive Heating acting simultaneously beneath the surface layer of Ti-6Al-4V ELI Powder bed





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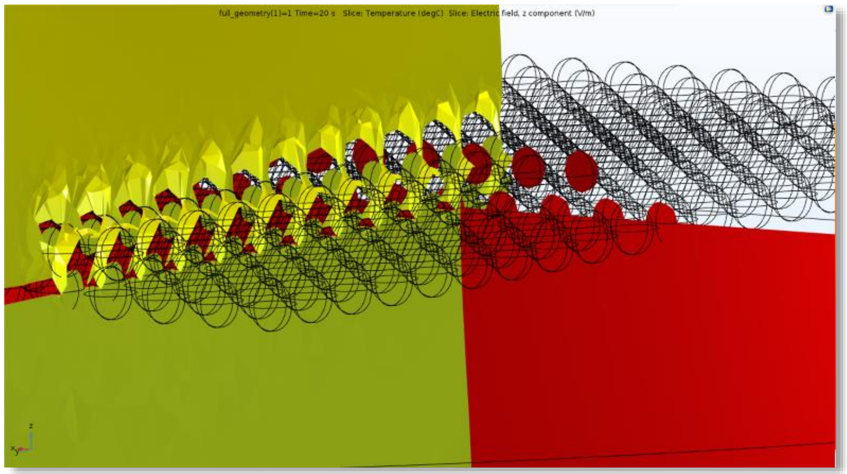
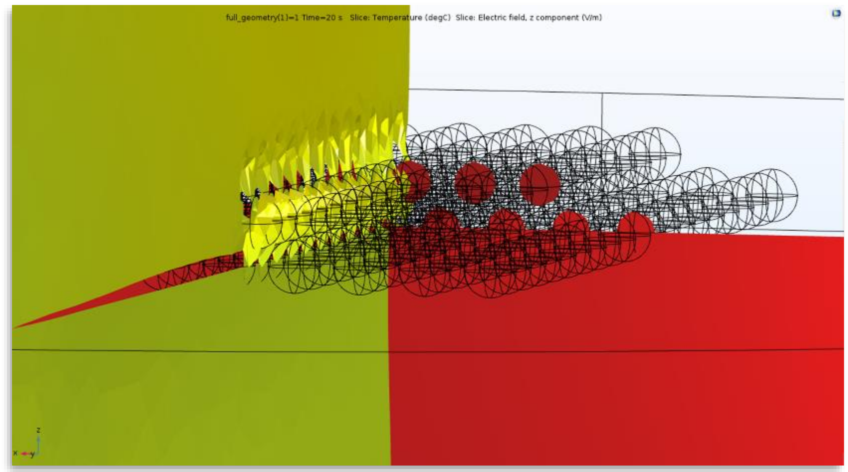
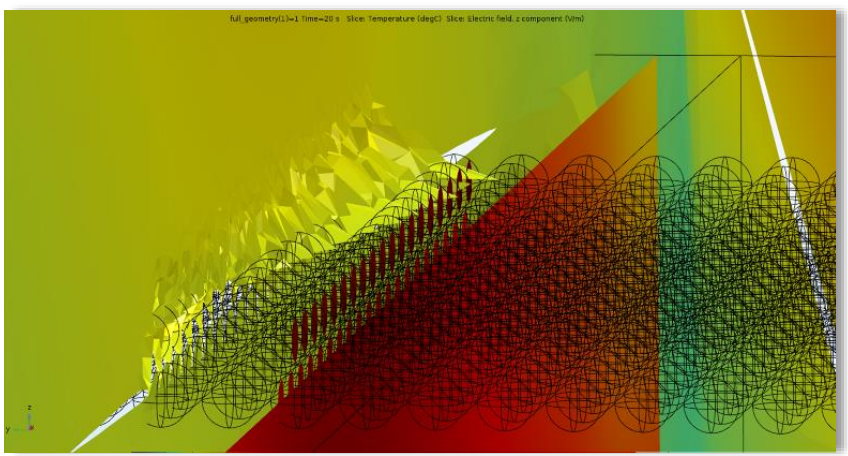
Conclusions







Microwave Field is readdressing the dynamics of Powder Bed Fusion during assisted DMLS:

- Progressive uniform heating of consolidated layers
- Pre-heating active layers (before DMLS spot action)
- Predictable (programmable) electromagnetic field properties
- Adjustable process parameters for biocompatible powder Ti-6Al-4V ELI (size – shape- functionalization)

Thank you

Contact: *elena.lacatus@upb.ro*