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Modeling of Susceptor Assisted Microwave Heating in Domestic Ovens

Krishnamoorthy Pitchai

Ph.D Scholar

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University of Nebraska - Lincoln

Outline

- Background
- Objective
- Simulation strategy
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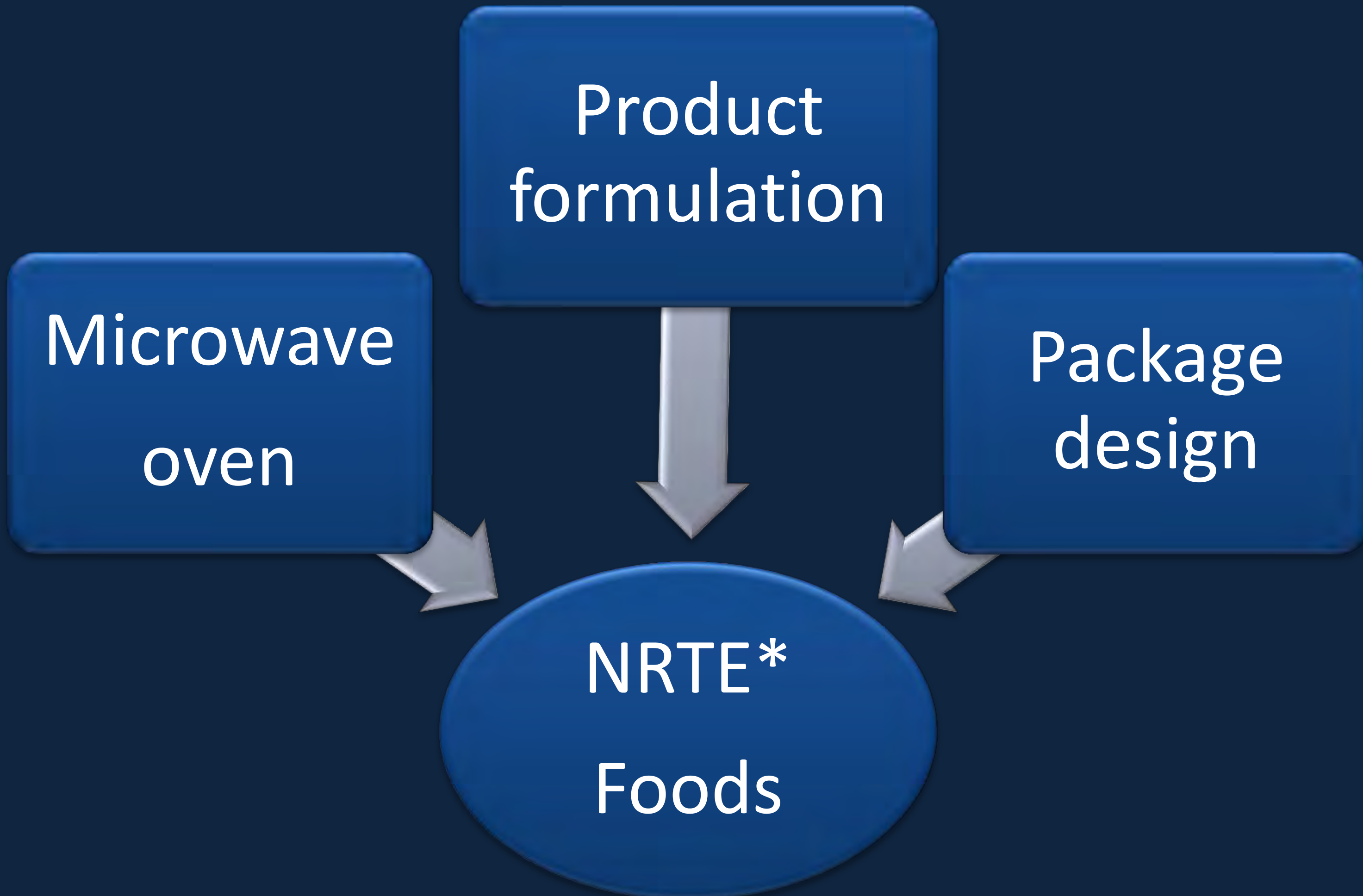
- Results
- Conclusion

Background



*Not - ready-to-eat foods which may contain foodborne pathogens

Why package is important in microwavable product?

- Extend the shelf life of the product
- Provide structural and holding facility
- Preferential heating
- Active package facilitates
  - crispiness
  - browning

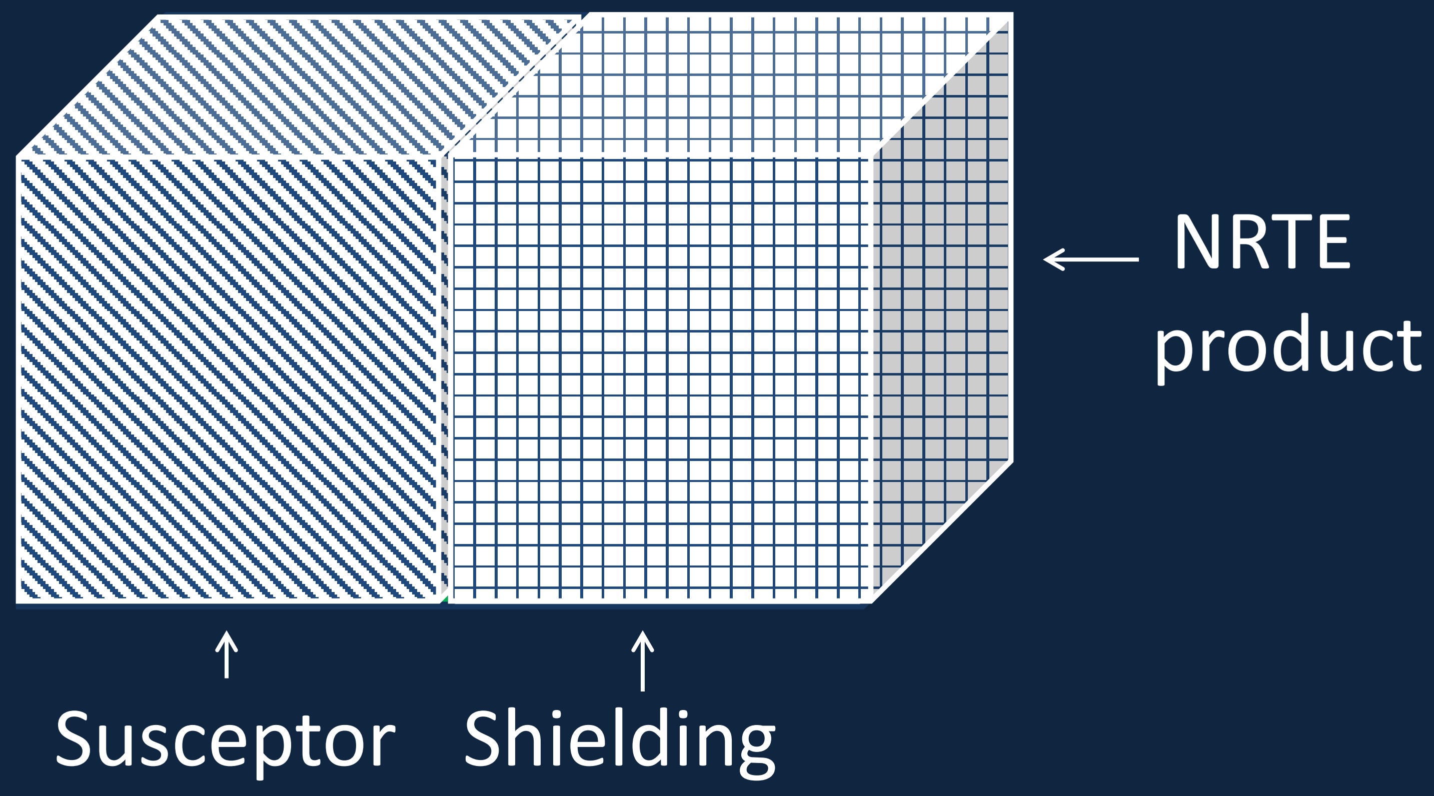
Package type

- Passive package - PET
- Active package - Susceptor
- Shielding

Passive package

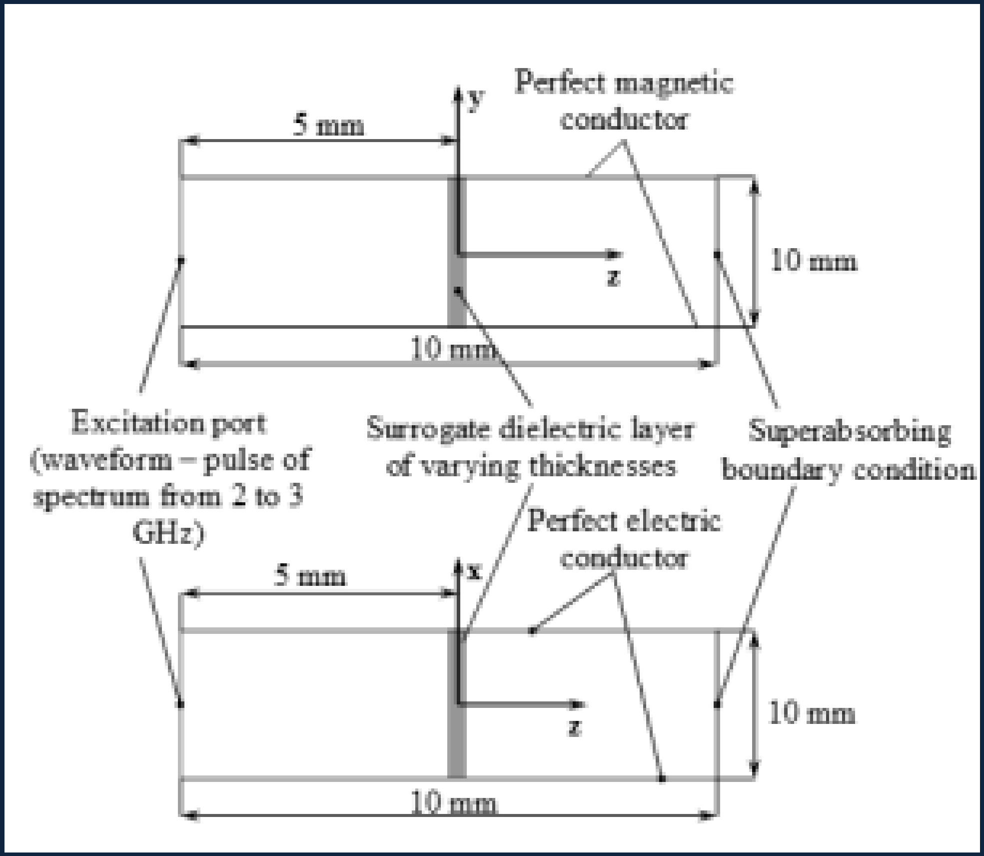
Active package

Susceptor & Shielding



Previous work

- Soltysiak et al. 2008 and Celuch et al. 2008



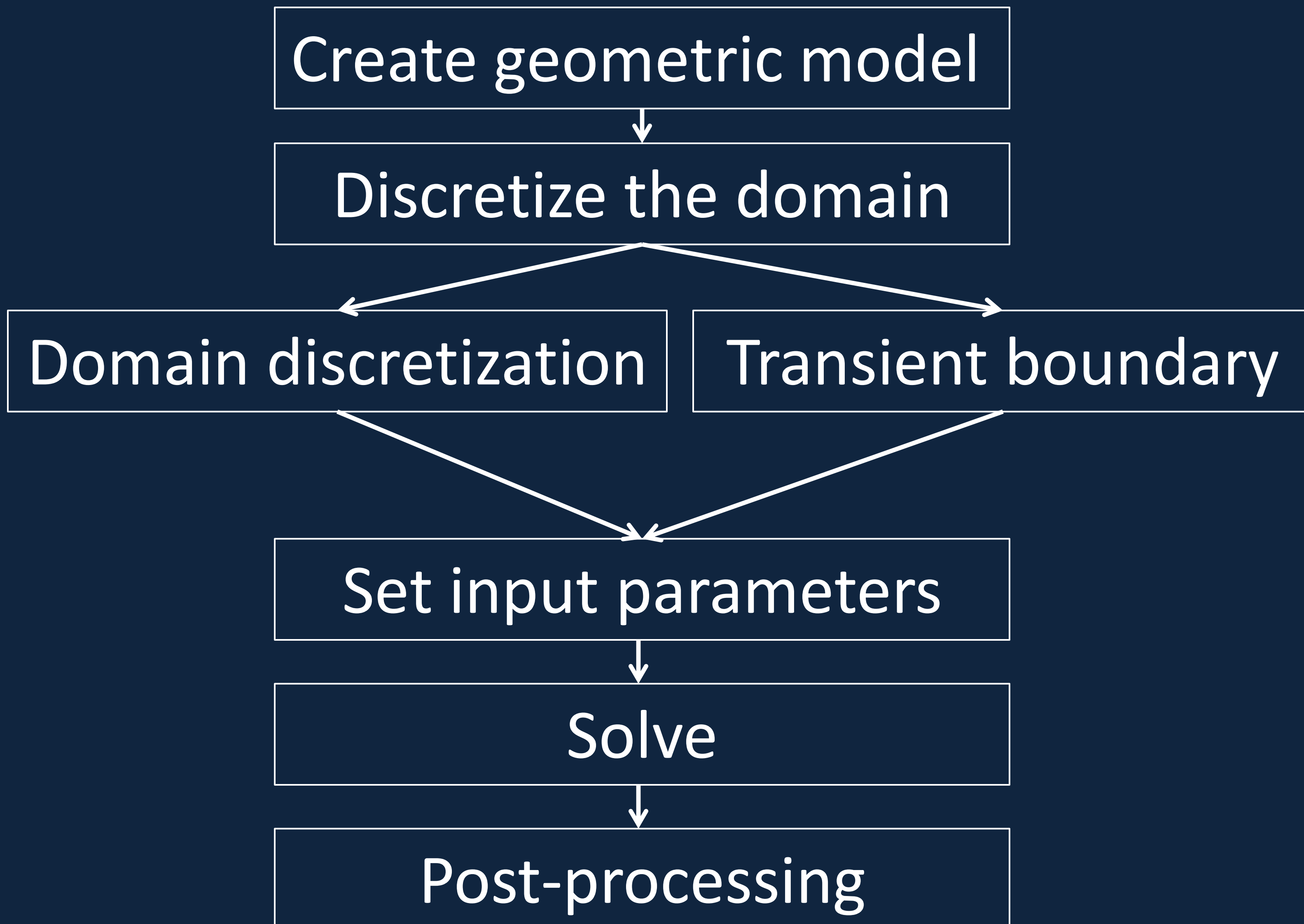
Objective

- Develop a computer model to simulate the interaction of food with an active package.

Specific objectives

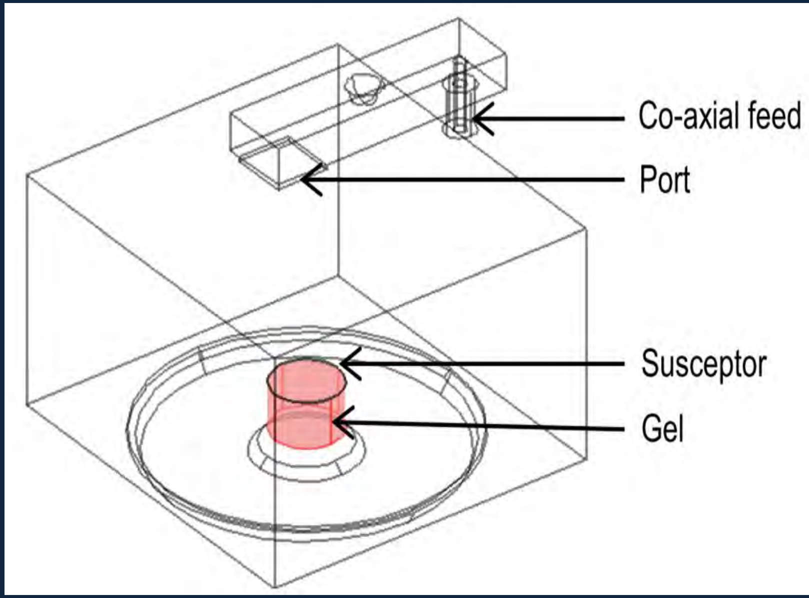
- Discretize the active package domain using two different methods and choose the best method based on accuracy and computational time.
- Validate the numerical model with an experimental condition.
- Explore the possibility of modeling shielding package.

Model development

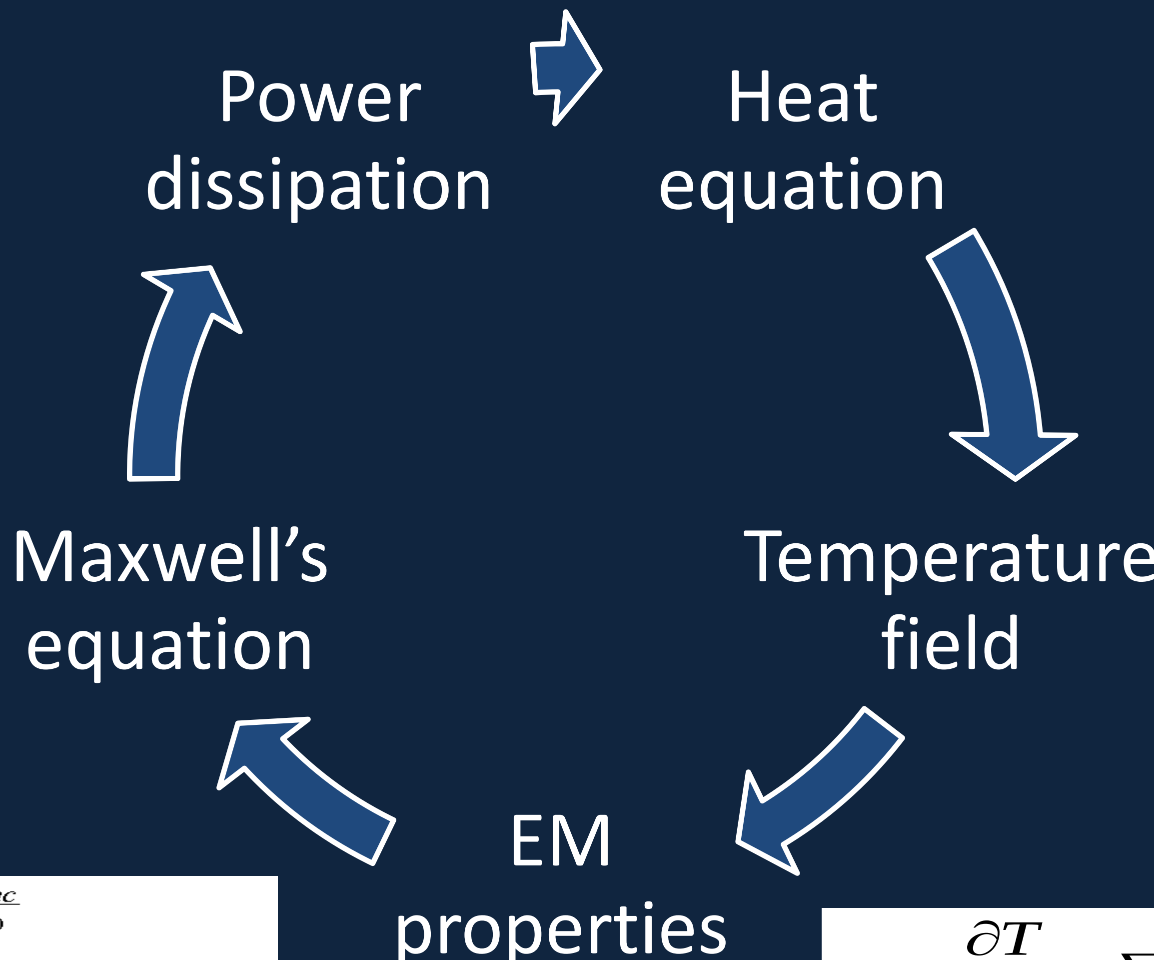


Geometric model

- 700 W microwave oven
- Cylindrical model food
- Susceptor on top of gel
- Co-axial feed



Solving coupled equation

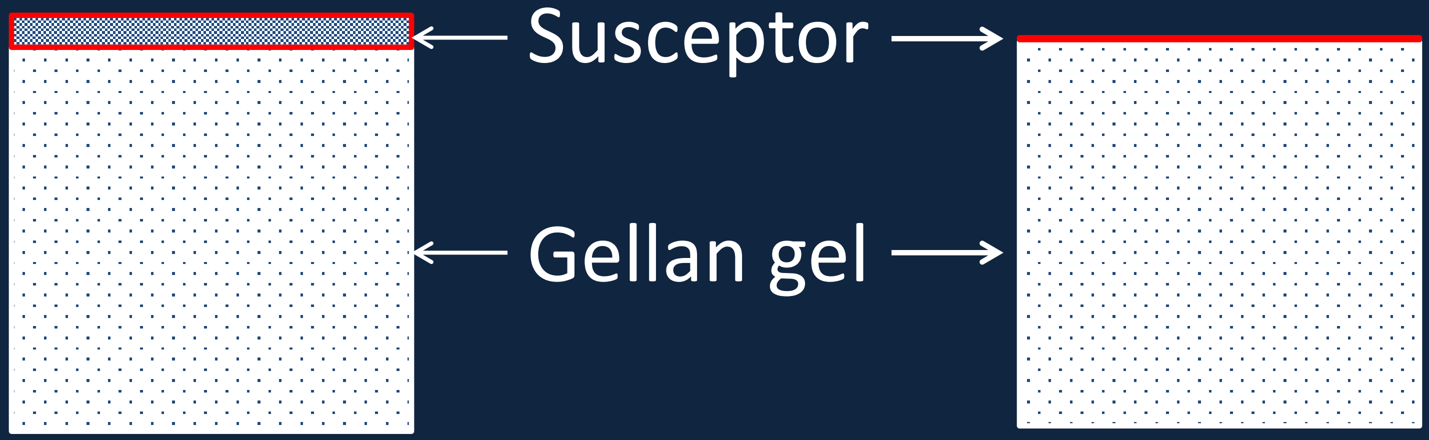


$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$
$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$
$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$
$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

$$\rho c_p \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + Q$$

Discretization approach

- Domain discretization
- Transient boundary



$$J_S = \frac{(Z_S \mathbf{E}_{t1} - Z_T \mathbf{E}_{t2})}{Z_S^2 - Z_T^2}$$

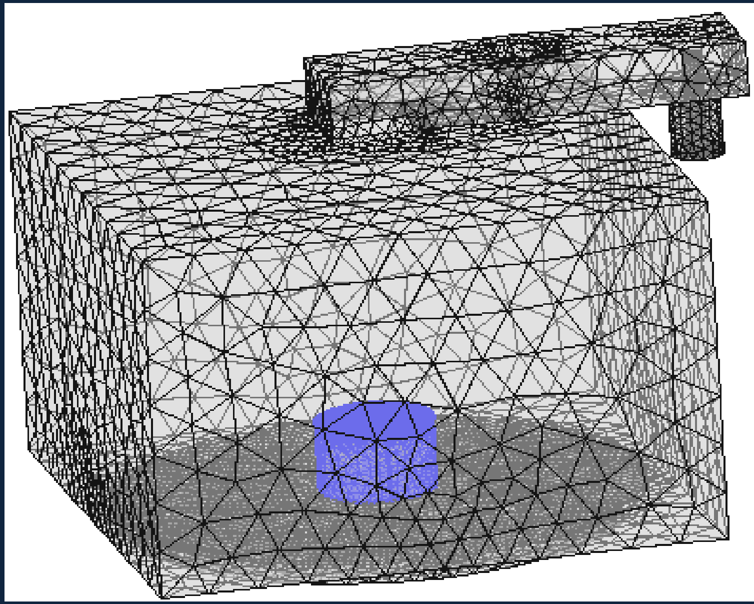
$$Z_S = \frac{-j\omega\mu}{\varphi} \frac{1}{\tan(\varphi d)}$$

$$Z_T = \frac{-j\omega\mu}{\varphi} \frac{1}{\sin(\varphi d)} \quad (6)$$

where $\varphi = \omega \sqrt{(\epsilon + \frac{\sigma}{j\omega})\mu}$

Meshing scheme

- Domain discretization method
  ~ 366,000 elements
- Transient boundary method
  ~ 210,000 elements



Simulation strategy

- Radio frequency and heat transfer modules of COMSOL Multiphysics v4.2
- Coupled approach using segregated steps
- Parametric sweep of conductance from 0.001 to 0.1 S
- Magnetron frequency of 2.45 GHz

Experimental setup

- A homogeneous gellan gel cylinder was used
- Microwave heating for 30 s
- Turntable was stationary
- A susceptor film laminated with paper and PET was placed on top of gel

Shielding

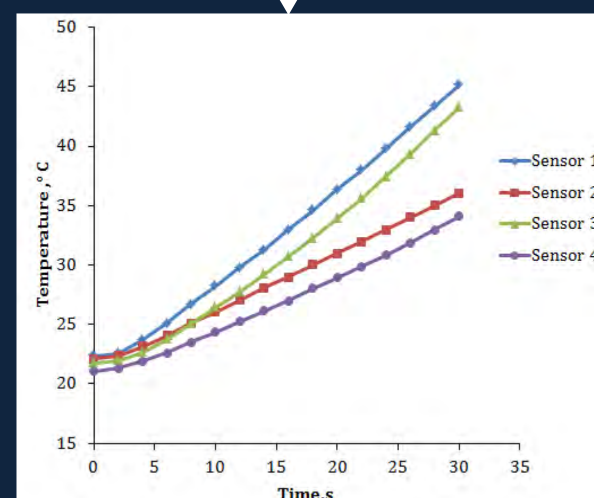
- Food grade aluminum foil was used
- Conductance of the material was 0.1 S
- Simulation was performed using transient boundary condition

Temperature measurement

Top image

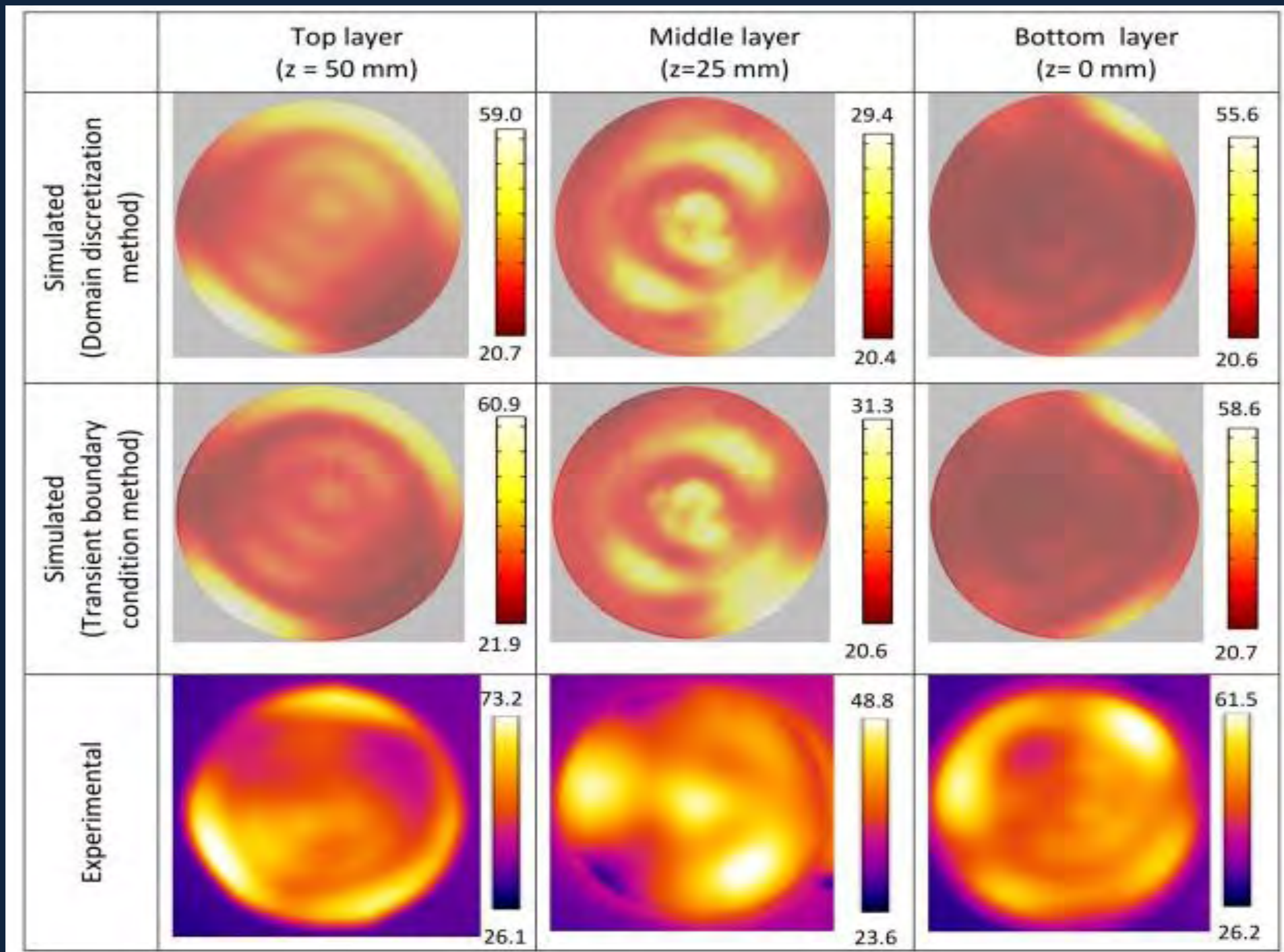
Middle image

Bottom image

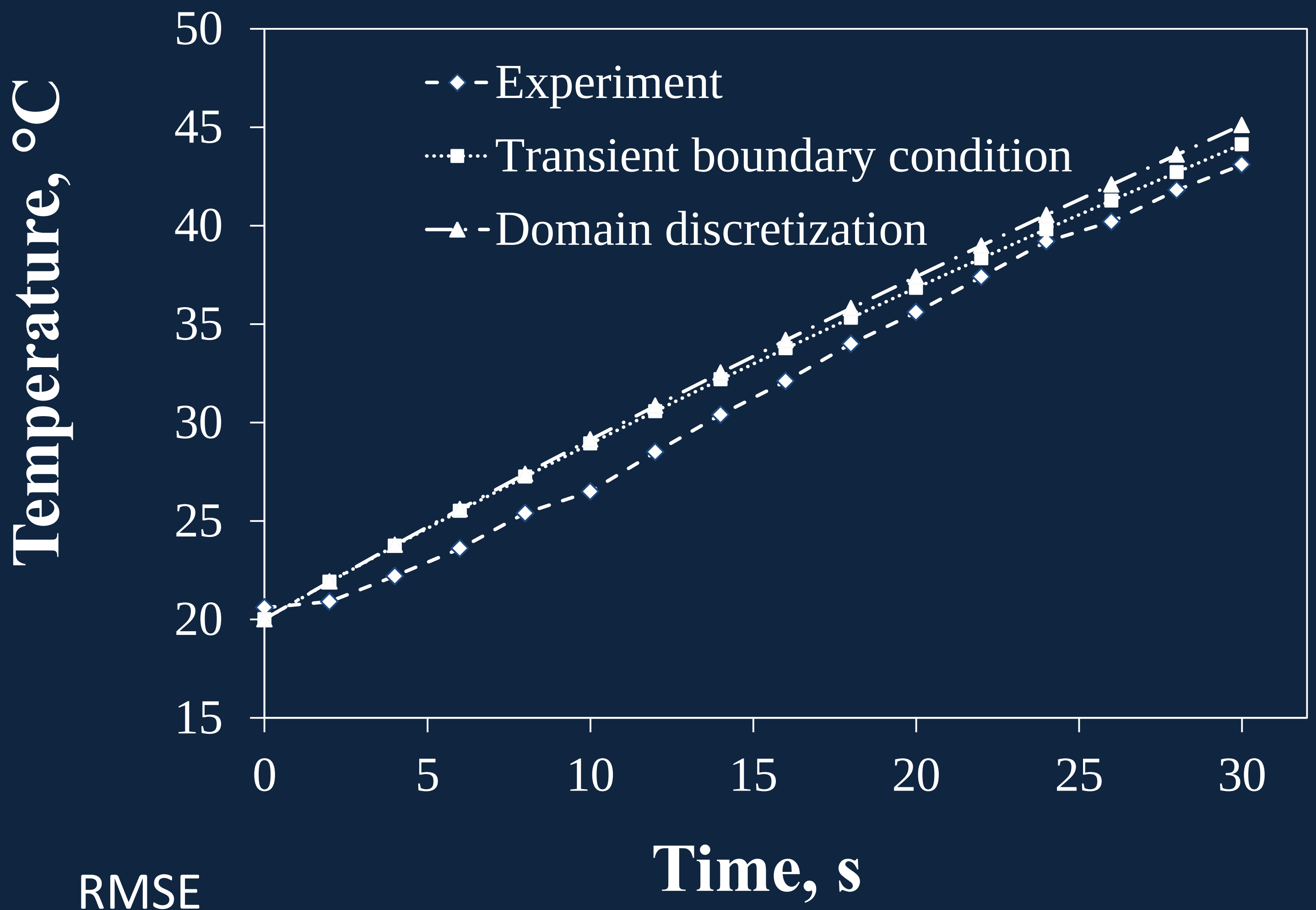


Results

Temperature profiles



Time–temperature profile



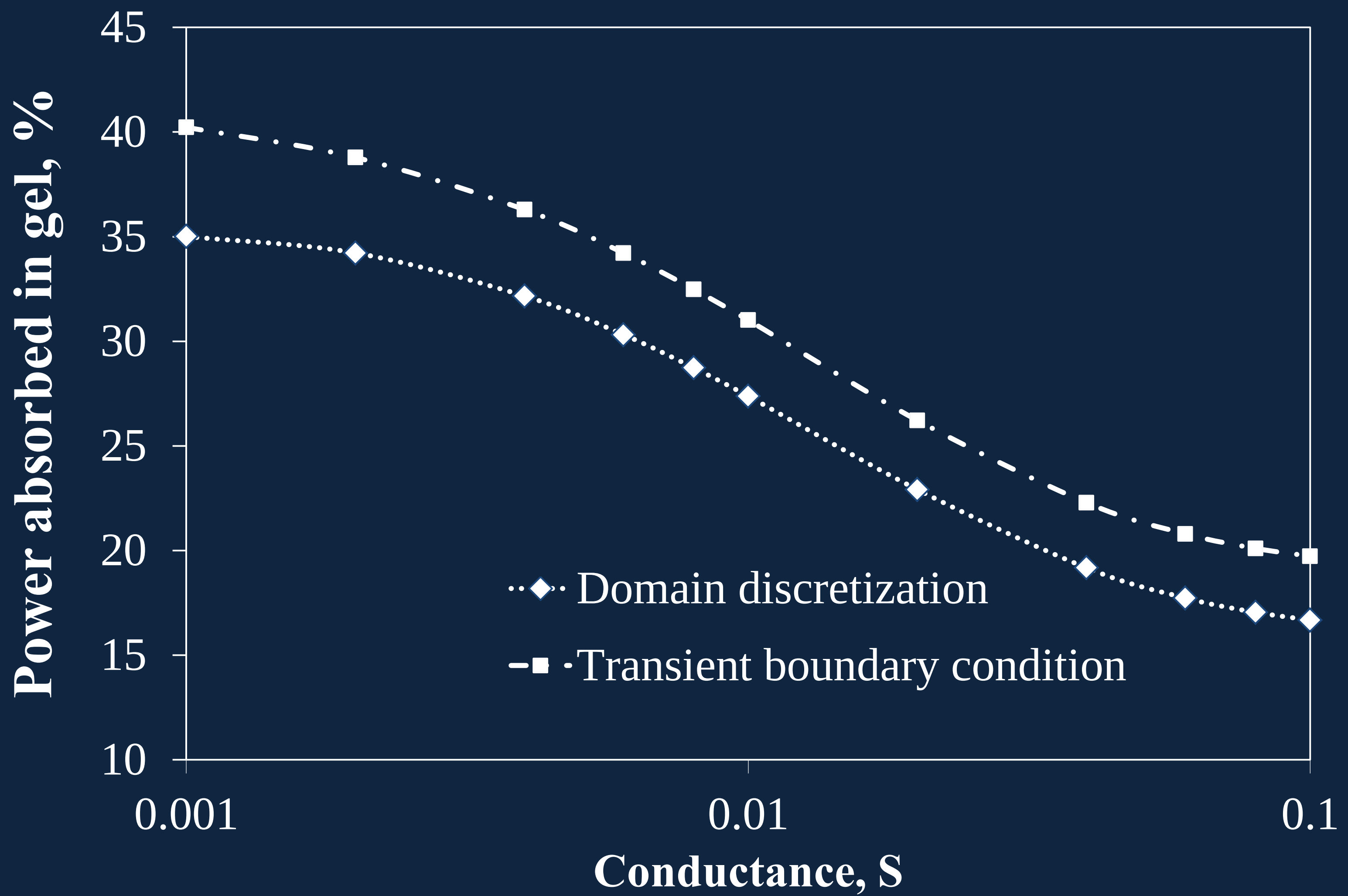
RMSE

Transient boundary condition	1.51°C
Domain discretization	1.76°C

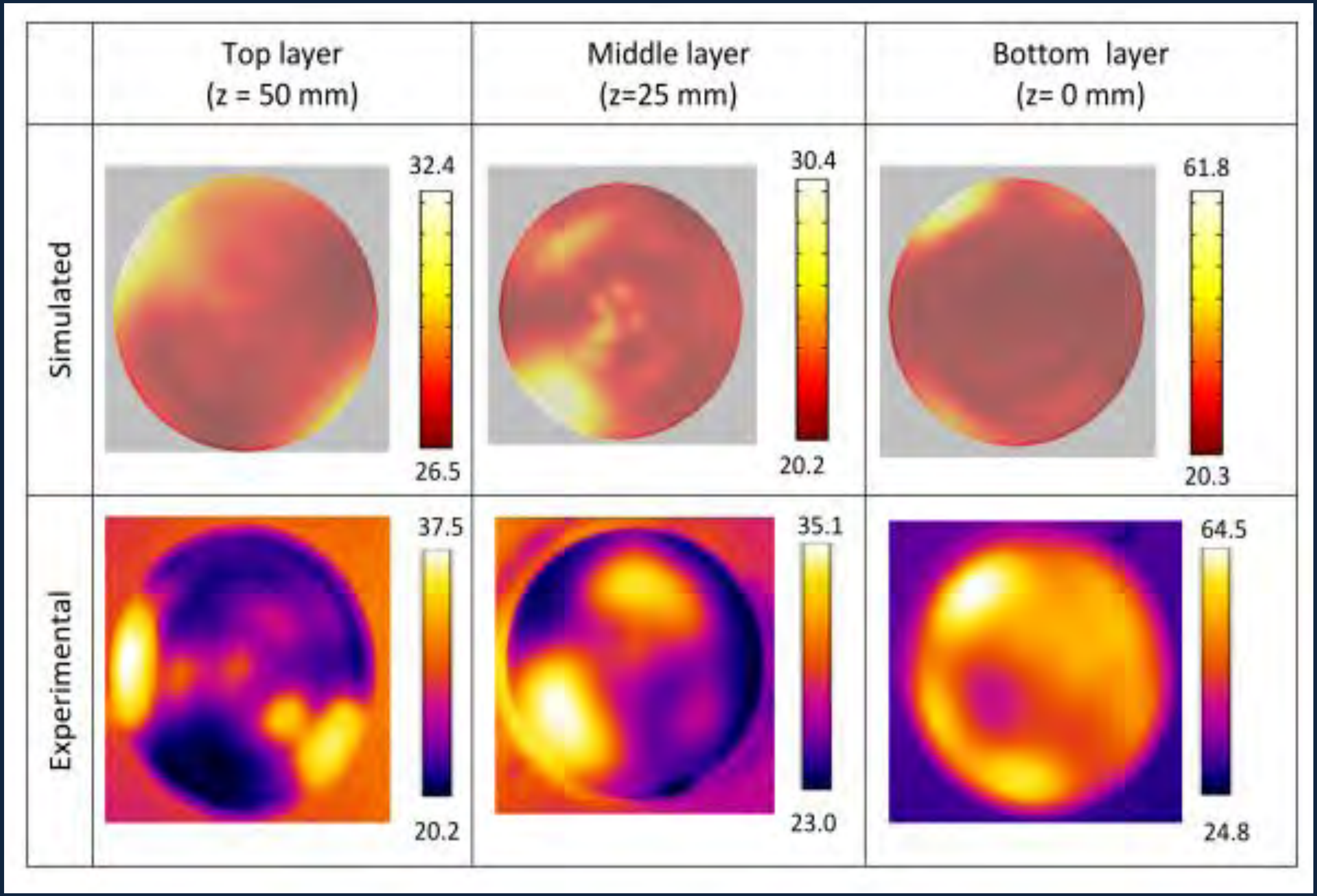
Comparison of approaches

	Transient boundary condition	**Domain discretization method**
Elements	Less elements	More elements
Computational time	~ 1 h	5 h
RMSE	1.51 °C	1.76 °C

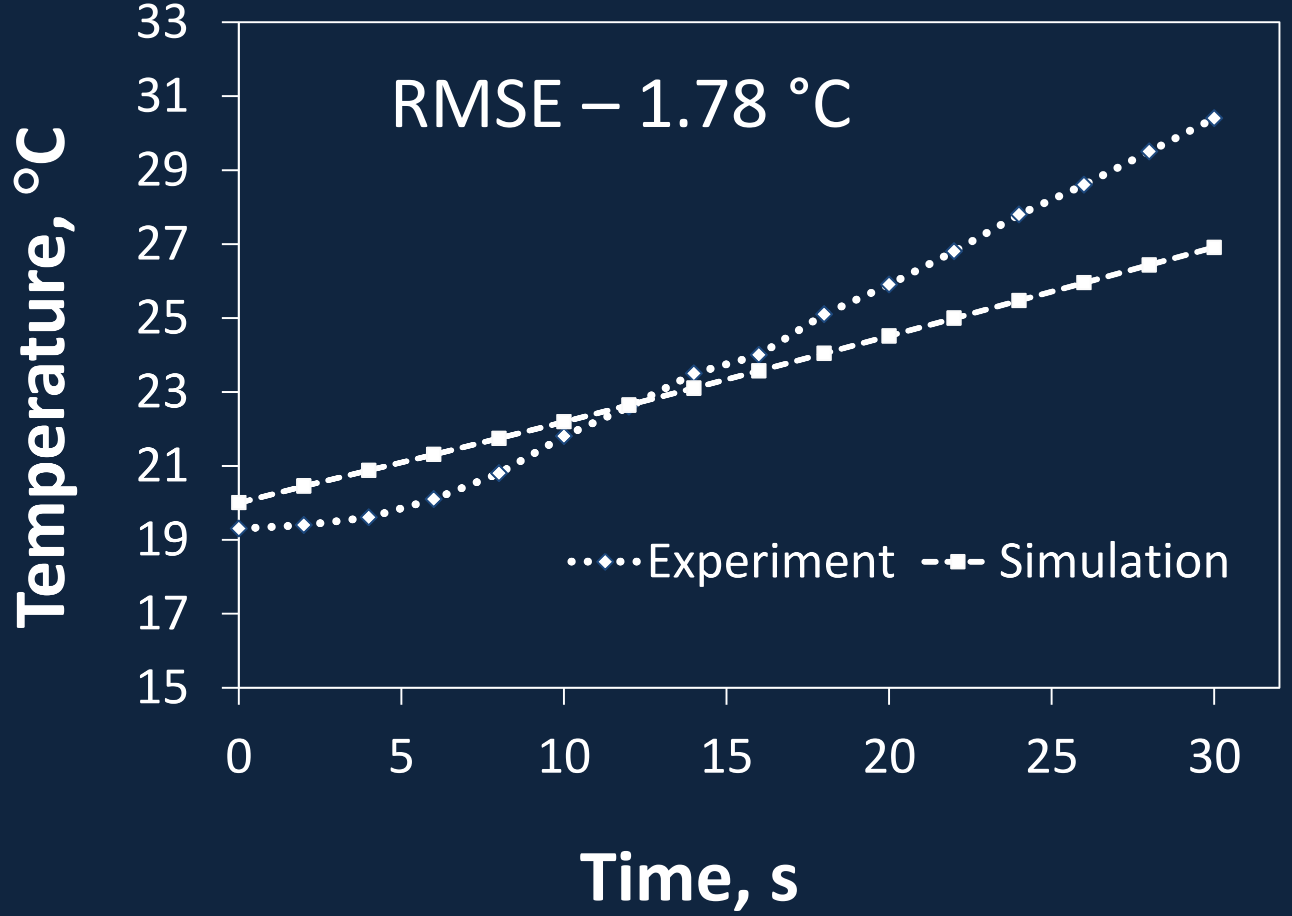
Effect of conductance



Shielding effect



Shielding effect – point temperature



Conclusion

- A simulation model was developed and validated for microwave interaction with model food and an active package
- Transient boundary condition method was best suitable one due to less computational time and better accuracy
- Model was also validated for shielding package

Acknowledgements

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Thank you