Multiphysics Simulation of Conjugated Heat Transfer and Electric Field on Application of Electrostatic Chucks (ESCs) Using 3D-2D Model Coupling

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Outline

i. Overview of Electrostatic Chucks (ESCs)

ii. Why is Multiphysics?

iii. Boundary Conditions
   a) Electric field model
   b) Conjugated heat transfer model

iv. Result of Simulation
   a) Electric field model
   b) Conjugated heat transfer model

vi. Conclusion
The main thermal resistances in the heat path are the ceramic and the transition from the ceramic to the cooling liquid. Thermal energy is transferred to the wafer surrounding through ion bombardment, and the chuck is required to remove large amounts of heat from the wafer while maintaining a stable and uniform temperature.

<table>
<thead>
<tr>
<th></th>
<th>AlN</th>
<th>Al₂O₃</th>
<th>Al6061</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Conductivity [W/mK]</td>
<td>180.0</td>
<td>35</td>
<td>167.0</td>
<td>150.0</td>
</tr>
<tr>
<td>Coefficient of thermal expansion [10⁻⁶/°C]</td>
<td>6.8</td>
<td>8.1</td>
<td>23.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
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**Multiphysics**

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**Cooper-Mikic-Yovanovich Correlation**

**Principal Dependencies of the Wafer Temperature**

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**Maxwell’s stress tensor**

\[ T_{ij} = \varepsilon E_i E_j - \frac{\varepsilon}{2} (E_k E_k) \delta_{ij} = \begin{bmatrix} \varepsilon (E_x^2 - E_y^2) & \varepsilon E_x E_y \\ \varepsilon E_x E_y & \varepsilon (E_y^2 - E_x^2) \end{bmatrix} \]

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**Navier-Stokes Equation**

\[ \rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \mathbf{T} + \mathbf{f} \]

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**Exploded drawing of the ESC**

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Boundary Conditions

<table>
<thead>
<tr>
<th></th>
<th>Silicon</th>
<th>AlN</th>
<th>Al₂O₃</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dielectric constant</strong></td>
<td>11.7</td>
<td>9</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

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Result for Electric Field

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National Taiwan University
Institute of Applied Mechanics
Boundary Conditions

Assumptions:

i. Stationary state
ii. Thermal insulation in the chamber
iii. Neglect the heat radiation effect
iv. Uniform heat source to the wafer from plasma
v. Neglect the heat of chemical reaction on wafers

Cooper-Mikic-Yovanovich Correlation

\[ h_s = 1.25 k \frac{m_{asp}}{\sigma_{asp}} \left( \frac{p}{H_c} \right)^{0.95} \]

Maxwell’s stress tensor

\[ T_{ij} = \varepsilon E_i E_j - \varepsilon \frac{1}{2} (E_k E_k) \delta_{ij} = \begin{bmatrix} \varepsilon \frac{1}{2} (E_x^2 - E_z^2) & \varepsilon E_x E_y \\ \varepsilon E_x E_y & \varepsilon \frac{1}{2} (E_y^2 - E_z^2) \end{bmatrix} \]

Principal Dependencies of the Wafer Temperature

\[ h_f = \frac{q}{A \Delta T} = \left( \frac{C}{p \alpha_a} + \frac{d}{\kappa} + \frac{C}{p \alpha_b} \right)^{-1} \]

Navier-Stokes Equation

\[ \rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \mathbf{T} + \mathbf{f} \]

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From the result of simulation, the deep blue is near to the cooling inlet. It means the temperature distribution largely depends on the geometry of cooling liquid. Due to the high thermal conductivity for AlN, most of the heat goes through ceramic material and is transferred to cooling liquid.
Simulation Result

Wafer temperature distribution (AlN)

AlN ceramic body

Wafer temperature distribution (Al2O3)

Al2O3 ceramic body
Simulation Result

For Al₂O₃ ceramic, most of the heat energy is transferred to backside helium due to low thermal conductivity. For AlN ceramic, most of the heat energy is transferred to cooling liquid due to high thermal conductivity.
I. The AlN ceramic body significantly reduces the wafer temperature and non-uniformity than Al₂O₃ does.

II. The non-symmetrical temperature distribution mainly results from the geometric design of cooling water channel.

III. The electrostatic voltage is a principal factor of the wafer temperature and the distribution.

IV. The top temperature slightly increases as backside pressure due to the less contact force of ESCs to the wafer.

V. Relationship between the electrostatic force and potential voltage is built up.
Thank You for Your Attention!

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