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

Kuo-Chan Hsu[1], Chih-Hung Li[1], Jaw-Yen Yang[1,2], Jian-Zhang Chen[1], Jeng-Shian Chang[1]

[1]Institute of Applied Mechanics, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan (R.O.C)

[2]Center for Advanced Study in Theoretical Sciences, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan (R.O.C)

Introduction: The temperature control of semiconductor wafers during processing is critical to ensure homogenous film processing on the wafer. In recent year, there has been considerable interest in the electrostatic chucks (ESCs). Wafer cooling by means of a gas (usually helium) at the backside of wafers plays an important role in electrostatic chucks and it uses an electrostatic potential to secure the wafer.

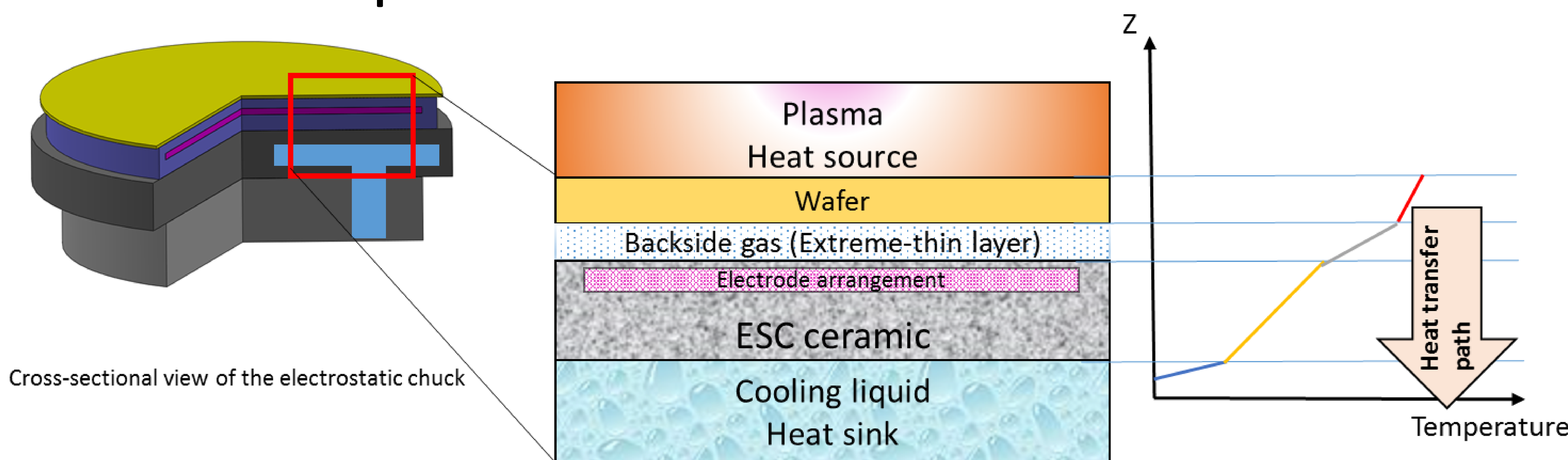


Figure 1 Schematic presentation of electrostatic chucks with heat transfer path.

Computational Methods: A finite element model of electrostatics chucks is developed using "conjugated heat transfer" and" electrostatic" to solve following principle equations.

- **Microscopic approach for heat flow between wafer and ESCs[1]**

$$\Delta T_{gas} \approx \Delta T_w + \Delta T_{coll} + \Delta T_{ESC} = \frac{P_{thermal}}{A_{wafer}}\left(\frac{C}{p\alpha_W} + \frac{d}{\kappa} + \frac{C}{p\alpha_{ESC}}\right)$$

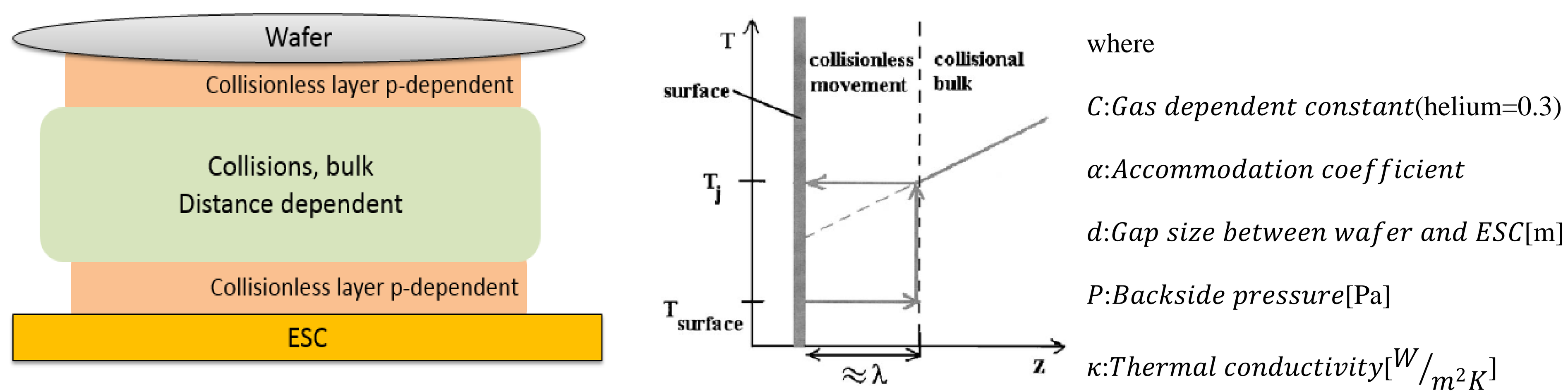


Figure 2 Explanation of the temperature jump appearing at a surface T_j is the temperature of atoms from the collisional regime and λ stands for the mean free path of atoms .

- **Cooper-Mikic-Yovanovich Correlation[2]**

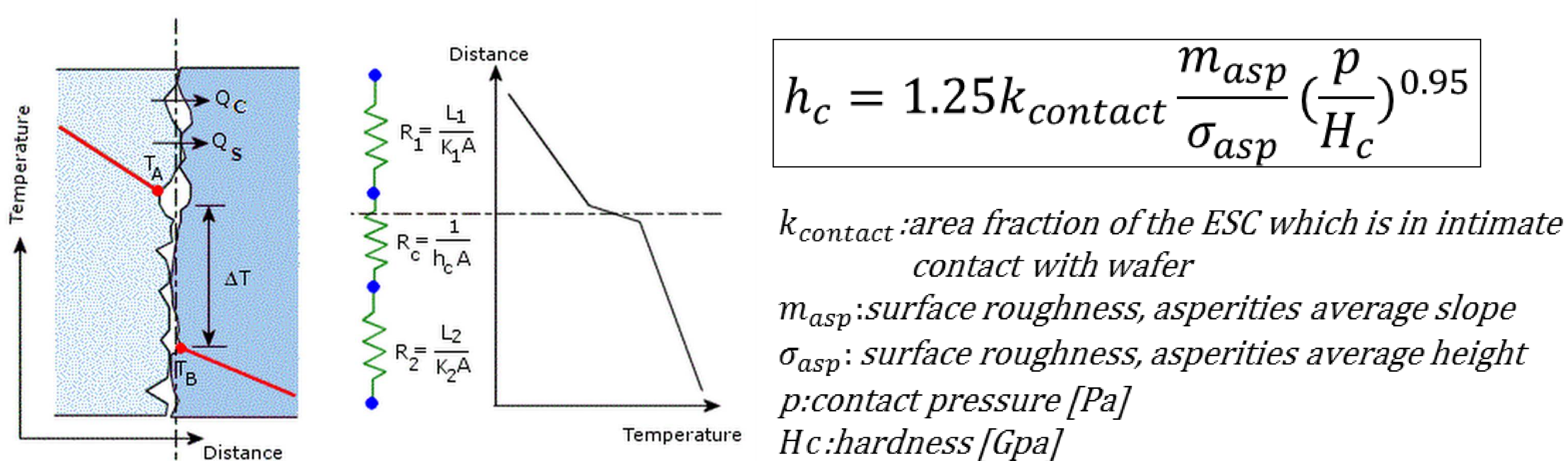


Figure 3 Temperature drop through the interface between the two contacting faces, two modes (Q_c and Q_s) of heat transfer exist.

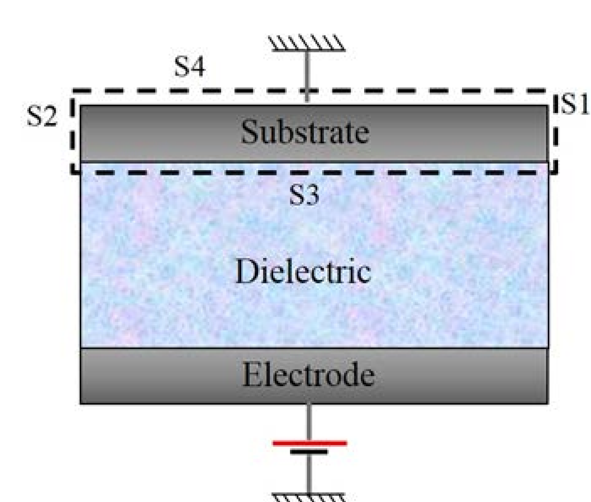
- **Maxwell's stress tensor [3]**

T_{ij} : Maxwell's stress tensor

E : Electric filed

ε : Electric permittivity

δ_{ij} : Kronecker delta



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

Figure 4 Electrostatic force calculation of ESCs

Results: Multiphysics simulation has been carried out to study the influence of electrostatic and helium backside pressure on temperature distribution of a wafer.

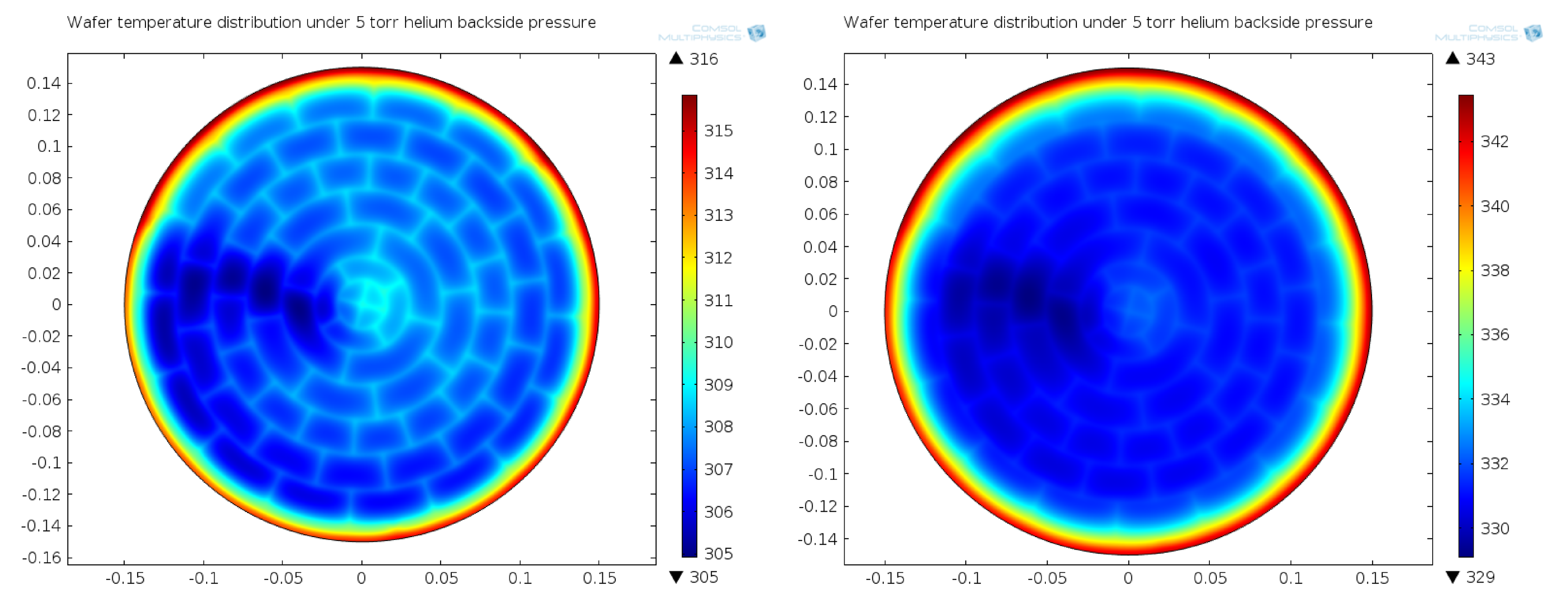


Figure 5 Wafer temperature distribution, two of the ceramic body are applied as (left-hand) AlN ceramic (right-hand) Al_2O_3 ceramic

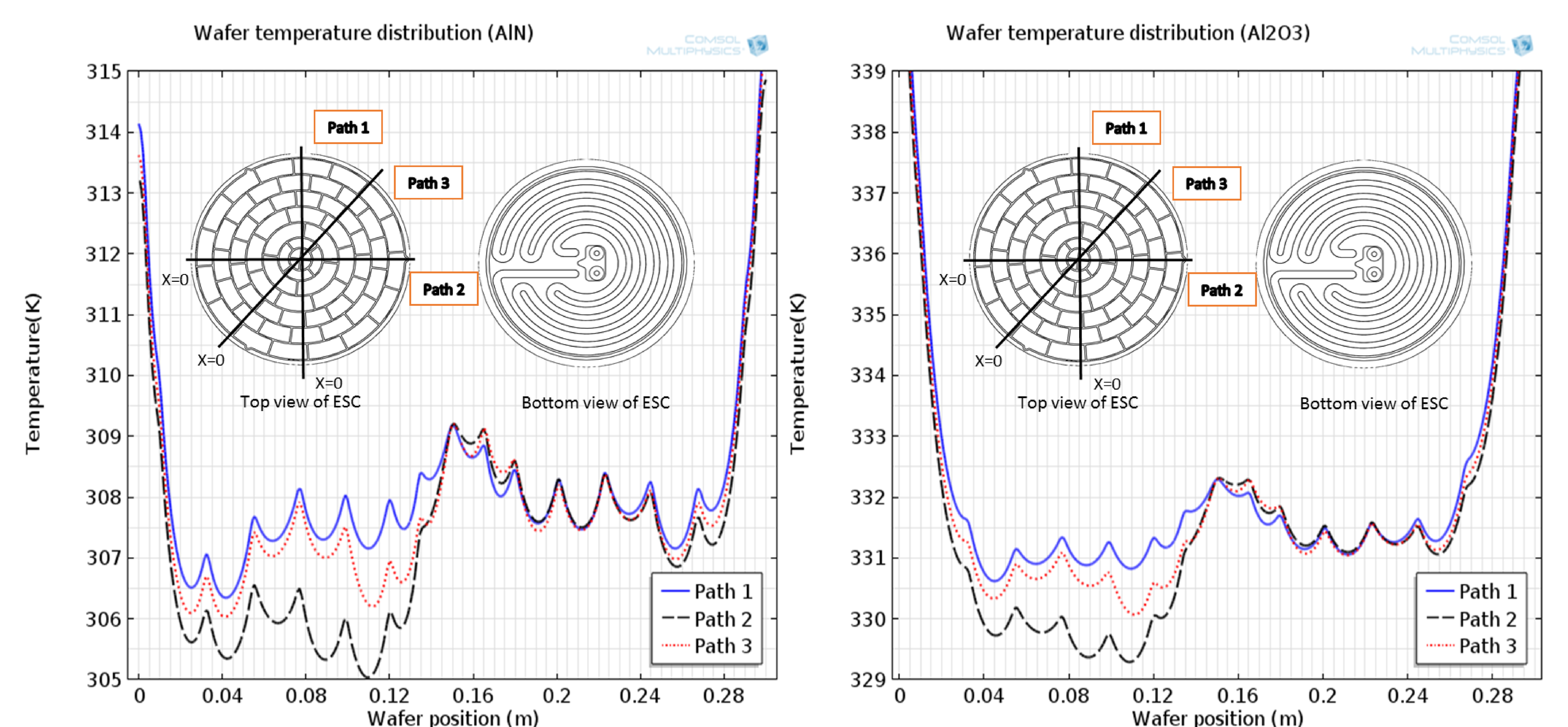


Figure 6 The wafer temperature distribution in three of the paths. The nonsymmetrical distribution is mainly due to the geometry of cooling water and groove of backside gas. AlN ceramic body (left-hand) Al_2O_3 ceramic body (right-hand).

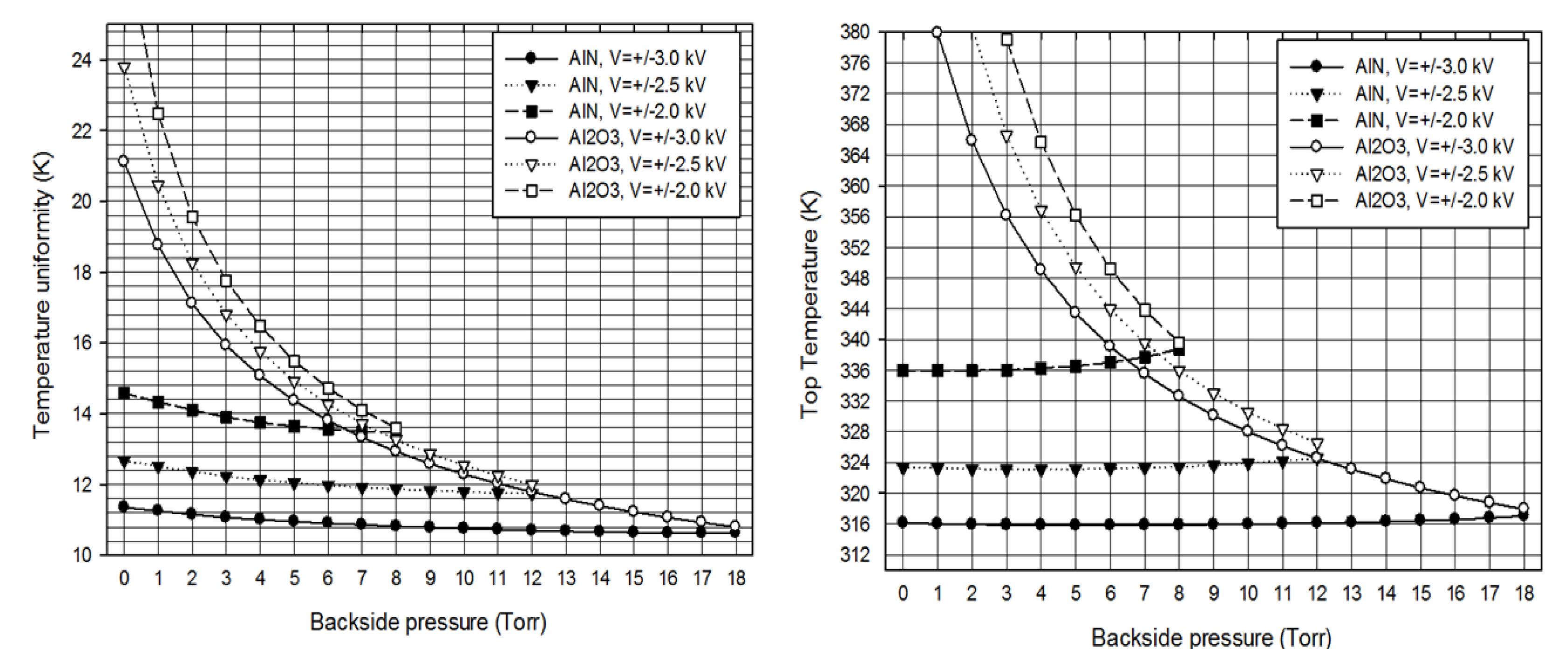


Figure 7 Wafer temperatures as a function of backside pressure and electric voltage. The effect of chucking voltage could be explained: with chucking force increase as voltage, the polyimide deformed and resulted in an effective large area for thermal conductance.

Results: ESCs with AlN ceramic body is evident to reduce wafer temperature and nonuniformity especially to wafer edge. We also built up a correlation of electric voltage and backside pressure to effect of temperature.

References:

1. Michael Klick and Mathias Bernt , Microscopic approach to an equation for the heat flow between wafer and E-chuck, JVST B, VOL.24, OCT 2006

2. M.Michael Yovanovich, Four Decades of Research on Thermal Contact, Gap, and Joint Resistance in Microelectronics, IEEE Transactions of components and packaging technologies, VOL.28, NO. 2, JUNE 2005

3. J.YOO et al., Proceeding of International Conference on Electrical Machines and Systems, 2007