

# Modeling of Thermophoretic and Electrophoretic Effects for Particle Transport and Deposition in EUVL Systems



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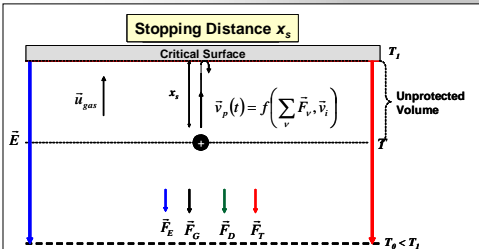
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## Motivation

Particle contamination control is crucial for protecting EUVL masks. Due to the small structure sizes, particles with diameters down to 30 nm can damage the mask performance. Therefore schemes are required to protect the mask from particle deposition during shipping, storage, in-fab handling under atmospheric pressure, as well as during application in process tools at reduced pressure, e.g., 50 mtorr. Two cases are considered: 1) particles injection from the bottom, and 2) injection from the side of the mask held face down in the chamber. Here we present analytical and numerical models for the particle motion for the two pressure cases.

## Bottom Injection Analytical Approach

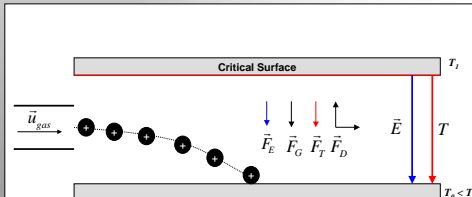


→ Stopping distance  $x_s$  defines the unprotected volume

## Considered Forces:

- Gravitational Force  $F_G$
- Drag Force  $F_D$
- Electrophoretic Force  $F_E$
- Thermophoretic Force  $F_T$
- Brownian Diffusion (only in numerical model)

## Side Injection Numerical Approach



Schematic of side injection case

## Derivation of the Stopping Distance $x_s$

Force balance: 
$$m_p \frac{\partial \vec{v}_p(t)}{\partial t} = \sum_i \vec{F}_i$$

Particle velocity: 
$$\vec{v}_p(t) = \frac{1}{m_p} \int \sum_i \vec{F}_i dt$$

Condition for stopping time: 
$$\vec{v}_p(t_s) = 0$$

Particle motion: 
$$x_p(t) = \int v_p(t) dt$$

Stopping distance: 
$$x_s = x_p(t_s)$$

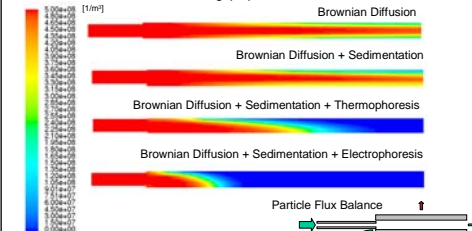
## Our Research Group



Dr. Kevin Oreck, Dr. Arun Ramamoorthy, and Dr. Pei-Yang Yan Intel Corporation

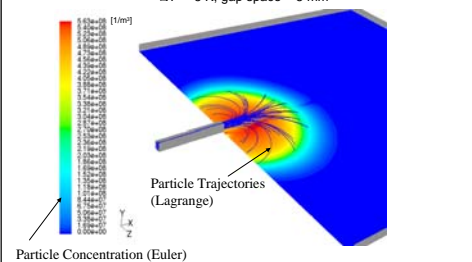
Related Presentations:  
Oral Presentation (Nov. 3, Ha01): Vacuum Chamber Study  
Other Poster (Ha01): Atmospheric Chamber Study

$P = 760$  torr, Flow Rate = 0.1 slpm;  $d_p = 125$  nm,  $N = 5 \cdot 10^8$  cm<sup>-3</sup>,  $E = 200$  V/cm,  $\Delta T = 5$  K, gap space = 5 mm



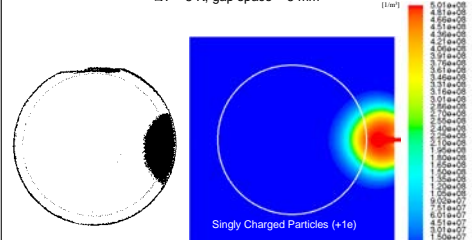
Effect of different forces on the particle concentration between the two plates for side injection for bottom plate

$P = 760$  torr, Flow Rate = 0.1 slpm;  $d_p = 125$  nm,  $N = 5 \cdot 10^8$  cm<sup>-3</sup>,  $E = 200$  V/cm,  $\Delta T = 5$  K, gap space = 5 mm

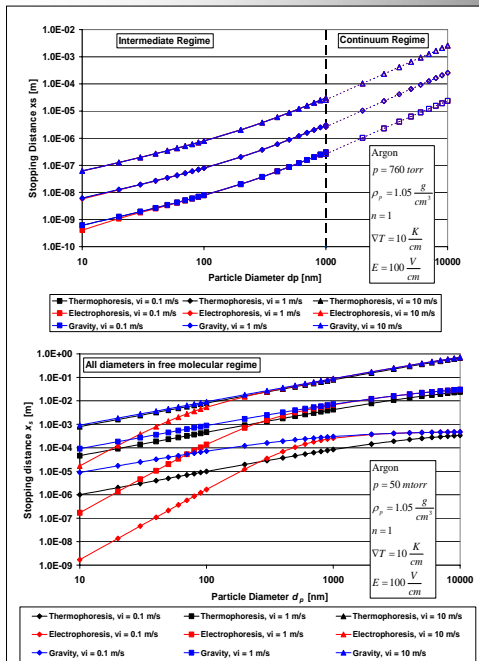


Comparison of Lagrangian (Discrete Phase Model) and Eulerian (Fine Particle Model) approach in FLUENT for bottom plate

$P = 760$  torr, Flow Rate = 0.1 slpm;  $d_p = 125$  nm,  $N = 5 \cdot 10^8$  cm<sup>-3</sup>,  $E = 200$  V/cm,  $\Delta T = 5$  K, gap space = 5 mm



Comparison of experimental and numerical results for bottom plate



Stopping distance vs. particle diameter for 760 torr (top) and 50 mtorr (bottom) for different initial particle velocities  $v_i$  for only gravity (blue), gravity plus electrophoresis with  $E = 100$  V/cm (red) and gravity plus thermophoresis with grad  $T = 10$  K/cm (black).

## Conclusions

- Gravity is effective in protecting face-down critical surfaces.
- Thermophoresis and electrophoresis become increasingly dominant with decreasing pressure.
- The applicable pressure range of the thermophoresis model requires further investigation and experimental verification.
- Good agreement is obtained between numerical results based on Lagrangian and Eulerian approaches at atmospheric pressure.
- Good agreement between numerical and experimental results is obtained for side injection at atmospheric pressure.