# Chrome Plating Process Optimization

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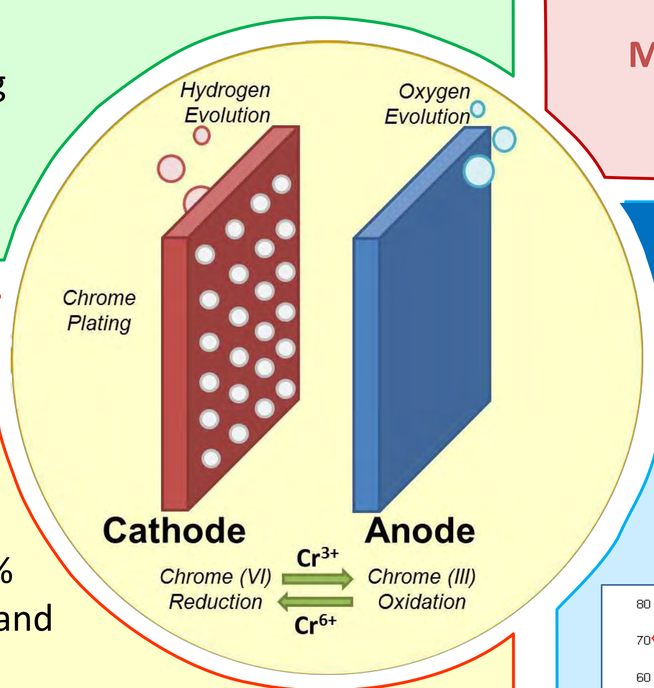
## Problem Definition

**Motivation:** Lack of a computer model leads to poor understanding of the process, resulting in energy and material waste

**Objective:** Model an existing chrome plating process in COMSOL to meet client specifications

**Goal:** Use model to optimize operating conditions and realize chrome and energy savings



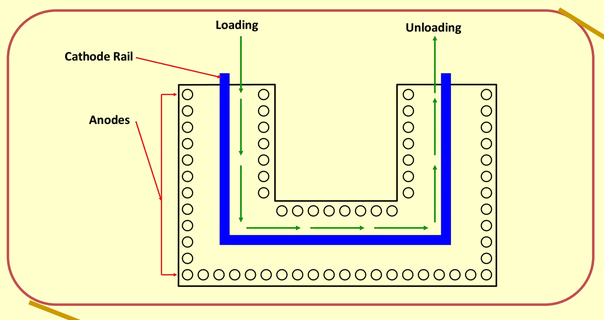

## Background

Plating occurs in two steps:

1. Dichromate reduces to $Cr^{3+}$
2. $Cr^{3+}$ reduces to $Cr^{0}$

Current efficiency of plating is only 15% due to competing hydrogen evolution and $Cr^{3+}$ reduction [1]

| Electrode | Material | Reactions |
|---|---|---|
| Cathode | Stainless Steel | $Cr^{3+} + 3e^- \rightarrow Cr^0$<br>$2H^+ + 2e^- \rightarrow H_2$<br>$(Cr_2O_7)^{2-} + 6e^- + 14H^+ \rightarrow 2Cr^{3+} + 7H_2O$ |
| Anode | Lead (Inert) | $2H_2O \rightarrow 4H^+ + 4e^- + O_2$<br>$2Cr^{3+} + 7H_2O \rightarrow (Cr_2O_7)^{2-} + 6e^- + 14H^+$ |




| Rinse 8 | Rinse 7 | Rinse 6 | Rinse 5 | Rinse 4 | Rinse 3 | Rinse 2 | Rinse 1 | Plating Bath |
|---|---|---|---|---|---|---|---|---|
| Electro-clean | | Rinse 1 | Rinse 2 | Rinse 3 | Reverse Etching | | | |

## Model Development

**Model:** Electrodeposition Moving Mesh Module in COMSOL
**Geometry:** 2D, 1 anode, 1 cathode, extremely fine mesh
**Kinetics:** Butler-Volmer at the electrode interface

$$i = i_o \left[ \exp\left(\frac{\alpha_a n_e F \eta}{RT}\right) - \exp\left(\frac{\alpha_c n_e F \eta}{RT}\right) \right]$$

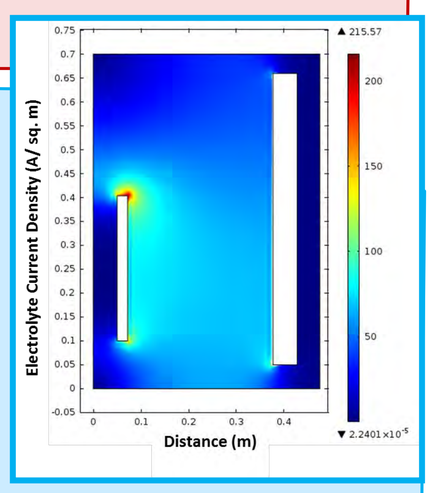
**Mass transfer:** Tertiary Nernst-Plank

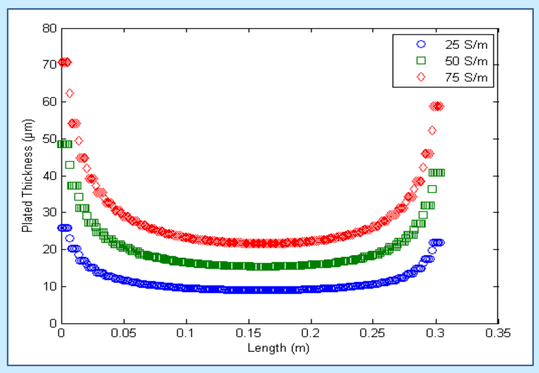
$$N_i = -D_i \nabla C_i - z_i u_i F C_i \nabla V$$

*Diffusion* *Migration*

## Results

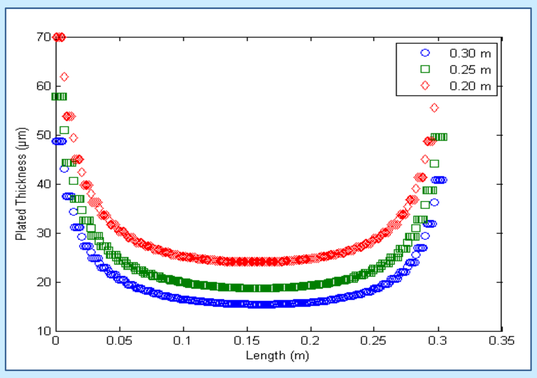
**Current** from the excess anode area accumulate at the top and bottom of the cathode

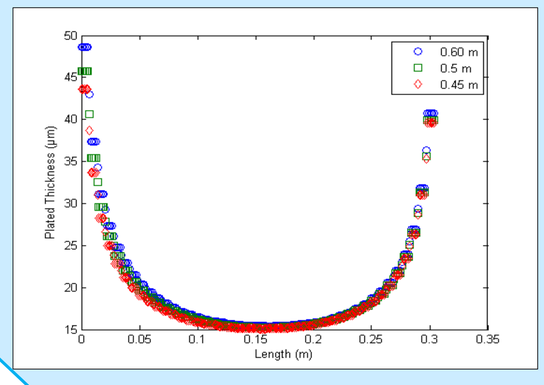



Plating thickness is directly proportional to **solution conductivity** however it also increases non-uniformity at higher values.

An increase in **anode-cathode spacing** decreases the plating thickness. Decreasing this distance results in much less uniformity.




**Anode height** appears to have little effect on plating. Further refinement of the model is required to incorporate process sensitivity to this parameter.

## Impacts

The model could be used to optimize the plating process and reduce chrome and energy consumption with the following outcomes:

**Environment:**

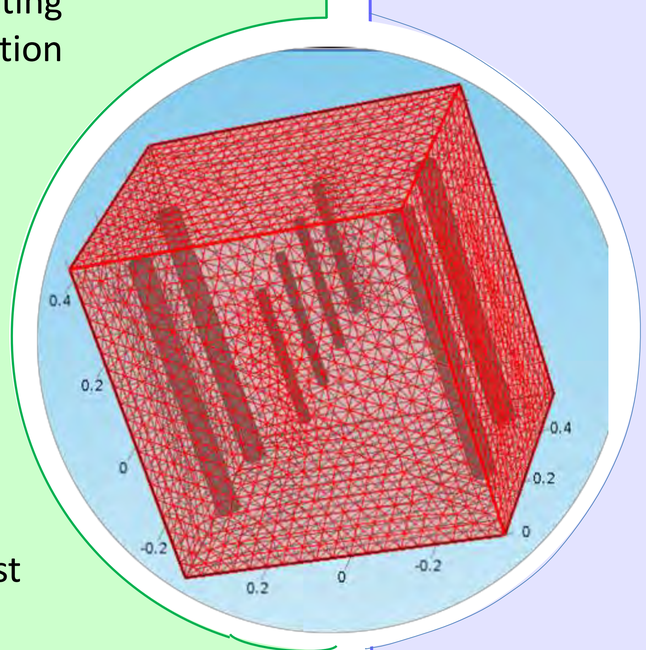
- Reduction of hazardous chrome emissions from
- the plating bath and the grinding operations
- Reduction of the carbon footprint of the plating process

**Health and Safety:**

- Decreased risk of worker exposure to chrome dust

**Economic:**

- Cost savings in raw materials (chrome) and utilities



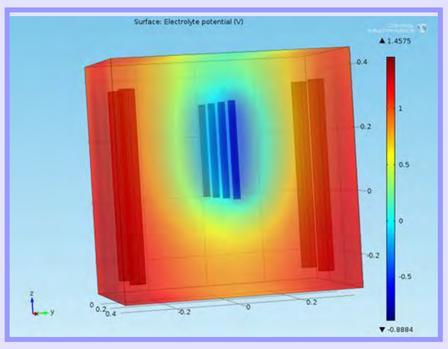
## Next Steps

**Refining the 2D model**

- Define system in terms of current density instead of electric potential for higher accuracy
- Include convective forces and effect of gas evolution in mass transfer calculations

**3D model**

- Determine if 3D model is feasible with current computational limitations
- Vary key parameters with a 3D model
- Validation with real process data
- Temperature effects

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