Effect of Mass Flow Induced by a Reciprocating Paddle on Electroplating.

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Abstract

In this work, the mass flow induced by a reciprocating paddle in the electroplating cell is studied by the finite element analysis software-COMSOL Multiphysics®. The reciprocating movement of the paddle is simulated by using the moving mesh technique (Arbitrary Lagrangian-Eulerian: ALE method). The solution of fluid flows stirred by the paddle is coupled into the calculation of tertiary current distributions.

Numerical model

Model geometry

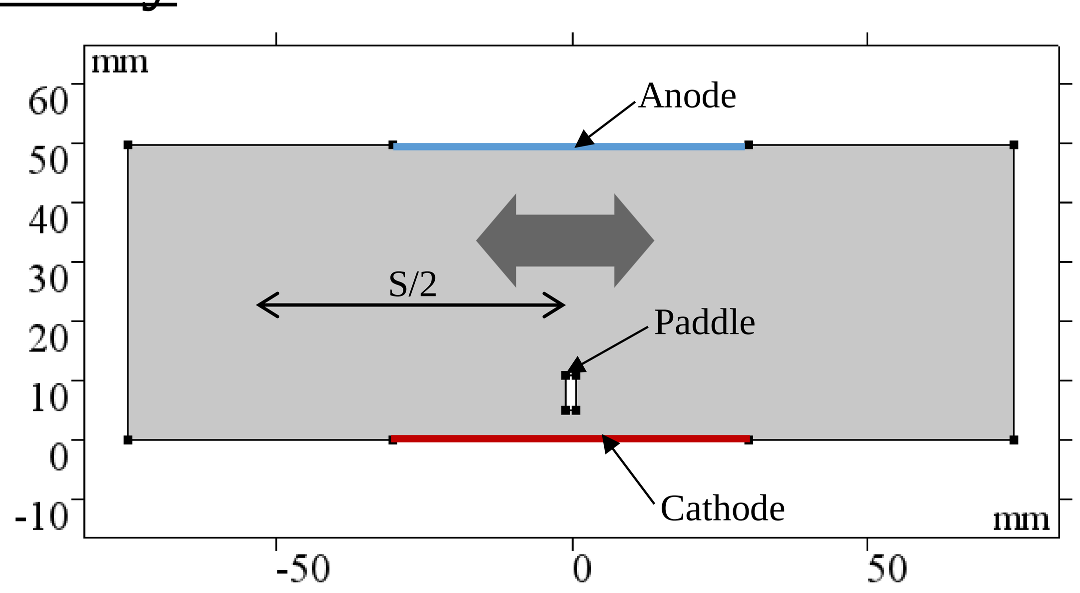

Figure 1. Schematic of a reciprocating paddle electroplating cell.

Equations

Continuity equation:

$$\nabla \cdot (\rho \mathbf{u}) = 0$$

ρ:density
$\mathbf{u}$:velocity vector
$\mathbf{F}$:volume force vector
$\mathbf{I}$: identity matrix

Momentum eqation:

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla \cdot \left(\mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3}\mu(\nabla \cdot \mathbf{u})\mathbf{I}\right) + \mathbf{F}$$

Material balance equation:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot \left(-D_i \nabla c_i - z_i u_{m,i} F c_i \nabla \phi_l + c_i \mathbf{u}\right) = R$$

Current density $\mathbf{i}_l$ in the electrolyte:

$$\mathbf{i}_l = F \Sigma_{i=1}^{n} z_i \left(-D_i \nabla c_i - z_i u_{m,i} F c_i \nabla \phi_l\right)$$

Charge balance in the electrolyte:

$$\nabla \cdot \mathbf{i}_l = Q_l$$

Electroneutrality equation:

$$\Sigma z_i c_i = 0$$

Tafel approximation:

$$i_{\mathrm{loc}} = -i_0 \left(\frac{C_s}{C_b}\right) \exp(-\eta / b_c)$$

c_i : concentration
D_i : diffusion coefficient
z_i : charge number
$u_{m,i}$: mobility
F : Faraday's constant
ϕ_l : electrolyte potential.
i_0 : exchange current density
c_s : surface concentration at the cathode
c_b : bulk concentration
b_c : Tafel slope

Coupled computation and mesh

Numerical solutions have been obtained by using finite-element analysis software COMSOL Multiphysics® 5.3. The fluid flow induced by the reciprocating movement of the paddle, mass transfer and current density distribution are fully coupled The reciprocation of paddle is simulated by the moving mesh (ale) technique.

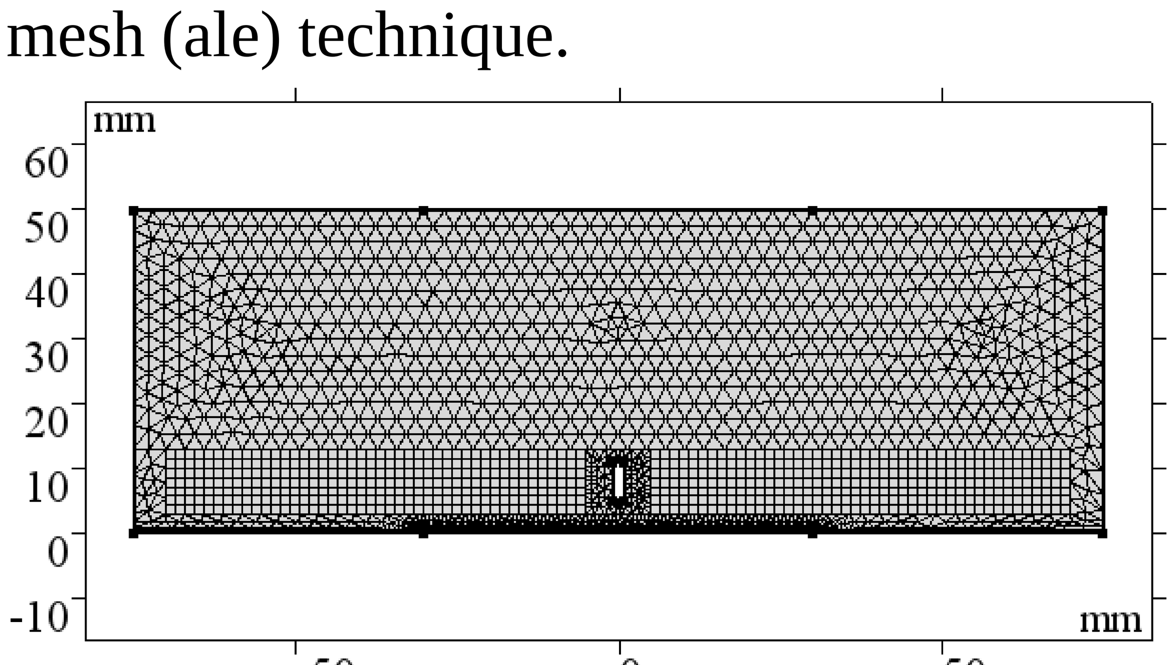

Figure 2. Computational mesh of an assembly geometry based on a reciprocating paddle of original condition

Results and discussions

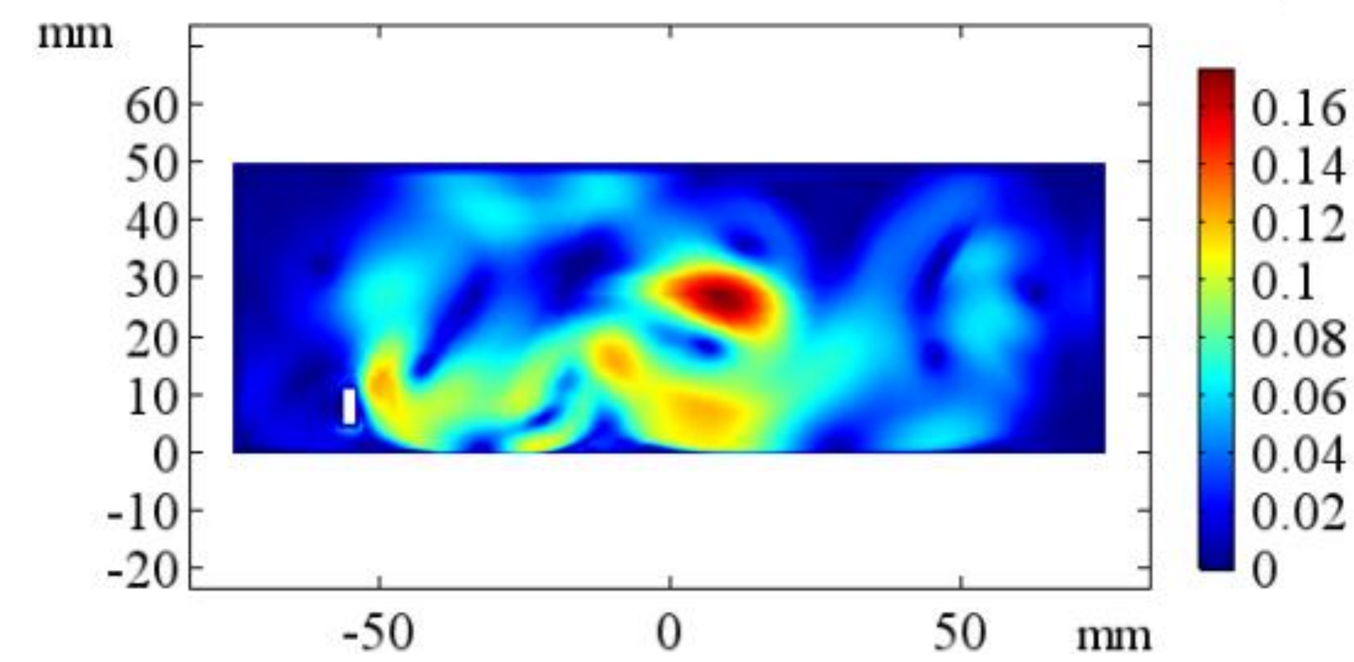

Figure 3. Velocity at t = 3T/4 (T is cycle period) .

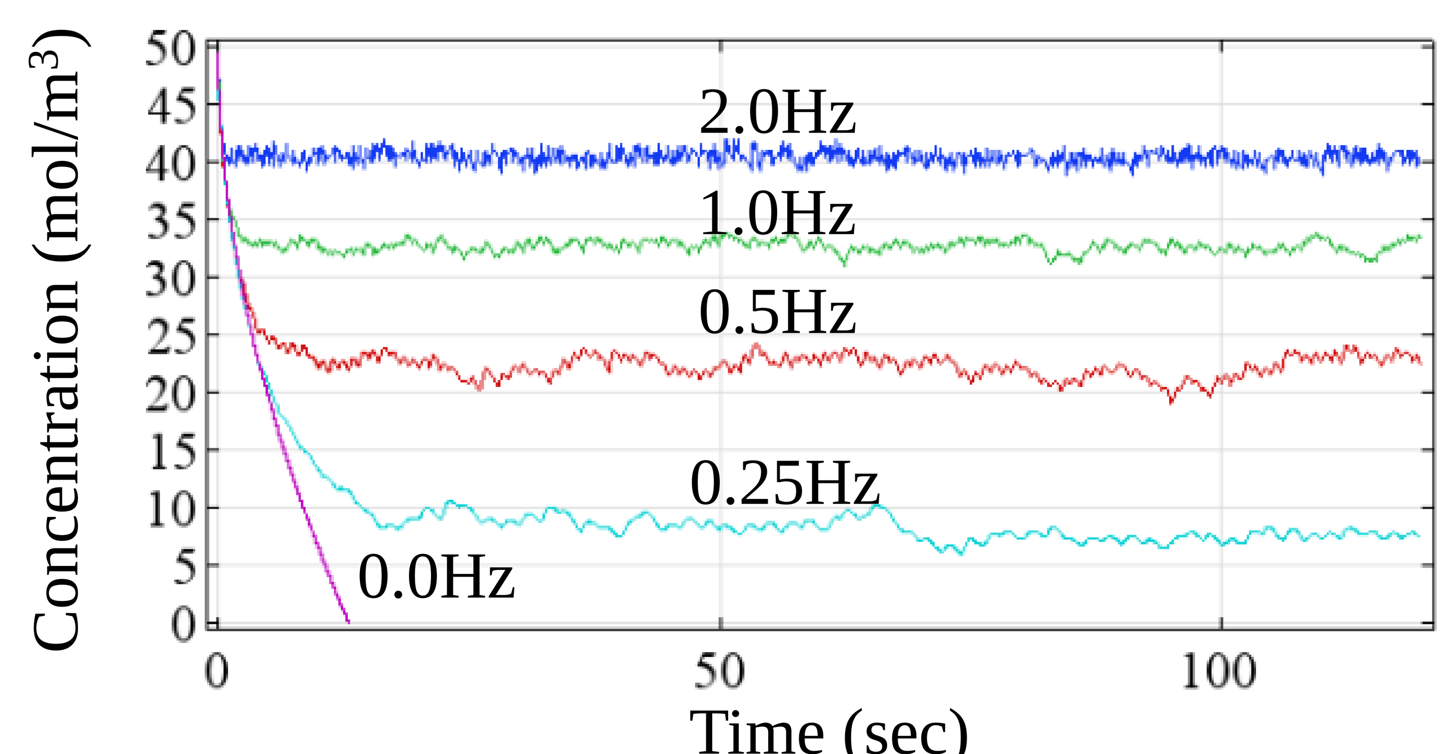

Figure 4. Temporal variations of averaged concentrations at the cathode

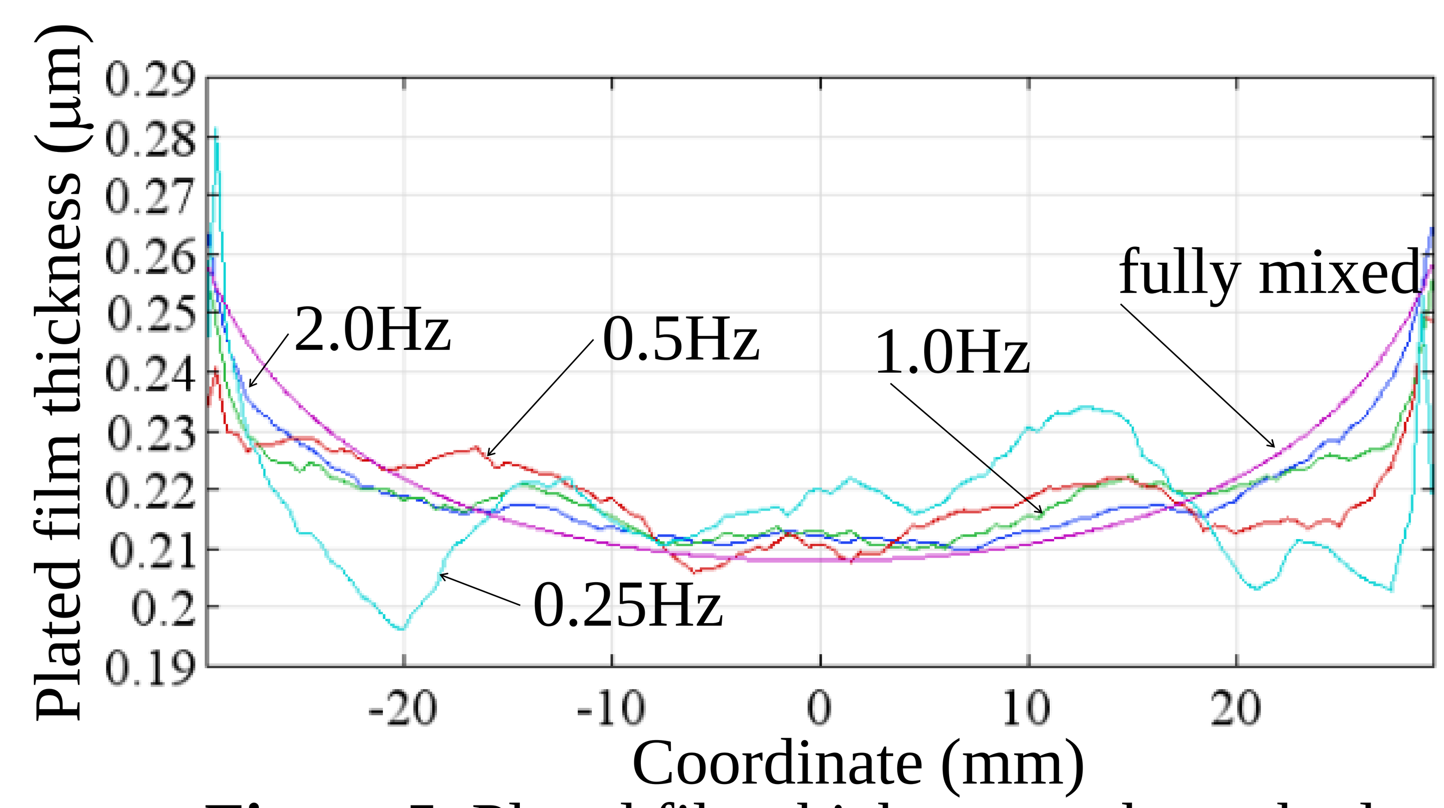

Figure 5. Plated film thickness at the cathode

The results show that the reciprocating movement of the paddle can effectively increase the concentration of cupric ions and improve plated film thickness distribution at the cathode

Concluding remarks

The effect of mass flow induced by a reciprocating paddle on the electroplating has been studied in this work by coupling the solution of fluid flows with the calculation of tertiary current distributions. The finite element analysis software-COMSOL Multiphysics® is used. The results show that the reciprocating movement of the paddle can effectively increase the concentration of cupric ions and improve plated film thickness distribution at the cathode The present research provides an efficient method to simulate the behavior of reciprocating paddle and the application of the method would be very beneficial in studying industrial reciprocating paddle electroplating systems.

References

1. J.S. Newman, and K.E. Thomas-Alyea, *Electrochemical systems*, 3rd ed., John Wiley & Sons, Hoboken, NJ (2004)

2. COMSOL Multiphysics 5.3-user's guide for CFD Module and Electrodeposition Module