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

M. Fukukawa\textsuperscript{1} and L. Tong\textsuperscript{1}

\textsuperscript{1}Keisoku Engineering System Co., Ltd, 1-9-5 Uchikanda, Chiyoda-ku, Tokyo 101-0047, Japan

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\textsuperscript{®}. 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](Image)

Equations

Continuity equation:
\[ \nabla \cdot (\rho \mathbf{u}) = 0 \]
Momentum equation:
\[ \rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla \cdot \left( \mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3} \nabla (\nabla \cdot \mathbf{u}) \right) + \mathbf{F} \]

Material balance equation:
\[ \frac{\partial c_i}{\partial t} + \nabla \cdot (D_i \nabla c_i - z_i u_m c_i \nabla \varphi_{l} + c_i \mathbf{u}) = R_i \]

Current density in the electrolyte:
\[ i_{l} = F \sum_{i=1}^{n} z_{i} (D_{i} \nabla c_{i} - z_{i} u_m c_{i} \nabla \varphi_{l}) \]

Electroneutrality equation:
\[ \sum_{i} z_{i} c_{i} = 0 \]

Tafel approximation:
\[ i_{i_{oc}} = -i_{0} \left( \frac{c_{l}}{c_{p}} \right) \exp \left( -\frac{\eta}{b_{c}} \right) \]

Coupled computation and mesh

Numerical solutions have been obtained by using finite-element analysis software COMSOL Multiphysics\textsuperscript{®} 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](Image)

Results and discussions

![Figure 3. Velocity at t = 3T/4 (T is cycle period)](Image)

![Figure 4. Temporal variations of averaged concentrations at the cathode](Image)

![Figure 5. Plated film thickness at the cathode](Image)

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\textsuperscript{®} 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

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