Materials and Design 90 (2016) 693–703

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Finite element modeling of silver electrodeposition for evaluation of thickness distribution on complex geometries

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ARTICLE INFO

Article history:
Received 20 May 2015
Received in revised form 20 October 2015
Accepted 3 November 2015
Available online 10 November 2015

Keywords:
Silver plating
Coating thickness distribution
Throwing power
Computer simulation
Finite element modeling

ABSTRACT

The paper reveals benefits of multi-disciplinary computer simulation and parametric studies in the design of silver plating process for improved coating distribution. A finite element model of direct current silver plating is experimentally validated for an Assaf panel without agitation. The model combines tertiary current distribution with Butler–Volmer electrode kinetics and computational fluid dynamics at a very low flow-rate. The effect of charge transfer coefficients on the throwing power of the process is quantified for the studied geometry, and variation of cathodic current density and exchange current density is investigated. A simpler model based on secondary current distribution is employed to quantify the effect of electrolyte conductivity on the throwing power of the process. A model combining tertiary current distribution and computational fluid dynamics has been developed and experimentally validated for simulation of complex telecom component electroplating in agitated electrolyte. The effect of current density on the process throwing power is quantified. Recommendations regarding modeling methodology and the effect of electrochemical and process parameters on the thickness distribution have been developed.

1. Introduction

Silver electrodeposition is an important process for electronics and telecom applications requiring high electrical conductivity, such as electrical contacts, RF filters and waveguides. Cyanide based electrolytes are typically used for silver electroplating, and throwing power (TP) is applied as a criterion to describe the uniformity of the surface coating [1,2]. Control of coating uniformity is especially important for substrates of complex shape, where some parts of the plated surface are hard to reach due to shielding of the electric field. This often requires time-consuming iterative steps for designing the plating cell set-up.

Three types of approximation of current distribution in the electrolyte and electrodes are considered in the design of electroplating cells: primary, secondary, and tertiary. The primary current distribution takes into account the solution resistance only. The secondary current distribution takes in to account both the electrode kinetics and the solution resistance. The current density as result of electrochemical reactions is modeled as a function of the activation overpotential. The tertiary current distribution includes the effect of variations in ionic strength and solution composition on the electrochemical reactions, as well as solution resistance and electrode kinetics. The latter accounts for activation and concentration overpotential [3].

Numerical modeling tools can be employed, in order to optimize cell geometry and process parameters in electroplating [3–8]. Recent developments in electrodeposition modeling include finite element (FE) based computational methods enabling the coupled numerical simulation of electrochemical systems, including ion-transport phenomena in dilute electrolyte solutions, i.e. convection, diffusion and migration [3,9,10]. Ion-transport in an electrolyte solution by convection is addressed by computational fluid dynamics (CFD) that employs numerical methods to solve problems involving fluid flows. The incompressible Navier–Stokes equations [11] establish a macroscopic model describing the dilute electrolyte flow in an electrochemical cell [12]. The equations are usually solved using stabilized finite element formulations for fluid flow [10].

In spite of the large research progress in FE modeling of electrodeposition, industrial application of FE simulation in plating process design is still not widely accepted, due to complexity and multi-disciplinary nature of simulation models for electrodeposition. Furthermore, experimental parametric studies to improve understanding of a particular plating process are too time-consuming and often poor from the methodological viewpoint. The combined effect of process parameters such as current density and plating time and electrochemical parameters such as charge transfer coefficients, electrolyte bulk conductivity, and exchange current density on the TP have not been systematically analysed and quantified for complex geometries with shielded parts.

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http://dx.doi.org/10.1016/j.matdes.2015.11.005

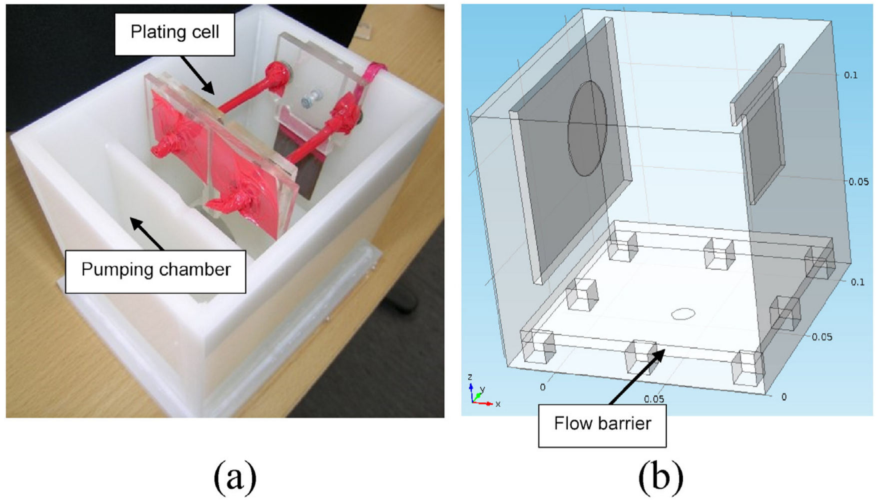

Fig. 1. The lab-scale setup (a), and a transparent 3D view, revealing the cell details (b).

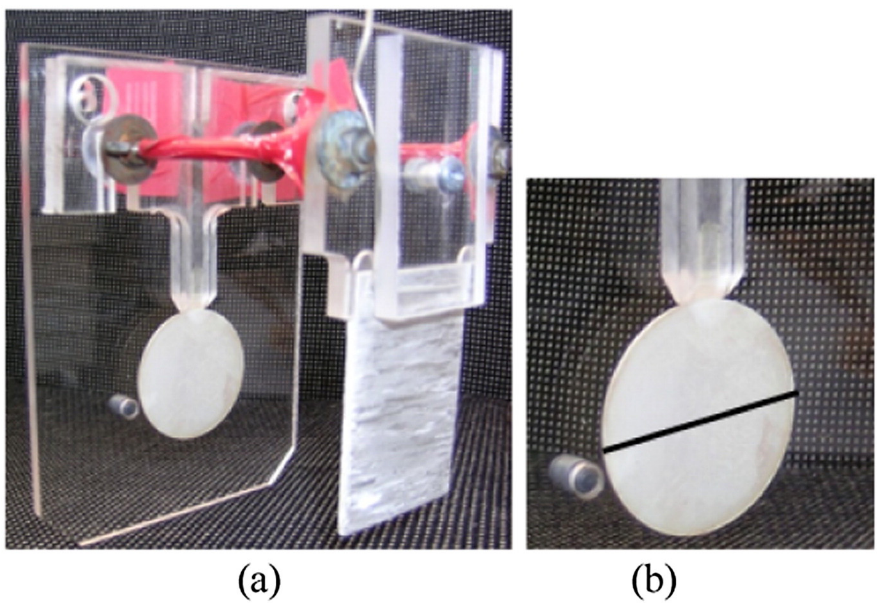

Fig. 2. Electrode arrangement (a); the close-up view of the Assaf panel with the centerline where the coating thickness is measured on both sides (b).

This paper provides both simulation and experimental studies of a direct current (DC) silver plating process operating in lab scale, and silver plating process for an industrial component of complex shape.

The objective of the paper is to evaluate a more accurate tertiary and more time efficient secondary current distribution modeling methods based on Butler–Volmer electrode kinetics, and develop and

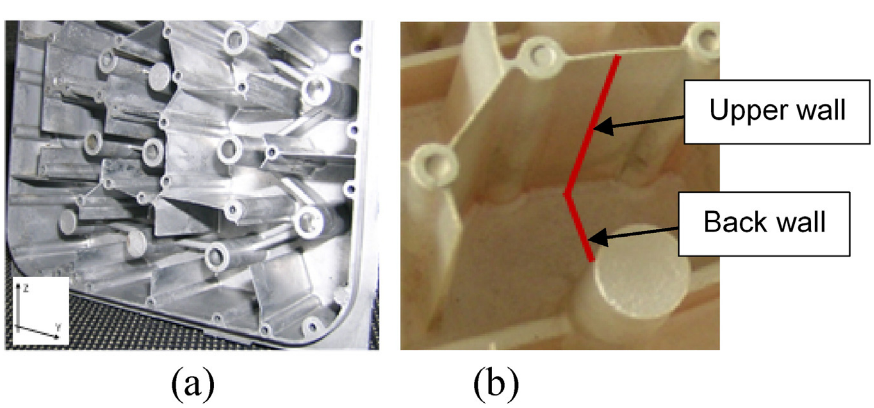

Fig. 3. A part of a cast aluminium component (a), and the cavity of the plated filter structure with indication of lines for thickness measurement (b).