

Modeling Electrochemical Deposition of Aluminum from Ionic Liquids for PCB Applications

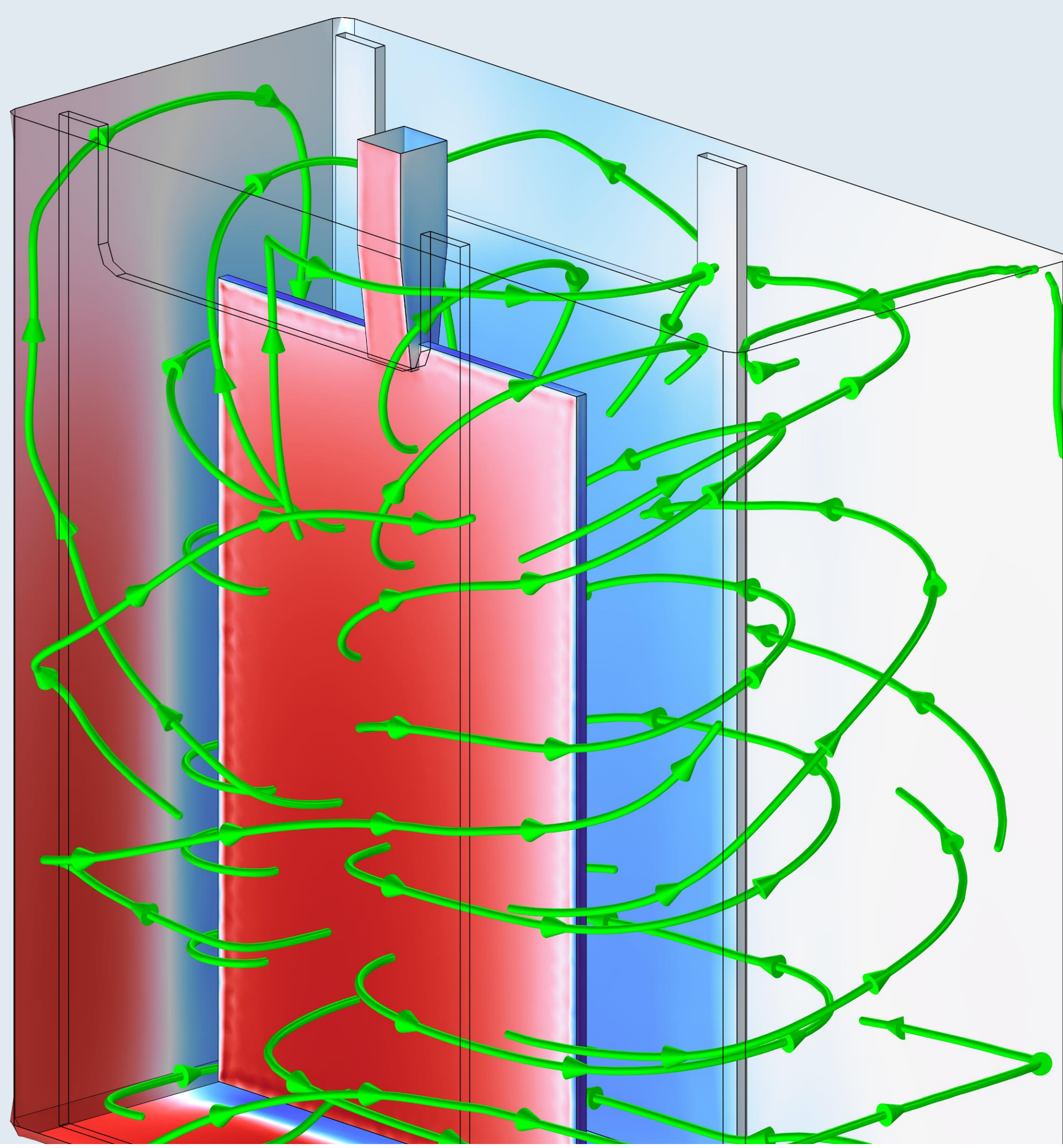
Substituting copper (Co) with aluminum (Al) in printed circuit board (PCB) technology requires the adaptation of established process technology. A cross-scale simulation approach is utilized to model the electrodeposition process in the vicinity of a through hole.

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Introduction

Both technological and economic reasons have been motivating research on substituting Co with Al in PCB technology (Ref. 1). Despite its 60 % higher specific electrical resistance, Al features twice the conductivity of Co per weight, enabling lighter weight applications where volume is no major constraint such as in aerospace technology.

To deposit Al electrochemically, ionic liquids (IL) – organic salts in liquid state at process temperature – mixed with Al salts can

be utilized as electrolytes. A major challenge poses the coating of vertical interconnect accesses (vias), which electrically connect both sides of a PCB. As IL-based electrolytes are comparatively viscous, sufficient electrolyte replacement within these through holes by means of a convective flow is critical. In this study, the deposition process of Al in the vicinity of a via in a PCB substrate, which is moved in a controlled manner through an IL-based electrolyte, is characterized.

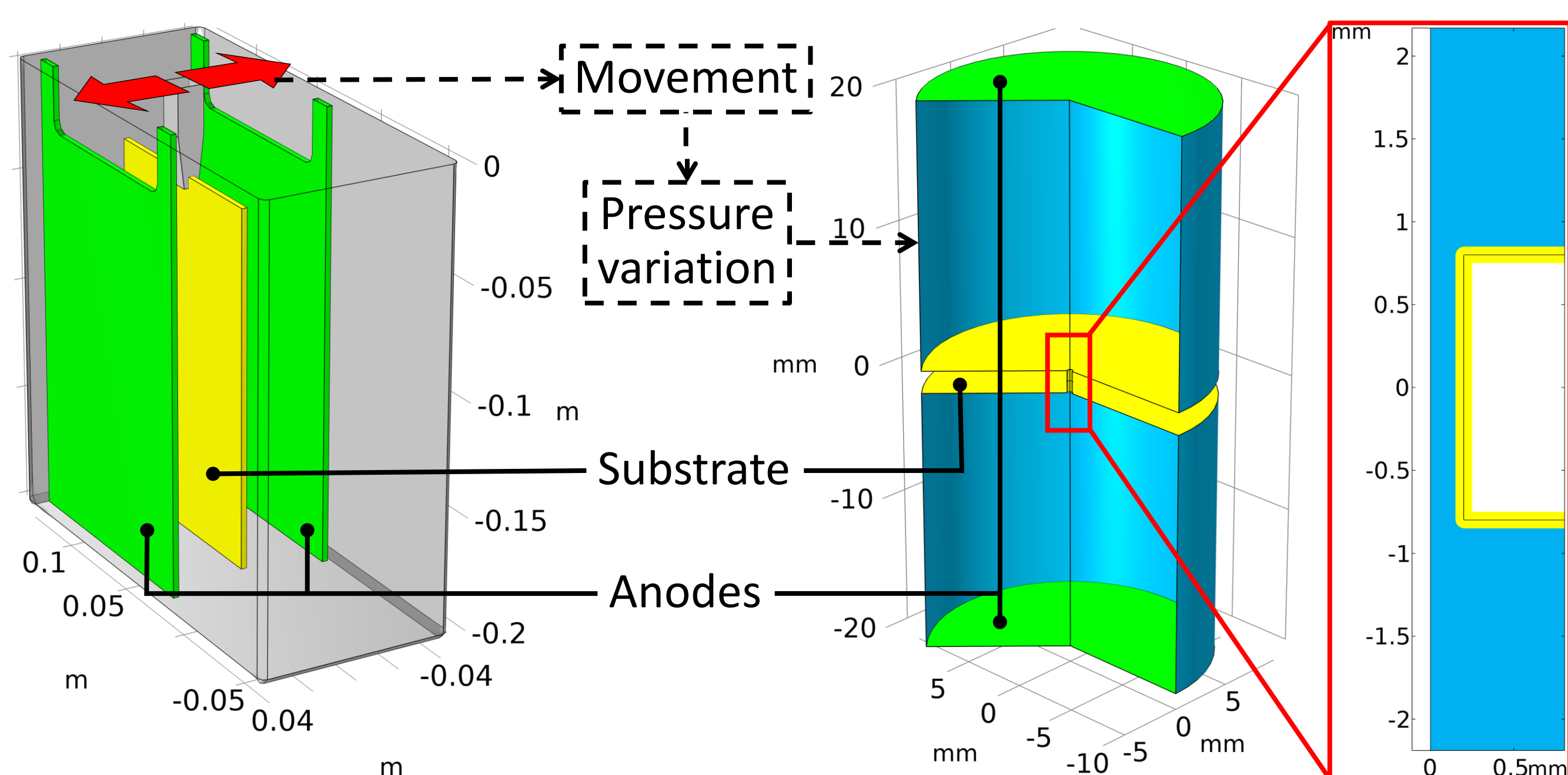


FIGURE 1. Left: 3D Macroscale model with moving substrate. Right: 2D axisymmetric microscale model with integrated pressure condition.

Methodology

To represent the electroplating process of Al on a PCB substrate containing vias by simulation, a two-stage modeling approach was developed. In the first stage, fluid dynamics within the process chamber ($\sim 10^{-1}$ m) were modeled in 3D. The resulting pressure variation between the opposing surfaces of the substrate was integrated into the second stage of the modeling approach. In this stage, a 2D representation of a via ($\sim 10^{-4}$ m) through the substrate was modeled utilizing rotational symmetry. Ion transport and reaction kinetics (Ref. 2) during the current-controlled process were calculated from Nernst-Planck equation and Butler-Volmer equation, respectively.

Results

Due to the substrate movement, concentration of the depositing Al species at the center of the via remains at above 70 % of its initial level after a process time of 60 minutes. Here, the deposition process is solely limited by electric current. In contrast, the deposition rate of $0.24 \mu\text{m}/\text{min}$ on the open substrate surface is limited by mass transport at this point. Near the edge of the via, both current density and ion concentration remain at high levels over the course of the process, resulting in a protrusion.

The simulation results are in good accordance with experimentally obtained deposition rates of $0.23 \mu\text{m}/\text{min}$ on the open surface. Comparing these results to Faraday's law confirmed a current efficiency close to 100 %.

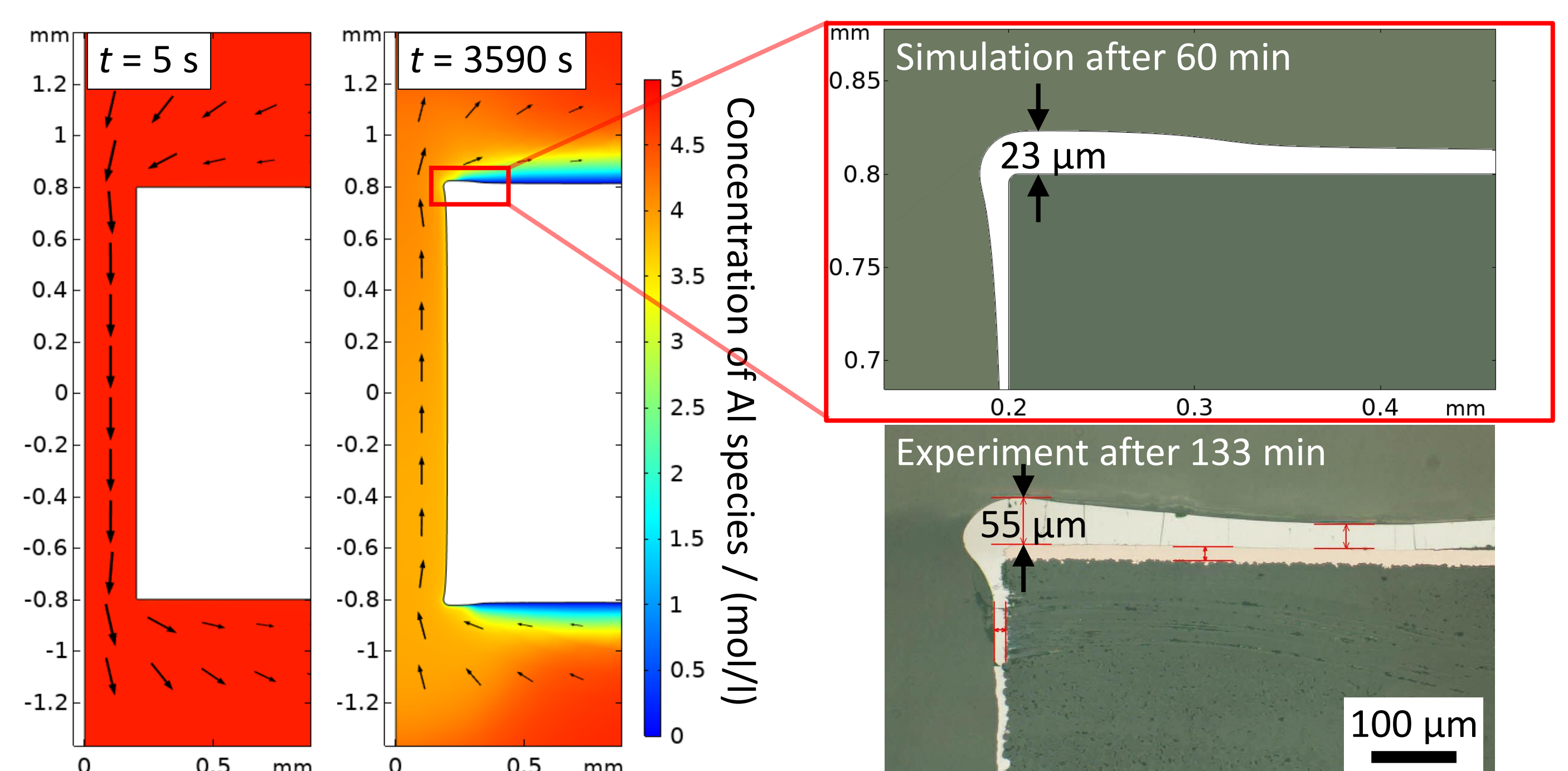


FIGURE 2. Left: Concentration of Al species and electrolyte flow at $t = 5$ s and $t = 3590$ s. Right: Comparison of deposited Al layer near the via edge between simulation and experiment. Images have been scaled to reflect differences in process time.

REFERENCES

1. M. S. Al Farisi, S. Hertel, M. Wiemer, and T. Otto, "Aluminum Patterned Electroplating from AlCl_3 -[EMIm]Cl Ionic Liquid towards Microsystems Application", *Micromachines*, Volume 9, Article number 589, 2018.
2. R. Böttcher, S. Mai, A. Ispas, and A. Bund, "Aluminum Deposition and Dissolution in [EMIm]Cl-Based Ionic Liquids—Kinetics of Charge—Transfer and the Rate—Determining Step", *J. Electrochem. Soc.*, Volume 167, Article number 102516, 2020.