Electro-Chemical-Mechanical Planarization (ECMP) of Copper

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Introduction: ECMP is an emerging technology for planarizing (polishing) of semiconductor wafers [1]. Feedback control is essential for meeting performance goals. The aim of this study, the development of a validated physical model, forms the basis of model-based control of ECMP.

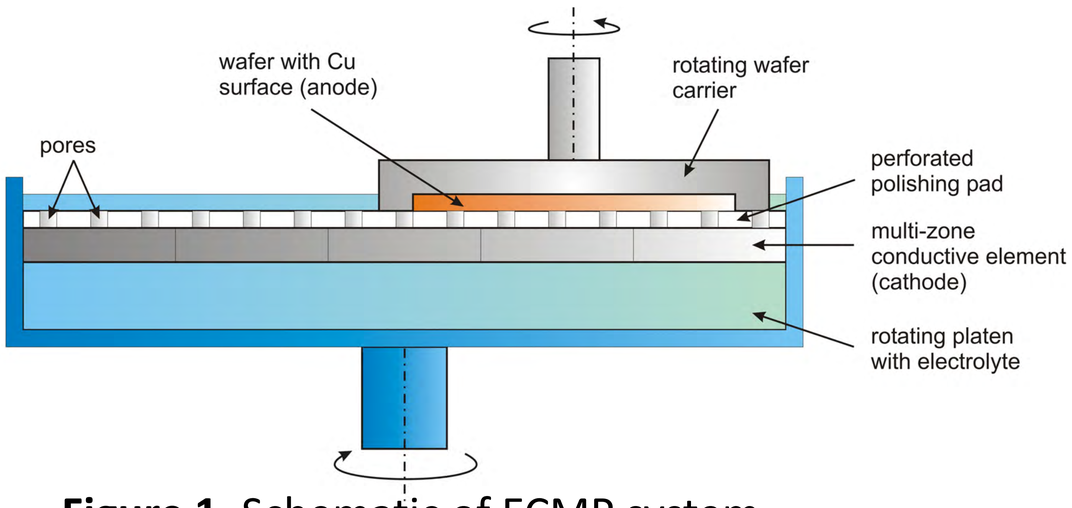

Figure 1. Schematic of ECMP system.

Computational Methods: The COMSOL model of electrochemistry and species transport predicts the dependence of the removal rate on other process parameters such as electrolyte concentration and applied voltages. The 2D model comprises of phosphoric acid solution (electrolyte) flowing between two parallel plates representing the pad and the wafer as shown in Figure 2.

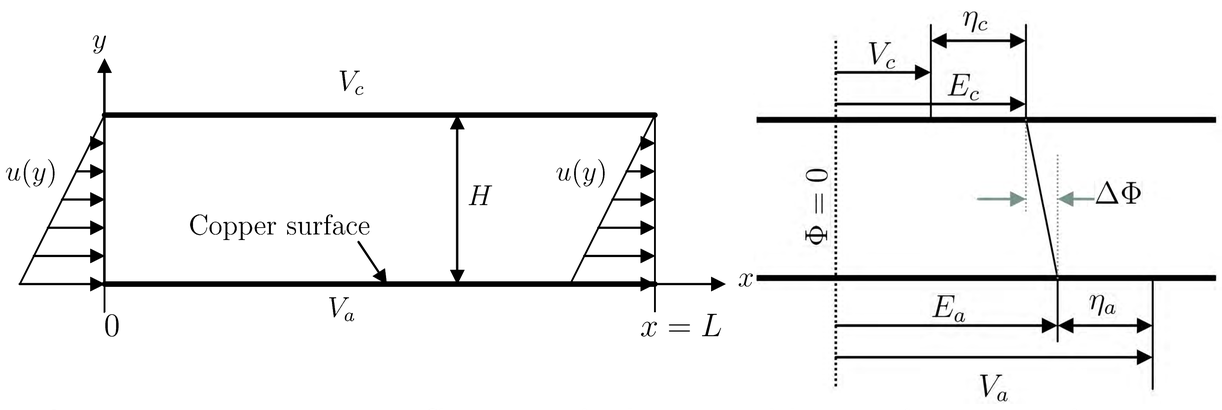

Figure 2: Geometry, flow and electrical boundary conditions.

The electrochemistry governing ECMP is [2]:

Anode: $Cu(s) + 6H_2O \rightleftharpoons [Cu(H_2O)_6]^{2+} + 2e^-.$

Electrolyte: $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+.$

The species flux is given by:

$$\mathbf{N}_i = \underbrace{-z_i u_i F c_i \nabla\Phi}_{\text{migration}} \underbrace{- D_i \nabla c_i}_{\text{diffusion}} \underbrace{+ c_i \mathrm{v}}_{\text{convection}}.$$

flux

COMSOL Multiphysics PDE (General Form) interface was used to implement the model.

Results: Figures 3 and 4 show sample results from the COMSOL model simulations. Figure 5 shows the setup for experiments, and Figure 6 shows comparison of data with model predictions for probe current along the length of the anode.

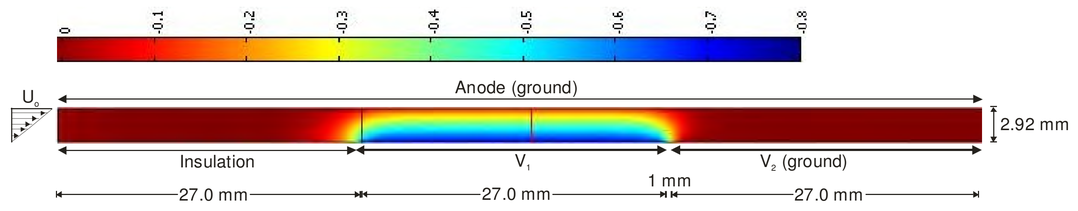

Figure 3. 2D COMSOL Model with potential map.

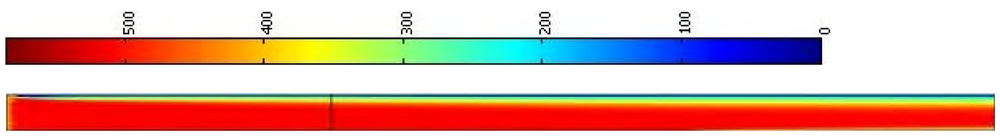

Figure 4. Hydronium ion, H_3O^+, concentration (moles/m^3).

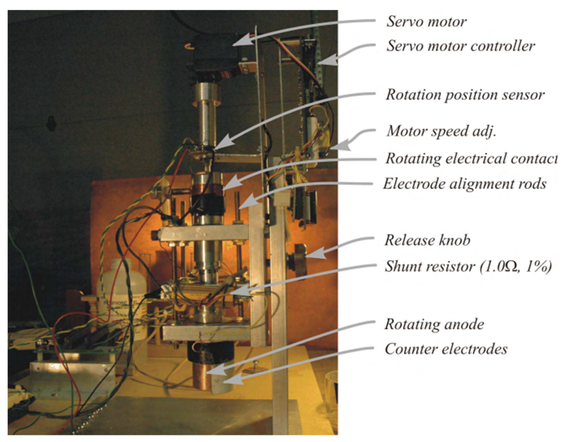

Figure 5. Experimental apparatus.

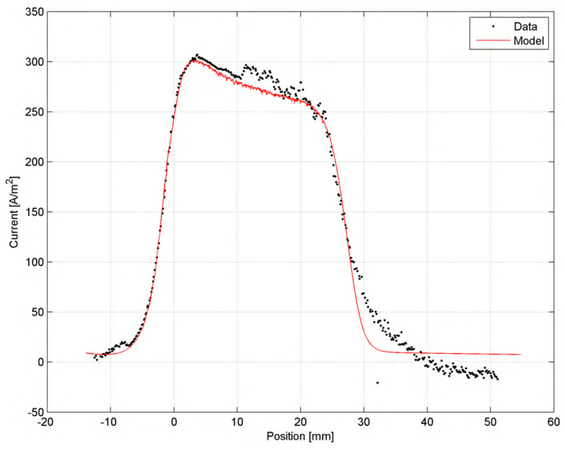

Figure 6. Comparison of anode current data (scaled) with COMSOL model predictions.

Conclusions: The excellent agreement of the COMSOL model predictions with experimental results validates the use of a reduced-order version of this model for ECMP process control.

References:

1. *Microelectronic Applications of Chemical Mechanical Planarization*, Ed. Y. Li, Wiley-Interscience, (2008).
2. R. Vidal and A. C. West, "Copper Electropolishing in Concentrated Phosphoric Acid II: Theoretical Interpretation," *J. Electrochem. Soc.*, Vol. 142, No. 8, pp. 2689-2694, (1995).