Experimental Validation of Model of Electro-Chemical-Mechanical Planarization (ECMP) of Copper

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Abstract

The goal of this work is to develop a model of Electro-Chemical-Mechanical Planarization (ECMP) using COMSOL Multiphysics, and validate the results by conducting an experimental study. ECMP is an emerging technology which is expected to complement conventional Chemical Mechanical Planarization (CMP) of semiconductor wafers. In particular, ECMP is applied to low-k interconnects at technology nodes of 32 nm and below. This polishing technique leverages electrochemical etching and gentle mechanical action to remove copper atoms, and has a very low down force that minimizes device pattern sensitivity associated with conventional CMP.

We developed a 2D model of flow of phosphoric acid solution (the electrolyte) between two parallel plates, the top plate representing the pad and the bottom plate representing the wafer, as shown in Figure 1. The pad moves with a constant velocity with respect to the reference frame of the wafer. The flow velocity profile in the gap is linear at steady-state. The wafer surface is the working electrode and is held at a constant potential Va, and is coated with a film of copper that would be removed using ECMP. The copper film is sufficiently thick that we can ignore potential drops through the film. The polishing pad is the counter-electrode and is kept at potential Vc (Figure 1). We assume the acid dissociates in the solution to form the hydronium ion, H3O+.

By using this relatively simple geometry, we were able to focus on the transport and electrochemistry involved in ECMP. The model includes steady-state copper dissolution and species transport inside the electrolyte, ion transport including convection, diffusion, and migration, and electrodic reactions represented by the Butler-Volmer equation. It computes the steady-state copper dissolution current density as a function of the voltage applied Ve = (Va   Vc).

An experimental set-up for validating this ECMP model was fabricated, and experiments were conducted to measure the anode current was measured at various spatial locations for different electrode potentials. Figure 2 shows the voltage contours predicted by the COMSOL model. As shown Figure 3, the results of the experiment and the COMSOL model are in very good agreement. As the probe sweeps from left to right (increasing position) the current suddenly rises at about 5-6 mm when the electrode region starts. After the peak, the current decreases gradually with increasing position due to thickening of the copper ion diffusion boundary layer, and then drops off suddenly as the probe exits the electrode area.

Our conclusions were that the validated COMSOL model was ready for use in model-based control of the ECMP process.

Figures used in the abstract

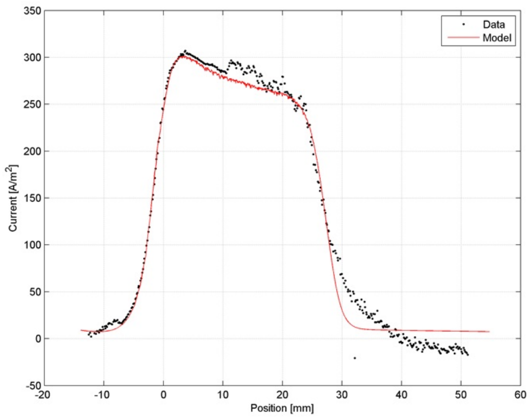

Figure 1: Figure 1: 2D geometry for ECMP model. The electrolyte flow enters from the left. Polishing occurs at the copper anode (bottom “wall” at potential Va) which is moving at velocity U0 with respect to the pad (top “wall” at potential Vc).