Integrated Multiscale Process Simulation of Damescene Structures

[1]Max O. Bloomfield, [1]Yeon Ho Im, [1,2]Jongwon Seok,
[1,2]Cyriaque P. Sukam, [1]John A. Tichy,
and [2]Timothy S. Cale
[1]Focus Center—New York, Rensselaer:
Interconnections for Gigascale Integration
[2]Department of Mechanical, Aerospace, &
Nuclear Engineering
Rensselaer Polytechnic Institute
110 8th Street
Troy, NY, USA 12180-3590

Manufacturing of integrated circuits (ICs) is an inherently multi-scale, multi-step, and multi-physics process. The size scale of the units of production (wafers and dies) is centimeters to decimeters, whereas the size scale of the produced structures (devices and interconnects) is micrometer and smaller. The sequential, many-step processing brings many different materials, technology, and physics to bear. If process simulation is to act as an effective tool in addressing issues of process integration, then they must first address the multi-scale, multi-step, and multi-physics aspects of the manufacturing process.

We have integrated a pattern scale/feature scale model of electrochemical deposition (ECD) with a wafer/asperity/feature scale model of chemical mechanical polishing (CMP). The ECD model correctly predicts trends[1,2] in the effect of pattern density on the superfilling behavior of additives during ECD processing, and is based on the work of West and co-workers [3,4]. The CMP model [5] is based upon statistical descriptions of contact modeling between pad asperities and the patterned surface of the wafer. It accounts for deformation of the pad, the asperities, the wafer, and the carrier film, as well as hydrodynamic pressure in the slurry phase.

We "virtually" process clusters of trenches, filling them with ECD copper (see Figure 1), and observe the resulting bump and plateau formation above them. We then proceed to remove the blanket copper using the CMP model (Figure 2) and examine the resulting single damascene structures.

Local values of material properties—in particular, the hardness and the subsequent value of a modified Preston's constant used in the CMP material removal rate calculation—of the as-deposited copper are taken to be functions of deposition condition, including growth rate and local additive concentration, and assumed to be grain-structural in origin. These local variations in material properties are reflected in the evolution of the superfilled structures during CMP. Further, preliminary simulations of re-crystallization and the accompanying evolution of the local values of material properties are made using a finite element based level set code.

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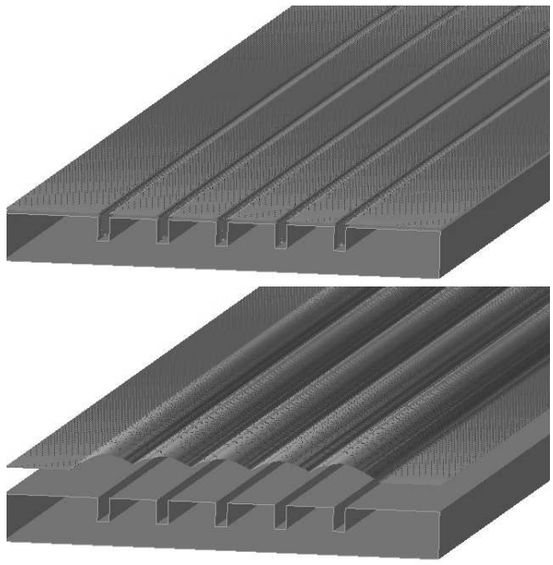

Figure 1: Electrochemical deposition of copper into a cluster of 5 aspect ratio 2, 1 micron-wide trenches. Top: Early stage, before complete fill. Bottom: late stage, after significant bumping.

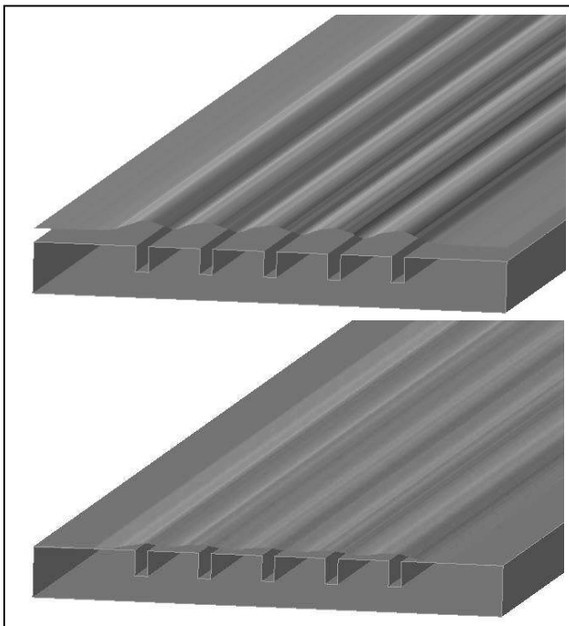

Figure 2: Chemical mechanical polish of copper-filled trenches from Figure 1. Top: Early stage, far from endpoint. Bottom: late stage, after initial breakthrough to barrier.