Copper plating uniformity on resistive substrate with segmented anode

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Copper plating is used to fabricate various interconnect structures for applications in microelectronics industry. The size of these features can range from tens of microns to tens on nanometers, and they spread on wafers as large as 300 mm in diameter. In a typical Cu interconnect fabrication process, a thin Cu seed is deposited on a barrier layer first by means of Physical vapor deposition, enabling easier implementation of the plating step. With decrease in feature size, the thickness of the Cu seed layer must also be reduced, or even replaced by an alternative, more uniform and conformal seed layer. Thinning of the seed layer leads to increase in the resistivity of the substrate, which in turn affects deposition current uniformity, i.e. difference in deposited Cu thickness along the wafer radius could become extreme.

One method to improve the wafer-scale copper plating uniformity on resistive substrates is using segmented anodes [1]. In such a plating cell setup instead of one circular anode, multiple ring-shape segments on which the input currents can be controlled are used. As the wafer scale plating experiments are both expensive and time-consuming, numerical simulation has been proven a very useful tool in the studies of plating uniformity. The wafer scale current distribution, as well as plating uniformity, has been examined numerically in previous studies under various conditions [2 - 4]. Based on a modeling approach similar to the on reported in [4], Cu electroplating on resistive substrates with segmented anodes was studied in this work. Fig. 1 shows a schematic cross-section of an anode configuration with three concentric segments. A 200mm wafer is assumed in this study, with r_0=10cm, H=10cm. The widths of the segments are set to w_1=0.2r_0, w_2=0.3r_0, w_3=0.4r_0. The distribution of deposition current density on the wafer surface can be adjusted through the allocation of current on the anode segments. Cylindrical insulating anode shields were used to further isolate the anode segments and control the current distribution. The impact of segmented anode on the current distribution during deposition on different (200 mm diameter) wafer-scale substrates is demonstrated in Figures 2 and 3. Fig. 2 compares the deposition current distribution with only one of the three segments used. On a highly conductive substrate, the effect of each anode segment on the distribution of plating current density is distinctive. The maximum deposition current density appears near the center of the segment used. On a resistive substrate with a sheet resistance of 25 Ω (~5nm Cu seed layer), such control effects are still evident but significantly weaker due to the strong terminal effect. The distance between the anode shield and the wafer surface, d, also affect the current distribution. Smaller d results stronger control effect. The number of segments, width of each segment and height of each shield can also be adjusted for better control. The plating uniformity can thus be improved by controlling the input current on different anode segments. During the plating process, as copper is being deposited on the substrate, the wafer becomes more conductive and the effect of anode segments changes with time. Therefore, the configuration of current allocation among the segments may need to be adjusted during the plating process to better compensate the terminal effect. Fig. 3 shows the post-plating thickness profiles on a ~5nm Cu seed layer, with a fixed average deposition current density of i_{avg} = -5mA cm^{-2} for 150s. For a continuous anode with the same radius as the wafer, the post-plating thickness profile is very non-uniform, with more copper deposition near the wafer edge then the wafer center. By controlling the current allocation on the anode segments shown in Fig. 1, the plating uniformity is significantly improved.

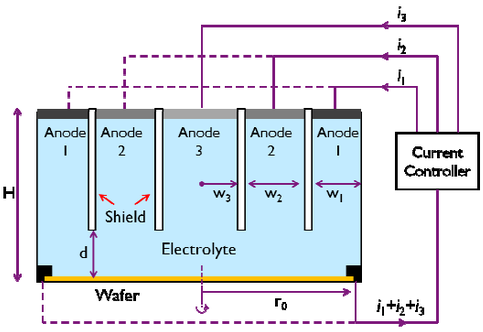

Fig. 1 Cross-section schematic of the plating chamber with segmented anode consists of three segments 1, 2 and 3.

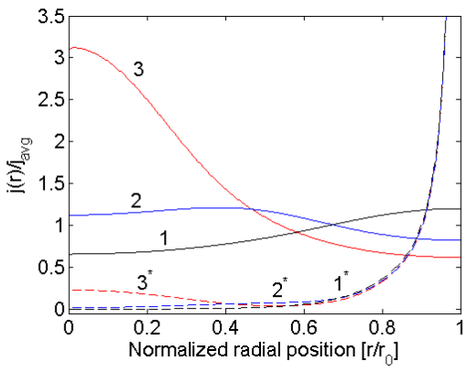

Fig. 2 Normalized current density for each anode segment shown in Fig. 1. Solid curves 1, 2 and 3 for an ideally conductive substrate, dashed curves 1*, 2*, 3* for an substrate with sheet resistance R_s=25Ω.

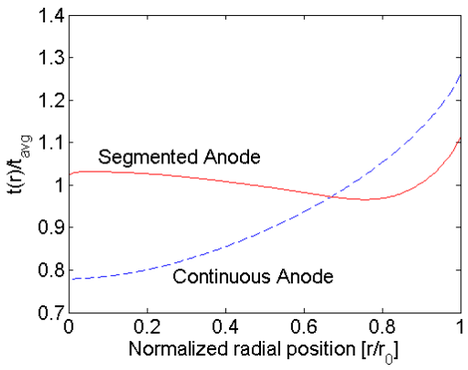

Fig. 3 Normalized deposition thickness after 150s deposition with i_{avg} = -5mA cm^{-2}. For the segmented anode, i_1:i_2:i_3 = 1:3:1 from 0s to 30s, 2:3:0 from 30s to 90s, 1:4:0 from 90s to 150s.

References:
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