Electrolytic Plating of Copper

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Abstract-- ReynoldsTech graciously donated a copper-electroplating tool to R.I.T., which speaks volumes and has far reaching potentials and challenges for, innovative research, patents and, incorporation of the damascene process into the thin film labs. Upon eventual integration into the classroom environment further designed experiments, process improvement and senior design projects, electroplating will eventually replace the existing aluminum metal layers with copper for the advanced 1.0µm and 0.5µm CMOS process currently used in the R.I.T. integrated circuit processing student run factory.

From a ground zero approach with safety issues in mind the ramping up of this new tool had to be installed, a comprehensive manual rewritten, copper sulfate and sulfuric acid electrolyte chemicals added, then characterized and tested to determine its unique capabilities and deposition rates. The experiment used for gathering data incorporated the use of Faraday's Law which states: "the amount of product formed is directly proportional to the charge passed" and "the mass of product formed is proportional to the electrochemical equivalent weight of the product." Following in these footsteps for the theoretical values the ampere-minutes were varied and mass calculated and then compared against the actual mass values by measuring the mass of the wafer before and after plating. An actual thickness was determined and compared against the theoretical values that Faraday calculated.

1. INTRODUCTION

With the introduction of the new Copper electroplating tool from ReynoldsTech into the R.I.T. cleanroom facility now a working reality. Integration into the classroom environment will be on the horizon. Students will learn and experiment that copper has a lower resistivity <2m µ-cm vs. Aluminum >3m µ-cm. Copper also has the following characteristics: a lower sidewall capacitance between adjacent lines, reduced RC time delay which leads to reduced power consumption. Copper also has superior resistance to electromigration, and the lines can be made smaller which equates to a tighter packing density, and the dual damascene process requires 20 – 30% less processing steps.

2. BACKGROUND

Much of the early research in electrochemistry was performed by Michael Faraday. It was he who coined the terms anode, cathode, electrode, and electrolyte.[1] In about circa 1833 – 1843, Faraday discovered that the amount of chemical change that occurs during electrolysis is directly proportional to the amount of electrical charge that is passed through an electrolysis cell. The reduction of copper ion at a cathode is given by the equation

$$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$$

The equation tells us that to deposit one mole of metallic copper requires two moles of electrons. The half-reaction for an oxidation or reduction, therefore, relates the amount of chemical substance consumed or produced to the amount of electrons that the electric current must supply.

Following in footsteps of Michael Faraday and his law and Faraday's constant the following relationship can be derived to find the theoretical weight:

$$Mass\,Deposited = \frac{63.546\,g/mol \times (amps \times time)}{2 \times 96{,}500}$$

Then to relate the mass deposited into a thickness the following relationship was derived

$$Density\,of\,Copper = \frac{Mass\,Deposited}{Volume}$$

$$8.9\frac{g}{cm^3} = \frac{Mass\,Deposited}{\pi \cdot r^2 \cdot Thickness}$$

$$Thickness = \frac{Mass\,Deposited}{\pi \cdot r^2 \cdot 8.9}$$

where r = 4.13cm

The only two variables in the above formulas are amperage and time. Those two variables were varied via the plating control terminal (PCT) installed on the electroplating tool. The 100mm wafers were prepared with a sputtered adhesion layer of 1000 angstroms of Tantalum

and Copper seed followed with another 1000 angstroms with excellent adherence. The same was sputtered to 0.7μm trench patterned wafers.

3. RESULTS

The preliminary experiments to determine how the tool would react initially revealed bipolar behavior. This phenomenon occurs when the electronic resistance of the seed layer has become smaller than the electrochemical resistance thus under plating the wafer. Evidence of this is when the seed layer at the electrical connection dissolves in and around the exclusion zone, thus creating a bulls-eye effect and under plating the center of the wafer. This was due in part to the electrolytic solution seeping in and behind the wafer and corrupting most of the data when comparing it against theoretical values. A single O-ring was placed behind the wafer to create two seals, one between the stainless steel and copper seed electrical connection and one behind the wafer. This fix steadied the voltage and substantially increased plating thickness bringing the values of theoretical closer to actual with good uniformity.

In the figure 1 below is a plot of sheet resistance as a function of theoretical deposited weight. This plot shows that as the deposited weight is increased the sheet resistance decreases as expected.

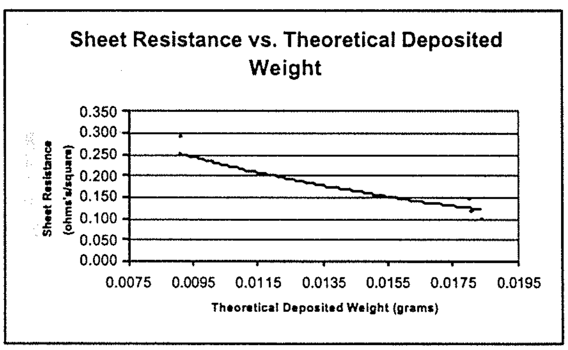


Figure 1

In figure 2 below is a plot comparing the theoretical to actual values for thickness vs. weight. The seven data points are the most recent, and this data represents how the electroplating reacted after the phenomenon of bipolar was concluded and a single O-ring was placed behind the wafer. For both of the graphs the conclusion is the bath concentration needs to be checked and continuously monitored. The bath has not been spiked for ~15 weeks since the volume of electrolytic solution consisting of: 38 liters of $CuSO_4$, 26 liters of H_2SO_4 and 72 Liters of H_2O was initially added.

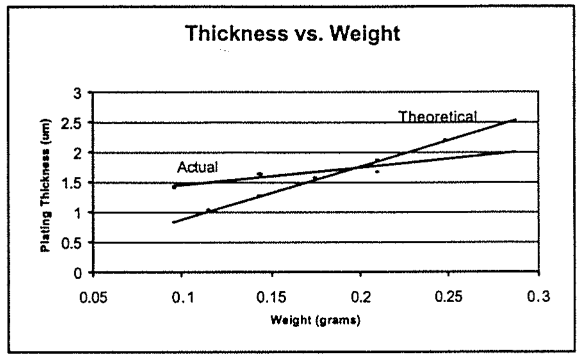


Figure 2

4. CONCLUSION

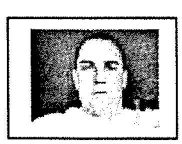
Copper is considered a fast diffuser and can act to "poison" a device in the active area so in taking the necessary logistic steps of isolating copper production a designated wet bench and cautious wafer process handling upgrades to the tool are being carried out. The comprehensive manual incorporates a further look into the various plating screens via the plating control terminal, a get started tutorial was added and a pulse mathematics section to determine and control the plating thickness. Working alone and with extensive tool knowledge a single operator can load the single wafer holder and throughput 6 wafers per hour depending upon the ampere – minutes but dual operator conditions would increase safety margins and shared workloads.

REFERENCES

[1] Brady and Holum, "Chemistry, The Study of Matter and Its changes", John Wiley & Sons, NY, p. 768, 1993.

ACKNOWLEDGMENTS

The author would like to acknowledge Mr. Scott Blondell, Mr. Richard Battaglia, Mr. Bruce Tolleson, Mr. Dave Yackoff for equipment support. Special thanks are due to Ms. Deepa Gazula for barrier and seed layer depositions. The author is grateful to Prof. Jorne of University of Rochester for guidance and to Dr. Santosh Kurinec for advising. The donation of the plating tool by Reynolds Tech is highly appreciated. The help provided by Veeco-CVC for resistivity mapping is acknowledged.



Keith M. Udut, originally from Lewiston, NY received B.S in Microelectronic Engineering from Rochester Institute of Technology in 2001. He attained co-op work experience at IBM. He is joining IBM as an equipment engineer starting June 2001.