Experimental study on sheet resistivity and thickness measurement in Copper Electroplating

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ABSTRACT

Electroplated copper thin films have been extensively used for interconnections in semiconductor devices. In this paper, electroplating of copper has been investigated to study the dependency of plated film thickness, current efficiency and sheet resistivity on current density. Copper film is electroplated on gold seed layer for via filling using different current densities varying from 10mA/cm^2 to 70mA/cm^2 at constant temperature (40°C). Annealing analysis for plated thick film is done at 200°C for 30 minutes. Surface roughness reduces along with resistivity with annealing.

Keywords: Electroplating, Current density, Deposition rate, Sheet resistivity, Current efficiency

1. INTRODUCTION

Electroplating is an electro deposition process for producing a dense, uniform and adherent coating, usually of metal or alloys, upon a surface by the act of electric current [1]. The coating produced is usually for decorative and or protective purposes, or enhancing specific properties of the surface. The surface can be conductor, such as metal, or nonconductor, such as plastics. The core part of the electroplating process is the electrolytic cell (electroplating unit). In the electrolytic cell a current is passed through a bath containing electrolyte, the anode, and the cathode as shown in figure 1. In industrial production, pre-treatment and post treatment steps are usually needed [2].

Copper is the most common metal plated, exclusive of continuous strip plating [3]. Major uses of electroplated copper are plating on plastics, printed wiring boards, zinc die castings, automotive bumpers, rotogravure rolls, electro refining, and electroforming [4]. Electroplated Copper is playing a major role in the change from aluminum to copper in semiconductor technology.

Copper is excellent choice for an under plate, since it often covers minor imperfections in the base metal. It is relatively inert in most plating solutions of other common metals, it has very high plating efficiency, resulting in excellent coverage even on difficult to plate parts, and lastly, it is highly conductive, making it an excellent coating for printed wiring boards or as a coating on steel wire used to conduct electricity.

2. THEORY AND CALCULATIONS

Electro deposition or electrochemical deposition (of metals or alloys) involves the reduction of metal ions from electrolytes. At the cathode, electrons are supplied to cations, which migrate to the anode. In its simplest form, the reaction in aqueous medium at the cathode follows the equation:

$$Cu^{2+} + 2e \rightarrow Cu \qquad (1)$$

Figur

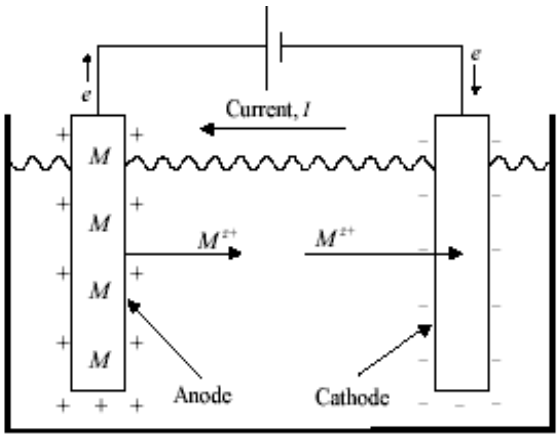

Figure 1 Electrodeposition cell

At the anode, electrons are supplied to the anions, which migrate to the anode. The anode material can be either a sacrificial anode or an inert anode. For the sacrificial anode, the anode reaction is:

$$Cu \rightarrow Cu^{2+} + 2e \qquad (2)$$

In this case, the electrode reaction is electro dissolution that continuously supplies the metal ions. Deposited Copper thickness calculated as [1]:

$$t = \frac{W}{A * d} \qquad (3)$$

Where, W= Weight of deposit, A = Area to be deposited, d = density of copper

The current efficiency CE of the *j*th process is defined as number of coulombs required for that reaction, Q_j, divided by the total number of coulombs passed, Q_{total} [5].

$$CE = \frac{Q_j}{Q_{total}} \qquad (4)$$

3. EXPERIMENTAL DETAILS

Here, we have successfully Electroplated Copper metal on gold base. Silicon substrate with gold seed layer of thickness 2000Å has been used as a substrate. Then the Copper was deposited on the gold layer by electroplating. The composition of the base electrolyte used for all plating test was 0.88M CuSO4.5H2O. The temperature of the plating solution was maintained at 40^0C. Area to be deposited was 70 mm^2. Electroplating time for all the samples was set to 20 min. With temperature and time constant for all the samples, current density was varied from 10mA/$cm^2$to 70mA/cm^2. The thickness of the electroplated copper was measured using surface profiler. Table 1 shows the experimental analysis of sample with current density variations.

Table 1 Experimental analysis

Test Sample	Current Density mA/cm^2	Q_{total}= I*t	Q_j	Theoretical Thickness, t_1(µm)	Actual Thickness, t_2 (µm)	CE
1	10	8.4	4	4.368	2.08	47.61
2	20	16.8	8	8.736	4.16	47.61
3	30	25.2	16	13.104	8.32	63.49
4	40	33.6	23	17.472	11.96	68.45
5	50	42	38	21.84	19.76	90.47
6	60	50.4	44	26.208	22.88	87.30
7	70	58.8	49	30.576	25.48	83.33

4. RESULT AND DISCUSSION

It was observed that with increase in current density, thickness of the deposit increases, as more number of copper ions gets reduced. Also, it was observed that current efficiency increases with current density up to certain current density and there after it starts decreasing as shown in table 1. The variation of theoretical and experimental electrodeposit thickness with respect to current density is shown in figure 2.

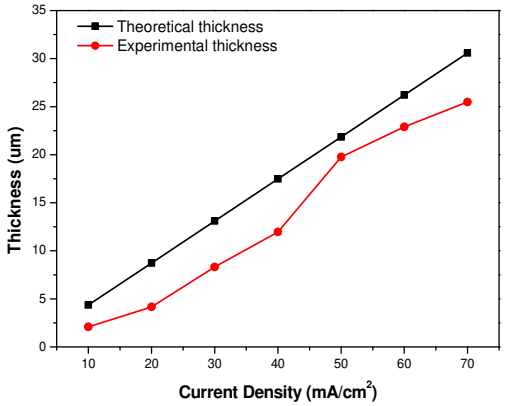

Figure 2 Thickness variations with current density

The SEM image of the samples was taken after electroplating, and it was observed that grain size increases with increase in current density. So, at higher rate more roughness was observed. To overcome this problem, we had done annealing on all the samples. Annealing was done at 200^0C for half an hour. It was interesting to note that along with roughness, sheet resistivity also gets reduced. Surface topographic variations and resistivity measurements with change in current densities were shown in Table 2. Experimentally extracted parameters were used for filling via cavity made of silicon. Figure 3 shows the SEM micrographs of silicon cavities and figure 4 shows cavity during Cu filling.

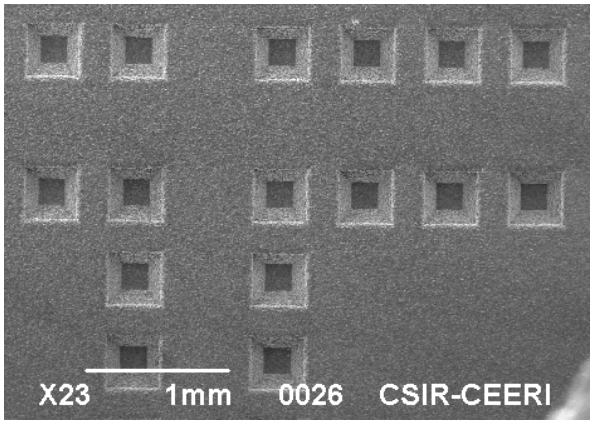

Figure 3 SEM micrographs of silicon cavities.

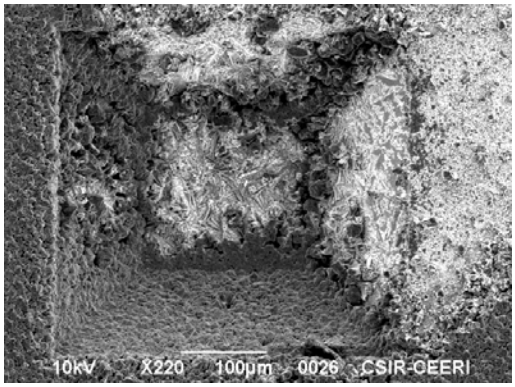

Figure 4 SEM micrographs of silicon cavity during Cu filling.

Table 2 SEM micrographs of the samples with resistivity

CD (m A/cm^2)	Surface Rougness (Before Annealing)	Sheet Resisance (Ω/□)	Surface Rougness (After Annealing)	Sheet Resistance (Ω/□)
10		$0.78*10^{-2}$		$0.431*10^{-2}$
20		$0.445*10^{-2}$		$0.268*10^{-2}$
30		$0.215*10^{-2}$		$0.194*10^{-2}$
40		$0.212*10^{-2}$		$0.931*10^{-3}$
50		$1.17*10^{-3}$		$0.786*10^{-3}$
60		$0.977*10^{-3}$		$0.591*10^{-3}$
70		$0.926*10^{-3}$		$0.336*10^{-3}$

CONCLUSIONS

It is concluded that the deposition rate as well as surface roughness increases while sheet resistivity decreases by increasing the current density during electro deposition. Thus, according to the need and purpose current density can be varied for getting suitable deposition rate and roughness.

For the purpose of via filling in through etched silicon cavity higher deposition rate (high current density) process is desired. But at higher rate more roughness was observed. To overcome this problem annealing was done. It is interesting to note that along with roughness, sheet resistivity also gets reduced which serve the purpose via filling.

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