A Review Of The Fundamentals Studies For The Electroplating Process

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ABSTRACT

In semiconductor industries, electroplating process have been widely used to manufacture integrated circuit (IC). Currently, in manufacture of lead frame, rubber masking is used as a selective plating method to cover the area not required to be plated in the electrolyte during electroplating process. The existing plating technique produced a plating area with tolerance due to the flexibility of the rubber. This tolerance becomes significant when a smaller plating area is required. Base on current situation, the IC product size is showing a reduction trend. Consequently, the plating area will also become smaller in the future. With the existing technique, the significant tolerance will cause to the rejection of customer. In order to overcome this problem, a new technique to produce tiny spot of plating area must be developed. In order to invent this new technique, fundamental aspects related to electroplating such as bath concentration, current density, agitation, bath temperatures, bath pH and the mass transfer rate (plating time) for the ions must be studied first. In this paper, a review of the effects of these fundamental aspects to the electroplating process is carried out to create more understanding on this process.

Keywords: Electroplating; Fundamentals studies; Operating parameters

1.0 INTRODUCTION

Electroplating is an electrochemical process of depositing a metallic coating on a substrate by passing a current through the liquid solution called an electrolyte or plating bath. In this process, the source of material to be deposited or the insoluble material will act as anode (positive terminal) and the substrate to be coated will act as cathode (negative terminal). The electrolyte is the medium that allows the metal ions to transfer when current is applied. Usually, the current is supplied through the DC power supply and the cyanide-based solution is used as electrolyte.

With the impressive progress and deeper understanding of the underlying electrochemical principles of electro-deposition, sophisticated plating baths formula have been developed and are being routinely employed. Those provide much greater control over the working characteristics of the deposition process than hitherto. Layer thickness, performance of electroplated finishes is among the attributes that have been brought under strict control. New developments enable greater plating speed, better throwing power (the ability of a plating solution to produce a relatively uniform distribution of metal upon a cathode of irregular shape), as well as a reliable plated finishes. In addition, electroplating of materials such as platinum, osmium and ruthenium are now broadly used in electronics for connectors, circuit boards, contacts etc. In future, many expect believes that new and innovative electroplating technology will facilitate the rapid expansion of the telecommunication industry. In general, the growth of the electronics industry as a whole, and the demand to support the expansion of its underlying infrastructure will continue to drive improvements in the electroplating industry [Schlesinger, 2002]. Thus, the further study of the fundamental aspects of the electroplating is needed in order to improve the existing plating solution performance.

In the electroplating process, the main objective of the process is to produce a uniform deposit on the metal to be coated. There are several parameters that influence the electroplating process and must be considered such as geometry of the bath, plating bath concentration, electrolyte movement, bath temperature, pH of plating bath, electro-deposition current and the cathode-anode separation [Lainer, 1970]. Thus, to produce a uniform coating with the good surface finishing, these parameters must be controlled properly. According to Lainer (1970), the crystallization process of electrodeposited metal is influenced not only by the composition and concentration of the electrolyte but also by the operating conditions such as current density, temperature, pH and agitation. The effect of current density on the structure of the electrodeposits is particularly high because it greatly changes the cathodic potential. A high current density has a beneficial influence on the structure of electrodeposited. However, hydrogen will also be produced at the cathode at high current density. Temperature and pH control are always desirable in plating operations because they affect the characteristics of plating solutions and/or the deposit. A high temperature usually permits current density to increase; this however does not always reduce the cathodic polarization. Agitation of plating solution is also usually helpful in influencing the structures of the metal. Although agitation causes the formation of course grained deposits, it permits the use of higher current densities. The intensity of agitation should vary directly with the current density if all other conditions are constant. Thickness of the electroplated layer on the substrate is determined by the time duration of the plating process. In other words the longer time the object remains in the operating bath the thicker the resulting electroplated will be. In this paper, the effect of these parameters to the electroplating process is reviewed.

2.0 THE INFLUENCE OF OPERATING PARAMETERS DURING ELECTROPLATING

2.1 Effect of Current Density and Distribution

The theoretical study of mass transport and current distribution in electrochemical has been carried out by several researchers such as Kohlschutter, Torrichelli, A.T. Vagramyan, Kasper, A.G. Samartsev , Wagner, Tobias, Wijsman, Heiling, Eisenberg, Tobias, Wilke, Levich, Klingert, Kardos and Lynn since 1932 [Lainer, 1970]. The basic principles governing mass and charge transfer in the electrochemical systems were presented in a unifying way by Newman, Selman, Tobias, Yeager, Bockris and Dossenbach [Datta & Landolt, 1999].

In the electroplating process, the sheer amount of material deposited on a cathode is practically not uniform and greatly influenced by the current distribution. In practice, the metal ions do not deposit as continuous sheets from one edge of the cathode to the other. In general, the metal ions are attached to the cathode at certain favored sites. This condition will possibly result to the presence of discontinuities in the form of pores, cracks or other irregularities. Thus, in electroplating, current density and its distribution play a centrally important role in determining the quality of the final deposit.

In the electroplating process, the current density over a cathode will vary from point to point. Current tends to concentrate at edges and protruding points. It tends to be low in recesses, vias and cavities because current tends to flow more readily to points nearer to the opposite electrode than to more distant points. This phenomenon sometimes can help in building deposits with uniform thicknesses. Therefore, in some cyanide metal baths (Cu or Zn), especially those with high cyanide: metal ratio, the CE drops as current density increase and this cause the thicknesses in regions of high current densities do not much exceed the average. On the other hand, sometimes the opposite is the case. For the example, in chromium plating baths, the cathodic CE increase with current density, resulting a great degree of nonuniformity of metal thickness. On small-scale profiles (such as in the case of printed circuitry), CE varies not only with current density but also with local variations of effective thickness of the diffusion layer. In cyanide-type baths these opposite influences tend to compensate each other.

In the electroplating process, cathode current density must be held within the proper interval with respect to bath composition and temperature. Insufficient current for given task will result in poor coverage of recesses/vias and low plating rate, while the presence of excessive current does not necessarily result in increased plating rate and is liable to create other difficulties. Low current densities tend to result higher impurity presence in the deposits. For the example, in Nickel-plating bath, low current densities produce high impurity content and this affects stress and other properties of the deposit. Table 1 shows the influence of current density in Nickel Sulfamate solution on impurity contents of deposits. However, excessively high current densities also produce dull or burned plate. The reason for this is that once over the limiting current density for good deposition, hydrogen discharge occurs. That in turn, increases the pH level at cathode and causing metal hydroxide to be included in the deposit. To summarize, the optimum current density range for given plating bath is depending on composition, operating conditions and the type of the plating sought.

Anode current densities are also an important plating parameter and should be controlled properly. This can be done through the adjustment of the total anode area and the proportion of it made up of the metal being deposited. The anode, plays two important roles in the plating operation: (1) helps to regulate the distribution of the current densities on the cathode by it physical location and geometry; and (2) to replenish the metal content of the bath as it is plated out.

In brief, deposited metal distribution depends on the shape and dimensions of the object, the geometry of the plating cell, the conductivity of the bath, the shape of the polarization curves, CE-current density curves and the effect of the agitation.

Current Density		Impurity Content (ppm)				
A/m^2	A/ft^2	C	H	O	N	S
54	5	70	10	44	8	30
323	30	80	3	28	8	8
538	50	60	4	32	8	6

Table 1: Influence of current density in Nickel Sulfamate solution on impurity contents of deposits [Milan Paunovic & Mordechay Schlesinger, 1998]

2.2 Effect of Temperature

An effective control of the deposition process operating temperature is vital for the consistent performance of any deposition bath. Deviations of more than 5°C from optimum temperature are sufficient to harm plate quality, deposition rate and other properties. Bath can usually be formulated and can operate satisfactorily at any given temperature within a relatively wide range (typically up to 60°C).

The advantages of higher temperature for the decorative coatings include higher plating rates, improved anode corrosion and the ability to operate more dilute baths without loss of performance. Figure 1 shows the effect of temperature on cathode efficiency. In general, the increase of temperature will increase performance of plating [Panouvic & Schlesinger, 1998].

Tan and Lim (2002) studied the uniformity of electro deposition. They found that the elevated temperature is one of the factors contributes to the uniformity of electro deposition.

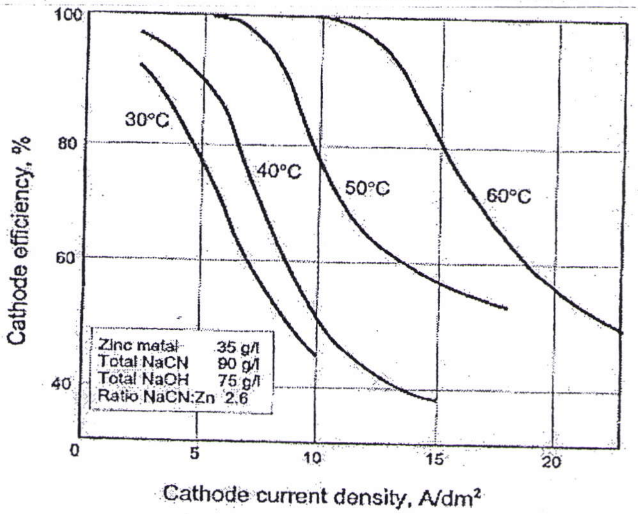

Figure 1: Effect of temperature on cathode efficiency
[Milan Paunovic & Mordechay Schlesinger, 1998]

2.3 Effect of pH

During electrolysis of aqueous solution, hydrogen ions are discharged together with the ions of the metal being deposited. The hydrogen evolved not only has a detrimental influence on the plating rate and on the cathodic current efficiency, but it often also unfavorably affects the structure and properties of the metal being deposited by causing spongy or powdery deposits, pitting or other defects. In the electroplating process, the metal of iron group or the metal with low hydrogen overvoltage are very sensitive to the concentration of hydrogen ions in the electrolyte; a change in the pH value considerably affects both the cathodic current efficiency and the structure of the electrodeposits [Lainer, 1970].

The pH value of the cathodic film is not always the same as that of the bulk of the electrolyte. The hydrogen ions take part in the electricity transport and also affect the changes taking place in the electrode film. The pH value of the cathodic film will in principle be higher than the bulk of the electrolyte if the number of hydrogen ions transported by the current is smaller than the number of the hydrogen ions discharged in unit time and vice versa. A change in the pH value of the cathodic film causes diffusion, which tends to equalize the activity of the hydrogen ions discharged in the bulk of the solution and in the cathodic film. The difference between the pH values of the cathodic film and the bulk solution, which tends to increase with the current density, either become stabilized or continues to increase, depending on the composition of the solution. [Lainer, 1970]

The studies on the variation of the pH value of the cathodic film in various electrolytes and at various temperature and various current densities was carried out by V.L. Kheifets, A.L. Rotinyan and T.M. Ovchinnikova [Lainer, 1970]. Effect of pH on the electrochemical deposition was study by Shen, Zhang & Li [Shen, Zhang & Li, 2001].

2.4 Effect of Agitation

In the electroplating process, agitation systems assures general solution uniformity as well as provide enough turbulence to prevent excessive ion depletion or gas accumulation at the anode and cathode surfaces. In other word, agitation provides sufficient mixing so that the chemicals reagent becomes intimate and reacts with each other. This factor influences the structure of the metal in the same way as an increase in the concentration of the metal, since it more rapidly compensates for the loss of the metal ions through discharge at the cathode. [Panouvic & Schlesinger, 1998]

In the plating process, although agitation sometime cause the formation of coarse-grained deposits due to the mechanical inclusion of sludge and other impurities suspended in the electrolyte, it permits to use at high current densities plating process. The intensity of agitation should vary proportionately with the current densities with all other conditions remain unchanged. To reduce the defect of coarse-grained cause by impurities in the electrolyte, agitation is often accompanied by filtration process. In the alloy electroplating, agitation promotes the deposition of the noble metal on the cathode. Vigorously agitated sulfate solution of zinc and cadmium (rotational speed of cathode = 13,000 rpm) yield deposits of pure cadmium even if its concentration in the solution is low [Lainer, 1970].

In brief, agitation system can greatly improve the plating performance since it provides sufficient mixing for the plating solution. However, this is true if the other parameters in the solution are controlled properly.

2.5 Effect of Bath Concentration

Generally, in the electroplating process, bath concentration playing an important role to the plating performance. In normal plating condition, the increase of bath concentration will increase the concentration of metal ions in solution. Therefore it will increase the deposition rate of the plating process. Table 3 shows the influence of copper concentration to the volumetric mass in plating process. From the table, it shows that the volumetric mass of copper will increase when the copper concentration increase. In others word, the higher copper concentration will cause higher copper deposition rate.

In the study of uniformity of electrodeposition by Tan and Lim (2002), bath concentration was found to contribute to the enhancement of current distribution uniformity when it assessed individually. In other word, it shows that bath concentration is one of the factors that contribute to the uniformity of the deposition.

Table 3:
The influence of copper concentration on volumetric mass. Cathodic current density: 8.6A/dm^2; Concentration of sulphuric acid: 150g/l; Temperature: 30°C; Plating time: 15 minutes. [Aurelian Calusaru, 1979]

Copper concentration, g/l	Volumetric mass, g/cm^3
5	0.420
10	0.663
15	0.723
20	0.776
25	0.870
30	1.060
35	1.419
40	2.040
45	2.440

2.6 Effect of Plating Time

In general, the plating thickness is increase proportionately to the plating time. According to the Faraday's Laws, quantity charge flow, Q in the solution is proportional to the current flow, I and also the flow time, t as show in equation below:

$$Q = I * t \tag{1}$$

$$\begin{aligned} m &= (Q / 96485.3415) * (M / b) \\ &= (I * t / 96485.3415) * (M / b) \end{aligned} \tag{2}$$

Where, m = Deposition weight; M = Atomic mass for metal; b = metal ion charge

From the equation, the mass of deposition is proportionately increased with the plating time t if the current density I and M / b are fixed.

The effect of plating time to the deposited weight for Zirconia deposit was studied by Zhitomirsky and Gal-Or [Dahotre & Sudarshan, 1999].

3.0 CONCLUSION

In conclusion, the parameters such as current density, temperature, agitation system, bath pH, bath concentration and also plating time playing very important roles in the performance of the plating quality. Thus, to achieve the high quality plating condition, these parameters must be studied properly. The understanding of these parameters is important to the plater and can help them to set the optimum condition for the plating operation. By achieving the optimum condition for the plating solution, it can improve the plating quality and reduce the production cost.

In general, high current density (below the limiting current density), high bath concentration, high bath temperature with the agitation is preferred to achieve the high cathode current efficiency. However, the detailed study must be carried out to get the optimum condition for these parameters. For the pH and plating time, there were no specify limitation but it is only depending on the type of solution used and regarded thickness in the process. However, the plating solution with alkaline base is most familiar since this type of solution has less effect caused by hydrogen evolution.

Several experiments were carried out by the researchers to study the effect of operating parameters in the electroplating process, such as Loshkarev, Gornostaleva and Kriukova have investigated the dependence of anodic and cathodic current efficiency on temperature, additives, current density and other electrolysis parameters for nickel powder deposition. Kuzmin and Motosova have studied the conditions of the deposition of alternate nickel and copper or zinc or iron layers. [Calusaru, 1979]. However, as the authors knowledge, there is no work has been carried out to study the fundamental aspects of silver-plating process and it is still open for research.

4.0 ACKNOWLEDGMENT

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