CHAPTER 1

INTRODUCTION

1.1 NANO PLATED MATERIALS

The nano plated materials are relatively new and the researchers have started exploring many potential benefits of these materials only for the past few years. The pulse plated materials find applications in several engineering domains such as all electronic components that make use of double sided and multilayered PCB, high efficiency gas turbines, aerospace technology and automotive components.

The improved hardness and strength coupled with better corrosion and wear resistance of nanocrystalline electrodeposits make them strong contenders for protective coating applications. Smaller grain size helps in high adhesion of materials.

A significant performance and power characteristics of circuits that make use of nano plating can lead to new applications. When any material is reduced to nanoscale dimensions, it reveals new properties that is desirable for extensive variety of tasks.

Nanomaterials have the structural features which stand in between of those of atoms and the bulk materials. While the most microstructured materials have similar properties to the corresponding bulk materials, the properties of materials with nanometer dimensions are significantly different
from those of atoms and bulks materials. This is mainly due to the nanometer size of the materials which render them: (i) large fraction of surface atoms; (ii) high surface energy; (iii) spatial confinement; (iv) reduced imperfections, which do not exist in the corresponding bulk materials (Guozhong 2004).

1.2 PRINTED CIRCUIT BOARD

Printed Circuit Board (PCB) is the heart of any electronic device. The use of miniaturization and sub miniaturization in electronic equipment design gave birth to a novel technique in inter component wiring and assembly. Printed Circuit Boards play a major role in today’s electronic industry. It is most frequently used in interconnection technology of components in electronic products. PCB industry is having rapid development. The line and space dimensions are decreasing and the number of hole diameters are also decreasing .PCB will have great functionality, density and cost effective processing. The printed circuit board provides both the physical structure for mounting and holding electronic components as well as electrical interconnection between them.

1.2.1 Types of Printed Circuit Board

There are three basic varieties of printed circuit board. They are

- Single-sided Printed Circuit Board
- Double-sided Printed Circuit Board
- Multi-layered Printed Circuit Board
1.2.1.1 Single sided printed circuit board

A single sided board is made from rigid laminate consisting of a woven glass epoxy base material clad with copper on one side of varying thickness. Figure 1.1 shows that the single-sided boards have the components on one side of the substrate.

When the number of components become too much for a single-sided board, a double-sided board is used.

![Figure 1.1 Single Sided Printed Circuit Board](image)

1.2.1.2 Double-sided printed circuit board

Double sided boards are made from the same type of base material clad with copper on two sides of varying thickness. Double sided board is of two types. They are non-plated through holes and another is plated through holes. In non-plated through holes there is no involvement of any metal for plating.
In plated through holes type PCB, metal is involved for connecting the top and bottom layer. Metal used is generally copper. Electrical connections between the circuits on each side are made by drilling holes through the substrate in appropriate locations and plating the inside of the holes with a conducting material. After plating, a combination of tin and lead alloy has to be applied for soldering. Figure 1.2 is double sided Printed circuit board that is done using plated through holes technique using copper for metallisation.

![Figure 1.2 Double-sided Printed Circuit Board](image)

**Figure 1.2 Double-sided Printed Circuit Board**

### 1.2.1.3 Multi-layered printed circuit board

The third type, a multi-layered board, has a substrate made up of layers of printed circuits separated by layers of insulation. The components on the surface connect through plated holes drilled down to the appropriate circuit layer. Figure 1.3 shows multilayered PCB with several layers and densely packed components.
Multi-layer boards are made from the same base material with copper foil on the top & bottom and one or more “inner layer”cores. The number of “layers”corresponds to the number of copper foil layers.

![Multi-layered Printed Circuit Board](image)

**Figure 1.3 Multi-layered Printed Circuit Board**

In this research Double sided printed circuit board is concentrated. The spatial, density requirement, and the circuit complexity determine the type of board produced. The conductive circuit in conventional type is copper. Here Silver is used for conduction. The complexity and density of components means much equipment has to use both sides of the PCB. Better products are developed with this plated-through-holes Technique of double sided PCB.

### 1.3 SILVER PLATING

Silver was found in 3400 B.C in Egypt. Silver is a white, lustrous metal which is extremely malleable and ductile. It is found in native. Its sources are ores of copper, copper-nickel, lead and lead-zinc. It has highest thermal conductivity and lowest electrical resistivity at normal temperatures. Silver is the only metal with which copper forms a simple eutectic between two well defined solutions. The fact that the eutectic is between two terminal
solid solutions, each having very similar properties is largely responsible for it. The factors determining the uses of silver are its beautiful white colour and its resistance to corrosion. Silver is a metal which has 7% higher conductivity than copper. Silver is the first metal to be electrodeposited commercially. It is applied for high frequency components in order to give high surface conductivity and enable higher efficiency.

**Table 1.1 Properties of Silver (Ag) and Copper (Cu)**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Silver</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Weight</td>
<td>107.8682</td>
<td>63.54</td>
</tr>
<tr>
<td>Density</td>
<td>10.49 gm/cm³</td>
<td>8.94 g·cm⁻³</td>
</tr>
<tr>
<td>Melting Point</td>
<td>961.78°C, 1763.2 °F</td>
<td>1084.62 °C, 1984.32 °F</td>
</tr>
<tr>
<td>Boiling point</td>
<td>2162 °C, 3924 °F</td>
<td>2562 °C, 4643 °F</td>
</tr>
<tr>
<td>Electrical Resistivity</td>
<td>15.87 nO·m</td>
<td>16.78 nO·m</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>429 W·m⁻¹·K⁻¹</td>
<td>401 W·m⁻¹·K⁻¹</td>
</tr>
<tr>
<td>Molar heat capacity</td>
<td>25.350 J·mol⁻¹·K⁻¹</td>
<td>24.440 J·mol⁻¹·K⁻¹</td>
</tr>
</tbody>
</table>

The comparison table 1.1 between copper and silver states that Electrical resistivity is low for silver. The conductivity is high for silver. Conductivity is an important characteristic of silver which is supporting silver to be used as plating element in the case of PCB. Observation shows that density is also high for silver when it is compared to copper.

Silver plating is the process of deposition of silver onto other metal or substrate. On deposition, the metal starts to acquire the characteristics of silver and its conductivity and reflectivity increases. The plating solution for silver is double cyanide of potassium and silver. Silver can be electroplated
only with such poisonous solutions. When other solutions are used for plating it does not give uniform plating and they are unstable also.

The creation of circuit patterns on PCB is accomplished by using subtractive methods. In subtractive method the entire surface of the substrate is first plated, and then the areas that are not part of the desired pattern are etched away. The conductive circuit is generally copper whereas here silver is used for the purpose of plating. The development of PCB industry has increased the circuit densities. The task of the plating department is to obtain high quality plated products especially by increasing the performance of the product. In more recent times it has been discovered that through controlling the grain size and microstructure, metals can be strengthened and hardened with little or no loss of ductility.

In PCB industry Direct Current (DC) plating is the most widely used technique. DC currents will be used to deposit copper on the substrate. The phenomenon of non-even copper distribution in holes is called “Dogboning”. Here pulse plating technology is used. Pulse plating is similar to DC plating but it has a square wave current. When the square wave is reversed it is called as Pulse Reverse plating.

The amount of silver deposited on the PCB should be controlled and that after attaining the amount of thickness required plating should be stopped. This correct calculation can be attained only on deposition of metals using electrochemical deposition (ECD). ECD requires an electrolyte. The electrolyte must fulfil a number of demands specific for the silver metal involved.
1. Potassium salts of the metal is dissolved in the electrolyte, at a temperature of 32 degrees and in sufficient concentrations.

2. The electrolyte is relatively good electrical conductor in order to get an even distribution of the material and to avoid extensive heating of the bath.

3. The PH-value of the bath is 11.76 and the concentration of complexing agents should be kept within a certain range so that reduction of the metal occurs before reduction of hydrogen.

As the size of the holes on the printed circuit boards is decreased and the thickness of the boards is increased, it is difficult to deposit enough silver in the holes. Using pulse reversal plating it is possible to improve the material distribution in high current density regions during the anodic periods. Under increasing requirements of industry (especially automotive) to reduce coating thickness and to prolong the service life of a coated material, the corrosion resistance has to be increased.

1.4 INTRODUCTION TO PCB MARKET

PCB market is a wide and fast growing market. Table 1.2 shows that every market is affected by Recession and it affects the Printed Circuit Market also. In the year 2010 only country that survived the recession is china. It also shows that there is steady growth in GDP of all countries in the world.
Table 1.2  Gross Domestic Product (GDP) Growth of Various Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>2.0</td>
<td>-2.1</td>
<td>2.9</td>
<td>3.2</td>
<td>3.8</td>
</tr>
<tr>
<td>USA</td>
<td>0.4</td>
<td>-2.5</td>
<td>2.8</td>
<td>3.0</td>
<td>3.9</td>
</tr>
<tr>
<td>EU</td>
<td>0.7</td>
<td>-3.9</td>
<td>1.0</td>
<td>1.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Japan</td>
<td>-0.7</td>
<td>-5.7</td>
<td>1.5</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Four Tigers</td>
<td>1.7</td>
<td>-1.8</td>
<td>4.2</td>
<td>4.3</td>
<td>4.5</td>
</tr>
<tr>
<td>China</td>
<td>9.0</td>
<td>8.2</td>
<td>8.9</td>
<td>8.5</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Source: N.T. Information Ltd

Figure 1.4 Graph Showing the World Electronic Equipment by Type
It is observed from Figure 1.4 there is a good growth rate for the
Electronic equipment. The production in every sector is increasing. As the
demand for Electronic equipment grows so does the production of printed
Circuit Board.

Table 1.3 World PCB demand/Product Consumption by Category

<table>
<thead>
<tr>
<th>Category</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business products</td>
<td>1110</td>
<td>1015</td>
<td>1060</td>
<td>1160</td>
<td>1270</td>
<td>1350</td>
</tr>
<tr>
<td>Communication</td>
<td>12110</td>
<td>10550</td>
<td>11625</td>
<td>12400</td>
<td>13800</td>
<td>15100</td>
</tr>
<tr>
<td>Consumer Electronics</td>
<td>6559</td>
<td>6335</td>
<td>6950</td>
<td>7450</td>
<td>8320</td>
<td>8595</td>
</tr>
<tr>
<td>Automotive Electronics</td>
<td>2920</td>
<td>2800</td>
<td>3065</td>
<td>3260</td>
<td>3750</td>
<td>4250</td>
</tr>
<tr>
<td>Computer</td>
<td>15300</td>
<td>13055</td>
<td>13685</td>
<td>15100</td>
<td>15960</td>
<td>16850</td>
</tr>
<tr>
<td>Military</td>
<td>2080</td>
<td>2175</td>
<td>2290</td>
<td>2370</td>
<td>2500</td>
<td>2640</td>
</tr>
<tr>
<td>Industry</td>
<td>5450</td>
<td>4495</td>
<td>4780</td>
<td>5235</td>
<td>5530</td>
<td>5770</td>
</tr>
<tr>
<td>Medical</td>
<td>4310</td>
<td>3965</td>
<td>4280</td>
<td>5235</td>
<td>5530</td>
<td>5770</td>
</tr>
<tr>
<td>Total PCB Count</td>
<td>49839</td>
<td>44390</td>
<td>47735</td>
<td>51525</td>
<td>55950</td>
<td>59655</td>
</tr>
</tbody>
</table>

Source: Electronic Outlook Corporation

As shown in table 1.3 there is an increasing growth in the
production of PCB especially in Computer and Communication purposes. 70% of mobiles make use of double sided PCB.
Table 1.4 Mass produced products (Million Units)

<table>
<thead>
<tr>
<th>Category</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Camera</td>
<td>135</td>
<td>140</td>
<td>135</td>
<td>145</td>
</tr>
<tr>
<td>Digital Camcoder</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>DVD Recorder</td>
<td>25</td>
<td>31</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>Digital Audio Player</td>
<td>170</td>
<td>180</td>
<td>175</td>
<td>185</td>
</tr>
<tr>
<td>Personal Navigation</td>
<td>27</td>
<td>32</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td>TV</td>
<td>194</td>
<td>235</td>
<td>220</td>
<td>293</td>
</tr>
<tr>
<td>PC</td>
<td>269</td>
<td>291</td>
<td>306</td>
<td>335</td>
</tr>
<tr>
<td>MOBILE</td>
<td>1141</td>
<td>1181</td>
<td>1220</td>
<td>1350</td>
</tr>
</tbody>
</table>

Source: Electronic outlook corporation

Table 1.4 shows that mobile is the majorly produced electronic component. Mobile is an equipment that should work at various temperature. Most of the mobiles in India does not work when it is exposed to water. One of the main reason is corrosion. Corrosion is high when copper is used for metallization of PCB. Corrosion is considerably reduced when silver is used for metallization. It is also observed that in India 92% of mobile chargers also make use of double sided PCB.

1.5 OVERVIEW OF PULSE PLATING

Pulse plating technology has been commercialized in the 1980s. Pulse plating technique has higher investment cost due to the rectifier compared to DC plating. Pulse plating is the method used for printed circuit board. In double sided PCB copper is a material used for plating. Here silver is used for plating inside the holes of double sided PCB. Pulse plating is used because it produces nano grain when plated. In conventional DC plating the grain obtained is in the size of micro meters. There are many good reasons for finding this change in the deposition of PCB. Nano grain by its nature is
very small in size of the order $10^{-9}$. Here grain sizes of the order less than 40 nm is obtained.

By scaling down the grain size, many advantages are observed. There is an increase in adhesion of the plated material on to the substrate, increase in hardness, current efficiency and high smoothness. Plating process is faster. It also has high production rates. The idea of pulse plating with silver on PCB can revolutionise many electronic products from its size to efficiency. The only disadvantage of pulse plating is that the pulse rectifier is a costlier equipment.

In the conventional direct current electro deposition, there is only one parameter namely the current density, which can be varied. However, in pulse methods there are three important variables: peak current density, current ‘ON’ time and current ‘OFF’ time. When all the three variables are used to control the grain size deposited on the PCB, it results to better PCB with great efficiency.

1.6 OVERVIEW OF PULSE REVERSE PLATING

Pulse reverse Current is similar to Pulse plating but the current is in negative direction. In pulse reverse current there are five variables available that can be controlled. When the controlling parameters increase it is possible to obtain plating of desired characteristics. A diffusion layer is formed due to plating. The reverse pulse current leads to uniform distribution of the metal due to the mass transport effect. When the pulse is relaxed after every pause it helps to improve the deposit characteristics of the metal. The reverse pulse improves the throwing power and improves the uniformity of metal. Pulse reverse plating reduces the surface thickness and also leads to smoother deposit inside the holes of PCB.
The response of the current density is an important index in determining the characteristic of coating done on PCB using reverse current. Pulse reverse plating is used for wide variety of applications namely micro electro mechanical systems used for sensor, optical device and advanced packing systems.

Pulse reverse plating is used to address the mass distribution problem. It is necessary to understand the influence of current density on mass distribution. If mass-transport effects are ignored, the local current density is determined by the Ohmic resistance in the electrolyte and the resistance associated with the deposition process at the observed point on the cathode surface. The lower the current density, the more limiting the electrochemical reaction at the cathode will be. If the current density is high, the mass distribution is determined from the resistance in the electrolyte and therefore by the geometry of the sample and the plating cell. As a consequence, the plating rate is normally higher along the boundary of the structures at high currents and a uniform mass distribution is achieved by plating at low current density. Investigation shows that a decreased plating rate near the edges for low current density. Thus, the uniformity is expected to be improved by application of higher current density.

1.7 APPLICATION OF PULSE PLATING AND REVERSE PLATING TECHNIQUE

There are variety of industries that make use of pulse plating and reverse plating technology.

1. Automobile Industry

Chromium plating is required for car parts. Wheel rims also require chromium plating.
2. **Electronics Industry**

Nickel plating is required for Electronic components. Copper plating is used in Printed Circuit Boards. Copper plating is required in motors, generators and transformers. Silver plating is done on wires and printed circuit boards.

3. **Medical Application**

Gold and Silver Plating is used in dentistry. Monitoring equipments require silver plating.

4. **Consumer Products**

Chromium can be used for bath taps and kitchen gas Burners. Silver plating is used in Jewellery. Gold Plating can be done in case of ornaments. Copper plating is used in Air conditioning and Refrigeration.

5. **Space craft applications**

Pulse reverse plating plays a major role in space industry. When PCB is designed to work in Radio frequency, a highly efficient PCB with an ability to work at any temperature can be designed using silver.

6. **Military Applications**

Heavy vehicles can be plated using pulse reverse plating. Wear and tear is less in the case of pulse plating.

7. **Others**

Silver and gold plating can be done to medals received in sports.
1.8 ORGANISATION OF THESIS

Chapter 1 This chapter discuss the basic terms and types of printed circuit board

Chapter 2 It presents the literature survey of pulse plating and pulse reverse plating techniques.

Chapter 3 It discuss about the procedure for working using OrCAD and the analytical model for the bath and Direct current plating method.

Chapter 4 Discuss the experimental method involved using pulse plating and the results obtained for current efficiency and hardness.

Chapter 5 Presents the experimental method and discuss the pulse reverse plating and its results on current efficiency and hardness.

Chapter 6 Presents the final conclusion and comparison between pulse plating and pulse reverse plating for the parameters current efficiency, hardness and corrosion.