Effects of Current Density on Surface Morphology and Coating Thickness of Nickel Plating on Copper Surface

Canute Sherwin [a], Suma Bhat [b], Sudheendra P Hebbar[c]

[a,b] Dept. of Mechanical Engineeering St Joseph Enineering College Mangalore, India
[c] Dept. of Mechanical Engineeering St Joseph Enineering College, Mangalore, India
[a]sherwin_canute@rediffmail.com, [b] sumabhat01@gmail.com, [c] sudheendrahebbar@gmail.com

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Abstract: Nickel (Ni) thin film was deposited on commercial pure copper using electrodeposition method. To understand the growth behavior of Ni nodules, deposition was done by varying the coating current density. The topography of coating was analyzed using Scanning Electron Microscope (SEM). The coatings were also analyzed for variation in amount of coating, cathode current efficiency and thickness of coating. The deposited Ni thin film was observed to be of coffee bean kind of secondary nodules with size varying from 400 to 800 nm and almost spherical primary nodules with size varying from 100 to 250 nm varying as a function of coating current density. At higher current density, the coatings were observed to be of multiple layers of nodules. This suggests the presence of defects like twins, dislocations and stacking faults. The nodules are observed to have fine crystallites in the nano range.

Keywords: nickel, copper, electrodeposition, scanning electron microscope

1. Introduction

Nickel is a noble metal and coating a base meal like steel or copper with Ni will result in an economic alternative for many industrial applications. Nickel as a coating material is being used from a long period of time because of its properties like good high and low temperature strength, high oxidation resistance and corrosion resistant. Nickel electroplating experienced an important historical development in the year 1916 with Watt's developing his formulation which is known as 'Watts bath' till date. This solution developed by Watt's increased the plating current density from around 0.5 A/dm2 to 40 A/dm2 [1-2]. Nickel plating for engineering purposes are usually from solutions that deposits pure nickel. The most important property in engineering end uses is, generally corrosion resistance, but wear resistance, solderability, and magnetic and other properties may be relevant in specific applications. Electroplating Ni on copper is employed in industries to achieve the above mentioned properties. Electrodeposition of Ni is observed to develop uniform size and shape grains of nano size with high density and least porosity [3 - 5]. From the literatures it is observed that nanocrystalline materials exhibit unique mechanical, physical and chemical properties. As a result, there has been considerable interest concerning the synthesis and applications of nanocrystalline materials. Recently, the synthesis of nanocrystalline nickel by electrodeposition has attracted much attention and researchers have produced nanocrystalline nickel with grain sizes in the range of 6–100 nm [6]. Electrodeposition is controlled by Faraday's law and by referring to the literatures it is observed that the amount of current supplied (Current Density) greatly affects the deposition process [7].

2. Experimental Procedure

Copper sheets are polished and buffed to give a mirror like finish. Nickel is deposited by electrochemical route using a DC power by varying the current. Pure Ni strip is used as anode and copper strip as cathode. After plating the samples are wiped gently with the help of a tissue and preserved in a desiccator. The plating parameters and electrolytic solution composition is represented in the table 1.

Table 1: Electrolytic Solution Composition And Plating Parameters

Chemical Name	**Composition**
Nickel Sulfate (NiSO4.6H20)	300 g/l
Nickel Chloride (NiCl2.6H20)	150 g/l
Boric Acid (H3BO3)	52 g/l
Operating Conditions	
Bath Temperature	30^0C

Type of Agitation	Air
Anode	Nickel
Cathode	Copper Strip
pH	3
Current Density	2-8 A/dm^2
Plating Time	10 minutes

During electrodeposition process Ni ions dissociate from nickel anode and get dissolved in the electrolyte. Ni ions from the electrolyte solution gets deposited on to copper cathode as Ni metal.

Anode Reaction:

$Ni = Ni^{2+} + 2e^-$ (1)

Cathode Reaction:

$Ni^{2+} + 2e^- = Ni$ (2)

3. Results And Discussion

Elemental Composition of the coated samples is performed using Energy Dispersive Spectroscopy (EDS). It is observed from the result that the average weight percentage of Ni in Ni plated sample is 84.45 %. Samples are weighed before and after coating. From this the variation of coating weight and current efficiency with respect to current density can be plotted.

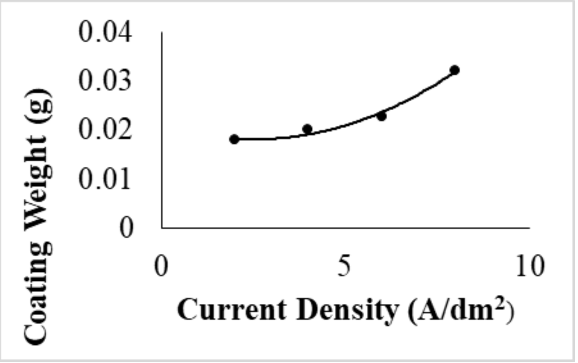


Fig. 1: Variation of coating weight with current density

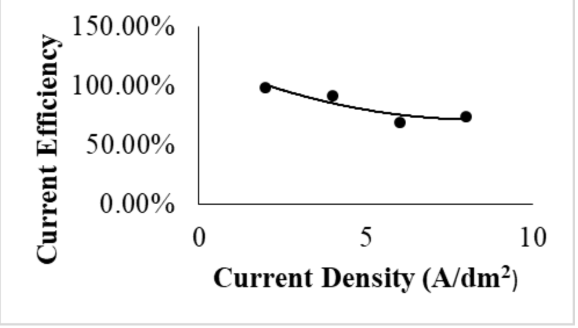


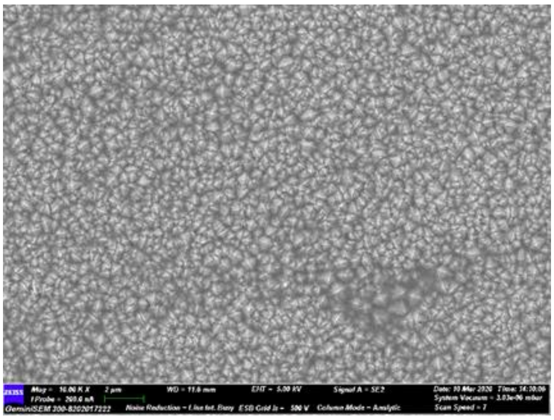
Fig. 2: Variation of Current Efficiency with Current Density

It is observed that if the current applied in the cell is increases, the amount of plated metal also increases in an almost directly proportional manner. This happens because increase in current leads to increased pumping of electrons to the cell. This leads to more reduction of ions and oxidation increasing the rate of electrodeposition. However the current efficiency reduces with the increase in current applied. This happens strongly due to the fact that there aren't enough Ni+ ions right at the cathode to match all the electrons you are pumping over it. This results in some electrons pulling H+ ions out of water, converting them to hydrogen gas, thereby reducing the current efficiency.

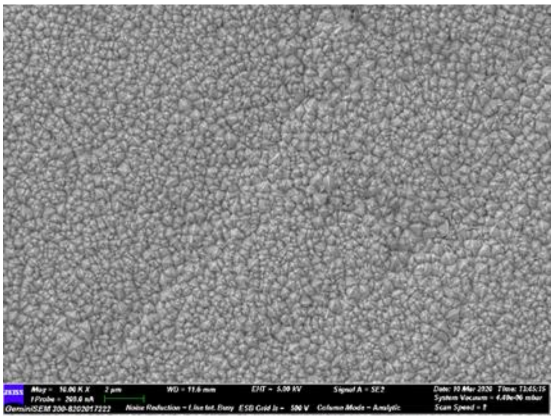
Thickness of Ni coating is calculated from Faraday's law. It is observed that the coating thickness almost increases linearly with increase in current density but the percentage increase in thickness showed a gradual dip at 8 A/dm2. This is related to the fact of greater reduction in cathode current efficiency at high current density.

Table 2: Variation Of Coating Thickness And Rate Of Deposition With Current Density

Current Density (A/dm2)	**Coating Thickness (μm)**	**Percentage Increase in Thickness (%)**	**Rate of Coating Deposition (μm/min)**
2	4.759	-	0.4759
4	5.7115	16.68	0.5712
6	8.5673	33.33	0.8567
8	11.4231	25	1.1423



a)



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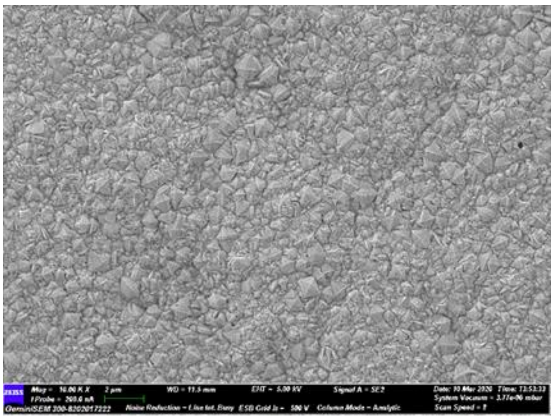

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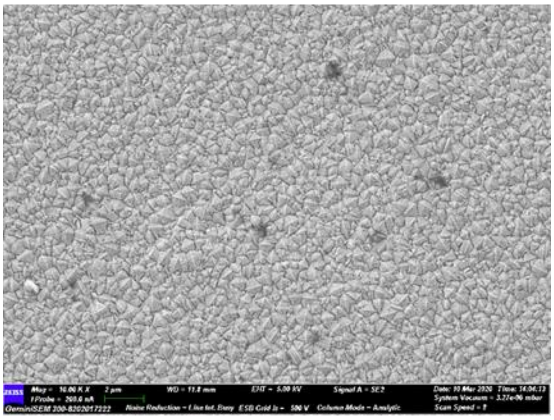
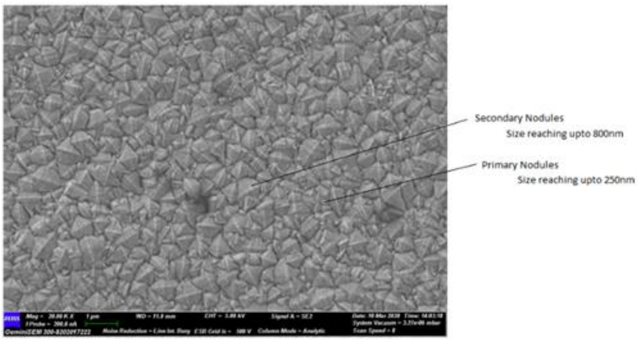


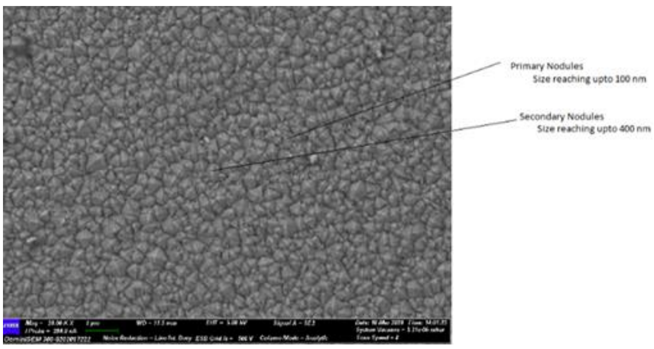
d)

Fig 3: Surface Morphology at 1000 X for a) 2 A/dm2 b) 4 A/dm2 c) 6 A/dm2 and d) 8 A/dm2

The coatings are observed to have nodular morphology showing nodular growth from the substrate surface. The primary nodules size in sample coated at 4 A/dm2 current density is observed to be smaller in size compared to sample coated at 2 A/dm2 indicating that the primary nodules size reduce with rise in current density. When the current density is less, nucleation is limited and the growth is limited. From the microstructure it is seen that for the sample coated at 2 A/dm2 there are some regions without any nucleation which will lead to porosity. Use of higher current densities will lead to liberation of Ni atoms from the bath at higher rate, leading to more nucleation at the surface. The nodules are observed to be in form of a coffee bean structure. For samples coated at 6 A/dm2 and 8 A/dm2 it is observed that above the fine layer of primary nodules there is a layer of course secondary nodules formed. The formation of coarse secondary nodules is a result of autocatalytic activity of the initially formed coating, whereas the base layer is due to nucleation. Hence as the current density increases, defected areas like crystalline boundary volume and twin boundary volume increases thereby increasing the amount of micro strain. For sample coated at 6 A/dm2 the coarse secondary nodules just start to be produced at specific locations. The intensity of secondary nodules increases for sample coated at 8 A/dm2.



a)



b)

Fig 4: Surface Morphology showing Primary and Secondary Nodules at a) 2 A/dm2 and b) 8 A/dm2 at 2000 X Magnification.

The above figures show the high magnification images of coated samples at 2 A/dm2 and 8 A/dm2 respectively. It is observed that there is almost 50% reduction in size of primary and secondary nodules for plated samples at 8 A/dm2 in comparison with samples plated at 2 A/dm2.

4. Conclusion

Nickel coatings were produced by direct current electrodeposition without using and additives. From the experimental investigations following conclusions can be drawn;

(1) The amount of Ni deposited increases almost linearly with rise in current density and the cathode current efficiency reduces almost linearly with current density.

(2) Coating thickness calculated from Faraday's law increases with increase in current density.

(3) SEM images indicate a good crack free deposition of Ni in the form of nodules with uniform surface morphology and deposition properties.

(4) The primary nodules reduce in size with rise in current density. At higher current density i.e at 6 A/dm2 and 8 A/dm2 secondary nodules layer starts developing predominantly over primary nodule layer showing the presence of defects like twins, dislocations and stacking faults.

(5) The microstructure study at high magnification shows that the secondary Ni nodules deposited is in the form of coffee bean kind of structure.

(6) At high magnifications images captured at the location containing both primary and secondary nodules for current densities 2 A/dm2 and 8 A/dm2 it is seen that there is almost 50 % reduction in size of these nodules for 8 A/dm2 in comparison with 2 A/dm2.

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