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MECHANICAL PROPERTIES OF NANOCRYSTALLINE PRODUCED BY ELECTRODEPOTION: AN REVIEW

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ABSTRACT

Electrodeposition of nanocrystalline is a technologically viable production route to synthesize alloys and metal matrix composites both in bulk from and as coating. Particle concentration in plating bath strongly affects the particle content in the composites produced. The presence of particles in composites changes their characteristics, making them better or worse with respect to tensile strength, hardness or surface texture. With decreasing grain size, the hardness materials initially increase following the regular Hall-Petch relationship.

Key Words: Electrodeposition,nanocrystalline, production route, alloys, tensile strength

1. INTRODUCTION

Nanocrystalline materials are of significant technological importance because they offer interesting properties, which cannot be obtained from conventional crystalline solids. Properties altered by grain size include increase hardness, wear resistance, corrosion, magnetic behavior, and even low-temperature ductility in some ceramics. In recent years, enhancing properties of magnetic materials by nano-processing techniques has been the focus of many studies which have dealt with magnetic materials in different configurations such as thin films, compositionally modulated thin films, granular films and bulk form (Cheung. et a1, 1995). More and more researchers realize that the control of materials structure on nanometer scale is the key to unique properties. Many synthesis techniques for the production of these materials have been developed. These include gas-condensations, ball-milling, sol-gel techniques, spark erosion, electrochemical deposition, etc..

U.Erb (1995) over the past 10 years has been concerned with electrochemical production methods. The techniques applied in their laboratory to synthesize nanocrystalline structures include conventional DC electroplating, pulse-current deposition, autocatalytic plating as well as co-deposition processes to produce nano-composite materials. Electrodeposition has many advantages over other nano-processing techniques including 1) the potentially very large number of pure metals, alloys and composite materials which can be electroplated with grain sizes less than 100 nm, 2) few shape and size limitations, 3) high production rates, 4) low initial capital investment requirements and 5) easy technology transfer from research laboratory to existing infrastructure in electroplating and electroforming industries. Over the past few years, the electrochemical processing for a number of pure metals, binary and ternary alloys as well as nanostructure metal matrix composites have been identified (Erb U, 1995). These materials can be deposited as thin films.

Fundamentally, electrodeposition yields grain sizes in the nanocrystalline range when the electrodeposition variables examples bath composition, pH, temperature, current density, etc. are chosen such that nucleation of new grains is favored rather than the growth of existing grains.

The objectives of this paper are to review the microstructure and microhardness of nanocrystalline produced by electrodeposition.

Microstructure

The codeposition of inert, semiconductive and conductive particle in copper coatings on metal substrate has reported (Stankovic et al, 1996). The electrolyte used in his study was an acid copper sulphate system, containing α-Al_2O_3, SiC, MoS_2, and graphite particles. It was shown that the increase in the particle content in coatings with increasing current density appears in the region where the reduction of metal ions occurs under charge transfer control and where the reduction of adsorbed cations onto the alumina particles is the rate-determining step. The codepotion process also depends on the particle concentration in the bath. Increased concentration of alumina particles in the electrolyte corresponds to increased particle content in the composite. The NiFe alloy is a good candidate for magnetic sensing applications due to its high magnetic permeability. Recently, much attention has been paid to the study of nanocrystalline

nickel-iron alloy due to their interesting mechanical and magnetic properties (Li H. et al, 2003). C. Cheung (1995) reported that iron content of the binary Ni-Fe electrodeposits as a function of the Ni^{2+} to Fe^{2+} ion ratio in the solution. At the highest Ni:Fe ratio of 50, the electrodeposits contain less 5 % iron. With decreasing Ni:Fe ratio, the iron content in the deposits increase rapidly leading to an alloy of approximately 72 % Ni - 28% Fe at the lowest Ni:Fe ratio of 7.5. The surface morphology of the electrodeposits is generally very smooth, for a deposit with a composition of 80 %Ni-20 %Fe.

In 2003, Hongqi Li and Fereshteh Ebrahmi reported that when Fe content was decreased to below 21%, the grain size increased very rapidly. However, the grain size remained approximately constant (~ 11 nm) for electrodeposited fcc alloys with iron content in the range from 21 to 51 %. When the Fe content was increased to about 69% (Li H. et al, 2003) and about 65% (Trudeau, 1999), the crystal structure of the alloy changed from face-centered cubic (fcc) to a mixture of body-centered cubic (bcc) and fcc. The change in structure resulted in a decrease in the grain size as well. Thus, for Ni-Fe-Co alloys, a mixture of fcc + bcc crystals would have a finer grain size than either bcc or fcc deposits. With most of the other parameters equals, plating at room temperature seems to lead more to the formation of bcc (high iron) alloys, while electrodeposition at temperature around 50 ^oC lead to the formation of the fcc phase (Trudeau, 1999).

The electrodeposition of Ni-Fe alloys has been investigated by several researchers and has been shown that the composition and grain size of the deposits can varied by controlling the deposition parameters. Nickel-iron FCC alloys with different composition were fabricated on annealed and cool-worked copper substrate using galvanostatic electrodeposition technique (Li H. et al, 2003). Changing the Ni/Fe ion ratio in the electrolyte varied the results of these studies led to the composition of the deposits.

Microhardness

The microhardness of the composite show the presence of particles exhibits two opposite effects. Hard particles involve a certain increase in microhardness while soft particles such as MoS_2, $BaSO_4$ or C incorporated into metal matrix have an opposite effects (Stankovic. et al, 1996). They also reported that the tensile strength of the Cu-Al_2O_3 composites increasing alumina particles content in the composite up to about 2 % by weight. Further increases in the particles content in the composite do not affect the tensile strength significantly. The presence of SiC particles in a small amount (less than 2% by weight) causes an increase the tensile strength of the Cu-SiC, similarly to the composite coating containing alumina particles. So particle content in the composite strongly influences the tensile strength.

The hardness of conventional polycrystalline nickel is 85 VHN. As the iron content increases, the hardness essentially remains constant up to an iron content of 51 wt. %. On the other hand (Cheung. et al, 1995), the hardness of the electrodeposited nickel is 490 VHN at grain size 21 nm. With increasing iron content, the hardness increases to about 625 VHN at grain size 14 nm and at an iron content 16.5 wt. %. At even higher iron contents, the hardness decrease again to about 580 VHN for the deposits containing 28 wt.%. Moreover, hardness depends on current density. Increase in current density,i.e. excess energy of cation reaching cathode, was accompanied by a higher hardness. An extremely high hardness for the substitution solid solution of Ni in αFe suggests the strengthening by small grain size.

The hardness of nanocrystalline materials has been the subject of numerous recent studies with particular reference to the validity of the Hall-Petch relationship for materials having very small grain sizes. The hardness decreases with further decrease in grain size leading to an inverse Hall-Petch behavior. Although the transition from regular to inverse Hall-Petch behavior at very small grain sizes is presently a controversial issue, some researchers have reported regular Hall-Petch behavior down to smallest grain size (Stankovic. et al, 1996).

Others observed a transition after reaching a maximum hardness similar to the one found in this study. This phenomenon is presently not fully understood, a number of theories considering different contributing factors to the softening observed at very small grain sizes have been proposed.

CONCLUSION

The results of this study led to the following conclusions.

1. The amount of particles incorporated in coatings during the electroplating process depends on the particles type, their concentration in a bath, an applied current density.
2. The grain size of materials decrease with increasing iron content in the deposit.
3. The deviation from regular Hall-Petch behavior was found to coincide with the onset of microtexture.
4. Microhardness is higher in composites containing hard particles while soft particles give softer coatings.
5. The increasing grain size, the microhardness shows a transition from regular to inverse Hall-Petch behavior.

In order to achieve nanocrytalline structure in electrodeposited, a literature review was carried out to investigate the factors affecting microstructure and microhardness.

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