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The effects of the pulse parameters (pulse waveform, pulse frequency and average current density) on the deposit structure and properties of these three systems have been investigated. Pulses have been defined based on the results of electrochemical measurements and numerical process simulation. The surface morphology, microstructure and microhardness of the deposit have been correlated to the pulse parameters applied.

The experimental results showed that applying pulse plating substantially altered the properties of the coatings. The resulting layers exhibited a nano-crystalline microstructure, improved layer compactness and hardness of the nickel-based alloy deposits.

Keywords: pulse plating, nickel alloy, tin-nickel, nickel-cobalt, nickel tungsten, microstructure

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1. Introduction

With increasing demands on multifunctionality of galvanic layers, e.g. excellent corrosion resistance combined with wear resistance and decorative appearance, the transition from a single metal layer towards metal alloy layers becomes more and more important. Additionally environmental concerns encourage the substitution of toxic electrolyte systems such as hexavalent chromium as been used for hard chromium coatings by non-toxic galvanic systems. Besides alloys such as NiCo [1-2], providing hardness as well as an increased corrosion resistance, the nickel-tungsten system

has been suggested as a possible substitute for hard chromium coatings [3]. Ni-W is quite corrosion resistant and significantly harder, providing more tensile strength than pure nickel deposits and therefore could be an alternative for high wear resistance coatings. The Ni-W alloy can also be used for electroforming applications. However, mainly due to the high level of residual stress, which causes a serious cracking problem in the deposits, the manufacturing of compact and well adherent Ni-W coatings using DC plating is still fraught with technical difficulties. The deposition mechanism of this alloy is special since tungsten cannot be electro-deposited as a

pure element from either aqueous solutions or organic electrolytes but is readily co-deposited together with iron group metals, following the mechanism of induced co-deposition and forming a stable alloy [4].

The electrodeposition of nickel-tin alloys has also gained importance over the last years and is widely used in the microelectronics industry in the packaging of semiconductor ICs due to the non-toxicity, excellent solderability and also corrosion resistance of tin [5-8].

From electrochemical point of view, in conventional DC plating there is only one parameter, namely current density (j), which can be varied. One of the advantages of pulse plating is an almost unlimited combination of different pulses with varying current densities in cathodic and anodic direction combined with pauses at different pulse frequencies [9-10]. It has been demonstrated that for pure single metal systems pulse plating offers the possibility to improve the microstructure and the functional properties of the electrodeposits by varying the pulse parameters [11-13].

Within this work a study of the effect of pulse plating on the properties of nickel-cobalt, tin-nickel and nickel-tungsten alloy deposits has been made. The change of crystalline size, structure

and hardness of the obtained coatings was set in relationship to the pulse parameters applied.

2. Experimental

Nickel-cobalt and tin-nickel alloy coatings were produced from a chloride-based electrolyte. Nickel-tungsten coatings were produced from a mixed sulfamate-citrate electrolyte. The basic electrolyte composition was selected as follows:

Tab. 1: Composition of the tested nickel-based alloy electrolytes

Concentration, g/l	Ni-Co	Sn-Ni	Ni-W
NiSO ₄ ·6H ₂ O	66	-	-
NiCl ₂ ·6H ₂ O	238	243	-
CoCl ₂ ·6H ₂ O	16	-	-
SnCl ₂ ·2H ₂ O	-	48	-
Additive (ml/l)	-	200	-
Ni(SO ₃ NH ₂) ₂	-	-	70.5
Na ₂ WO ₄ ·2H ₂ O	-	-	30
C ₆ H ₅ Na ₃ O ₇	-	-	90
H ₃ BO ₃	30	-	-
Na(CH ₃ COO)·3H ₂ O	23	-	-
C ₁₀ H ₅ (NaSO ₃) ₃	3	-	-

Tab. 2: Measured electrolyte properties

Parameter	NiCo	SnNi	NiW
Temperature	50°C	65°C	55°C
Conductivity	0.095 S/cm	0.185 S/cm	0.0432 S/cm
Density	8.9 g/cm ³	8.9 g/cm ³	8,9 g/cm ³
Atomic Weight	58.693 g	58.693 g	58,693 g
EMF	-0.505 V	-0.358 V	-0.586 V
Ion Charge	2	2	2
Cathodic Tafel Coeff.	1.07	0.825	1.683
Anodic Tafel Coeff.	0.93	1.175	0.316
Ni-Concentration	1.25 mol/l Ni	1.022 mol/l Ni	0.281 mol/l Ni

The electrochemical characterisation of the three electrolytes was performed by rotating disc measurements and with an electrochemical analysis tool (L-Cell), measuring polarization curves, kinetics and conductivity. Table 2 shows the electrolyte parameters, which were measured and used for selecting the pulse parameters.

Measurements at the rotating disk electrode were done with a classical three-electrode configuration. A rotating disk electrode (surface area 1 cm²) made of steel was used as cathode, a Hg/Hg₂SO₄/SO₄²⁻ (sat.) as reference electrode and a nickel sheet as anode. A Jaislle PGU 20V-2A-E potentiostat/galvanostat system controlled by an EcmWin software package was used for this experiment. Prior to each run the steel disc was mechanically polished and rinsed with deionised water. A portable PC-based digital SDS 200/SoftScope oscilloscope was used to observe the signal voltages for the applied pulses during the pulse-potential measurements. A computer controlled pulse reverse power supply system (Plating Electronic pe86) was used for the plating experiments.

Steel platelets with an active surface area of 9 cm² (3 cm x 3 cm) were used as substrates for the electrodeposition of the alloys. The thus prepared layers were investigated regarding surface morphology determination, alloy composition, micro-structure and micro-hardness. Prior to deposition, the steel substrates were electro-

lytically degreased, rinsed with distilled water, activated in 10 % hydrochloric acid solution and rinsed again with distilled water.

Table 3 summarizes the deposition parameters for the preparation of the nickel-based alloy coatings. The surface morphology and the elemental composition of the obtained alloy coatings were investigated using a scanning electron microscope (FE-SEM, Hitachi S4800) with an EDX (energy dispersive X-ray) detector. The phase composition of the deposits was examined using X-ray diffraction analysis (XRD). The surface hardness of the deposits was measured by a Vickers micro-hardness tester under a given load of 100g and duration of 10s. Five measurements were made for the hardness analysis on each sample and the average value was calculated.

The layers were deposited using pulse plating techniques, varying the pulse plating parameters such as current density, pulse frequency and duty cycle. DC plating of the three nickel alloys was performed as a reference deposition.

3. Results and discussion

3.1. Electrochemical electrolyte characterisation

The most important requirement for any development of an applicable pulse sequence is the knowledge about the electrochemical properties of the electrolyte system used. This set of electro-

Tab. 3: Electrodeposition conditions

	Ni-Co	Sn-Ni	Ni-W
Temperature	50°C	65°C	55°C
pH	5.0	4.5	6.5
(Average) current density	2.0-12 A/dm ²	0.75-3.0 A/dm ²	0.3-1.0 A/dm ²
Type of current	DC, PP	DC, PP	DC, PP
Pulse frequency	12.5-62.5 Hz	2-80 Hz	6.6-66.0 Hz
Anode	Nickel	Nickel	Stainless steel

lyte properties includes electrochemical kinetics of the alloy deposition reaction, possibly occurring anodic passivation effects and degradation of components under current load.

Polarization measurements were performed for the basic characterization of the whole deposition process. Figure 1 shows the polarization curves for the cathodic regime at a rotating disk electrode for all three nickel-based alloy electrolyte systems at different rotation speeds and a sweep rate of 10mV/s.

The knowledge of the diffusion limited current is important for the design of a plating process because the current densities used during plating should be lower than the diffusion limited currents in order to stay at the secondary current distribution regime; under limiting current conditions (tertiary current distribution) mass transport will become dominant and the morphology of the resulting deposit becomes dendritic and the layer will appear rough and burnt.

At the stationary electrode, NiCo deposition started at about -750mV against the $\text{Hg}/\text{Hg}_2\text{SO}_4/\text{SO}_4^{2-}$ (sat.) reference electrode and is shifted slightly to less cathodic potentials with increasing rotation speed. The cathodic branches of the current-voltage curves for the Ni-Co system showed a linear rise over a large range, which is typical for the pure nickel system [14]. The linear, nearly ohmic behaviour of the polarization curve is usually caused by a preceding or consecutive reaction step proceeding with a constant reaction rate. The diffusion limited current, which occurs when every ion that reaches the electrode surface is instantly reduced (deposited) can be derived by the observation of a characteristic plateau in the current with increasing (applied) potential for most deposition systems. In case of the investigated Ni-Co system this plateau is not visible in the polarisation curves due to the overlapping of metal reduction with the start of the hydrogen gas evolution. The expected instation-

ary appearance of the polarisation curve does not occur at the rotating disc measurements due to a homogenous electrolyte flow towards and along the electrode surface that will lead to an immediate desorption of gas bubbles up to quite high applied cathodic potentials.

The Sn-Ni system exhibits a limiting current plateau at low rotation speeds up to 100rpm. After this threshold value the diffusion layer becomes too thin and the diffusion limit would occur in a potential region where the hydrogen evolution is the dominant reaction. The Sn-Ni system system showed a linear relationship between potential and current, which indicates a similar deposition mechanism as was found for the Ni-Co system. In these system the deposition speed is correlated to a preceding adsorption step of a hydroxylated intermediate.

The Ni-W system however is different because tungsten cannot be galvanically deposited in pure form from an aqueous electrolyte, but forms alloys with the iron-group metals which can be electrodeposited. The polarisation curve showed a diffusion limited current at all rotational speeds before the hydrogen evolution started. The diffusion limit is visible in this electrolyte because of the lower nickel concentration, which in turn is caused by the limited solubility of the components.

When pulse reverse plating is applied the anodic branch of the polarisation curve becomes relevant. From this anodic polarisation curves the limits for the anodic dissolution of the deposit can be evaluated; these can be either a diffusion limit (like in the cathodic case) or a limit caused by a passivation reaction. In the latter case pulse reverse plating is of limited use.

The Ni-Co system shows a typical anodic behaviour; at the dissolution potential the current starts to rise sharply and no practical limit is detected. This system allows the unrestricted use of pulse reverse plating.

The Sn-Ni deposit dissolves inhomogeneously, at lower potentials tin is selectively dissolved from the alloy, only at higher potentials both metals are dissolved. As a consequence pulse reverse plating may alter the composition of the resulting alloy.

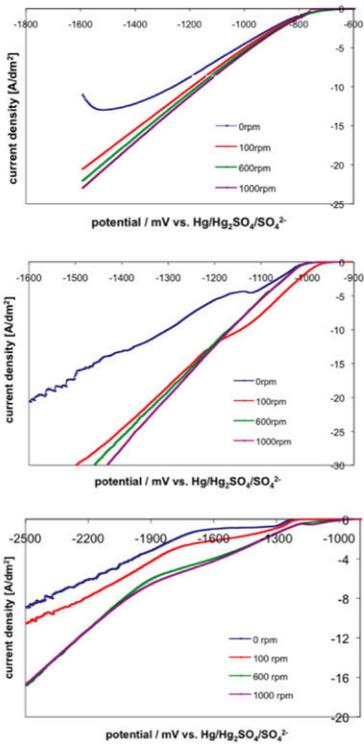


Fig. 1: Cathodic polarisation curves for (a) Ni-Co, (b) Sn-Ni and (c) Ni-W electrolyte systems recorded at a scan rate of 10mVs^{-1} on a rotating disk electrode at different electrode rotating velocity: 0, 100, 600 and 1000rpm

The anodic polarisation of Ni-W shows the typical behaviour of a passivating system, which is characterised by a sharp drop in current density at higher anodic potentials. The formation of a passivation layer has to be avoided during deposi-

tion, so the use of reverse pulses is restricted, although they can be used under carefully controlled conditions.

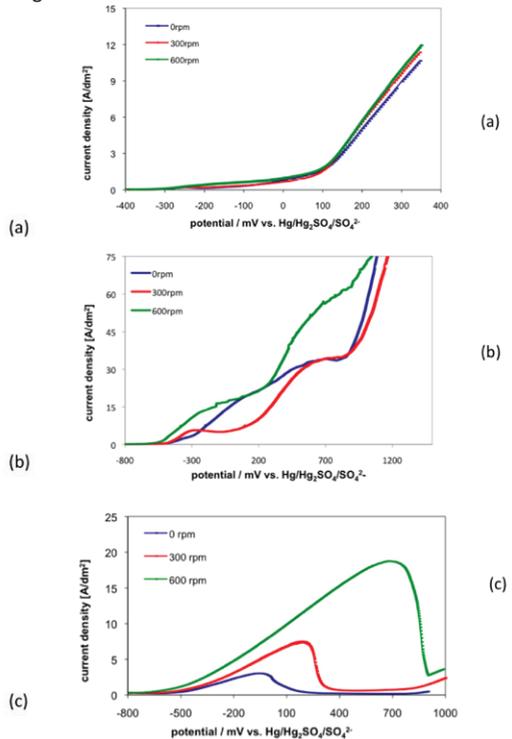


Fig. 2: Anodic polarisation curves for (a) Ni-Co, (b) Sn-Ni and (c) Ni-W electrolyte systems recorded at a scan rate of 10mVs^{-1} on a rotating disk electrode at different electrode rotating velocity: 0, 300 and 600rpm starting at an OCP of -400mV (a) and -800mV (b and c)

Pulse potential measurements were carried out in order to investigate the response of the nickel-based alloy electrolytes on pulse plating. These measurements allow a preliminary estimation of the maximum applicable pulse frequency. The speed of the potential changes at the electrode surface at fast current pulses and the time of the

charge/discharge of the electrolytic double layer are crucial system properties that determine the response to applied current pulses. The time required for charge and discharge of the double layer should be much shorter than the on-time and the off-time between the pulses. Pulses in the frequency range, where capacitive effects are relevant affect the amplitude of the pulses and hence, the structure and the properties of the deposit. These effects may even counteract the main effects of pulse plating.

The effect of such capacitive damping on deposit uniformity and morphology has been examined in a number of pulse plating studies [15-17].

The pulse-potential measurements performed on the Ni-Co system revealed a fast response of the electrolyte system to the applied pulses. While for the Ni-Co system the dampening effect on the faradaic current due to the capacitive charging/discharging of the electrolytic double layer [9] can be neglected (Fig. 2, (a)), the Sn-Ni and Ni-W systems show markedly dampened signals at a pulse length of 50ms (Fig.2, (b) and (c)). Shorter pulses will be significantly altered and thus cannot be used for a technically reproducible coating process. For these two systems longer pulse times have to be applied so that the electrochemical conditions aimed for will be correctly reproduced at the cathode surface.

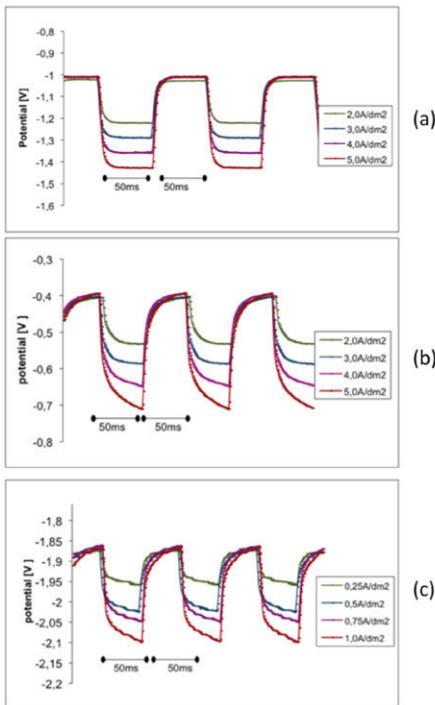


Fig. 3: Pulse-potential measurements for nickel-based alloy systems at different pulse current densities for 50ms on and 50ms off pulse time for (a) Ni-Co, (b) Sn-Ni and (c) Ni-W system

3.2. Structure and morphology

Direct current plated alloy deposits were prepared as reference samples and as a preliminary assessment regarding the effect of the current density on the morphology of the electrodeposited coatings. Figure 4 displays the surface topography of the three nickel alloy deposits electroplated under direct current conditions. The DC deposit obtained from the Ni-Co electrolyte (Fig. 4, (a)) appeared to be rougher, were dark grey in appearance and showed pores. Varying the applied current density did not lead to an improvement in the appearance of the Ni-Co coatings. The DC tin-nickel (Fig. 4, (b)) and cracked nickel-tungsten (Fig. 4, (c)) deposits are bright and exhibited some random pores.

Applying unipolar pulses instead of DC plating brought no significant improvement of the properties, such as structure and hardness, of the obtained Ni-Co and Sn-Ni layers. For the Ni-W system, unipolar pulses did not change the surface structure but reduced the level of internal stress significantly, visible by the absence of cracks in the deposit for the unipolar pulsed deposit.

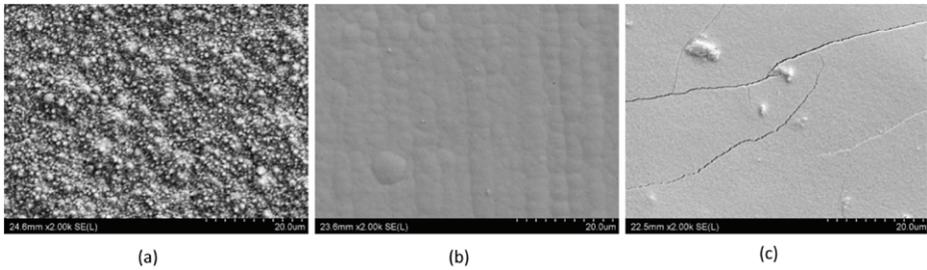


Fig. 4: SEM images at a magnification of 2000x of the surface of the deposits obtained under DC plating, electrodeposited from three different nickel alloy electrolyte systems (a) NiCo at $1.5\text{A}/\text{dm}^2$, (b) SnNi at $2.5\text{A}/\text{dm}^2$ and (c) NiW system at $0.3\text{A}/\text{dm}^2$

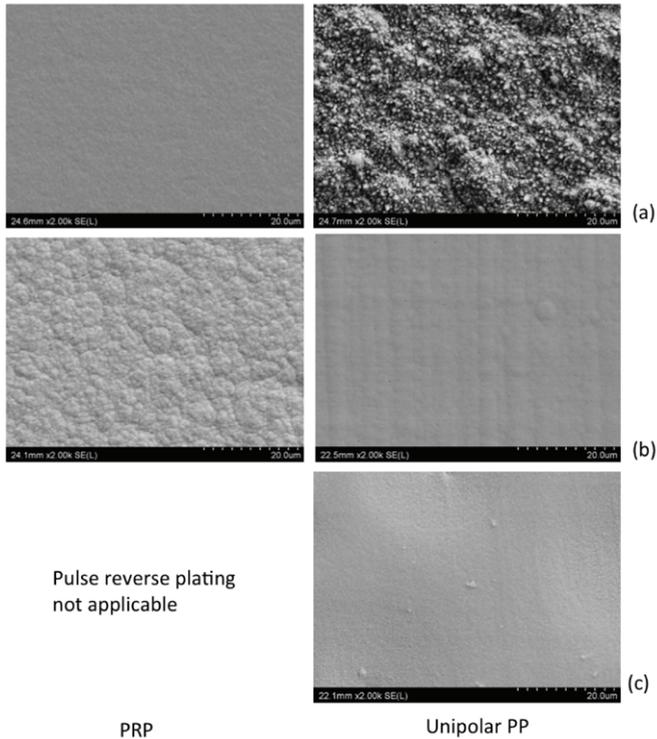


Fig. 5: SEM images at a magnification of 2000x of the surface of the nickel-based alloy coatings electrodeposited under pulse plating conditions: pulse reverse plating at 50Hz (PRP, left column) and unipolar pulse plating at 50Hz (right column) with (a) being NiCo, (b) SnNi and (c) NiW alloy layer

Pulse reverse plating had different effects on the three different alloy systems.

The resulting Ni-Co layers electrodeposited under pulse reverse plating conditions (Fig. 5, left column, (a)) are dense and compact without pores and exhibit excellent thickness distribution. The average current density applied has a minor effect on the alloy composition in a relatively wide range. For a bath concentration of 4.0g/l cobalt the obtained cobalt content in the deposit varies only within tight limits from 24.0 to 27.0 wt.% Co, depending on the pulse wave form. The Ni-Co alloy deposition is governed by the higher adsorption ability of Co(OH)^+ compared with that of Ni(OH)^+ , therefore the Ni-Co alloy gets rich in cobalt because of an anomalous deposition mechanism. Therefore, the quantity of Co in the electrolyte was kept low in order to deposit cobalt under mass transfer control. The application of pulse reverse plating led to a significantly smoother surface.

For the Sn-Ni alloys, the SEM images of the surface of the pulsed layers show differences in morphology, depending on the pulse sequence applied. By applying pulse reverse plating, the deposit becomes slightly rougher than the equivalent deposit plated with DC and unipolar pulses. This might be caused by the different anodic dissolution rates of the two alloy components.

The nickel tungsten system behaves differently because of the special deposition mechanism. The double layer capacity for this system is higher than in the two other systems, which is caused by the chemical reactions prior to deposition as well as the fact that in the case of tungsten an anion has to be adsorbed at a cathode and reduced [9]. This means that the minimal duration of the cathodic pulses has to be longer than in the other two systems. The onset of a passivation reaction on the anodic side limits the application of anodic pulses in this system. This shows that any pulse plating process has to be

adjusted to the electrolyte system and cannot easily be transferred to a system with different chemical composition.

3.3. XRD measurements

The crystallographic structures of the three deposited alloy systems have been evaluated via XRD measurements. Figures 6, 7 and 8 show the measured crystallite size for the pulse-deposited Ni-alloy coatings, deposited at different pulse frequencies (a) and different average current densities (b).

The Ni-Co and the Sn-Ni system show similar dependencies of crystallite size on the electrochemical parameters. The crystallite size shrinks with increasing current density, which is expected since this will follow the increased nucleation rate at higher current densities [9].

The effect of the pulse frequency is not as straightforward; the two systems Ni-Co and Sn-Ni both show a minimum crystallite size at intermediate frequencies. This effect is probably caused by the interruption of the crystallisation process due to the off-time. At low frequencies there are fewer interruptions of the crystallisation reaction, while at higher frequencies the gap between interruptions becomes too small to interfere.

The Ni-W system shows a totally different relationship. The crystallite size is almost constant over the whole range of pulse parameters, and there is only a small dependency visible. The crystallite size rises slightly with the current density, and the frequency dependence shows a maximum at intermediate frequencies. This system seems to favor nucleation over continuous growth, and in contrast to the other systems an interruption or an increased current density forces the crystals to grow further. A closer determination of the actual reaction mechanism has to be made in the future.

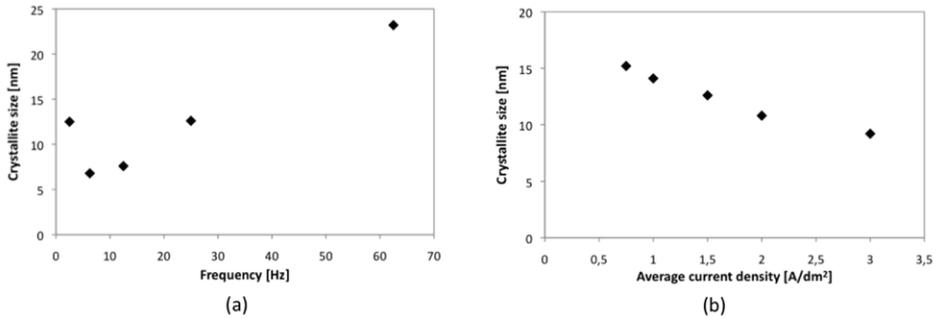


Fig. 6: XRD-determined crystallite size for the Ni-Co alloy obtained by applying reverse pulse plating at different pulse frequency with constant current density of (a) 1.5A/dm² and (b) different average current density at 25Hz pulse frequency

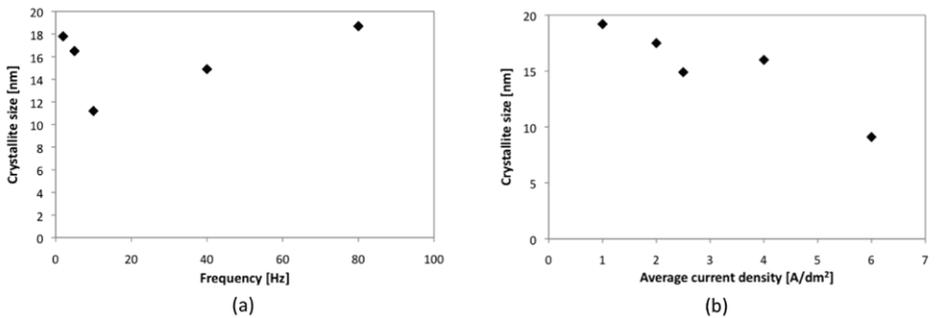


Fig. 7: XRD-determined crystallite size for the Sn-Ni alloy obtained applying unipolar pulse plating at different pulse frequency with (a) constant current density of 2.5A/dm² and (b) different average current density at 40Hz pulse frequency

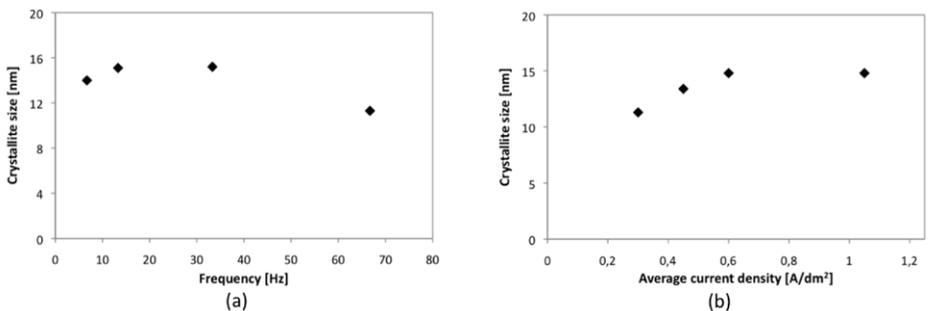


Fig. 8: XRD-determined crystallite size for the Ni-W alloy obtained applying unipolar pulse plating at (a) different pulse frequency and constant current density of 0.3A/dm² and (b) different average current density at 66.7Hz

3.4. Hardness

One of the critical parameters for the technical usability of these coatings is the surface hardness, especially for a designated substitution of hard chromium coatings. Therefore, the micro hardness of the pulse plated alloy coatings was determined and compared with the hardness values of the respective DC plated alloy deposits.

Tab. 4: Microhardness of nickel-based alloy deposits from DC and pulse plating experiments

System	microhardness
NiCo DC	401 HV _{0.1}
NiCo PRP	480 HV _{0.1}
NiCo PP unipolar	410 HV _{0.1}
SnNi DC	627 HV _{0.1}
SnNi PRP	724 HV _{0.1}
SnNi PP unipolar	759 HV _{0.1}
NiW DC	643 HV _{0.1}
NiW PP unipolar	735 HV _{0.1}

The results show that the pulse-plated deposits generally exhibit higher hardness values than the comparable DC layers for all three investigated systems. For the NiCo system it has been found that the highest hardness of this alloy was obtained applying pulse or pulse reverse plating with a resulting alloy composition of 30 at.% Co and 70 at.% Ni [1-2]. For Ni-Co and Sn-Ni the increased hardness is due to the Hall-Petch effect; smaller crystallites increase the hardness because there are more grain boundaries which hinder the deformation of the material. In the case of Ni-W there is a different hardening mechanism at work; the tungsten content of the pulsed deposit is higher than in DC deposits, and the hardness of Ni-W increases with the tungsten content by a mixed crystal hardening mechanism. The maximum hardness values found for the three alloys

are in the range of 730-760 HV_{0.1} and with this still about 25% below the hard chromium reference.

4. Conclusions

Ni-Co, Sn-Ni and Ni-W deposits with improved morphology and enhanced hardness could be produced by optimizing the pulse parameters. Although the three systems are based on nickel the deposition mechanisms are quite different, requiring an individual adjustment of pulse parameters for each system. Ni-Co shows excellent deposition-dissolution reversibility and the properties of the layer can thus be significantly improved by pulse reverse plating. The electrochemical behavior of the Sn-Ni deposition process is similar to the Ni-Co deposition, but the application of reverse pulses leads to a slightly increased surface roughness. The reason might be faster dissolution of tin compared to nickel by anodic pulses. Ni-W is unlike the other systems due to its drastically different deposition mechanism (tungsten co-deposition instead of classical alloy deposition). Nevertheless, the deposit properties can still be improved in terms of coating hardness and reduced internal stress by application of pulsed current. For the latter alloy system, the hardening mechanism is based on a higher tungsten content due to the pulse plating process, while for Ni-Co and Sn-Ni simply a grain refinement leads to harder coatings.

The primary crystal size is in the nano-scale range as soon as pulse plating is applied and does change in small steps with changing pulse conditions only. Still with higher pulse current density, the crystal size is reduced, as expected according to the influence of pulse plating on the nucleation process [9]. Ni-W is an exception to this general characteristic with hardly any changes in the (nano-) crystallite size. This again can be related to the deposition mechanism with an increase of W co-deposition counteracting the typical increase in polarization

resistance by increasing pulse current density, causing the grain refinement observed.

The resulting hardness level is in the region of up to above 700 HV_{0,1} for Sn-Ni and Ni-W without the use of organic hardener systems, which is a significant increase in comparison to pure nickel layers. Still, the surface hardness of both alloys is about 30% below the reference hard chromium system. The level of internal stress is for the investigated nickel-alloys on the other hand dramatically lower than hard chromium that might still allow the application of the alloys as a substitute of hard chromium when durability and toughness is preferred over simple hardness. For all three systems current efficiency is almost three times higher (above 85%) than the efficiency of chromium deposition (with common efficiency values of below 30%). In technical use, this will reduce endangerment of hydrogen embrittlement and will thus save thermal treatment requirements of the plated parts.

The correlation between numerical simulation of the deposition processes and the investigation of the effect of addition of organic hardener systems in addition to the application of pulse plating processes will be the scope of consecutive research.

References

- [1] W.E.G. Hansal, B. Tury, M. Halmdienst et al., *Electrochimica Acta*, 52 (2006) 1145
- [2] P.T. Tang, *Electrochimica Acta*, 47 (2001) 61
- [3] S. Franz, A. Marlot, P. L. Cavallotti, D. Landolt, *Trans IMF* 86 (2008) 92
- [4] A. Brenner, *Electrodeposition of Alloys*, Vols. 1 and 2, (1963) Academic Press, New York
- [5] M. Jordan, *The electrodeposition of Tin and its Alloy*, 19-59; 995, Saulgau, Eugen G. Leuze Publishers
- [6] Y. Liu, and M. Pritzker, *J. Appl. Electrochem.*, 33 (2003) 1143
- [7] K. L. Lin and L. M. Sun, *J. Mater. Res.* 18 (2003) 2203
- [8] J.-C. Puipe and F. Leaman, *Pulse Plating*, (1986) Eugen G. Leuze Publishers, Bad Saulgau
- [9] W.E.G. Hansal, Sudipta Roy, *Pulse Plating*, (2012) Eugen G. Leuze Publishers Bad Saulgau
- [10] M.S. Chandrasekar, Malathy Pushpavanam, *Electrochimica Acta*, 53 (2008) 3313
- [11] W. Paatsch, *Metall.*, 40 (1986) 387
- [12] G.W. Jernstedt, *Plating*, 7 (1948) 4404
- [13] E.A. Pavlatou, M. Raptakis, N. Spyrellis, *Surf. Coat. Technol.* 201 (2007) 4571
- [14] W.E.G. Hansal, *AIMF*, 3 (2007) 140
- [15] J.-Cl. Puipe and N. Ibl, *J. Appl. Electrochem.*, 10 (1980) 775
- [16] G. Holmbom and B. E. Jacobsson, *Surf. Coat. Technol.*, 35 (1988) 333
- [17] W-C. Tsai, C-C. Wan and Y-Y. Wang, *J. Electrochem. Soc.*, 150 (2003) C267

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