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Electrodeposition and electrocatalytic performance of Ni-Co alloy

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1. Introduction

Energy demands of the globe are today met by massive utilization of nuclear and fossil fuels, but they are accompanied by the destruction and pollution of the environment [1]. The need for an eco-friendly, renewable and efficient energy source with the potential to replace the commonly used nuclear and fossil fuels is growing each day. Hydrogen, the most abundant element on earth, happens to be a clean and ideal fuel with all the desirable properties, and is considered as

the fuel of the future [2, 3]. In this direction, new hydrogen technologies have been started practicing as a potential solution for current power crisis in the international level.

Hydrogen is the simplest and lightest chemical element of the periodic table, with a density of 0.0899 kg/Nm^3 , it is 15 times lighter than air. The energy content per unit mass is highest among known fuels [1, 4]. Presently, up to 96% of hydrogen is produced from fossil fuels and the other 4% from water [5, 6]. In this direction, water is a

potential renewable resource of great interest for hydrogen production. Here the main production method is the electrolysis, though thermal and photo catalytic decompositions were tried [1]. The water electrolysis method could be used to produce large quantities of hydrogen and oxygen with high purity. However, the cost and energy consumption required for the electrolysis of water is very high [7].

Electrolysis being an electrode reaction and its operational voltage depends on the overpotential for the cathodic and anodic reactions and internal resistance of the cell [8]. The cost of electrolysis can be reduced drastically by decreasing the overpotential of the electrode reaction and selecting inexpensive electrode materials. Generally, the desirable properties for an ideal electrode for electrolysis of water is large active surface area, good electrochemical stability, high electrical conductivity, low overpotential, selectivity, low cost and ease of its fabrication [9]. The electrodes with nanostructured surfaces provide an advantage high real surface area per unit geometric area [10]. In this regard, transition metals and their alloys are found to be the potential candidates for water electrolysis, as electrodes. However, these materials show inherently high over-potential and need to be reduced by proper manipulation of their synthesis routes [11].

Several electrodeposited transition metals (like Ni, Co, Fe, Mo and Mn) and their mutual alloys and their few composites have been used as electrodes for electrolysis of water, and they offered several advantages. This is due to the fact that electrodeposition being an atomistic deposition process, the property of the coatings can be controlled closely by regulating the deposition parameters and bath composition. Moreover, such electrodeposited materials do not require any post-preparation treatment before to use as

electrocatalysts [12]. In this direction, electrodeposition and electrocatalytic behaviour of Ni-Fe coatings were studied by Solmaz and co-workers. Experimental investigations have revealed that Ni-Fe coating is a better electrocatalyst for water splitting process than its constituent metals. Elisa and co-workers have studied the electrocatalytic activity of Ni, Ni-Mo, Ni-W and Ni-Fe for HER reaction in acidic medium. The experimental results showed the increased HER activity of the alloy coatings while demonstrating the beneficial effect of alloying of Ni with Fe, Mo and W [2]. Song and co-workers developed Ni-Fe-C composite electrodes electrolytically for HER in seawater, and studied the relation of grain size to the carbon content in the electrode, consequent to HER efficiency [13].

The bipolar performance of Ni-Fe electrodeposits in alkaline 5M KOH was studied by Hu and co-workers [14]. The deposits of varying composition were developed, and their electrocatalytic behaviours for hydrogen and oxygen evolution reaction were studied simultaneously. The HER on smooth Co and electrodeposited Ni-Co ultra-microelectrodes (UME) at several temperatures by steady state polarization curves were reported by Correia and co-workers. It was observed that alloying of Co with Ni has increased the HER activity, consequent to increase of real surface area due to alloying [15]. Further, It was demonstrated that alloying Ni with Co can also improve the intrinsic catalytic activity of the binary alloy coatings, and was attributed to synergistic effect of catalytic properties of nickel (low hydrogen overpotential) and of cobalt (high hydrogen adsorption) [16].

It is fact that hydrogen and fuel cell technologies are considered as a key element in the future clean energy market. Even though they are now ready for large scale commercialisation, further

cost reduction and quality advancement is of high concern to make them available for everyone at a low price. In this direction, enormous reports are available in the literature pertaining to development of many mutual alloys of transition metals, as efficient electrode materials for HER's and OER's to be used in fuel cell applications. However, there is no much report on quantitative measurement of gases evolved (H_2 and O_2) on electrolysis of water, using binary alloys of transition metals as electrode materials. In pursuit of that, the present study is for development of nanocrystalline Ni-Co coatings of varying composition from a new electrolytic bath by simple and straight forward electrodeposition method and to test their stability in strong alkaline medium. The electro catalytic performance of deposits developed under different conditions of c.d., in terms of HER and OER have been analysed in relation to their surface morphology and phase structure.

2. Experimental

2.1 Electrodeposition of Ni-Co alloy coatings

Ni-Co alloy films can be fabricated in several methods such as smelting and electrodeposition. However, the method of electrodeposition is the simplest, most economical, reliable and reproducible technique. The functional properties of electrodeposited Ni-Co alloy coatings depend greatly on their composition, which should be strongly affected by deposition parameters [17]. The electrolysis bath was prepared from analytical grade reagents, using de-ionized water. The optimal bath composition was arrived by employing Standard Hull cell method [18]. The bath consisting of $NiSO_4 \cdot 6H_2O$ (100g/L), $CoSO_4 \cdot 7H_2O$ (25g/L), H_3BO_3 (20g/L) as buffer, ascorbic acid (5g/L) as antioxidant and sodium lauryl sulphate(SLS)(1g/L) as surfactant was used in the present study. The pH of the bath was adjusted to

3.5 using either 10% NaOH or 10% H_2SO_4 and then filtered before each deposition. All Ni-Co coatings have been accomplished on copper plate, and cross sectional area of the copper rod (both having same specifications) of known surface area, depending on the requirement of characterization need to be done on electrodeposits. The effect of c.d. on surface morphology and composition of the alloy was studied, by coating the alloy on substrate (copper plate) using conventional cell. All electrochemical and electro-catalytic study of the alloy was made, by coating the alloy on substrate (on cross sectional area of the copper rod) using customized glass cell, with set up shown in Figure 1.

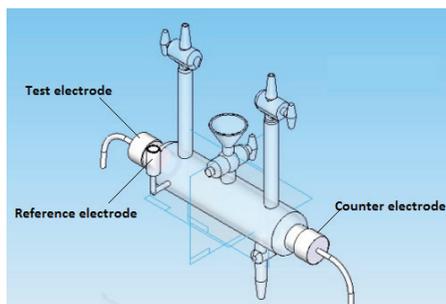


Fig. 1: Customized tubular three electrode cell with provision to collect liberated O_2/H_2 on electrode surface

Mirror polished copper surface was electro-cleaned, and then pickled in 1:1 mixture of 0.5M HNO_3 and 0.5M H_2SO_4 to activate the surface. The coatings were carried out on copper having effective exposed area of $1.0cm^2$ (in case of both plate and rod). Pure Ni strip having equal exposed surface area was used as anode. The cathode and anode were placed parallel at 5 cm distance during plating. All electrodeposition were carried out galvanostatically from still bath for duration of 900s, for comparison purpose. All Ni-Co alloy coatings have been accomplished on copper substrate using high sensitive power source (Agilent N6705A DC power analyser).

2.2 Characterization

The electro-catalytic study of Ni-Co alloy deposits have been made in a customized three-electrode tubular glass cell, with arrangements as shown in Figure 1. The said electrochemical cell is designed for quantitative measurement of hydrogen and oxygen, when electrodeposited Ni-Co alloy is subjected to cathodic and anodic polarization respectively. Electrodeposited Ni-Co alloy formed at different deposition conditions, i.e., current densities were used as test electrode; the platinised platinum of same surface area (1.0 cm^2) was used as counter electrode. A saturated calomel electrode (SCE) was used as reference electrode. All potentials reported in the present study are referring to SCE. A Luggin's capillary with Agar-Agar-KCl salt bridge was used to minimize the error due to Ohmic drop. Electrochemical behaviour of the Ni-Co alloy deposits, in terms of HER and OER were evaluated by subjecting them to cyclic voltammetry (CV) and chrono-potentiometry study in 6M KOH medium, using computer controlled Potentiostat VersaStat3-400 (Princeton Applied Research, USA). The cell is fitted with a gas collector (with markings to read the volume of gas liberated as result of electrocatalysis), where the liberated hydrogen/oxygen replaces corresponding amount of solution. This arrangement allows to calculate the amount of gas liberated (during definite time) on electrode materials, deposited at given c.d. The corrosion behaviour of electrodeposited Ni-Co coatings have been also been evaluated by potentiodynamic polarization method at scan range $\pm 250 \text{ mV}$ from OCP at 1 mVs^{-1} scan rate. The surface morphology of Ni-Co coatings were characterized using Field Emission Gun Scanning Electron Microscope (FEGSEM). The elemental composition and phase structure were analysed using Energy Dispersive X-ray (EDX) analysis interfaced with FEGSEM and X-ray Diffraction (XRD) techniques, respectively.

3. Results and Discussion

Prior to electro-catalytic study of the electrodeposited Ni-Co alloy coatings, they have been subjected to their physical, compositional and electrochemical characterizations, and corresponding results are presented in the following sections.

3.1 Surface and compositional characterization

3.1.1 XRD analysis

The phase compositions of all Ni-Co alloy coatings, deposited at different c.d. were determined by XRD analysis. The characteristic XRD patterns of Ni-Co coatings corresponding to different c.d. are shown in Figure 2.

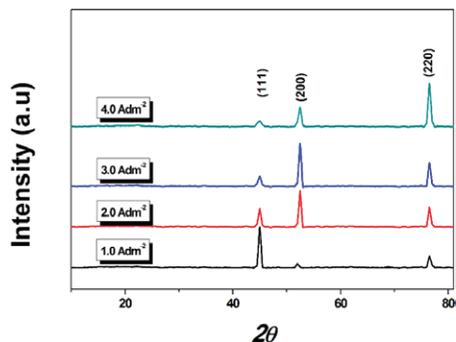


Fig. 2: XRD diffraction patterns of monolayer Ni-Co coatings developed at different current densities

The clear difference in XRD patterns, as the deposition c.d. is changed from 1.0 Adm^{-2} to 4.0 Adm^{-2} indicated that c.d. plays a crucial role on phase composition of the alloy. At low c.d. side, (111) reflections of bcc phase was found to be dominant, with low intensity reflections of (200) phase. As the c.d. is increased, gradual decrease reflection corresponding to (111) phase was observed, with increase of intensity corresponding to (220) reflections. Further, it may be noted

that there exist increase of intensity corresponding to (220) reflection, as the c.d. is increased as shown in Figure 2. As Ni-Co alloy forms solid solution, the texture coefficient is known to vary with applied c.d., and hence at very high c.d., the coatings showed very small amount of bcc phase.

This difference in the phase structure of the coatings may be attributed to the change in nucleation process caused by electrode kinetics, controlled by applied cathode c.d. It may be further noted that the dominant (111) and (200) reflections from fcc phase observed at high c.d. range gradually diminished at low c.d., and has replaced by (220) reflections as shown in Figure 2. The Scherrer formula was applied to XRD patterns and the grain size were found to be within 100nm for all the coatings [19]. Thus, XRD peaks shown in

Figure 3, confirms the fact that c.d. plays a decisive role on deposit characters, consequent to the phase structure of the coatings.

3.1.2 FEGSEM image analysis

The effect of c.d. on surface morphology of electrodeposited Ni-Co alloy coatings was studied by FEGSEM analysis. The microstructure of the coatings at different c.d. is shown in Figure 3. It should be noted that the surface morphology of coating is greatly influenced by the c.d. employed for its deposition. At low c.d., the coating with fine granular structure, with low wt % of cobalt was observed as seen in Figure 3a. However, increase of c.d. resulted in the formation of nanocrystalline microspheres as seen in Figures 3b-3d. This may be attributed to the agglomera-

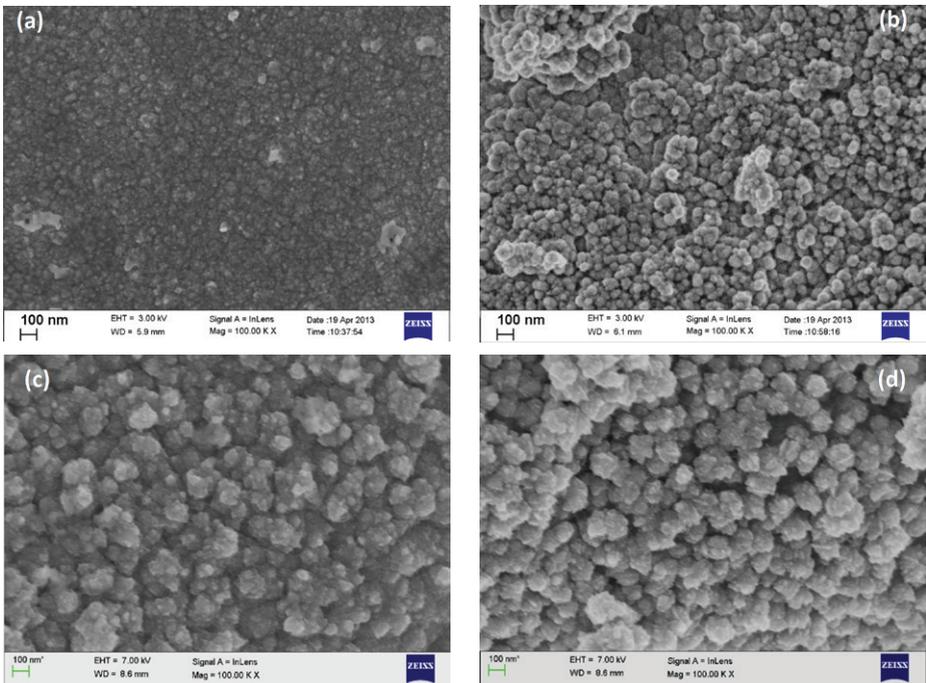


Fig. 3: FEGSEM images of Ni-Co coatings deposited at a) 1.0 Adm⁻² b) 2.0 Adm⁻² c) 3.0 Adm⁻² and d) 4.0 Adm⁻²

tion of fine grains due to heavy of surge of metal ions towards cathode. The observed increase of surface roughness due to increase of deposition c.d. is highly beneficial for electrocatalytic applications of the Ni-Co alloy coatings as envisaged in the literature [20].

3.1.3 Composition and hardness analysis

The composition of Ni-Co coatings deposited at different c.d. from the proposed electrolytic bath is reported in Table 1. As electrodeposition of Ni-Co coatings are known to follow peculiar anomalous codeposition (i.e. wt. % of a metal in deposit is always less than that in bath), the wt. % of Ni in the deposit was found to be less than that in the bath (80 %) at all c.d.'s studied.

Moreover, Ni content in the alloy was found to decrease with increase of c.d. as may be seen in Table 1. This decrease of noble metal (Ni) content at high c.d. can be attributed to increased suppression of Ni deposition by Co(OH)_2 formed at the cathode interface, due to increased local alkalinity. This decrease of noble metal content at high c.d. is well explained by hydroxide suppression mechanism. The local alkalinity is due to increased evolution of H_2 as the deposition c.d. is increased. This is further supported by decreased hardness, and increased thickness of the coatings with increase of c.d. as reported in Table 1.

3.2 Electrochemical characterization

3.2.1 Corrosion study

The corrosion stability of electrodeposited Ni-Co coatings in its operating medium of fuel cell application is an important parameter in qualifying it as an effective electrode material. Hence, the corrosion behaviour of Ni-Co alloy coatings, deposited at different c.d. were evaluated by potentiodynamic polarization method using 6 M KOH as the corrosion medium, and corresponding data are reported in Table 1. The comparison of corrosion data testifies the fact that Ni-Co coatings under working condition of its electrocatalytic study show a maximum corrosion rate of $\sim 2.6 \times 10^{-2}$ mmpy, which falls well within the tolerable limit of electrode reactions. Thus the above corrosion tests qualified the electrodeposited Ni-Co alloy coatings as safe electrode material for water electrolysis in 6 M KOH.

3.2.2 Cyclic voltammetry study for HER

The catalytic activity and stability of developed Ni-Co electrode materials was tested by cyclic voltammetry in the potential range of -0.5 to -1.6 V at a scan rate of 50 mV/s. Figure 4 shows the CV curve for HER of Ni-Co alloy coating deposited at 4.0 Adm^{-2} . It may be noticed that in first cycle the current density peaks at -1.6V, which eventu-

Tab. 1: The composition, hardness, thickness and corrosion behaviors of electrodeposited Ni-Co alloy coatings at different current density

C.d. A/dm^2	Wt. % of Ni	Vickers micro hardness (V_{500})	Thickness (μm)	$-E_{\text{corr}}$ (V vs. SCE)	i_{corr} ($\mu\text{A} \times 10^2$)	C.R. ($10^{-2} \times \text{mmpy}$)
1.0	75	250	4.2	0.390	2.23	2.63
2.0	53	285	5.3	0.404	1.09	1.27
3.0	37	320	6.5	0.384	0.81	0.95
4.0	29	360	10.2	0.364	0.35	0.42

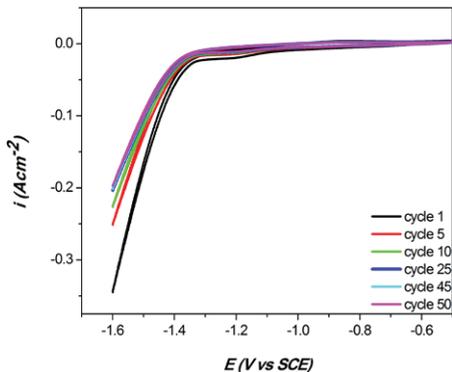


Fig. 4: Representative CV curves for HER on Ni-Co coating at 4.0 Adm^{-2} in 6M KOH showing a decrease in the peak potential with the number of cycles and the stabilization after 25th cycle, leading to overlapping of curves

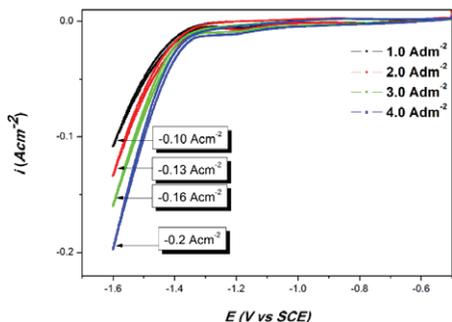


Fig. 5: The 50th cycle voltammograms for Ni-Co coatings at different c.d. showing an increase in the peak current for coatings at higher c.d. value

ally decreased as the number of cycles increased. The decrease of peak c.d. may be ascribed by the resistance induced by the formation of hydrogen bubbles on the catalyst surface [21]. The stabilization of CV curves for HER was reached after 25th cycle, indicating a state of equilibrium for formation and detachment of hydrogen bubble [22].

Generally in heterogeneous electro-catalysis, the morphology of the electrode surface bears close relation with rapid attainment of equilibrium between formation and detachment of

hydrogen bubbles [23]. Similarly, CV curves of Ni-Co coatings deposited at different c.d. showing relative peak current density for HER, corresponding to stable 50th cycle is shown in Figure 5, and corresponding electrochemical data (onset potential for H_2 evolution and the volume of H_2 evolved) are given in Table 2. It was observed that at -1.6V , the peak cathodic current density for HER on electrode surface increased as deposition c.d. increased, and it reached its maximum value (-200mA cm^{-2}) for Ni-Co coating corresponding to 4.0 Adm^{-2} , confirming that Ni-Co coating at c.d. = 4.0 Adm^{-2} exhibits the highest activity for HER.

Physical characteristics of the electrocatalytic materials, namely porosity and specific surface area, have long been understood to play a key role in stabilizing active components of the catalysts in dispersed state. Explicitly or implicitly, they reflect topological properties of the surface. The electro-catalytic behavior of any material can also be visualized in terms of the presence of active surface site, having an electron transfer pathway. Hence electrocatalytic behaviour originates from the very morphology of the electrode surfaces. As envisaged by many, the cathodic HER is considered to have basically four steps starting from discharge of hydrogen ions till the formation of gaseous molecular hydrogen. Out of these four steps any one may be the rate determining step and is responsible for the appearance of hydrogen over potential. At the same time, it is important to know that electrocatalysis for any reactions is due to presence of such active surface site, which allows an easy electron transfer. Thus electrocatalysis is largely influenced by the nature of the electrode material and the morphology of the electrode surfaces. Therefore the observed high cathodic peak current density of Ni-Co coating, deposited at 4.0 Adm^{-2} is due to controlled structure of the coatings with

increased surface area. This is further evidenced by FEGSEM image of Ni-Co alloy coatings at high c.d., shown in Figure 3d.

The formation of Ni-Co coatings with increased internal porosity, and hence high surface area is further supported by decrease of hardness and increase of thickness as reported in Table 1. Hence, highest hydrogen gas liberation corresponding to coating at 4.0 Adm^{-2} may be attributed to increased surface area. Hence it may be concluded that Ni-Co alloy deposited at high c.d., having high porosity showed the highest HER activity, and is characterized by prominent (220) peaks in XRD analysis. It is state worthy that the onset potential for HER on all Ni-Co alloy coatings under study is almost same, irrespective of the c.d. at which they are deposited. This indicates that initiation of nucleation takes place almost simultaneously on all electrode surfaces regardless of the morphology of the surface. The observed cathodic peak potential in case of Ni-Co coatings at -1.6V in 6M KOH medium is higher than the normalized values reported by Ahn and co-workers on electrodeposited Ni dendrites [10]. The intrinsic activity is higher than the values reported by Solmaz and Kardas on Ni-Fe in 1M KOH studied by cyclic voltammetry and chrono-potentiometry [7]. Ivelina and co-workers have reported the water-oxidising performance of MnO_2 without a quantitative report on HER and OER, using it as electrode material [24].

3.2.3 Chrono-potentiometry study for HER

The electro-catalytic behaviour of electrodeposited Ni-Co coatings were assessed by yet another approach, namely chrono-potentiometry method. In this method a constant current is made to flow between two electrodes while the potential of one electrode is monitored as a function of time with respect to a suitable reference electrode. The solution is usually, but not necessarily, unstirred and contains an excess of a supporting electrolyte so that diffusion is the principal mechanism of mass transport. The high concentration of K^+ and OH^- ions reduces the effect of dissolved oxygen and eliminates the need for de-aerating the medium. The chrono-potentiometry study for evolution of hydrogen on Ni-Co alloy coatings, deposited at different c.d. was made at constant current of -300 mAcm^{-2} for duration of 300s. The electro-catalytic behaviour of each coating was evaluated by measuring the amount of H_2 liberated for first 300s. The nature of chrono-potentiogram for each Ni-Co coatings are shown in Figure 6 and volume of hydrogen liberated on these coatings for first 300s are also shown in the inset of Figure 6, in addition to the data given in Table 2.

It is important to note that the Ni-Co coating deposited at 4.0 Adm^{-2} produced the maximum amount of H_2 in comparison to other coatings. This confirmed the fact that Ni-Co coating at

Tab. 2: The hydrogen evolution reaction parameters for Ni-Co alloy coatings developed at different c.d. from optimal bath

Coating configuration	Cathodic peak c.d. at $-1.6\text{V}(\text{Acm}^{-2})$	Onset potential of H_2 evolution (V vs SCE)	Volume of H_2 evolved in 300s (cm^3)
1.0 Adm^{-2}	-0.10	-1.38	4.1
2.0 Adm^{-2}	-0.13	-1.35	4.5
3.0 Adm^{-2}	-0.16	-1.31	5.6
4.0 Adm^{-2}	-0.20	-1.29	7.0

4.0 Adm^{-2} is the most electrocatalytically active. Further, an initial sharp decrease of potential immediately after starting of electrolysis (not seen distinctly in plot) was observed in all four coatings studied. As the electrolysis proceeds, there was a progressive depletion of electrolyzed species at the surface of working electrode. This is due to fact that as the current pulse is applied all H^+ is reduced to H_2 after certain stabilisation time is reached. Further, chrono-potentiogram for Ni-Co coatings at 4.0 Adm^{-2} demonstrated more potential stability for HER compared to those at other c.d. as may be seen in Figure 6.

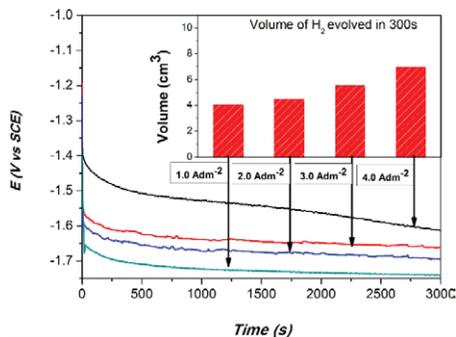


Fig. 6: Chrono-potentiometry curves for Ni-Co alloy coatings under impressed cathodic current of -300 mAcm^{-2} . Inset: Volume of H_2 evolved on each test electrodes in 300s interval

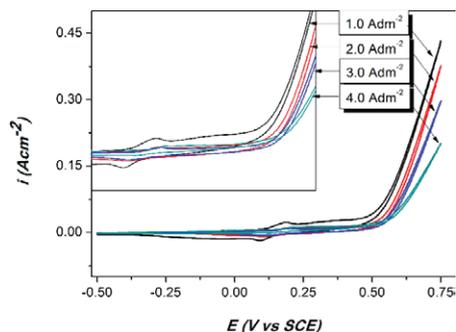
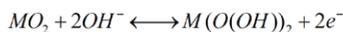


Fig. 7: Cyclic voltammograms of Ni-Co alloy coatings electro-deposited at different c.d. values, in 6M KOH solution showing an increase in anodic peak current, the redox couple for Ni-Co alloy is shown in inset

3.2.4 Cyclic voltammetry study for OER

The cyclic voltammetric experiments for Ni-Co coatings deposited at 1.0, 2.0, 3.0 and 4.0 Adm^{-2} were conducted in potential range of 0-0.75 V at 50 mVs^{-1} scan rate and corresponding cyclic voltammograms are shown in Figure 7. It may be noted that there exists an intermediate peak in the potential window of voltammogram, for each alloy coatings studied. It may be explained as follows: evolution of oxygen believed to be catalysed by the redox transitions of interfacial oxy-cations between higher and lower oxidation states [25, 26]. Hence oxygen evolution activity on Ni-Co deposits is a function of the electrochemical properties of the redox pair prior to the onset of oxygen evolution. It is supported by CV of electro-deposited pure nickel in 1M KOH, exhibiting anodic and cathodic peaks at 0.362 and 0.265 V respectively, corresponding to the $\text{NiOOH}/\text{Ni}(\text{OH})_2$ transition [27]. In the present Ni-Co alloy coatings, the redox couple occurring is due to the following reactions.



where M indicates the Ni-Co alloy.

It is important to note that anodic peak current is shifting towards positive potentials as the deposition c.d. increases i.e., as the composition of the coating is changed. Further, the total charge associated with CV corresponding to 1.0 Adm^{-2} is much higher than that for coating at 4.0 Adm^{-2} , as shown in Figure 8. Onset potential of oxygen is basically a decomposition potential of water under the anodic polarization. The oxygen evolution reaction is an irreversible reaction with a high activation over potential (1.48V) [14]. The onset potential for continuous evolution of O_2 gas were found from the CV curves and are reported

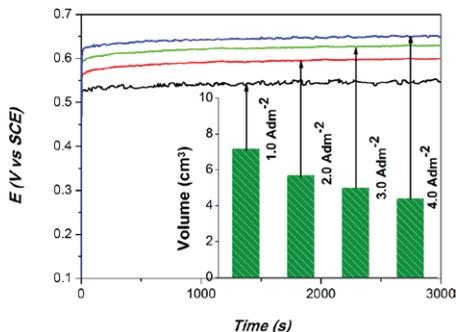


Fig. 8: Chrono-potentiometry curves for Ni-Co alloy coatings under impressed anodic current of $+300 \text{ mA cm}^{-2}$. Inset: Volume of O_2 evolved on each test electrodes in 300s interval

in Table 3. Here, it is worth to note that the coating deposited at 4.0 Adm^{-2} shows highest onset potential, while the coating at 1.0 Adm^{-2} is less. The coating at 1.0 Adm^{-2} was found to show the least onset potential and maximum anodic peak at 0.75 V . This is being the most desired character for a good electrocatalyst, the Ni-Co coating at 1.0 Adm^{-2} is the most effective electrocatalyst compare to other two for OER activity.

3.2.5 Chrono-potentiometry study for OER

The efficiency of electroactive coatings of Ni-Co alloy for OER has also been tested using chrono-potentiometry. The amount of oxygen evolved

was measured in the similar way as discussed earlier, but by taking electrode material as anode and corresponding chrono-potentiogram is shown in Figure 8. As the current pulse of $+300 \text{ mA}$ was applied, a sharp increase in potential was observed until a potential at which OH^- oxidized to O_2 is reached. In other words an equilibrium state is reached between newly forming bubble and bubbles escaping from the surface of the electrode [28, 29]. The inset of Figure 8 shows relative amount of O_2 liberated in 300s on Ni-Co coatings deposited at different c.d., and accordingly volume of O_2 evolved on different coatings are given in Table 3. It should be noted that the amount of O_2 liberated on Ni-Co coating, deposited at 4.0 Adm^{-2} is least compare to that on other coatings. Further, on Ni-Co alloy deposited at 1.0 Adm^{-2} more O_2 is evolved at least potential. In other words, Ni-Co alloy coating deposited at 1.0 Adm^{-2} is most electroactive for OER reaction compared to other coatings. This confirms the fact that the electrode surface favouring the cathodic reaction has adverse effect of anodic reaction and vice versa. It may be attributed to the inherent phase structure, composition, specific surface area and porosity of the materials under test, determined principally by cathode current density at which they have been deposited from the bath.

Tab. 3: The oxygen evolution reaction parameters for nanocrystalline Ni-Co coatings electrodeposited at different c.d. values

Coating configuration	Redox couple peaks (V vs SCE)		Onset potential of O_2 evolution (V vs SCE)	Anodic peak current at $0.75 \text{ V (Acm}^{-2}\text{)}$	Volume of O_2 evolved in 300s (cm^3)
	Anodic peak	Cathodic peak			
1.0 Adm^{-2}	0.18	0.09	0.36	0.43	7.2
2.0 Adm^{-2}	0.19	0.10	0.38	0.37	5.7
3.0 Adm^{-2}	0.20	0.10	0.42	0.29	5.0
4.0 Adm^{-2}	0.22	0.13	0.46	0.20	4.4

4. Conclusions

Ni-Co alloy has been electrodeposited as electrode material on copper at different c.d. ranging from 1.0 to 4.0 Adm⁻² from acid sulphate baths. The electro catalytic behaviour of the coatings for HER and OER have been studied in alkaline medium of 6M KOH. The FEGSEM study revealed that all Ni-Co alloy coatings, deposited at different c.d. are having nanocrystalline in nature with grain size of 10-25 nm. The chrono-potentiometry study revealed that the Ni-Co alloy coating deposited at 4.0 Adm⁻² is more electro active for HER, and at 1.0 Adm⁻² is more electro-active for OER. Experimental results evidenced that Ni-Co alloy coatings deposited at 4.0 Adm⁻² and 1.0 Adm⁻² can be used as an efficient electrode material for, respectively HER and OER reactions in fuel cell applications, demonstrated by cyclic voltammetry (CV) and chrono-potentiometry study. The characteristic electro catalytic behaviour of the coatings for HER and OER are attributed to the inherent phase structure, composition, specific surface area and porosity of the coated materials under test, determined by the cathode current density at which they are deposited, supported by FEGSEM and XRD study.

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