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Author(s)
Kihara, Sorin; Yoshida, Zenko; Matsui, Masakazu

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Electrodeposition of Polonium and Interaction between the Deposited Polonium and Based-Electrode Materials

Sorin Kihara*, Zenko Yoshida** and Masakazu Matsui*

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The electrodeposition of far less than monolayer of 210Po on various metal or carbon electrodes was investigated. A special attention was paid on the penetration of Po deposited at the surface into the bulk of electrode materials, Mel. The extent of the penetration (D) was estimated measuring the energy of α particle emitted from deposited 210Po by means of α-ray spectrometry and taking the stopping power of Mel for 4He into account. The deposited Po easily penetrate into such metals as Pb, Tl and Te, but hardly into such Mel as stainless steel, glassy carbon or metals of Pt, Ta, Co, Ni, Nb, Mo and W. The extent, D. also depends on the deposition potential.

KEY WORDS: Electrodeposition of polonium/ Various electrode materials/ Underpotential deposition/ Penetration of Po(0)/ Deposition potential

INTRODUCTION

The electrodeposition process of a metal on a metal electrode, Mel, can be categorized into following four steps1; (1) the mass transfer of the metal ion in solution to the surface of Mel, (2) the discharge of the ion producing the metal atom, M°, (3) the crystallization of M° on the surface of Mel and (4) the penetration of M° deep into Mel from the surface due to the diffusion of M°, the dissolution of M° in Mel and/or the formation of metallic compounds between M° and Mel.

Step (4) is considered to be important not only in the elucidation of the electrode process but also in the estimation of the stability of the deposited layer and in the improvement of the sensitivity to analyze trace metal ions in solutions by the anodic stripping voltammetry2,3. Studies on step (4), however, are very few compared with those on the other steps, (1) to (3), and such detailed investigations as on the extent or the rate of the penetration have not been available.

In the present work, 210Po is electrodeposited on various Mel from an extremely dilute aqueous solution and the penetration of discharged Po into Mel is measured by means of the α-ray spectrometry taking the stopping power of Mel for α particle into account4. 210Po decays emitting α-ray of 5.3 MeV and produces stable 206Pb (half-life; 138.38 days).

II. EXPERIMENTAL

Chemicals

The carrier-free 210Po stock solution (Product of AMERSHAM Co. Ltd., Lon-
don) was about 1 mCi·ml⁻¹ in Po and 0.5 M in HNO₃. The Po solution was used within 2 months after preparation. Other reagents used were of reagent grade.

**Electrode materials**

Metal plates (0.1 cm t) of Ag, Al, Au, Pd, Pt (more than 99.99% purities), Bi, Cd, Co, Cu, In, Mo, Nb, Ni, Pb, Ta, Sb, Sn, Te, W, Zn (more than 99.9% purities) and stainless steel (SUS 304), and a glassy carbon plate (0.2 cm t, Tokai Carbon, GC-20) were employed as electrode materials, Mₑ, after polishing by means of emery paper (No. 1200) to mirror like surfaces or electropolishing (in case of Pb) followed by washing with ethanol and then water under ultrasonic treatments. The electrode surface area was 0.2 cm².

**Apparatus**

²¹⁰Po was deposited on various Mₑ by the electrolysis using a potentiostat (Hokuto Denko Co., Type HA-211) with the aid of a calomel (sat. KCl) reference electrode (denoted as SCE) and a platinum wire counter electrode. The α-ray spectra were measured by a silicon surface-barrier detector (Seikigogyo Lab., Type SVC-9) and a multichannel analyzer (ORTEC, Model 6240B).

Electrolyses were carried out at 25±1°C and α-ray spectra were measured at room temperature.

**III. RESULTS AND DISCUSSION**

**Electrodeposition of ²¹⁰Po**

After electrolysis for 30 min at a definite potential in 10 ml of stationary solution which was 10⁻¹¹ M in ²¹⁰Po and 0.5 M in HNO₃, the amount of Po electrodeposited (Qₑ) on an electrode was determined by the α-counting. Electrode materials which do not dissolve even at fairly positive potentials were selected for this study. The relation between Qₑ and applied potentials thus obtained is plotted in Fig. 1. The diffusion-controlled limiting Qₑ attained at sufficiently negative potentials is far less than the amount for mono-layer deposition (ca. 0.2 μg·cm⁻²). Therefore, the contribution of the interaction among Po atoms themselves at the surface of the electrode can be neglected in the electrodeposition and the penetration processes of Po.

Defining the half-deposition potential, E₀/², as the potential where Qₑ is a half of the limiting Qₑ in the ordinary voltammetry, E₀/² for the deposition of Po are +0.63, +0.51, +0.44 and +0.06 V vs SCE at Pt, Au, Ta and GC electrodes, respectively.

Since the bonding energy between discharged Po(0) and carbon is extremely small and, hence, the deposition of Po on GC requires the crystallization overpotential to form the Po(0)-Po(0) bonding, E₀/² at GC lies at more negative potential than the formal potential for Po(0)/Po(II) couple, ca. +0.40 V vs SCE.

At metal electrodes (Mₑ), E₀/²'s are at more positive than the formal potential because of bonding between Po(0) and Mₑ (Underpotential deposition). Generally,
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the extent of the underpotential, $U_p$, is correlated to the difference of work function, $\Phi$, of the depositing metal, $M_\theta$, and that of $M_{el}$ by eqn. (1)\(^6\,7\):

$$U_p = \frac{1}{2e} \{\Phi(M_\theta) - \Phi(M_{el})\}$$

where $e$ is the elementary charge.

Although the critical evaluation of $U_p$ for the deposition of Po based on eqn (1) is difficult at the moment because of the uncertainty in $\Phi$ of Po reported, the order of $E_y\,\theta$ at Pt, Au and Ta electrodes is essentially the same as that of $\Phi$ for these metals ($\Phi$: 5.40, 5.0 and 4.15 eV for Pt, Au and Ta, respectively\(^7\,8\)).

Distinguishable discrepancy was not observed in $E_y\,\theta$ when the concentration of Po in the electrolytic solution was changed from $10^{-11}$ to $10^{-9}$ M.

**Penetration of discharged polonium, Po(0), into electrode metals**

The penetration of Po(0) discharged at the surface of $M_{el}$ into $M_{el}$ was investigated by measuring the $\alpha$-ray spectra of deposited $^{210}$Po.

If the deposited Po penetrate deep into $M_{el}$, the energy of $\alpha$-ray is lowered by the stopping power of $M_{el}$. Hence, the extent of the penetration (D, $\mu$m) can be determined from the energy shift of $\alpha$-ray using $^{4}$He projected ranges ($R_p, \mu$m)” given as eqn (2) by Ziegler\(^9\).

$$R_p(E) = \exp(A_1 + A_2 EE + A_3 EE^2 + A_4 EE^3 + A_5 EE^4 + A_6 EE^5)$$

$$D = R_p(E_0) - R_p(E_i)$$

In eqn (2), $E$, $EE$ and $A_i$ are the energy of $\alpha$ particle in keV, ln $E$ and constants given for individual metal, respectively. $E_0$ and $E_i$ are the energy of $\alpha$ particle emitted from $^{210}$Po deposited at the surface of $M_{el}$ and that penetrated to a definite distance from the surface (cf. Fig. 2). Equation (2) is valid for $\alpha$ particle of $E$
Fig. 2. Energy of α particles emitted from ²¹⁰Po at the surface and penetrated in a metal electrode.

Fig. 3. α-ray spectra of electrodeposited ²¹⁰Po. Deposited at −1.0 V vs SCE for 3 hrs in a solution of 0.016 μCi·ml⁻¹ (1.68 × 10⁻¹¹ M) in ²¹⁰Po and 0.5 M in HNO₃. Electrode materials: 1: Pt, 2: Bi, 3: Pb. Amount of ²¹⁰Po deposited on Pt, Bi, and Pb were 0.60 × 10⁻⁶, 1.2 × 10⁻⁶ and 1.3 × 10⁻⁶ μg·cm⁻², respectively.

between 1 keV and 10 MeV.

Figure 3 realizes α-ray spectra of ²¹⁰Po obtained by the following procedure; ²¹⁰Po was electrodeposited on various Mₑ at −1.0 V vs SCE for 3 hrs in a solution which is 0.016 μCi·ml⁻¹ (1.68 × 10⁻¹¹ M) in ²¹⁰Po and 0.5 M in HNO₃, and the Mₑ with deposited Po was washed with water and then acetone. After drying the Mₑ was set in a vacuum chamber and the α-ray spectrum was measured by a surface
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barrier type detector. The deposition potential, $-1.0 \, V$, is negative enough for the deposition of Po and, at this potential, the dissolution of all $M_{el}$ investigated does not take place even in acidic media.

The penetration of Po into Pt is considered to be negligible since the spectrum exhibited a sharp peak at around 5.3 MeV which is the energy of $\alpha$-ray from $^{210}\text{Po}$ itself. The obvious tailing toward lower energy range was observed in the spectrum when $M_{el}$ was Pb or Bi indicating the serious penetration of $^{210}\text{Po}$ into these $M_{el}$.

In Fig. 4, $\alpha$-ray spectra in Fig. 3 are replotted as functions of the logarithm of counts vs energy. In the followings we will discuss the extent of the penetration ($D$) employing the energy ($E_D$) at which the extrapolation of the straight part in the logarithmic plot (indicated by broken lines in Fig. 4) merges in the background under the assumption that $E_D$ is the energy of $\alpha$ particle emitted from $^{210}\text{Po}$ which penetrated into the deepest part in $M_{el}$. Substituting thus obtained $E_D$ into eqns (2) and (3), $D$ is estimated as 0.46, 3.0 or 5.1 $\mu$m for Pt, Bi and Pb, respectively. In this connection, when $M_{el}$ on which Po had been deposited were stood for 3 days at room temperature in air, the increase of $D$ was not observed.

Following to the procedure mentioned above, $D$ for various $M_{el}$ other than Pt, Bi and Pb were examined. Although the results were not so reproducible, roughly speaking, $D$ were more than 3 $\mu$m when $M_{el}$ were Te and Tl, 1 to 3 $\mu$m when Cd, In, Sn and Sb, and less than 1 $\mu$m when Al, Co, Ni, Cu, Zn, Nb, Mo, Pd, Ag, W, GC and stainless steel (SUS 304).

These results suggest that $D$ is strongly related to melting points and/or hardness of metals which are controlled by lattice energies of metals. Po may penetrate
Fig. 5. Effect of deposition potential on α-ray spectra of 210Po deposited on Pb.
Electrodeposition for 3 hrs in a solution of 0.016 μCi·ml⁻¹ (1.68×10⁻¹¹ M) in 210Po and 0.5 M in HNO₃. Deposition potential; 1: —0.60, 2: —0.75, 3: —1.00, 4: —1.50, 5: —1.75 V vs SCE. Curves 6 and 7; as curve 1, but electrolyzed for 12 hrs at —0.75 and —1.50 V, respectively, in 0.5 M HNO₃ without Po after deposition at —0.60 V.

The relation between the extent of penetration and the electrode potential for the electrodeposition of Po was also studied using Pb as Mₑal. Curves 1 to 5 in Fig. 5 are the results obtained by the same procedure as that for Curve 3 in Fig. 4 but varying the electrodeposition potential to a potential between —0.6 and —1.75 V vs SCE where the dissolution of Pb does not occur. Po penetrated deeper with the deposition potential more negative in the range —0.6 to —1.5 V. When Pb electrode on which Po had been deposited at —0.6 V under the same condition as for Curve 1 was further electrolyzed for 12 hrs at —0.75 or —1.50 V in 0.5 M HNO₃ solution in the absence of Po, the penetration proceeded depending on the electrolysis potential as demonstrated in Curve 6 or 7. Employing Bi as Mₑal instead of Pb, similar phenomena were observed.

The effect of electrodeposition or electrolysis potential on the penetration of Po indicates that the energy level of free electron in Mₑal plays very important role in the mobility of such discharged atoms as Po(0) in Mₑal.

REFERENCES

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