Behavior of Phosphoric Acid Anodized Oxide on Aluminum in Phosphate Buffer Solutions

Phan Trung Thanh*, Akitane AKIYAMA* and Takashi SAJI*

Behavior of anodic oxide films formed on 1100-Al in a phosphoric acid bath have been investigated in phosphate buffer solutions of pH 1.40, 6.23, 11.30 and an Al saturated neutral phosphate solution. The amount of dissolved Al ions into the buffer solutions, the open circuit potential and the polarization resistance were measured as a function of immersion time. The results were compared with those of anodic oxide films formed in a sulfuric acid bath for more detailed discussions. It was found that the phosphoric acid anodized (PAA) oxide films were more corrosion resistive in acidic and alkaline buffer solutions than the sulfuric acid anodized films. However, in a neutral solution, the results were opposite and were explained by the degradation converging upon active sites within the PAA oxide. The open circuit potential transients were interpreted by the distribution profiles of Al, P and S within the anodic oxides which were analyzed by an X-ray micro-analyzer.

1 Introduction

Anodized aluminum finds increasing use in building and aerospace industries because of its excellent corrosion resistance and other abilities. The surface preparation of aluminum for adhesive bonding receiving great interest in the aircraft industry is anodization in phosphoric acid¹⁾. Other extensive applications of phosphoric acid anodized (PAA) aluminum are found for Al print plate²⁾ and for electroplating of various metal^{3,4)}.

In the past, most investigations of PAA aluminum were on the film formation kinetic^{5,6)}, on the film structure⁷⁻⁹⁾ and on the chemical and physical properties¹⁰⁾. The structure of the PAA oxide consists generally of duplex layers: a porous top layer constructed of closely packed columnar cells, each with a central pore, and a simple dense layer of uniform thickness, as so-called barrier layer⁷⁾. This is a common structure of porous-type anodic oxides formed in various acidic electrolytes, e. g. sulfuric acid, chromic acid, phosphoric acid, *etc.* However, it is found strictly that there were many differences in the morphology, the chemical and electrochemical natures and other characteristics of these oxides. The electroplating of various metal on the PAA oxide films has been investi-

gated in our laboratory, in comparison with the oxide films formed in sulfuric acid¹¹⁾. Recently, the investigations on the morphology and crystalline structures of the two oxide films have been described by Thompson, *et al.*^{7,11)}. However, there is a paucity of literature on the chemical and electrochemical natures of the PAA oxide film. Lack of information on these natures has contributed to obscurity in the oxide growth mechanism and to uncertainty in predicting the durability of PAA oxides for industrial applications.

A number of works have been done regarding the electrochemical behavior and structure of the Al anodic oxide film formed in a neutral borate solution using the same solution¹²⁾, and regarding the hydrogen evolution reaction on the Al hydrated oxide in a weak acidic acetate solution¹³⁾. It should be noted that Al ions have a comparatively high solubility in the borate electrolyte and this fact can be explained by taking into account the formation of soluble complexes between Al and anions. The electrolytes chosen in the present work are phosphate buffer solutions, not only because the PAA oxide film contains phosphate ions, but also because of its buffer action in three acidic, neutral and alkaline regions.

The purpose of this work is to investigate the behavior of the PAA oxide film in the phosphate buffer solutions and, as shown later, the aluminum saturated neutral phosphate solution is found as a new, suitable electrolyte in the electrochemical study. The results are co-

* Tokyo Institute of Technology, Graduate School at Nagatsuta (4259 Nagatsuta-cho, Midori-ku, Yokohama)

Key Words: Phosphoric Acid Anodized Aluminum, Anodic Oxide on Aluminum, Dissolution in Phosphate Buffer Solutions

mpared with those of anodic oxide films formed in sulfuric acid for more detailed discussions.

2 Experimental

2.1 Electrode

A rod of commercially pure Al (1100-Al) containing 0.2% Cu, 1% Si and Fe, 0.1% Mn and 0.1% Zn as major impurities was cut into cylinder of approximately 1 cm long and 1 cm in diameter. The electrode was center drilled and attached to a stainless steel mounting rod and three teflon compression gaskets¹⁴⁾. Before use, the electrode was abraded with SiC paper from #800 to #1500, cleaned by an ultrasonic rinse in distilled water and stored in a desiccator. The aluminum-teflon electrode assembly, before anodizing, was degreased at 65°C in 1.13 M NaOH solution for 10 s, rinsed for 2 min with gentle agitation in distilled water and transferred into the anodizing bath without drying.

2.2 Anodizing

Anodic oxide films were formed in 3.57 M H_3PO_4 and in 2.83 M H_2SO_4 solutions at $25 \pm 1^\circ\text{C}$ with a cylindrical lead cathode. The operating conditions for anodizing are shown in Table 1. The electrolyte was agitated with a magnetic teflon stirrer during experiment. The electrode anodized in the phosphoric acid bath and in the sulfuric acid bath was named P and S electrode, respectively. The electrode represented by A was not anodized and the surface

was covered by a very thin air-formed film¹³⁾.

2.3 Polarization

The polarization experiments were performed in a six neck polarization cell¹⁴⁾ with two platinum counter electrodes and a mercurous phosphate reference electrode (MPE, $E_o = 649.3 \text{ mV}$ vs. NHE at 25°C). Both the cell and the MPE were kept in a thermostat bath at $25.0 \pm 0.1^\circ\text{C}$. Three buffer electrolytes (total concentration 0.5 M) were prepared from reagent grade phosphoric acid and its sodium salts and the pH values were 1.40, 6.23 and 11.30. The experiments were also carried out in an aluminum saturated neutral solution (pH 6.23) containing 20 mg dm^{-3} Al ion. Dissolved oxygen was removed by bubbling nitrogen gas before and during experiment.

The anodized electrode was rinsed in distilled water for 1 min and immersed immediately in the polarizing electrolyte. The open circuit potential (ϵ_{ocp}) was recorded through a high input impedance voltage follower and displayed by a digital voltmeter. The electrode potential reported refers to the MPE. The polarization resistance (R_p) measurement was conducted intermittently for 2 days by applying very small constant cds (ca. 10^{-5} A/m^2) for 15 s causing overvoltages within $\pm 5 \text{ mV}$. This polarizing time was chosen, not only because it caused no appreciable change in the film nature during polarization, but also because it was long enough to charge up the double layer¹⁵⁾. The R_p values were calculated from the slope of the

Table 1 Anodizing conditions, film thicknesses (θ) and amounts of Al within oxide films (C_o)

Electrode		Anodizing cd/Am ⁻²	Anodizing time/min	Anodizing voltage/V	Thickness θ/μm	C _o /mg dm ⁻³	C _o × θ ⁻¹
H ₃ PO ₄ bath	P1	100	20	66.0	8.5	11.2	1.3
	P2	100	40	65.0	8.5	12.4	1.5
	P3	100	60	65.5	9.0	12.6	1.4
	P4	130	30	82.0	7.8	13.2	1.7
	P5	50	80	40.0	3.9	6.3	1.6
H ₂ SO ₄ bath	S1	100	20	9.1	2.9	24.4	8.4
	S2	100	40	10.0	10.0	57.2	5.7
	S3	100	60	11.0	14.9	71.8	4.8
	S4	130	30	13.0	10.2	58.2	5.7
	S5	50	80	6.4	10.9	53.6	4.9
A		0	0	—	—	—	—

linear polarization curve.

2.4 Chemical analysis

The amount of dissolved Al ion (C_d) into the buffer solutions was determined as a function of immersion time by analyzing the solution sample of 2 cm³ with an oxinate extraction method¹⁶⁾. The pH of each solution sample was adjusted with 2 M sodium acetate solution to 9.00 just before the extraction in order to avoid interference of phosphorus. The absorbance of the chloroform extract was read with a spectrophotometer at 390 nm after removing droplets of water by 1 g of anhydrous sodium sulfate crystal. The calibration curve was obtained with a standard solution of potassium alum. Furthermore, the amount of Al contained in anodic oxide (C_o) was measured by dissolving oxide film into the well-known stripping solution of 5% H₃PO₄ and 4% K₂Cr₂O₇ solution at 85°C for 30 s and analyzing with the above method. The results are also listed in Table 1.

2.5 X-ray microanalyzer (EPMA) analysis

The distributions of Al, P and S in the cross-sectional view of anodic oxide film were measured by EPMA analysis. A thin vacuum evaporated coating was prepared on the sample cross-section embedded in epoxy resin. The incident electron beam of about 200 Å in diameter produced informations within a region of 1~2 μm in depth and in diameter.

3 Results

Depending on the anodizing bath, a typical open circuit potential (ϵ_{ocp}) transient of the P and S anodic oxide electrodes in the alkaline polarizing electrolyte has one of the two patterns shown respectively in Figs. 1 and 2 (solid lines). The ϵ_{ocp} transient of A electrode is also shown in the figures (dotted lines). The amounts of Al ion dissolved into the polarizing electrolyte during immersion (C_d) are also shown in the figures in comparison with that of A electrode. The vertical broken line (t_h) in the figures represents the time of hydrogen evolution seen with the naked eye. Both Figs. 1 and 2 share several features in common. (1) The ϵ_{ocp} has a sharp decrease towards the cathodic direction immediately upon immersion and a nearly constant value in the final stage.

Fig. 1 Open circuit potential (ϵ_{ocp}) and amount of dissolved Al ions (C_d) of P electrodes in the alkaline buffer solution (solid lines)

Anodizing conditions: 100 A/m², 40 min (P2). The dotted lines represent the results of the non-anodized electrode (A)

Fig. 2 Open circuit potential (ϵ_{ocp}) and amount of dissolved Al ions (C_d) of S electrodes in the alkaline buffer solution (solid lines)

Anodizing conditions: 100 A/m², 40 min (S2). The dotted lines represent the results of the non-anodized electrode (A)

(2) The C_d increases steadily with the immersion time in the first stage, *i.e.* the dissolution rate is constant, but it changes to a smaller value in the later stage. The final dissolution rate is exactly same as that observed for A electrode.

In addition to the above common features, each of the two patterns has its distinct characteristics. Figure 1 (for P electrode) shows a gradual decrease of the ϵ_{ocp} , but the ϵ_{ocp} in Fig. 2 (for S electrode), in contrast, has a plateau at about -1.0 V before the sharp decay towards the final steady value. Furthermore,

the C_d of the S electrode, at a certain time, is greater than that of the P electrode.

The same ε_{ocp} and C_d transients of both electrode types (S and P) are observed in the other unsaturated electrolytes. That is, (1) the ε_{ocp} , in the case of P electrode, decreases gradually in the cathodic direction; but in the case of S electrode, it has usually a potential plateau, (2) the dissolution rate is constant in the first stage and changes to a smaller value in the final stage which is identical with the dissolution rate of A electrode. However, the C_d values in the neutral electrolyte is very small compared to those in the acidic and alkaline electrolytes and has a constant value (ca. 18 mg dm⁻³) for all electrodes in the final stage.

The experimental results obtained in three polarizing electrolytes are summarized in Tables 1 and 2. θ in Table 1 represents the oxide film thickness obtained from the optical microscopic observation of the specimen cross-sectional view. C_h in Table 2 is the amount of dissolved Al ion into the acidic and alkaline electrolytes at the hydrogen evolution time t_h . The dissolution rates in the first stage (a) obtained from the initial linear portions of the C_d transients are also listed in Table 2.

The polarization resistances (R_p) obtained in the saturated neutral electrolyte as a function of immersion time are typically shown in Fig. 3. A decrease of R_p with the immersion time is observed for P electrode (solid line); however, for S electrode (broken line) R_p is high

and relatively constant. The R_p value of A electrode (dotted line) is very small at all immersion time compared with those of the anodized electrodes.

The depth profiles of Al, P and S in the respective anodic oxide films are shown in Figs. 4a and 4b. In the P electrode (Fig. 4a), the Al profile shows an increase from the oxide surface to the Al matrix and the P profile has a maximum at about 1/3 of the oxide film from the oxide-metal interface. In the S electrode (Fig. 4b), the Al and S profiles are

Fig. 3 Polarization resistance of electrodes in the Al saturated neutral buffer solution

S2: Electrode anodized in sulfuric acid,
P2: Electrode anodized in phosphoric acid, A: Non-anodized electrode

Table 2 Results of the open circuit dissolution of the anodic oxide films in three phosphate buffer solutions

Electrode	t_h/min		$C_h/\text{mg dm}^{-3}$		$a/\text{mg dm}^{-3} \text{ min}^{-1}$		
	acidic	alkaline	acidic	alkaline	acidic	alkaline	neutral
P1	91.5	32.5	17.4	10.6	0.24	0.30	0.014
P2	91.5	40.0	21.6	17.5	0.31	0.47	0.017
P3	93.5	30.0	22.8	13.0	0.32	0.42	0.016
P4	97.5	—	25.7	—	0.35	—	0.014
P5	85.0	—	7.1	—	0.22	—	0.013
S1	26.0	14.0	26.0	26.5	1.60	2.24	0.016
S2	34.5	22.0	57.0	47.0	2.41	2.91	0.019
S3	37.0	24.0	73.0	68.0	3.33	2.24	0.020
S4	37.0	—	57.0	—	2.48	—	0.017
S5	23.0	—	28.0	—	2.40	—	0.018

Fig. 4 Distribution profiles of Al, P and S in the anodic oxide film formed in a phosphoric acid bath and in a sulfuric acid bath

(A) : P electrode, (B) : S electrode

constant in the middle of the oxide film. These results, as discussed later, show that the film composition seems to be homogeneous in the S electrode, but it varies with the distance from the Al matrix in the P electrode.

4 Discussion

4.1 Formation of oxide film in phosphoric acid anodizing solution

The morphology and the composition of the PAA oxide film have been yielded in some studies⁷⁻⁹⁾ with different anodizing conditions. The oxide film thickness is generally as a function of the anodizing time and the solution concentration. In the present work, it should be noted that the oxide film thickness (θ) was independent of the anodizing time in phosphoric acid at a constant cd ; whereas, θ increased linearly with anodizing time in sulfuric acid (1, 2 and 3 electrodes in Table 1). Alternatively, when both the anodizing cd and time were changed giving a constant anodizing charge (2, 4 and 5 electrodes in Table 1), θ was nearly constant for S electrodes as predicted, but it was different for P electrodes. In addition, the ratio values of C_o/θ was nearly 1.5 and 5 for P and S electrodes, respectively, and independent of the anodizing conditions. This suggests that C_o also represents the oxide film thickness.

It has been known that the so-called field-assisted dissolution participated during anodization was a key mechanism of porous oxide growth¹⁷⁾. According to this theory, once the porous structure initiated, each pore grew by preferential oxidation and dissolution at the bottom of the

pore where the field strength was greatest. The anodizing voltages of P electrodes were much higher than those of S electrodes (Table 1), and, as a result, the high dissolution at the pore bottom hindered the increase of the oxide film thickness and provided a constant thickness within this anodizing time range. The constant film thickness after a certain anodizing time was also reported in some works^{1,9)}, although a smaller anodizing potential has been applied. The small anodizing voltages of S electrodes caused reasonably a lower dissolution rate and provided a linear increase of the film thickness. A similar result was reported by Thompson, *et al.*¹¹⁾ using an electron microscopy method. The results obtained for oxides formed in constant charge were also understood by the above discussion.

4.2 Open circuit dissolution of oxide film in phosphate buffer solutions

The open circuit dissolution of porous oxide film has been investigated in some works^{18,19)} and may be chemical rather than electrochemical in nature; however, it remains an open question. It is noted that the dissolving solutions in these experiments were unbuffered ones. The chemical dissolution, in which whether anion is involved or not, should be dependent on the pH of the dissolving solution. Thus in this work, it is reasonable to consider that the dissolution rate in the acidic and alkaline buffer solutions is very much higher than that in the neutral solution.

The dissolution rates (a), obtained from the initial linear portions of the C_d transients, of P electrodes in the acidic and alkaline solutions were smaller than those of S electrodes (Table 2); even if the difference of the ratios C_o/θ (Table 1) was considered. This suggests that the PAA oxide film is more corrosion resistive in acidic and alkaline media than the sulfuric acid anodized film. On the other hand, in the neutral solution, the dissolution rates of P electrodes were higher than those of S electrodes, if also taking consideration of the C_o/θ values.

The amount of dissolved Al at t_h (C_h) was almost the same value as the corresponding amount of Al within oxide film (C_o) (Tables 1 and 2). This indicates that, in the acidic and alkaline solutions, the original oxide film was

dissolved completely at t_h ; indeed, after this period, the dissolution rate decreased to the value of the bare A electrode (Figs. 1 and 2). This decrease suggests the presence of the underlying barrier layer. The more pronounced (longer time) decrease for P electrode than for S electrode, as seen in Figs. 1 and 2, suggests that the barrier layer thickness of P electrode was thicker. This fact is reasonable since the applied voltage of P electrode was higher than that of S electrode. When t_h became long, the C_h value tended to increase and this may be caused by the dissolution from the Al substrate before t_h .

According to Abd Rabbo *et al.*²⁰⁾, the phosphate anions ($H_2PO_4^-$, HPO_4^{2-} , *etc.*) was strong chemisorptive and degraded the Al anodic oxide in a neutral phosphate solution. The degradation of the anodic oxide may become appreciable to the above chemical dissolution in the unsaturated neutral solution and should be considered even in the saturated neutral solution. The higher dissolution rate for P electrodes than for S electrodes in the unsaturated neutral solution, as described above, was interpreted by this aggressive nature and by existence of active sites containing in the oxide film. The studies on electroplating^{3,4)} and on corrosion¹⁵⁾ of anodic oxide film had suggested there are many active sites at the surface of the PAA oxide. The film degradation converging upon these active sites caused the decrease of the polarization resistance in the saturated neutral solution (Fig. 3), in which the chemical dissolution was negligible. Namely, the polarization resistance (R_p) of P electrode was very high at the very early stage, but decreased with immersion time; while the polarization resistance of S electrode was constantly high throughout the experiment. In addition, the initial R_p value right after the immersion was higher for P electrodes than for S electrodes. This result was substantiated by the fact that the barrier layer of P electrode was thicker as noted above. The nature and the formation of the active sites will be discussed in detail in a further study²¹⁾.

4.3 Relation between the ϵ_{ocp} transients and the film composition

The distribution of Al, P and S in the cross-

sectional view of the oxide film were quite different for the two electrodes (Fig. 4). These distributions have been investigated in a number of works: with an indirect method using the dissolution experiment in an acidic solution¹⁹⁾ and with a direct method using many electron spectroscopy analyses, *e. g.*, Auger electron spectroscopy^{1,22,23)}, secondary ion mass spectroscopy²⁰⁾, ion scattering spectroscopy²⁴⁾ and X-ray microanalyzer analysis²⁵⁾. There were some discrepancies between these studies; however, the common picture of the distributions of Al, O and anions (P and S) were as follows. (1) The distribution profiles of Al and O were relatively identical, indicating that the stoichiometry of the anodic oxide was invariant with depth, and were nearly constant through the oxide film. (2) P distributed largely within the region adjacent to the oxide surface and decreased gradually in the oxide film. (3) S distributed uniformly through the oxide film.

In the analysis of the depth profiles obtained with a X-ray microanalyzer, the amplitudes of Al and anions were small in the surface region (Fig. 4). This finding is in agreement with the result of Takahashi, *et al.*²⁵⁾ who studied various anodic oxide on pure Al and its alloy with the same method. This fact has been interpreted by the funnel shape of the pores which became large as near as the oxide surface²⁶⁾. Furthermore, as a characteristic of this method, the information obtained was one of relatively large region, as noted above, and seemed to be dependent closely upon the oxide surface morphology. Taking consideration of this characteristic, the distributions of Al, P and S in Fig. 4 may be coincident with the results described above.

The ϵ_{ocp} transients with the immersion time was also quite different (Figs. 1 and 2) and could be explained with knowing the film composition²⁷⁾. Namely, in the case of S electrode (Fig. 2), the oxide film was homogeneous; therefore, the open circuit dissolution of the porous layer caused the reduction of film thickness, but not the change of film composition. The potential plateau at ca. -1.0 V was observed until the porous layer had completely dissolved off and followed by the drastic potential decrease before the hydrogen evolu-

tion. On the other hand, in the case of P electrode (Fig. 1), the composition of the porous layer was changed with depth; therefore, upon the open circuit dissolution from the film surface, the ϵ_{ocp} changed gradually with the immersion time and the potential plateau was not observed.

This explanation of the ϵ_{ocp} transients is, of course, not yet sufficient. Other factors such as impurities or alloy components, film morphology etc. may play a role in the open circuit dissolution. Further studies along this line are needed to clarify this dissolution type.

Finally, the saturated neutral phosphate buffer solution is concluded as a suitable electrolyte for an electrochemical study, specially for an evaluation of corrosion resistance²¹⁾ because the chemical dissolution of anodic oxide during immersion in this solution is thermodynamically impossible. The aggressive nature of phosphate anions converging upon the active sites within oxide film might occur in this system; however, it may be negligible in a measurement during a short period of time.

References:

- 1) J.S. Solomon and D.E. Hanlin, *Appl. Surface Sci.* **4**, 307 (1980).
- 2) 日本特許公報, 昭 46-26521 (1971).
- 3) A. Akiyama, K. Yasuhara, T. Tanaka and T. Saji, *Plating* **58**, 594 (1971).
- 4) 佐治 孝, 秋山明胤, 真野 徹, 金属表面技術 **24**, 323 (1973).
- 5) J.P. O'Sullivan and G.C. Wood, *Proc. Roy. Soc. A* **317**, 511 (1970).
- 6) G.E. Thompson, R.C. Furneaux, G.C. Wood, J.A. Richardson and J.S. Goode, *Nature* **272**, 433 (1978).
- 7) G.E. Thompson, R.C. Furneaux, J.S. Goode and G.C. Wood, *Trans. Ins. Met. Finish.* **56**, 159 (1978).
- 8) 高橋英明, 永山政一, 日本化学会誌 **453** (1974).
- 9) J.S. Ahearn, T.S. Sun, C. Froede, J.D. Venables and R. Hopping, *SAMPE Quarterly*, 39 (1980).
- 10) K.V. Heber, *Electrochim. Acta* **23**, 127 (1978).
- 11) G.E. Thompson, R.C. Furneaux and G.C. Wood, *Trans. Ins. Met. Finish.* **55**, 117 (1977).
- 12) H. Takahashi and M. Nagayama, *Electrochim. Acta* **23**, 279 (1978).
- 13) A.K. Vijh, *J. Phys. Chem.* **73**, 506 (1969).
- 14) N.D. Greene, *Electrochemical Electrode Kinetics*, New York (1965).
- 15) P.T. Thanh, A. Akiyama and T. Saji, 防食技術 **30**, 265 (1981).
- 16) Snell and Snell, *Colometric Methods of Analysis*, Vol. IIA (1959).
- 17) J.M. Diggle, *Oxide and Oxide Films*, Vol. 2, p. 354 (1973), Marcel Dekker, New York.
- 18) J.W. Diggle, T.C. Downie and C.W. Goulding, *J. Electrochem. Soc.* **116**, 1347 (1969).
- 19) M. Nagayama and K. Tamura, *Electrochim. Acta* **12**, 1097 (1967).
- 20) M.F. Abd Rabbo, J.A. Richardson, G.C. Wood and C.K. Jackson, *Corr. Sci.* **16**, 677 (1976); **16**, 689 (1976).
- 21) P.T. Thanh, A. Akiyama and T. Saji, *Electrochim. Acta*, in preparation.
- 22) R. Bador, G. Bouyssoux, M. Romand, J.S. Solomon and W.L. Baun, *Mater. Res. Bull.* **12**, 197 (1977).
- 23) T.S. Sun, D.K. Mc Namara, J.S. Ahearn, J.M. Chen, B. Ditchek and J.D. Venables, *Appl. Surface Sci.* **5**, 406 (1980).
- 24) H.H. Stekblow and D.L. Malm, *Corr. Sci.* **19**, 469 (1979).
- 25) 高橋俊郎, 長野年宏, 和田健二, 池ヶ谷正志, 田賀井秀夫, 金属表面技術 **23**, 18 (1972).
- 26) K. Huber, *J. Colloid. Sci.* **3**, 3, 197 (1948).
- 27) K.J. Vetter, *Electrochim. Acta* **16**, 1923 (1971).

(Received Jun. 16, 1981; Accepted Aug. 26, 1981)

<本会刊行図書案内>

電池技術委員会 30 周年記念 電池 技術

電気化学協会電池技術委員会編 B5判 本文 155 ページ 頒布価 5,000 円 (送料 300 円)

☆本書は、電池技術委員会の設立 30 周年を記念して、委員会の各メンバーが分担執筆してまとめたもので、業界と学界の協力により総合的、かつ普遍的に、電池全般の現況が紹介されています。省資源、省エネルギーはエネルギーの有効利用と両輪をなすものであり、高いエネルギー効率を特徴とする電池系によるエネルギー変換法は、今後ますます重要なものとなり、しかも移動用、携帯用電池としての電池の応用は拡大されるばかりであります。本書が大方のお役に立てうればと願っております。

☆内 容 ○一次電池の技術 ○マンガン乾電池 ○酸化銀電池 ○リチウム電池 ○その他の一次電池 ○二次電池の技術 ○鉛蓄電池 ○ニッケルカドミウム蓄電池 ○その他の二次電池 ○燃料電池 ○太陽電池 ○資料

☆申込先 ☎565 吹田市山田丘 2-1 大阪大学工学部応用化学教室内 電気化学協会電池技術委員会 (☎ 06-877-5111 内線 4301),

☎100 東京都千代田区有楽町 1-12-1 新有楽町ビル 電気化学協会 (☎ 03-214-6001)