DIFFUSION OF MAGNESIUM IN Al-Zn-Mg ALLOYS

S.-I. Fujikawa

Tohoku University, Sendai 980, Japan
Department of Materials Science, Faculty of Engineering,

ABSTRACT

The tracer diffusion coefficients of ^{28}Mg at 743 K in the region of α-solid solution of the pseudo-binary Al-$MgZn_2$ alloys were determined using the residual activity method. Carrier-free radioactive tracer ^{28}Mg was prepared by using the photonuclear reaction, $^{30}Si(\gamma, 2p)^{28}Mg$. The dependence of the diffusion coefficients on $MgZn_2$ concentration in the Al-$MgZn_2$ alloys was determined.

Keywords: *Al-Zn-Mg Alloys, pseudo-binary Al-MgZn2 alloys, tracer diffusion, Mg diffusion, diffusion coefficients*

1. INTRODUCTION

Al-Mg-Zn alloys are practically very important precipitation-hardening alloys. The diffusion data of Mg and Zn in the alloys are indispensable to analyze the fundamental behavior of the alloying elements in the alloys and control the various heat treatments such as homogenization, quenching and aging treatments of the alloys. The diffusion data for Zn in an Al-Zn-Mg alloys have been already reported [1]. However, no diffusion data of Mg in the alloys have been yet reported because of generally unavailable radioactive tracer ^{28}Mg with very short life-time ($t^{1/2}$=7.54x10^4 s). Recently, the diffusion coefficients of ^{28}Mg in Al-Mg-Si alloys have been measured [2]. As shown in Fig. 1, the Al-Zn-Mg system forms the pseudo-binary Al-$MgZn_2$ alloys [3]. In the present work, the tracer diffusion coefficients of Mg in the pseudo-binary alloys were determined as preliminary studies at 743 K using the tracer ^{28}Mg prepared by myself.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of carrier-free ^{28}Mg

The details of the preparation of 28Mg have been already described in elsewhere [4]. The 99.999 mass% purity silicon wafers for semiconductor industry was used as the target and was sealed in quartz tube of 10 mm in diameter. Bremsstrahlung irradiation was carried out at an electron energy of 60 MeV for 8.64x10^4 s by 300 MeV linear electron accelerator of Tohoku University. The sample tube was placed horizontally on the axis of the electron beam in close contact with the back of a Pt converter and cooled by running tap water. The chemical separation procedure for carrier-free ^{28}Mg is shown in Fig. 2. The radiochemical purity of ^{28}Mg was ascertained by measuring the γ-ray spectrum with Ge(Li) detector connected with multichannel pulse-height analyzer. The result is shown in Fig. 3. It shows that the separation of carrier-free ^{28}Mg and ^{24}Na is satisfactory.

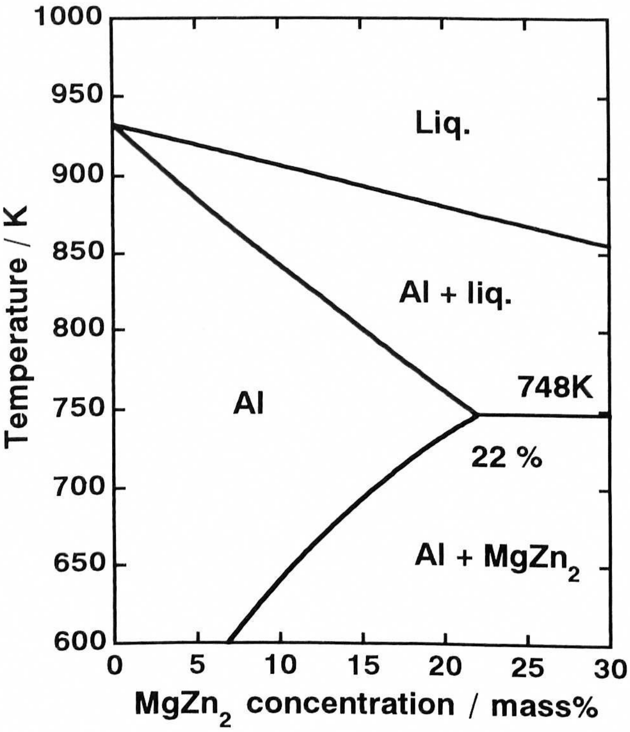

Fig. 1 Al-rich side phase diagram of pseudo-binary Al-MgZn2 system.

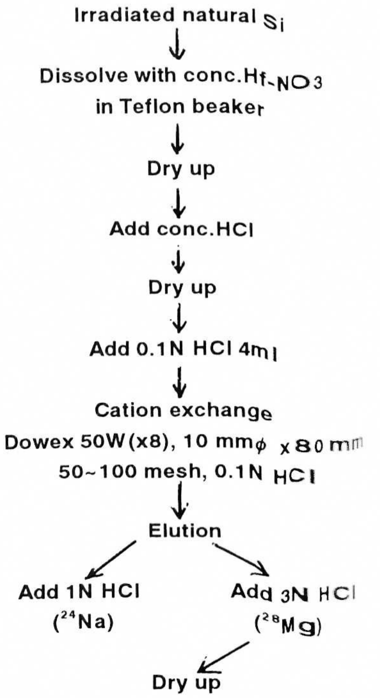

Fig. 2 Flow chart of production process of carrier-free ^{28}Mg from irradiated Si.

2.2 Diffusion experiment

The Al-Zn-Mg alloys prepared 99.99 mass% Al, 99.999 mass% Zn and 99.9 mass% Mg using a high-frequency induction furnace and cast into an iron mold. The ingots were finally machined into cylinder type specimens with 13 mm in diameter and 13 mm in height. The chemical composition and density are in Table 1. The density were determined by measuring the weight and volume. The specimens were annealed at 773 K for 1.3x10^6 s in order to homogenize the composition and make grain growth. The resultant grain size of the specimens was

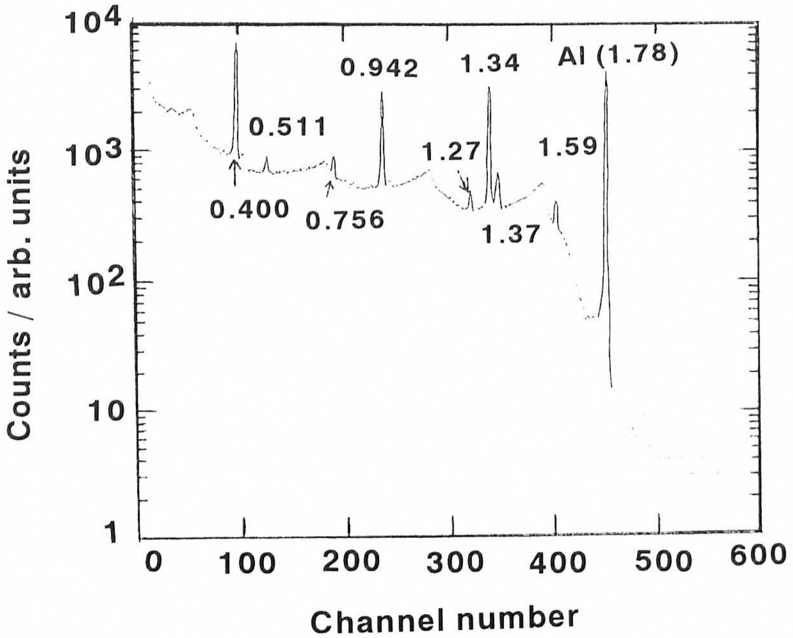

Fig. 3 γ–ray spectrum of ^{28}Mg obtained in the present work.

Table 1 Chemical composition and density of pseudo-binary Al-$MgZn_2$ alloys.

$MgZn_2$ mass%	Zn mass%(at.%)	Mg mass%(at.%)	density kg m^{-3}
2	1.89 (0.79)	0.23 (0.26)	2706
4	3.28 (1.38)	0.51 (0.58)	2728
6	5.21 (2.22)	0.80 (0.92)	2754
8	6.50 (2.79)	1.20 (1.38)	2775
10	8.10 (3.50)	1.49 (1.73)	2793
12	10.2 (4.47)	1.87 (2.20)	2828
14	11.4 (5.03)	2.06 (2.45)	2854
16	13.0 (5.79)	2.42 (2.90)	2880
18	14.7 (6.63)	2.65 (3.21)	2907
20	16.6 (7.56)	3.08 (3.73)	2932

about 2 mm. One face of each specimen was ground carefully with Si carbide paper. To remove the Al oxide layer, the specimens were electropolished in a solution of ethyl alcohol and perchloric acid. ^{28}Mg in the form of chloride was dried on the flat surface of the specimens. The metallic tracer was produced by the reaction of the chloride with aluminum in the very early stage of diffusion annealing. The specimens were then annealed in quartz tube containing about 27 kPa of high purity He gas at 293 K and a small amount of Mg tips to avoid evaporation of ^{28}Mg. The diffusion annealing was carried out at α-phase region, according to the phase diagram in Fig. 1. After the diffusion anneal, the cylindrical surface and the bottom of the specimens were reduced by a depth of about 1 mm using a precision lathe. This procedure eliminated the possible effects of surface diffusion and evaporation of ^{28}Mg from the deposited layer. Each specimen was analyzed by the residual activity technique whereby thin layers from the specimen surface were removed successively by grinding parallel to the flat surface with Si carbide paper. To count the total residual-activity of the bulk of the specimens after each grinding, a well-type NaI(Tl) scintillation counter and multi-channel pulse-height analyzer were used. The channel width of the latter was adjusted to count the γ-radiation of 0.942 and 1.34 MeV energies. The thickness of each section removed was measured by the weight-loss method using a microbalance.

3. RESULTS and DISCUSSION

The solution of Fick's second equation for a very thin radioactive layer at the end of a sufficiently long rod, analyzed by the residual-activity technique is given by

$$\begin{aligned} \mu I_n - dI_n/dX_n &= k_1 \bullet C(X_n) \\ &= k_2 \bullet \exp(-X_n^2/4Dt) \qquad (1) \end{aligned}$$

where μ is the linear absorption coefficient of the γ-radiation of ^{28}Mg in Al-Mg-Si alloys in m^{-1}, I_n is the bulk activity in counts per unit time after a layer of thickness X_n is removed, k_1 and k_2 are constants. $C(X_n)$ is the radioactive concentration at a distance X_n from the original surface. D is the diffusivity in m^2s^{-1} and t is the

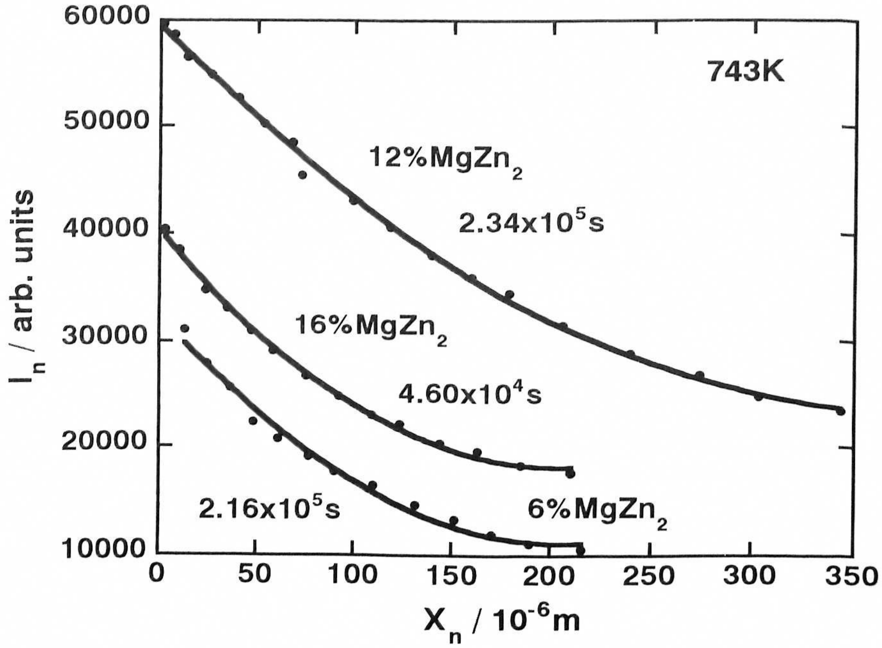

Fig. 4 Typical I_n vs. X_n plots for diffusion of ^{28}Mg in Al- $MgZn_2$ alloys.

diffusion time in seconds. The value of μ for the energy of the γ-radiation used in the present work was calculated using the values of μ for pure metals [5] and the composition of the Al-Zn-Mg alloys. It is found that the term of μI_n in the present work is negligibly small, in comparison with the term of $(-dI_n/dX_n)$. Consequently, the diffusion coefficients were determined from the plots of Log $(-dI_n/dX_n)$ vs. X_n^2 by Eq. 1. Fig. 4 shows the typical plots of I_n vs. X_n for each composition. Fig. 5 shows the typical plots of $C(X_n)$ vs. X_n^2 for each composition. Fig. 6 shows the dependence of the tracer diffusion coefficients on $MgZn_2$ concentration in the pseudo-binary Al-$MgZn_2$ alloys, in comparison with self-diffusion coefficients of aluminum [6] and the impurity diffusion coefficients of Mg in aluminum [7,8,9]. The tracer diffusion coefficients of ^{28}Mg in the pseudo-binary Al-$MgZn_2$ alloys increase with MgZn2 concentration.

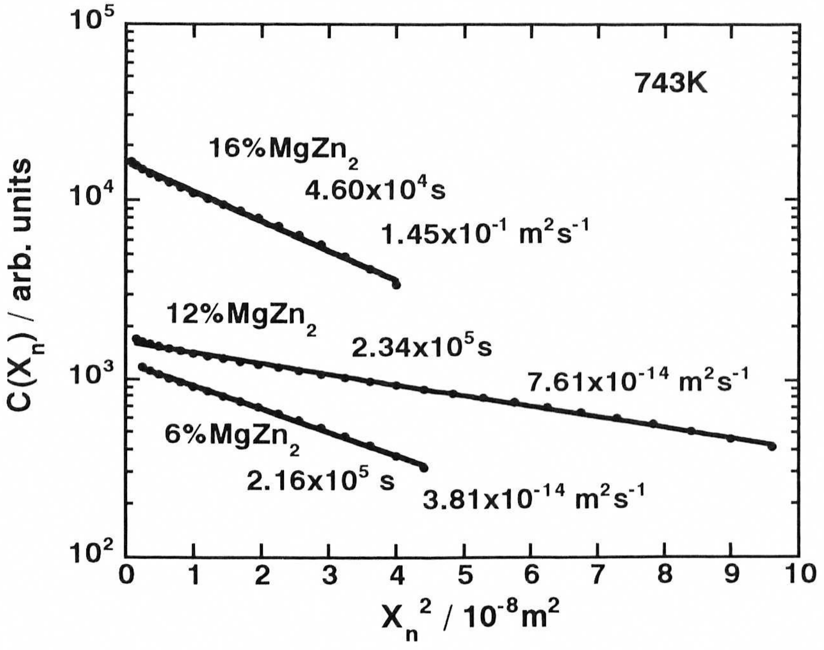

Fig. 5 Typical $C(X_n)$ vs. X_n^2 plots for diffusion of ^{28}Mg in Al-$MgZn_2$ alloys.

4. CONCLUSIONS

The tracer diffusion coefficients of ^{28}Mg in the region of α solid solution of the pseudo-binary Al-$MgZn_2$ alloys were determined using the residual activity method. The dependence of the tracer diffusion coefficients of ^{28}Mg on $MgZn_2$ concentration was clearly observed in the pseudo-binary Al-$MgZn_2$ alloys.

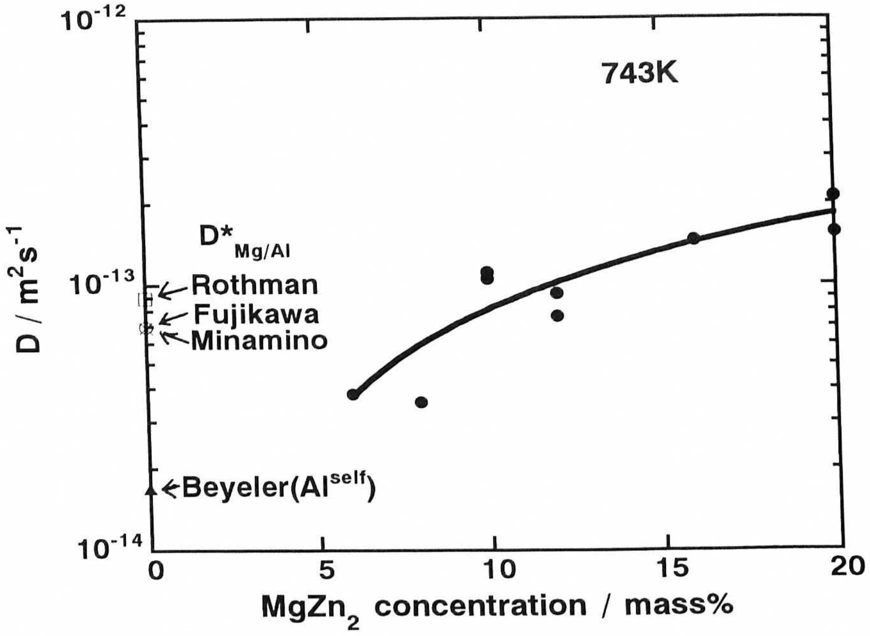

Fig. 6 Concentration dependence of tracer diffusivity of ^{28}Mg in Al-$MgZn_2$ alloys, in comparison with those for impurity diffusion of Mg and self-diffusion in aluminum.

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