Effects of Al$_2$O$_3$ Films on the Reliability of Au/Al Joint

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Abstract:

Effects of Al$_2$O$_3$ films in the system of Au/Al joint widely used in semiconductor devices at present have been studied. In the experiment, a thin film of Au/Al$_2$O$_3$/Al was used, and the diffusion of Au atoms across through Al$_2$O$_3$ films and the formation of intermetallic compound at temperatures between 25°C and 500°C were observed by using Auger electron spectroscopy, X-ray photoelectron spectroscopy, electric resistance measurement and secondary ion mass spectrometer with using ^{18}O as a tracer. It has been cleared from test results that, (1) Au diffuses through Al$_2$O$_3$ films and reacts to Al, (2) as temperature rises up, the intermetallic compound grows in an island formation for Au/Al$_2$O$_3$/Al system, and (3) the behavior of its growth varies with the presence of oxygen in the atmosphere applied. On the basis of the above results, the effects of Al$_2$O$_3$ films on the reliability of Au/Al joint are discussed in this paper.

1. Introduction

Recently, in parallel with the trend to miniaturization and increased functionality of electronic equipment, technologies aimed at achieving higher density and reliability in semiconductor packaging have become a key focus of attention. IC packaging is the process of connecting the LSI's electrode terminals with external terminals while protecting the LSI from the external environment through LSI encapsulation. This electrical connection has conventionally been accomplished between an LSI electrode film made of Al alloy and a lead frame or a substrate by connecting an Au bonding wire.

As packaging becomes more dense, fine pitch bonding intervals between electrodes less than 80μm are required. In this case, the diameter of the Au ball is reduced to 50μm. Ensuring the reliability of this connection presents an important development task

for guaranteeing the long-term usefulness of the devices.

Reliability of joints between Au balls and electrode films have been discussed since 1970[1-4]. Observing the cross-section of defective joints, there are cases in which electric continuity failure occurs due to voids formed in the neighborhood of the joint surface caused by the diffusion of Au/Al (see **Photo. 1**)[5]. The mechanism by which voids are formed has been discussed in various ways. Research regarding intermetallic formation occurring on the interface and the influence of the annealing atmosphere has been published[2]. However, we have not been able to explain the presence or absence of IC failures in individual devices in an integrated manner. It is still seen as a cause for failure during use and lower yields observed in heating tests before distribution.

The present study focuses on the close relationship between these voids and the diffusion behavior in interface of Au/Al after joining. Assuming that this diffusion behavior depends on the distribution of Al$_2$O$_3$ films on a joint interface and diffusion behavior

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in oxide film, we made a detailed survey on the diffusion behavior of $Au/Al_2O_3/Al$'s diffusing couple (abbreviated below as $Au/Al_2O_3/Al$).

2. Previous Works[5, 6)]

Wire bonding methods, supply wires to a capillary and the tip of the wire is transformed into ball-like shape through application of an arc discharge. This bonded ball is connected onto an Al electrode using thermo-compression bonding with a ultrasonic vibration applied. When this ball is attached, Al_2O_3 films on the surface of the Al electrode is destroyed by elastic deformation of Au and Al. The Au/Al interface after bonding has parts in which Au and Al are joined at the active surfaces and those on which Al_2O_3 films remain as shown in **Fig. 1**.

The reliability of joints between the Al electrode and the Au bonding wire is extremely important for guaranteeing the IC a long life span. To predict the life span of an IC, acceleration tests by heating are often conducted. In this case, Al_2O_3 films on the Al vapor deposited film existing in the joint interface as in **Fig. 1** inhibit homogeneous diffusion of Au/Al to facilitate void formation in the joint interface causes IC failure.

The tip of the Au wire drawn to diameter of 25µm (purity greater than 99.999%) was transformed into a ball (75µm ϕ) by an arc discharge. This ball was jointed with an Al electrode (coating thickness of 1µm) on an Si chip using thermo-compression bonding accompanied by ultrasonic vibration (initial shear strength 0.37N). The results of the experiment using this diffusion couple showed that the generation of intermetallic compounds in the Au/Al interface is relatively homogeneous, when annealed in vacum, as illustrated in **Fig. 1** with almost no voids. However, when annealed in the atmosphere, voids inside the Au-Al diffusion layer become easily noticeable[5)]. When homogeneous intermetallic compound is formed through annealing, void generation was not observed even after being annealed in the atmosphere. On the other hand, when inhomogeneous growth of compounds

occurs due to initial annealing in the atmosphere, the generation of voids cannot be inhibited even with vacuum annealing afterwards. Even using identical Al films and Au wires, the formation behavior of intermetallic compounds in the interface and formation of voids in the Al-Au diffusion layer depend on jointing conditions and the ambient atmosphere after jointing[5)]. We consider that Al_2O_3 films in Au/Al interface act as a barrier to diffusion in Au/Al and as a result, surplus atomic vacancys do not disappear and make cluster which grows into voids. However, its details have not been elucidated yet.

3. Experimental Methods
3.1 Production of samples

Diffusion behavior of the Au/Al couple having Al_2O_3 films in the interface was studied by means of surface density variation measurement. Current research used multi-layered films produced by vapor-deposition. As shown in **Table 1**, to clarify the diffusion behavior of Al into Al_2O_3 films without Au film, we used 3 types of samples: (1) Al_2O_3/Al couple, (2) Au/Al couple without Al_2O_3 films and (3) $Au/Al_2O_3/Al$ couple. The method of production is presented below.

(1) Vacuum deposit of Al's (purity > 99.99%) coating thickness of 1µm were formed on an SiO_2/Si substrate. After depositing, Al_2O_3 films were formed in the atmosphere after 30 minutes annealing at a temperature of 400°C in vacuum (< 10^{-4} Pa). The thickness of the Al_2O_3 films was evaluated to be 32Å by variation of the effective escape depth of the electron emission angle by XPS measurement. We also identified the structure of Al_2O_3 films to be amorphous through high sensitivity reflectivity measurement (IR-RAS method) using Fourier transformed infrared spectroscopy (FT-IR).

(2) After vapor-deposit Al films on an SiO_2/Si substrate, vapor deposit of Au (purity > 99.999%) with coating thickness of
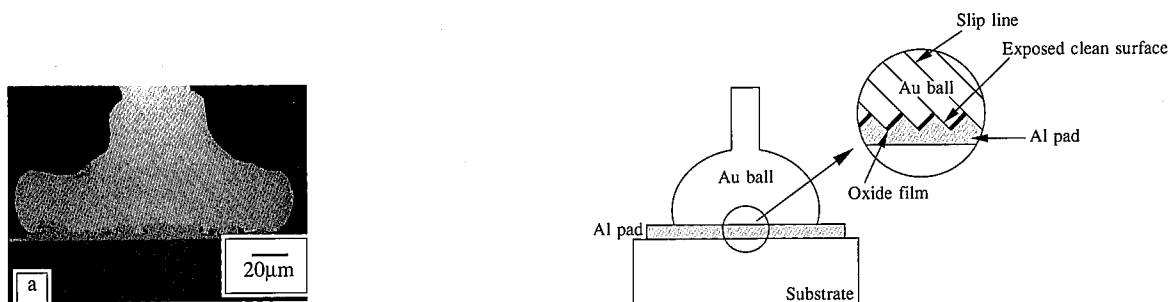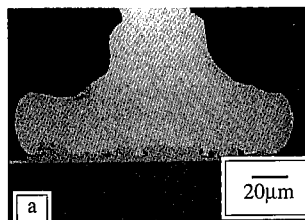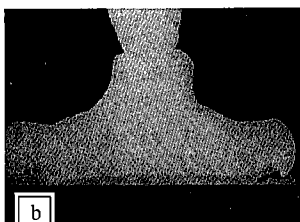

(a) Annealing of 100 hours at atmospheric pressure and a temperature of 175°C (initial shear break strength 0.37N)

(b) Annealing of 100 hours in a vacuum at a temperature of 175°C (initial shear break strength 0.37N)

Photo. 1 Au bonding wire -Al electrode joint cross-section photograph

Fig. 1 Schematic illustration of the destruction of Al surface oxide film caused by elastic deformation on Au/Al interface

Table 1 Samples

Sample No.	Film structure	Thickness of Au (nm)
(1)	Al_2O_3/Al	
(2)-1	Au/Al	200
(2)-2		50
(3)-1	$Au/Al_2O_3/Al$	200
(3)-2		50

200nm or 50nm was continuously formed on Al films in a depositing chamber to avoid samples from forming Al_2O_3.

(3) Vapor deposit of Au with coating thickness of 200nm or 50nm was formed on sample (1). As shown in **Fig. 2**, a Al_2O_3 films was sandwiched by Au/Al interfaces.

3.2 Measurement of surface density changes in diffusion experiments using ultra high vacuum chamber

Samples were heated inside the ultra high vacuum chamber with auger electron spectroscopy (AES: ULVAC-PHI AQM808, PERKIN-ELMER PHI600) and X-ray photoelectron (XPS: PERKIN-ELMER PHI5500) device to study Al_2O_3 films mediating atomic diffusion of Au/Al through the variation of surface concentration of each element. AES allows chemical element analysis of selected areas ($\sim\mu m\ \phi$), while XPS provides information concerning the chemical states of each of the chemical elements in a relatively wide area on the surface ($\sim mm\ \phi$). Furthermore, in situ surface analysis of the samples heated in ultra high vacuum enables analysis of metallic Al that was particularly easily oxidized.

The samples were attached to the holder of which back side was heated by electron bombardment (AES) and by electrothermic system (XPS). Measurement was taken in a vacuum of less than 10^{-7} Pa at temperatures between 200 to 500°C to investigate the influence of temperatures. The temperature of the samples was measured by a thermocouple which touched the surface of the samples.

3.3 Measurement of variation in electric resistance of samples heated by using far infrared radiation furnace

Using electric resistance measurement, the influence of the presence of Al_2O_3 on the intermetallic compounds' formation process in the Au/Al interface was studied. Since resistance varies according to types and volumes of intermetallic compounds formed by the Au/Al reaction, electric resistance measurement is an effective means for observing intermetallic compounds' formation behavior.

Samples used are Au/Al and Au/Al_2O_3/Al couple deposited on a strip of width 2 mm and length 21 mm. To study the influence of temperatures, isotherm annealing was performed using far infrared radiation furnace at temperatures between 150 and 250°C. To observe influence of annealing atmosphere, annealing (isotherm annealing) was conducted for 30 minutes in vacuum and in air at the temperatures between 100 and 300°C. Electric resistance measurement on samples after annealing was taken using quatro-poles method. With regard to influence of temperatures, Cross-cut method was used to calculate effective activation energy of intermetallic compound growth. SEM was used for observation on shape change of intermetallic compounds of Au/Al couple and Au/Al_2O_3/Al couple under the annealing condition at 250°C in the atmosphere, and in the vacuum.

3.4 Diffusion experiments using tracer

As mentioned in Chapter 2, we obtained results showing clear differences between intermetallic compounds' formation in Au/Al interface when Au bonding wire/Al electrode joint couple was annealed in vacuum and when heat processed in the atmosphere. To clarify the effects of annealing environment on the diffusion in Au/Al_2O_3/Al system, we used gas tracer to observe behavior of intermetallic compounds' generation. We used tracers, ^{18}O to study the location in which oxygen diffuse when diffusion couples are annealed in the atmosphere and to analyze oxidizing behavior through secondary Ion Mass Spectrometry (SIMS: CAMACA

IMS-3F type). By using ^{18}O in the oxidizing ambient atmosphere, ^{16}O, which is oxygen in Al_2O_3 films originally in samples, can be distinguished from the targeted oxygen. Through this method, it was made possible to analyze diffusion routes of oxygen during oxidizing. Enclosing ^{18}O gas with samples in a glass tube, measurement was taken after 4 hours of annealing at the temperature of 250 °C using electric furnace. Using C_s^+ as primary ions, we detected $^{16}O^+$, $^{18}O^+$, $^{27}Al^-$ and $^{197}Au^-$.

4. Results and Discussion

4.1 Atomic diffusion in Au/Al_2O_3/Al system

Fig. 3 (a) shows the temperature dependence of the surface concentration measured by AES. Symbols ■ in the figure represent peak height ratio of Al to Au (I (Al) /I (Au)) in an Au/Al couple -- 1). Symbols ○ represent peak height ratio of Al to Au (I (Al) /I (Au)) in an Au/Al_2O_3/Al couple (sample (3) - 1).
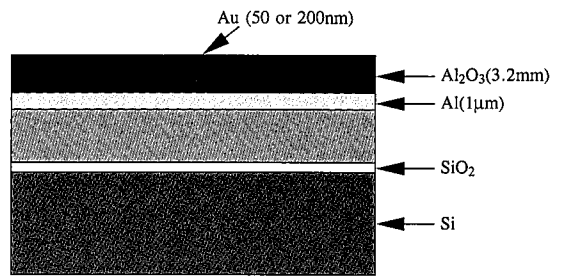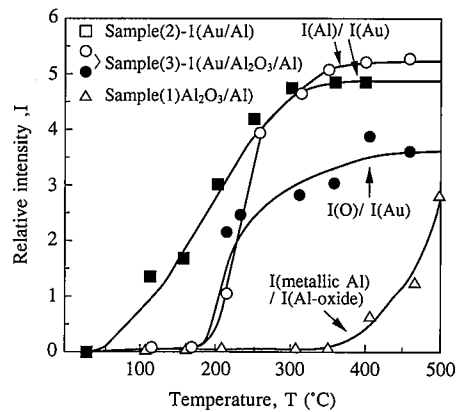

Fig. 2 Geometry of Au/Al_2O_3/Al couple

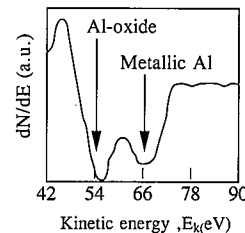Fig. 3 (a) Temperature dependence of the surface concentration

Fig. 3 (b) Auger spectrum of Al-oxide and metallic Al
Arrows in the figure show peaks of Al (Al^{3+}5lev) in Al_2O_3 and metallic Al ($Al^0$68ev).

Symbols ● represent peak height ratio of O to Au (I (O) /I (Au)) in an Au/Al₂O₃/Al couple. Measured peaks of Au (239eV), Al(1396eV) and O(503eV) were chosen to avoid overlaps with peaks of other chemical elements.

Temperature dependence in surface concentration of metallic Al to Al in Al_2O_3 were represented in **Fig. 3** as ●. Since chemical peak shift was observed between Auger peaks of Al (Al^{3+} 51eV) in Al_2O_3 and metallic Al (Al^0 68 eV) as shown in **Fig. 3** (b), separation of peaks was possible. Estimated concentration of Al in Al_2O_3 and metallic Al films are compared using each peak intensity.

As shown in **Fig. 3** (a), I (Al) /I (Au) (shown with ■) of Au/Al couple increases with increasing annealing temperature from 100 to 350 °C and reaches a constant value at 350°C. On the other hand, I (Al) /I (Au) (shown with ○) of Au/Al₂O₃/Al couple does not change at temperatures less than 200 °C but starts to increase with increasing annealing temperature over 200°C. From the above results, the temperature at which Al was detected on the surface for the Au/Al₂O₃/Al system was shifted to about 100°C higher in comparison with Al/Au system. This indicates that the rate of Au/Al diffusion was limited by the presence of Al_2O_3 films in Au/Al interface which act as a diffusion barrier.

Arrows in the figure show peaks of Al (Al^{3+} 51eV) in Al_2O_3 and metallic Al (Al^0 68 eV).

Furthermore, as shown in **Fig. 3**(a) as ●, O peak was detected on the surface of Au/Al₂O₃/Al system over 200°C. The detected O peak is understood as either due to Al_2O_3 films or absorbed oxygen. To study the influence of absorbed oxygen, Al exposed with active surface by sputtering was held in the vacuum chamber for 2 hours. However, since the O peak was not detected, the influence of absorbed oxygen can be safely ignored. Therefore, we consider that the O peak detected during experiments is caused by Al_2O_3 films. This suggests the possibility that the Al_2O_3 films, which were in the Au/Al interface before annealing, are exposed to the surface. That is, formation of intermetallic compounds through Au and Al diffusion suggests the possibility that intermetallic compounds might have been generated under Al_2O_3 films.

As shown with △, metallic Al was not detected on the surface of Al₂O₃/Al system annealed below 350°C. The surface was covered with Al_2O_3 films up to 350°C which is about 150°C higher than that where Al is detected in Au/Al₂O₃/Al system. This suggests that Au, but not Al, diffuses through the Al_2O_3 films and diffusion of Au controls the growth of Au-Al intermetallic phases.

Furthermore, to show diffusion of Au into Al_2O_3 films, we present **Photo. 2** of the SEM image of cross-section of the Au/Al₂O₃/Al system annealed for 30 minutes at 250°C. From **Fig. 3**(a), this annealing condition is considered amounting to initial stages of Au/Al diffusion. From SEM images, Au-Al intermetallic compounds growth fans out into Al layer from the point at which diffused Au reaches the Al layer. This is caused by intermetallic compounds growth due to local diffusion of Au into Al_2O_3 films reaching at Al layer. There are 5 kinds of Au-Al intermetallic compounds: $AuAl_2$, $AuAl$, Au_2Al, Au_5Al_2 and Au_4Al[9]. Through X-ray analysis, the layer at which intermetallic compounds are generated accompanied with disappearance of Au was determined to be an Al_2Au structure.

Fig. 4 shows a schematic illustration of the diffusion of the Au/Al₂O₃/Al couple inferred from these results. We consider that Au diffuses into Al_2O_3 films locally reaching the Al layer and Au

reacts with Al at points on the Al layer at which Au reaches Al to generate Al_2Au. Al_2Au grows up in Al layer. Al_2Au grows up in an island formation with a supply of Au at the surface. As a result, Au found at points where Al_2O_3 films are functioning as a barrier starts to dissipate ending up exposing Al_2O_3 on the surface.

4.2 Effective activation energy for growth of intermetallic compound layer in Au/Al and Au/Al₂O₃/Al diffusion.

Through heating experiments inside AES, Al_2O_3 films, which were formed on the surface of Al exposed to the atmosphere, act as a barrier against diffusion. Furthermore, to quantitatively assess the influence of the presence and absence of Al_2O_3 films on Au/Al diffusion, isotherm annealing was conducted to calculate effective activation energy of Au/Al diffusion and intermetallic compounds in Au/Al₂O₃/Al system through time dependence electric resistance changes.

Fig. 5 (a) shows the changes of electrical resistance across time at 160°C (■), 210°C (▲) and 250°C (●) for Au/Al system. **Fig. 5** (b) shows changes of electrical resistance across time at 200°C (▲), 220°C (■) and 235°C (●) for Au/Al₂O₃/Al system. For both Au/Al and Au/Al₂O₃/Al system, electric resistance increases in time to reach an constant value. This rise of electrical resistance is considered to be related with generation of layer composed of intermetallic compounds due to diffusion of Au and Al.

Next, following the cross-cut method we show in **Fig. 6** the logarithm of time t taken to reach 30% of the total increment (increment under heat processing at 250°C for 150 minutes), Ln(t), plotted against 1/T (where T represents annealing temperature). The ● and ▲ are the Arrhenius plots of the Au/Al system and the Au/Al₂O₃/Al system respectively. Effective activation energy for growth of intermetallic compounds is determined by each line's slope to be 72 kJ/mol (0.75eV) and 110 kJ/mol (1.1eV) for the Au/Al system and Au/Al₂O₃/Al system, respectively. The difference of activation energy in these two types of
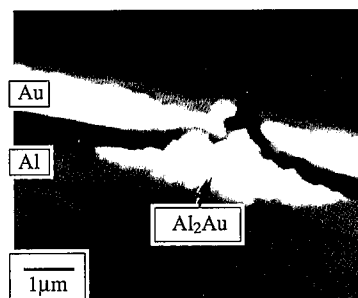

Photo. 2 SEM image at cross-section of the Au/Al₂O₃/Al system

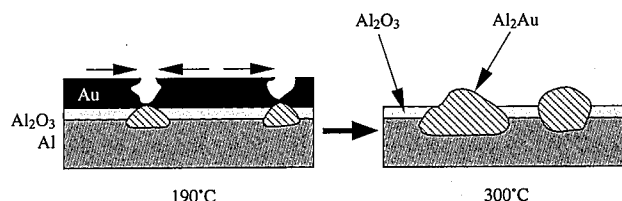**Fig. 4** Schematic illustration of diffusion process for Au/Al₂O₃/Al system

couple shows their dependence of generation behavior of intermetallic compounds on presence and absence of Al_2O_3 films. Furthermore, large values of activation energy obtained for $Au/Al_2O_3/Al$ system show Al_2O_3 films's barrier action on Au/Al diffusion.

With regard to activation energy of intermetallic compounds' growth by Au/Al diffusion, several reports have been published so far [10-15]. The activation energy of intermetallic compounds' growth by Au/Al diffusion obtained in present experiment, 72 kJ/mol (0.75eV), is remarkably close to Kashiwabara et. al.'s [10] 75.42 kJ/mol (0.78 eV) measured using Au/Al wire couple.
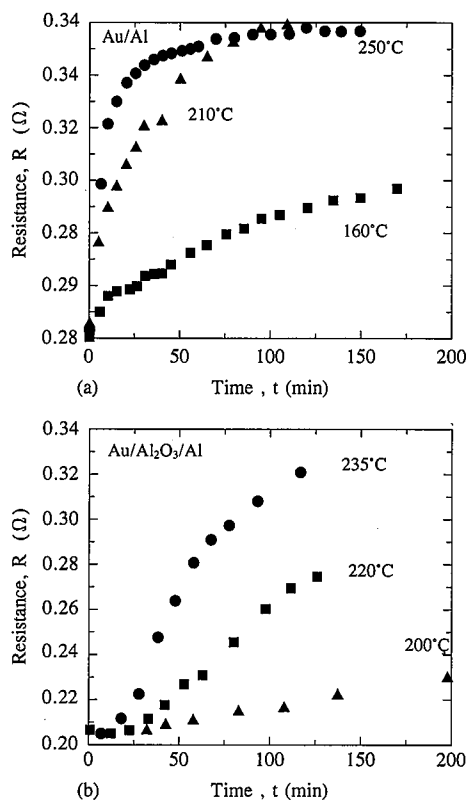

(a)

(b)

Fig. 5 Electrical resistance measured at room temperature as a function of annealing time for various temperature
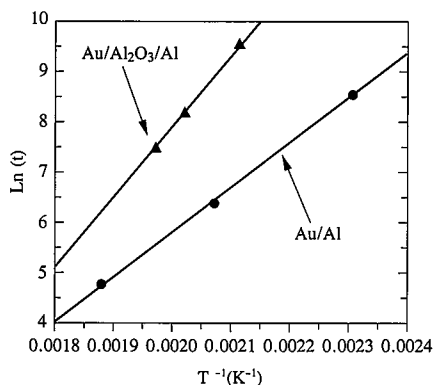

Fig. 6 Arrhenius plots of Ln (t) as a function of T^{-1} for Au/Al and $Au/Al_2O_3/Al$ systems

However, other papers report different activation energy values such as 53.0 kJ/mol (0.55 eV) [14] and 115.8 kJ/mol (1.2 eV) [15]. From the results of the present study, it is clear that the activation energy of growth of the intermetallic compound layer depends largely on the presence or absence of Al_2O_3 films. Therefore, when there is a possibility of generating Al_2O_3 films due to exposure of Al to the atmosphere during the sample preparation process, it is necessary to analyze the activation energy of the growth of the intermetallic compound layer through clarifying the existence of Al_2O_3 films and their structure.

4.3 Influence of oxygen inside ambient atmosphere in $Au/Al_2O_3/Al$ diffusion

SEM image of samples treated with annealing mentioned in Section 3.4 is shown in **Photo. 3**. The photographs (a), (b) and (c) show Au/Al system annealed in vacuum, $Au/Al_2O_3/Al$ system annealed in vacuum and $Au/Al_2O_3/Al$ system annealed in the atmosphere, respectively. In the case of Au/Al diffusion without Al_2O_3 layer, intermetallic phases grew homogeneously (a). However for Au/Al_2O_3 system, (b) and (c) in which Al_2O_3 films exists, the diffusion was localized and intermetallic phases grow in an island formation. In particular, local diffusion becomes conspicuous when samples are annealed in the atmosphere. When annealed in the atmosphere, the number of the intermetallic nucleation is decreased.

Fig. 7 shows changes in Au-4f peak obtained through XPS measurement after 30 minutes of heat processing at 250°C in vacuum and the atmosphere. When annealed in vacuum, the peak shifts to higher energy indicating a generation of intermetallic phases equivalent to Al_2Au.

On the other hand, when annealed in the atmosphere, the Au-4f peak shift was seldom detected but with an increased bandwidth. This suggests a mixture of metallic Au and Al_2Au. Considering the fact that XPS spectra are obtained through averaging information from measurement domains with a diameter of several mm, a large part of this Au-4f spectrum carries information of residual Au on Al_2O_3 films, which has a large proportion of area covered the films, without diffusion. Al_2Au has only a little overlap on them.

Fig. 8 shows the results of electric resistance measurements in an ambient atmosphere after 30 minutes of annealing of $Au/Al_2O_3/Al$ system and Au/Al system at 100 to 300°C in vacuum and in the atmosphere. Symbols ●, ○ and ▲ in the figure
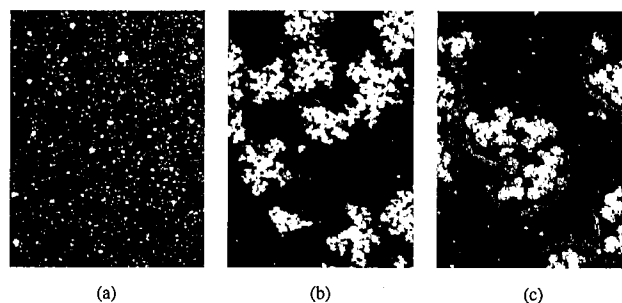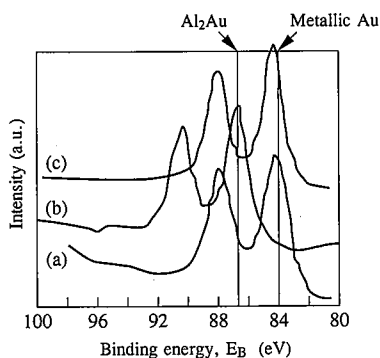

(a)   (b)   (c)

Photo. 3 SEM images: (a) Au/Al system annealed in vacuum, (b) Au/Al_2O_3 system annealed in vacuum and (c) Au/Al_2O_3 system annealed in the atmosphere
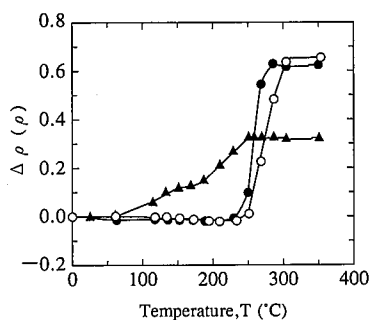
Fig. 7 Au-4f peak of Au/Al$_2$O$_3$/Al system
(a) Before annealing   (b) After annealing in vacuum
(c) After annealing in the atmosphere

represent a proportion from the change in electric resistance (ρ_T - ρ_0)/ ρ_0, measured from the Au/Al$_2$O$_3$/Al system annealed in vacuum, Au/Al$_2$O$_3$/Al system annealed in the atmosphere and from Au/Al system without oxide films in the atmosphere. From the results of Au/Al diffusion (see ▲ in the figure), the proportion from the change of electric resistance increases as more intermetallic compounds are generated by the duffusion of Au and Al. There are a stage with temperatures ranging from 100 to 200°C and that with temperatures greater than 250°C. X-ray analyses revealed that the stage at lower temperatures corresponds to generation process of AlAu$_2$ and that at higher temperatures corresponds to generation of Al$_2$Au. Increase in electric resistance is considered to correspond to the growth process of intermetallic compounds.

Fig. 8 shows changes in electric resistance (○ in the figure) when annealed in the atmosphere shifting to higher temperatures compared to changes in electric resistance (● in the figure) when annealed in vacuum. This is explained as a delay in the generation process of intermetallic compounds when annealed in the atmosphere. The reason for this delay is considered to be localization of Au due to Al$_2$O$_3$ films acting as a barrier against Au's diffusion into Al$_2$O$_3$ films during the heating. This result fits well with XPS's result shown in Fig. 7.

Furthermore, at 350°C, where all Au and Al reacted to finally generate Al$_2$Au, the proportion of change of electric resistance for Au/Al$_2$O$_3$/Al system is greater than that of the Au/Al system.
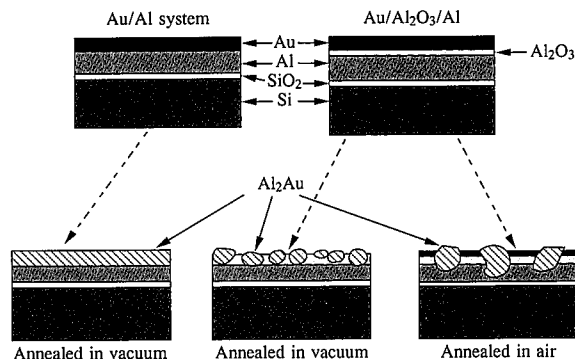
Judging from the observed results of SEM shown in Photo. 3, this comes from the difference in shape of intermetallic compounds. That is, intermetallic compounds are homogeneously generated in the Au/Al system while intermetallic compounds grow up in an island formation in Au/Al$_2$O$_3$/Al system.

Based on the above results, Fig. 9 shows a schematic illustration of generation process of intermetallic compounds by annealing in vacuum and in the atmosphere. When oxide films do not exist in interfaces, diffusion occurs uniformly. However, when oxide films exist in interfaces, diffusion is localized as in an island formation. This is considered to be caused by Al$_2$O$_3$ films inhibiting Au/Al's diffusion to allow intermetallic compounds to have Au diffuse through cracks and pin holes in Al$_2$O$_3$ films and to enable reaction with Al. Furthermore, even when Al$_2$O$_3$ films exist in intefaces, annealing in vacuum generates intermetallic compounds by Au diffusing through Al$_2$O$_3$ films to react with Al more often than annealing in the atmosphere. However, the number of routes allowing Au in Al$_2$O$_3$ films to diffuse in annealing in the atmosphere is less than that in vacuum. As a result, generation of intermetallic compounds is localized and the growth pattern assumes the island formation. Oxygen supply occuring at the time of annealing in the atmosphere is considered to cause the reduction in the number of Au diffusing routes generated by oxidization of the Al-rich area inside Al$_2$O$_3$ films and the Al films under the Al$_2$O$_3$ films. Continuous Al$_2$O$_3$ films are generated as a result of annealing in the atmosphere, which is considered to be caused by the reduction in the number of Au diffusing routes.

Fig. 10 shows a cross-section of Au/Al$_2$O$_3$/Al couple annealed in ^{18}O atmosphere: (a) shows the distribution of ^{18}O and (b) shows the distribution of Al. From Fig. 10 (b) we can see in the annealed diffusion system that the layer structure of Au/Al$_2$O$_3$/Al present before annealing is destroyed and Al is detected even in Au films. As shown in a schematic illustration in Fig. 9, intermetallic compounds are partially generated through the mediation of Al$_2$O$_3$ films. Moreover, Fig. 10 (a) shows ^{18}O can be identified near Au/Al interface in line-like shape. Reaction of Al with ^{18}O diffusing in Au during annealing is consider to be the cause of this phenomenon. That is, by Au/Al$_2$O$_3$/Al system is annealed in the atmosphere, oxygen diffuses in Au and further oxides Al on the Au/Al interface where Al$_2$O$_3$ films lie. This oxidization is suspected to cause the reduction of the number of Au's diffusing routes due to continuous Al$_2$O$_3$ films. We consider that generation of intermetallic compounds is more effectively inhibit-

Fig. 8 Relationship between annealing temperatures and resistivity
○ Au/Al$_2$O$_3$ system annealed in the atmosphere
● Au/Al$_2$O$_3$ system annealed in vacuum
▲ Au/Al system annealed in vacuum

Fig. 9 Au-Al intermetallic compound's growth model in various annealing environments

(a)

0   5   10   15   20   25

0   50   100   150   200   250
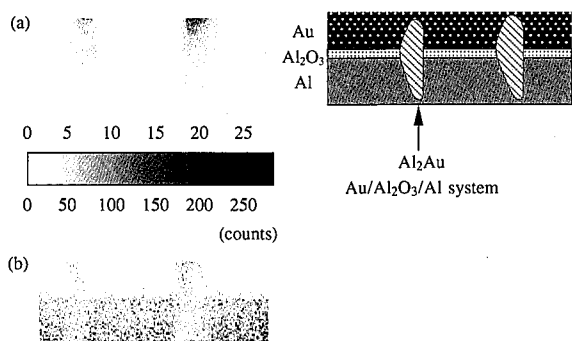(counts)

(b)

Au
Al₂O₃
Al

Al₂Au
Au/Al₂O₃/Al system

Fig. 10 Ion images for cross-sections of Au/Al₂O₃/Al system annealed for 2 hours at 200°C in ^{18}O atmosphere: (a) ^{18}O image and (b) Al image

ed by more continuous Al₂O₃ films acting as a barrier.

From the above results of experiments using films, it became clear that under the influence of Al₂O₃ films Au-Al intermetallic compound formation differs in vacuum and in the atmosphere. The difference agrees with the results observed in Au/Al diffusion in Au bonding wire/Al electrode interface. As already mentioned above, when Au bonding wire/Al electrode joint couple is annealed in vacuum, intermetallic compounds are homogeneously generated. However, when annealed in the atmosphere, the growth pattern becomes inhomogeneous to generate voids. Generation of voids, which are suspected to be Kirkendall voids, is considered to be caused by the inhomogeneous growth direction of layers due to Au/Al interdiffusion[5]. Further, considering the results of experiments, we can conclude that inhomogeneity of Au/Al interdiffusion is triggered by continuous Al₂O₃ films in joint interface acting as a barrier when subjected to annealing in the atmosphere.

4. Conclusion

The influence of Al₂O₃ films on Au/Al joints was studied with a model system of Au/Al₂O₃/Al films controlled with respect to presence and absence of Al₂O₃ films by vapor deposit method through a new experimental technique. Heated surface analyses in ultra high vacuum, measurement of changes in electric resistance and analysis of oxidizing mechanisms using ^{18}O were performed. The resultant consequences are summarized below. (1) Au diffuses inside Al₂O₃ films to react with Al to generate at the side of Al-layer intermetallic compounds in an island formation. (2) Al₂O₃ films can act as a barrier against this reaction. (3) When oxygen exists in the annealing atmosphere, Al₂O₃ films become continuous and they in turn act as an effective barrier against generation of intermetallic compounds and thus intermetallic compounds are localized.

It is necessary to destroy Al₂O₃ films during jointing operation of the Au wire bonding on Al electrode surface. Through this study, it became clear that diffusion inside film, which are on interfaces, also influences final jointing states. Al₂O₃ films used in the present experiments are approximately 3.2 nm thick Al₂O₃ films and are amorphous, which has relatively many defects. However, to discuss the reliability of Au/Al joints in the actual manufacturing process, it is necessary to give a full consideration to states of Al₂O₃ surface films and a possibility of generation of

thick oxide films on Al electrodes, that of crystallized Al₂O₃ films and that of fluorides during manufacture.

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