Al-Cu Metal Bond Pad Corrosion During Wafer Saw

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Abstract

This paper examines various techniques ON Semiconductor explored which may be used to reduce the extent of bond pad corrosion during wafer saw on product that uses Al-Cu alloys for chip metallization. While the most effective place to preclude bond pad corrosion is in wafer fabrication, wafer lots are processed and delivered to the production floor only to have corrosion discovered as a by-product of wafer saw. The usual result is scrapping of whole wafer lots with attendant loss of wafer costs and production line upsets. The purpose of this paper is to outline various methods explored to minimize corrosion and avoid line shut downs. Some of the methods discussed in this work were successful and some were not, leading to a better process for sawing wafers. Methods explored to inhibit corrosion consisted of effects of machine parameters (time, saw speed, amount of water used, and lighting effects), partial sawing techniques, plus metal and organic coatings (not technically post wafer fabrication processes). Of all the methods explored, a final top metal deposition of Al-Si proved the most effective deterrent followed by the partial saw cut technique.

Keywords:
Al-Cu Corrosion, Wafer Saw, and Pitting Corrosion.

1. Introduction

ON Semiconductor, as the industry in general, uses aluminum as a thin film metallization for contacting silicon and forming interconnection lines on integrated circuits. To avoid electromigration issues incident to thin interconnection lines and high voltages, copper is often added to the aluminum to form an alloy. Copper content can range from 0.5 to 4.5 percent by weight. Inherent in the use of Al-Cu alloys is the increased susceptibility of the films to corrosion during wafer fabrication and post wafer fabrication assembly. According to Reference¹, there are essentially three types of corrosion that can occur in a wet environment that are of interest in microelectronics; namely,

- galvanic or dissimilar metal cells
- concentration cells
- electrolytic cells.

The basic requirements for corrosion in all three types of cells are two electrodes, an interconnecting solution, and a driving force. For galvanic corrosion, the two electrodes are dissimilar metals connected through an electrolyte. The driving force is set up by a difference in electrochemical potentials. For concentration cells, the two electrodes are the same metals with the driving force resulting from a concentration gradient. With electrolytic corrosion cells, the two electrodes can be the same or dissimilar metals since the driving force is set up through an applied potential difference between them.

Aluminum forms a protective oxide, Al₂O₃, which inhibits galvanic corrosion and corrosion in a concentration cell as long as the film remains intact and is not broken. Aluminum oxide protected metal, however, will corrode in an electrolytic cell when there is an applied bias. A simple electrolytic cell² can form...
with the electrolyte being absorbed water plus any dissolved impurities on the surface connecting the two electrodes. According to Reference2, when moisture condenses on the surface of the bond pad, hydrolyzable impurities are transported to and dissolve into the water film forming the electrolyte. Ions from the electrolyte interreact with the native aluminum oxide to locally depassivate the protective layer. Hall3 investigated the effect of phosphorus content in passivation glass on the corrosion rate of aluminum bond pads when exposed to 85°C and 85% relative humidity. The corrosion rate depended on the applied bias; occurred at the negative electrode (cathode) and depended on the amount of phosphorus present in the glass.

2. Wafer Fabrication

Al-Cu films have been shown to be more susceptible than pure aluminum to in-process corrosion during wet chemical and dry (reactive ion) etching1. Corrosion on aluminum alloy films containing copper were found to occur at metal etch and post metal etch processing steps such as plasma ashing, deionized (DI) water rinsing, and solvent cleaning5,6,7. High concentrations of fluorine were found to be deposited on bond pads during a polyimide passivation film etch, Reference2, and if not adequately removed during subsequent plasma ashing resulted in corrosion. The authors did establish that as long as the native Al2O3 oxide layer existed on a bond pad intact with no major voiding corrosion would not occur during wafer processing. The effect of DI water cleaning and subsequent hot air drying on corrosion of Al/0.8% Si/0.5% Cu was investigated in Reference8. Experimental data from a wirebond study showed that as temperature decreased for both processes so did the rate of corrosion.

K. Siozawa et al.9 plasma deposited SiN films on TiN/AlCu, applied photoresist and etched using a O2/CF3 plasma to open windows to the Al-Cu. Corrosion was observed on the pads after exposure to the plasma process. In contrast, the authors found no evidence of corrosion for plasma deposited SiO2 on TiN/AlCu nor in the case of no film on the bond pad (such as photoresist applied directly to the Al-Cu). The investigation indicated that NH3 molecules desorbed from the SiN and absorbed by the Al-Cu surface reacted with the matrix metal to produce corrosion by a chemical reaction. This study also showed that a post etch treatment by O2 plasma and DI water rinse lowered the concentration of NH3 and reduced the rate of corrosion.

The effect of grain boundaries on the corrosion behavior of Al-1%Cu etched using a SiCl4/Cl2/He/CHF3 plasma gas mixture was investigated, Reference10. Corrosion was found to occur mainly at the grain boundaries due to their affinity for retaining chlorine from the plasma gas.

3. Package Assembly

Films of organic contamination left on bond pads due to incomplete rinsing after etch processes were found to cause corrosion during the wafer saw operation11. DI water used during saw provided the requisite electrolyte. Al2Cu (theta) particles formed as a by-product of the wafer fabrication process depleted copper from the surrounding aluminum matrix. In the presence of water used during the saw operation, the theta particles and surrounding aluminum created dissimilar metal electrodes in direct contact with each other. The Al2Cu particles acted as local cathodes in contact with the more anodic aluminum and corrosion proceeded as a galvanic cell in the presence of water and organic impurities. In a study performed12, Al-Cu metal films sputter deposited from a target containing 1.5% copper by weight experienced a high incidence of non-stick on pad (NSOP) during thermosonic gold ball bonding. Analysis showed highly localized pitting 1-2 µm in diameter on the bond pads. The pits were shown to occur after wafer saw and were due to improper drying techniques that did not completely remove water from the wafer following saw. These authors also explained the process via a simple galvanic corrosion cell phenomenon. Theta particles and less rich copper areas formed the electrodes for a simple galvanic cell. No impurities were needed to drive the process. The localized corrosion process proceeded around each theta particle forming distinctive pits that deepened until the theta particle separated from the aluminum matrix effectively breaking the electrical connection. The corrosion rate was found to be dependent on the distribution and size of the particles. The corrosion product Al(OH)3 was determined to be the cause of poor bond quality.

4. Objective of Work

The most effective place to preclude bond pad corrosion is in wafer fabrication, however, that effort has proven elusive and inconsistent, very often ending up with wafer lots processed and delivered to the production floor with corrosion discovered belatedly at wafer saw. The usual result is scraping of whole wafer lots with attendant loss of wafer costs and production line upsets. At this point, a method to save wafers has cost savings potential. The purpose of this paper is to outline various methods explored within ON Semiconductor to minimize corrosion and avoid line shut downs. Some of the methods discussed were successful and some were not, leading to a better process for sawing wafers.
5. Saw Process Overview

5.1. Definition of Problem

BiCMOS wafer product containing Al-Cu bond pad metal has always experienced corrosion to varying degrees during wafer saw. The degree of corrosion has been found to be wafer and machine dependent. In most cases, only certain pads on each die corrode. Typical of the type of product reported, pads connecting an n-region to a p-region corrode while those connected directly to the substrate do not. According to Reference12, time and temperature parameters at post etch anneal determine the degree to which Al2Cu forms, and thus the severity of corrosion. Also, any post anneal exposure to oxygen such as a plasma clean will affect the degree of corrosion through the thickening of the natural oxide layer. Of the various machine parameters that can affect corrosion resistance of a wafer, the important ones are the amount of time the wafer is in the saw (i.e. saw speed), water temperature, color and intensity of light used (photovoltaic effect), and static charge buildup on the saw blade.

5.2. Theory of Corrosion

According to Reference7, the investigation involved CMOS devices in a Tetra-Methyl-Ammonium Hydride (TMAH) solution (basic with pH ~ 12), both V_{ss} and V_{dd} bond pads corroded but the V_{ss} pads always corroded first and V_{dd} last. In CMOS processing, the V_{ss} and V_{dd} pads connect p-well to n-well regions. Regardless of the type of substrate (p-versus-n-type), the galvanic cell that forms was always the same. Since the electrolyte was a base and the V_{ss} pads (anode) are more positive than the V_{dd} pads, the reaction rate for corrosion was higher at V_{ss}.

Figures 1a-d show typical bond pads from both wafer lots used in this study. The photos show bond pads before and after a minimum of one hour in the saw. Figure 1e is a SEM photo showing a typical corrosion pit. This pit is the same as seen by Reference12 in their investigations. Subsequent Auger analysis confirmed the corrosion mechanism was unaided by any corrosive species such Cl or HN3. In most cases, the theta particle was absent from the bottom of the pits; most likely due to the post saw wafer wash process. It is evident from 1a and b that only certain pads on the die corrode or tend to corrode faster than other bond pads. These tended to be mostly pads in an isolation region. The wafers used in this study are based on BiCMOS technology. To provide additional signal isolation between noisy NMOS circuits and adjacent noise sensitive circuits, an isolated P well is used. This isolated P well is surrounded by a N well and N+ buried layer. The BiCMOS technology is an N+ well process; thus, P-type substrates are used. The N-isolation regions are connected to the most positive supply, which would be the bipolar supply bond pads. If this is the case, one would then have an np junction (photovoltaic cell) connected to the bond pad with AlCu cells. The addition of the saw blade results in a complete circuit being formed as shown in Figure 2.
Figure 1C. Typical bond pad on RF BiCMOS wafer product before saw.

Figure 1D. After exposure to wafer saw operation for a minimum of one hour, severe corrosion is evident.

Figure 1E. SEM micrograph of a typical corrosion pit seen on samples used in this study. This pit is the same as seen by Reference12 in their investigations. Subsequent Auger analysis confirmed the corrosion mechanism was unaided by any corrosive species such Cl or HN₃. In most cases, the theta particle was absent from the bottom of the pits most likely due to the post saw wafer wash process.

6. Sample Preparation/Machine Set Up

6.1. Sample Preparation

Wafers used in the experiments came from two distinct sources. Initial studies were conducted using Motorola MOSAIC V BiCMOS wafers with 5.5 to 6.0 KÅ Al-1.5%Cu. Wafers used in the later studies were Mixed-Signal RF BiCMOS with basically the same bond pad structure.

6.2. Machine Set Up

All saw experiments were conducted on a Disco DAD 320 automatic dicing saw using a Semitec S1230 blade. Spindle speed was set at 30,000 rpm. Feed rate was varied from .06 to .23 inches per second. The slower speeds were used to purposely keep the wafer in the saw for a minimum of one hour.

6.3. Wafer Analysis

Wafer analysis consisted of optical microscopy for detection of corrosion, Scanning Electron Microscopy to verify corrosion pits and Auger spectrometry to analyze the corroded surfaces.
SEM analysis was performed with a Hitachi S-4100 Field Emission SE Microscope equipped with an Oxford Instruments ISIS Scanning Electron Microscopy – Energy Dispersive Spectrometer (SEM-EDS). Auger analysis was performed using a Physical Electronics 670A Field Emission Scanning Auger Nanoprobe with an accelerating voltage of 10kV and a 20nA beam current for data collection.

6.4. Pass/Fail Criteria

Pass-fail criteria consisted solely of low and high power microscopy. No attempt was made to develop a scale other than specifying no evidence of discoloration as a clean surface. The only apparent difference between a good bond pad and a bad pad was the telltale discoloration signifying evidence of AlOH₃ residue. As revealed later in this paper, SEM analysis for distribution and quantity of pits proved inconclusive. Even on ‘clean’ surfaces (i.e. no evidence of any discoloration), pits were found during SEM examination.

7. Experiment/Results

7.1. Initial Experiments

Several small experiments were conducted in order to determine the relevant wafer and machine parameters that affected the degree to which a wafer would corrode.

The amount of time a wafer was in the saw proved to be a critical factor. Wafers sawn with fast speeds (about 20 minutes in the saw) tended to corrode much less than those sawn at normal speeds (in saw for approximately 60 minutes). If no other option is available, wafers can be mounted, cut into “quarters”, re-mounted individually and sawn with minimal corrosion. A wafer placed in a beaker containing DI water for 60 minutes showed no evidence of corrosion. Also, a wafer placed in the saw with flowing DI water for 60 minutes showed no signs of corrosion either. UV tape was then placed on top of a wafer to block water and the wafer sawn for 60 minutes without any evidence of corrosion. This shows that water is necessary but not sufficient to cause the reaction.

It was also discovered that a wafer could be sawn in either direction for over one hour with no visible signs of discoloration. However, once the cut was started in the opposite direction (i.e. die separation occurs), the corrosion process started. No change in impedance to ground was measured when the wafer chuck rotated. Figure 3a shows a portion of a wafer sawn for over one hour in one direction only. No evidence of corrosion was noted anywhere on the wafer. Once the wafer was rotated on the saw chuck and cut in the opposite direction, the corrosion process started but only on that portion of the wafer where cuts in both directions separated individual die [Figure 3b]. Wafer regions in front of the blade remained clear of corrosion. At this time, no clear explanation can be determined for this phenomena. It is assumed that as long as the dice are connected to each other, the electrolytic circuit can not be established. It is believed the wafer substrate effectively creates a short with the saw blade until cross-cuts are made and the dice are separated into individual units.

Since the wafer saw used in the experiment places a 5-volt charge on the saw blade during blade height measurements, it was decided to measure voltages in other modes. The voltage from the saw blade to the wafer chuck (saw in rest mode) and the blade spindle to machine case were measured to be 2 millivolts for each case. In actual saw mode, the voltage between the blade spindle and frame increases to 100 millivolts. This implies that there may be a potential difference applied during saw. However, when the machine was modified to connect the spindle to a hard ground during the saw operation, no visible improvement in corrosion resistance was noted.
Light was found to have an effect on corrosion intensity. Figure 4a-c shows three wafers sawn in various modes of lighting starting with the normal process that uses both room light and machine vision light (in this case green) and ending with almost total darkness. The wafers sawn with both room and vision light and with vision light only did not differ significantly from each other. However, when almost all light was removed, the amount of corrosion observed was much less.

Figure 4A. Wafer sawn with machine vision light and room light corrodes as shown above.

Figure 4B. Wafer sawn with vision light only (light blanket placed over machine) shows no improvement.

Figure 4C. When the vision light is turned off and the light blanket used to block out room light the wafer is essentially sawn in the dark. As is seen, there is a sharp reduction in the extent of corrosion after one hour in the saw.

The quantity of water used also has an effect. When a second source of water was installed directly over the wafer, a slight improvement in corrosion resistance was indicated. Figure 5 shows the effect of standard water line configuration versus the addition of the second source of water.

Figure 5. The photo on the left shows the effect of standard water line configuration on corrosion. On the saw used in this study, one source of water exists which is directed to the front of the saw blade. The photo on the right shows the results of adding a second water nozzle that directed a water blanket over the entire wafer directly in front of the saw blade. There is a very slight improvement in corrosion resistance.
7.2. Methods to Inhibit Corrosion

7.2.1. Protective Coatings

Protective coatings can be grouped into three broad categories, native oxide layers, organic coatings, and non-corroding metal layers. Each of the three groups are explored further.

- Plasma generated oxide layer

Exposing the wafer to oxygen plasma just before wafer saw can generate a protective oxide layer that covers Al$_2$Cu particles. Denying access of the theta particles to water and light should be able to arrest the tendency to corrode. Figures 6a and b show the results of sawing a wafer that was exposed to O$_2$ gas for 20 minutes at 600 watts and 100% flow (pressure = 490 mtorr). The photos show what appears to be a lot less discoloration than is nominally seen on untreated samples. AES elemental depth profile did not indicate any increase in oxide thickness, however, some sort of oxide enhanced protection mechanism must be in effect.

Figure 6A. Exposing the wafer to oxygen plasma for 20 minutes (600 watts/100% O$_2$ flow) may be developing a thicker Al$_2$O$_3$ oxide layer that covers the theta particles and protects the pad from corroding. This wafer was in the saw for over one hour.

Figure 6B. A close up photo of the left side pad in Figure 6A.

A small experiment was conducted in which a wafer was cut into quarters, optically inspected to verify no corrosion, then each quarter exposed to oxygen plasma for 20, 40, 60, and 80 minutes. Each wafer quarter was sawn within 20 minutes of exposure. Time in the saw was set up to be approximately 60 minutes. Post saw inspection showed very little evidence of corrosion. A Shinkawa UTC-100 gold ball thermosonic wirebond machine was set up with one mil wire to give acceptable bond quality on the sample cleaned for 20 minutes. Once good bond strength was established, the other samples were wirebonded with the same machine parameters. Wire pull and ball shear tests were conducted and the results compared to a control wafer. No difference was noted with wire pull strengths for all groups. Average pull strength ranged from 12 to 13 grams with less than 1 gram deviation. Failure modes consisted of almost all first bond breaks or wire breaks. However, a difference was detected in ball shear strength. Figure 7 shows shear strength as a function of exposure time in the oxygen plasma. With the exception of the 40-minute data point, exposure to oxygen seems to have a slight negative impact on ball shear strength.

- Organic Coating

Although not technically a ‘post wafer fabrication’ process, organic coatings can be applied to a wafer as a last step in wafer fabrication. The ideal coating would be able to be applied at room or low temperature, withstand epoxy or solder die attach temperatures without degrading or curing (i.e. cross linking), and be easily removed with normal solvents after die attach. As a proof of principle, Kodak DPL polyacrylate organic coating was spun on a wafer at approximately 70°C to remove solvents but not cure (no cross linking occurs). This coating withstood an epoxy die attach temperature of 150°C without cross-linking and was removed with Xylene after die attach with no effect on die or package. Figure 8 shows the difference between a protected and unprotected die. Wirebond tests were not performed in this instance but have been previously proven in a production environment.

Figure 7. Gold ball shear strength as a function of exposure time to oxygen plasma (600 watts, 490 mtorr pressure) for 0, 20, 40, 60 and 80 minutes. With the exception of the 40-minute data point exposure to oxygen seems to have a slight negative impact on ball shear strength.

Figure 8. The difference between a protected and unprotected die.
Figure 8. Photo showing two dice placed side by side. The die on the left was sawn in the normal manner while that on the right was coated with the DPL organic coating prior to saw.

• Metal Coatings
  Another option to cover theta particles is the application of a thin film metal layer over the Al-Cu bond pads as a last step in wafer fabrication. An ideal metal layer should not corrode (i.e. be mono metallic), not have to be removed (i.e. support wirebonding), and be more robust to wirebonding than Al-Cu. Two examples of metallic protective coatings would be TiN and pure Al or Al-Si, which forms no second phases that can become corrosion cells. TiN is used over bond pads as a standard process in wafer fabrication as a sinter cap and is usually etched away after sinter. Leaving the TiN metal on the bond pads may allow it to function as a corrosion barrier during saw. Sample wafers were prepared with 250 angstroms TiN and 10, 20 and 30K angstroms of Al-Si. Both wafers were sawn with little evidence of corrosion and submitted for wirebond tests.

7.2.2. TiN Metal Cap
  Wire pull and ball shear were performed before and after exposure to 200°C for 24 hours. Table 1 shows the results. Failure mode for aluminum wire was 100% first bond break in both cases so the drop in bond strength after temperature exposure was due to wire annealing. There appeared to be no difference before and after temperature exposure for the gold wire pull strength, however, temperature did have an effect on ball shear strength. Shear strengths started out low in the as-bonded condition with a mixture of ball shears and lifts, stayed low after temperature soak, but standard deviations got much worse after exposure. Since no attempt was made to optimize the process, it is not known if temperature exposure represents a reliability hazard. TiN is known to present a very hard surface, which is not a desirable attribute for gold ball bonding. Future work should concentrate on thinner layers and investigation of wirebond parameters.

<table>
<thead>
<tr>
<th>Wire pull strength as bonded</th>
<th>Wire Pull strength 200°C/24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25 mil Al wire:</td>
<td>11.59 ± 0.47 grams</td>
</tr>
<tr>
<td>1.25 mil Al wire:</td>
<td>6.80 ± 0.53 grams</td>
</tr>
<tr>
<td>1.0 mil Au wire:</td>
<td>10.28 ± 0.49 grams</td>
</tr>
<tr>
<td>1.0 mil Au wire:</td>
<td>9.67 ± 0.41 grams</td>
</tr>
<tr>
<td>Ball shear strength as bonded</td>
<td>Ball shear strength 200°C/24 hours</td>
</tr>
<tr>
<td>17.6 ± 4.9 grams</td>
<td>19.0 ± 16.29 grams</td>
</tr>
</tbody>
</table>

7.2.3. Al-Si Metal Cap
  All three Al-Si metal cap thicknesses provided satisfactory wirebond quality. There were no differences detected in mean values of wire pull strength for neither aluminum nor gold wire with all failures occurring by first bond breaks. Only the ball shear values showed any differences. The one-micron thick layer gave superior results with 60.23 grams versus 43-46 grams for the two thicker layers.
  The Al-Si metal layer proved more robust than TiN for wirebond and is a proven system from electrical standpoint but represents an added wafer process whereas TiN is already used as part of the wafer fabrication toolkit and as such is an easier process to incorporate. However, the shear strengths for gold wire on TiN were lower than those for Al-Si and showed some temperature related degradation after 24 hours at 200°C.

7.2.4. Partial Cut Technique
  Taking advantage of the fact that corrosion does not proceed until the dice are actually separated from one another, an experiment was performed in which a through cut was made in one direction and a partial cut in the other. The partial cut was taken at about 80% of the wafer thickness. Figure 9 shows the results of a wafer cut with all machine parameters set in normal mode and the partial cut made from the top to the bottom of the photo (can not be discerned in the photo due to shadowing effect in saw kerf). Some evidence of corrosion was noted but far less than is normally seen and not enough to represent a wirebond problem. The particular direction in which the partial cut was made did not seem to affect results. The same results were achieved when the through and partial cuts were reversed. Neither time in saw nor water source affected the results. An Auger analysis performed on a sample wafer from this group revealed Al, O, and trace amounts of N, C, and F which is normal for a metallic Al surface exposed to air. No evidence of any corrosive species such as Cl or NH\(_3\) was detected which implies the corrosion cell is a simple galvanic/electrolytic type as postulated by Reference12. In a production environment final separation of the die can be made using a rubber roller that cleaves the remaining portion of the cut. This process was quite common in the late 1970’s and early 1980’s.
7.2.5. SEM Analysis Results

SEM photos of wafer samples taken from a normal process, partial cut process, and plasma clean/partial cut process are shown in Figures 10 a-c. As opposed to optical photos which showed a difference in discoloration, the SEM analysis proved inclusive in determining any difference between the samples for number and distribution of pits.

8. Conclusions

• A variety of factors affect the ability to initiate corrosion of wafer bond pads with AlCu top metal while in a wafer saw. The die must be electrically separated from one another. It appears that light, water, and a voltage charge on the saw blade are also needed to start the corrosion process. While none are singularly sufficient to initiate the process, various combinations of two or more factors will cause corrosion to proceed.
• More than one corrosion mechanism may be in effect. It appears that a simple galvanic cell in operation possibly aided by a photovoltaic effect provided light intensity is great enough. It also appears that voltage generated through the saw blade also causes an electrolytic cell to operate.
• Various methods exist which can reduce the level of corrosion to an acceptable quantity. These methods include protective coatings that stop the water from interacting with the surface constituents, sawing at fast speeds, and making partial cuts on the saw with final cleavage (separation) after wafer wash and drying.

• The amount of time a wafer was in the saw proved to be a critical factor: Wafers sawn with fast speeds (about 20 minutes in the saw) tended to corrode much less than those sawn at normal speeds (in saw for approximately 60 minutes). If no other option is available, wafers can be mounted, cut into “quarters”, re-mounted individually, and sawn with minimal corrosion.

• Exposing wafers to oxygen plasma just before saw tends to reduce the amount of corrosion detected. While there was no detectable difference in wire pull strengths for samples exposed from 20 to 80 minutes, there was a degradation in ball shear strength.

• Of all the methods explored a final top metal deposition of Al-Si proved the most effective deterrent. Capping the bond pad with this metal effectively covers the theta particles, thereby, denying the system the metal electrodes needed to set up a corrosion cell.

• The partial saw cut technique proved to be the next best deterrent. Taking advantage of the fact that individual die begin to corrode once isolated from each other, making partial cuts into the wafer effectively keeps all dice connected.

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References


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