

A METHOD TO PREVENT CORROSION OF BOND PAD STRUCTURE

FIELD OF THE INVENTION

[0001] The present invention relates generally to integrated circuit fabrication methods and particularly, to fabrication methods that mitigate the problem of bond pad corrosion.

BACKGROUND OF THE INVENTION

[0002] Integrated circuits are used in many portable electronic products, such as cell phones, portable computers, voice recorders, etc. as well as in many larger electronic systems, such as cars, planes, industrial control systems, etc. Integrated circuits may include a combination of active devices, passive devices and their interconnections. In order to electrically connect the integrated circuit components to a point external of it, bond pad structures are provided.

[0003] The schematic cross-section of Figure 1 illustrates a known integrated circuit system 100 comprising a substrate 101 having a top metal layer 112 embedded within an interlayer dielectric 110. Attached to a lower surface of the top metal layer 112 is a via 114 which may be connected to an underlying metal layer or circuit components (not shown). A bond pad 120 is formed at an upper surface of the top metal layer 112. The bond pad is conductive and may comprise metals such as aluminum-based alloys (such as Al-Cu or Al-Cu-Si). A passivation layer 140 is formed over the interlayer dielectric 110 and the bond pad 120, with an opening created in the passivation layer 140 so that an upper surface portion of the bond pad 120 is exposed. As illustrated in Figure 1, a ball bond 160 is formed in contact with the exposed portion of the bond pad. The ball bond 160 has a wire bond 162 attached thereto for connecting the bond pad 120 and hence integrated circuit to a location external of it. The location external of the integrated circuit may include packaging leads, a circuit board or another integrated circuit.

[0004] A problem often encountered in the fabrication of integrated circuits is bond pad corrosion which is the depletion of materials used in the bond pad. This phenomenon is undesirable because it results in the formation of pits or pinholes at the upper surface of the bond pad which can affect the adhesion reliability of subsequent bonding contacts such as ball bonds to the bond pad. Therefore, fabrication processes that can mitigate the problem of bond pad corrosion are desirable.

SUMMARY OF THE INVENTION

[0005] The present invention relates generally to methods for fabricating integrated circuits and in particular, to methods for preventing the corrosion of bond pads.

[0006] In accordance with one aspect of the invention, there is provided a method for fabricating an integrated circuit comprising providing a substrate with a bond pad formed thereover, the bond pad having a top surface for the formation of bonding connections. A passivation layer is provided over the bond pad followed by the formation of a masking layer over the passivation layer. The passivation layer is subsequently etched in accordance with the masking layer to form a patterned passivation layer with an opening that exposes a portion of the top surface of the bondpad. After etching the passivation layer, the masking layer is removed and a bond pad protective layer is subsequently formed on the exposed top surface portion of the bond pad.

[0007] These and other objects, along with advantages and features of the present invention herein disclosed, will become apparent through reference to the following description and the accompanying drawings. Furthermore, it is understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] In the drawings, like reference numbers generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, embodiments of the invention will now be described, by way of example with reference to the drawings of which

[0009] Figure 1 is a schematic cross-sectional view of a known integrated circuit system comprising a bond pad structure;

[0010] Figures 2 to 5 are schematic cross-sectional views illustrating the results of progressive stages in fabricating an integrated circuit system in accordance with one embodiment of the invention; and

[0011] Figure 6 is a schematic cross-sectional view illustrating an integrated circuit system in accordance with another embodiment of the invention.

DESCRIPTION OF THE INVENTION

[0012] The present invention will now be described with reference to the attached figures, wherein like reference numerals are used to refer to like elements throughout.

[0013] Figures 2-5 are cross-sectional views illustrating by way of example and not by limitation, an exemplary process flow for the formation of an integrated circuit system 200 according to an embodiment of the present invention. It is to be understood that a plurality of conventional processes that are well known in the art and not repeated herein, may precede or follow Figures 2- 5.

[0014] Referring now to FIG. 2, therein is shown a partial cross sectional view of an integrated circuit system 200 in an intermediate stage of manufacture. The integrated circuit system comprises a substrate 201 having a top metal layer 212 embedded within an interlayer dielectric 210. Although not illustrated in Figure 2, the substrate typically also comprises a

plurality of active and passive devices formed below the top metal layer 212 and interconnect structures linking some of the devices to the top metal layer 212. The interconnect structures typically comprise metallic traces and vias embedded in one or more layers of dielectric material. Attached to a lower surface of the top metal layer 212 is a via 214 which may be connected to an underlying interconnect or circuit components (not shown).

[0015] A first dielectric layer 220 is provided over the interlayer dielectric 210 and top metal layer 212. In one embodiment, the first dielectric layer 220 comprises silicon oxide. Alternatively, other dielectric layers such as TEOS may also be suitable. An opening is created through the first dielectric layer 220 and filled with a bond pad 260 the bottom surface of which contacts a top surface of the top metal layer 212. As shown in Figure 2, the top surface of the bond pad 260 is situated above the height of the first dielectric layer 220. The bond pad is electrically conductive in nature and may comprise metals or alloys thereof such as Aluminum copper or aluminum silicon copper. Alternatively, other conductive materials may also be used and the bond pad may also be a laminate structure made up of additional layers of material such as copper, titanium, titanium nitride or combinations thereof.

[0016] A passivation layer 280 is formed over the bond pad 260 and first dielectric layer 220 such that the bond pad is embedded in the passivation layer 280. The passivation layer 280 protects underlying components of the integrated system 200 from external contaminants such as moisture and mechanical damage. In one embodiment, the passivation layer 280 comprises silicon nitride. Alternatively, other materials such as silicon oxynitride and polyimide may also be used as a passivation layer in addition to or in place of silicon nitride.

[0017] A photoresist layer is deposited on the entire surface of the passivation layer 280 and selectively exposed and developed to form a masking layer 290 for patterning the passivation layer. As shown in Figure 2 the masking layer 290 includes an opening situated at a location overlying the top surface of the bond pad 260.

[0018] Figure 3 shows the semiconductor system 200 of Figure 2 after the passivation layer 280 has been etched in accordance with the masking layer 290 by a reactive ion etching (RIE) process. The masking layer 290 prevents passivation layer regions underlying it from being etched while exposed portions of the passivation layer 280 are removed during RIE. The etching process creates an opening 282 in the passivation layer such that a top surface portion of the bond pad 260 is exposed thus allowing connections such as ball bonds that electrically couple the integrated system to external locations to be formed on the bond pad.

[0019] In one embodiment, the passivation layer 280 comprises silicon nitride and is etched using a fluorine based chemistry comprising CF_4 , SF_6 , or C_4F_8 or a combination of two of more of these gases. Alternatively, other combinations of gases that are suitable for selectively etching the passivation layer 280 without damaging the bond pad material may also be used. In a preferred embodiment, a high frequency megasonic rinse in de-ionized (DI) water may follow after the completion of the passivation etch process. The megasonic rinse helps to remove etch by-products such as floating residue and/or polymer that has carbon and fluorine content.

[0020] Figure 4 shows the semiconductor system 200 of Figure 3 after the masking layer 290 has been removed. In one embodiment, the masking layer 290 is photoresist and it is removed by an oxygen based plasma process. Preferably, the oxygen based plasma process comprises a combination of a first oxygen containing gas chemistry and a second gas chemistry that aids in etch residue removal. During the RIE process for patterning the passivation layer 280, etch residues, a by-product of the plasma etching process are formed. These etch residues may include hardened photoresist material, etch residue generated as a result of chemical reactions occurring during the plasma etch process, sputtered on materials, re-deposited materials or combinations thereof. A resist stripping process that is purely oxygen based does not assist in the removal of these etch residues and as such the inclusion of a second gas chemistry for etch residue removal is preferred. In one embodiment, the etch residue removal gas chemistry is a fluorine based chemistry such as but not limited to CF_4 or SF_4 .

[0021] Following the removal of the masking layer 290, the integrated circuit system 200 is subjected to a wet solvent clean process to further remove any remaining etch residue. Commercially available chemical solvents such as EKC-265, Aleg310 and NE-111 may be used in the wet solvent clean process. Alternatively, other chemical solvents that are capable of removing etch residue without damaging the components formed on the integrated circuit may also be suitable.

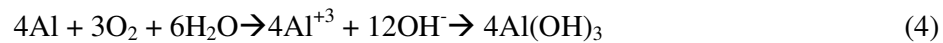
[0022] In processes where the preceding photoresist strip involves the use of fluorine-based gases, the wet clean process also has the added advantage of removing residual fluorine introduced by the use of such gases. These residual traces of fluorine are undesirable as they may react with the bond pad material to bring about bond pad corrosion. For example, if the bond pad is composed of aluminum (Al) or an alloy thereof, the residual traces of fluorine may cause fluorine-induced bond pad corrosion by reacting with the aluminum to form aluminum fluoride (AlF_x) on the surface of the bond pad. If moisture is present, aluminum fluoride oxide ($\text{Al}_x\text{F}_y\text{O}_z$) may also be formed.

[0023] Figure 5 shows the integrated circuit system of Figure 4 after a bond pad protective layer 520 is grown on the exposed top surface portion of the bond pad 260. The bond pad protective layer 520 protects the top surface of the bond pad from being corroded. In one embodiment, the bond pad is composed of Aluminum alloys (such as Al-Cu, Al-Cu-Si) and the oxide layer 520 grown is aluminum oxide (Al_2O_3).

[0024] A possible reason for bond pad corrosion is due to the formation of an electrochemical cell when two electrochemically dissimilar metals are placed in contact. When the electrochemical cell is exposed to water, (for example, when an IC is rinsed in water during processing steps subsequent to bond pad formation or moisture in the atmosphere), water acts as an electrolyte which facilitates the occurrence of galvanic corrosion. During galvanic corrosion, one of the metals acts as an anode that loses electrons and metal ions while the other metal acts as a cathode that gains electrons. Using the example of an aluminum-copper bond pad as an

illustration, an electrochemical cell is formed as a result of the electrochemical differences between aluminum and copper (illustrated in equations (1) and (2)). In particular, aluminum acts as an anode that corrodes preferentially with respect to copper when the metals are exposed to moisture or water because it has a more negative electrical potential compared to copper. As illustrated in equations (3) and (4), aluminum loses electrons and aluminum ions by reacting with OH⁻ ions in water to form aluminum hydroxide (Al(OH)₃). Copper, on the other hand, acts as a cathode that gains electrons. In this situation, aluminum corrodes faster than it would compared to when pure aluminum is used while copper, which acts as a cathode, corrodes more slowly compared to pure copper. However, aluminum is typically mixed with copper to form an alloy that is used for the bond pad metallization because of the superior qualities that copper has in the prevention of electromigration.

[0025] Galvanic Corrosion (Al-Cu)



[0026] By providing a protective layer of aluminum oxide (Al₂O₃) 520 on the surface of the bond pad, aluminum in the bond pad is shielded from exposure to moisture or water thus preventing the resultant corrosive reaction (4) from occurring. This is illustrated in equation (5) below.



[0027] In one embodiment, the aluminum oxide layer 520 may be formed via a plasma oxidation process involving oxygen or oxygen based gases. Preferably, the plasma oxidation process occurs at a chamber temperature of at least 200°C so that moisture trapped at the edges

of the bond pad may be removed concurrently with the oxide growth. In alternative embodiment, the oxide layer 520 may be grown thermally in a high temperature thermal oxidation process. Preferably, the aluminum oxide layer 520 formed by either processes is between 50 to 55 angstrom. Alternatively, other values of aluminum oxide layer thickness, which are sufficiently thick to act as a barrier to water while still allowing the successful formation of electrical contacts to the top surface of the bond pad may also be used.

[0028] As evident from the above description, the bond pad protective layer 520 is only formed after the removal of the photoresist masking layer 290 in a plasma strip process followed by a wet solvent clean process to remove any remaining etch residue or polymer left behind by the passivation layer 280 RIE. This sequence of steps is critical as the plasma strip and wet clean facilitate the removal of any contaminants such as etch and photoresist residue that may inhibit the growth of a uniform bond pad protective layer. A non-uniform bond pad protective layer 520 may leave some portions of the bond pad surface less protected and more vulnerable to galvanic corrosion. Furthermore, separating the photoresist removal and passivation layer formation steps also makes it possible to introduce a fluorine-based component into the photoresist removal step. As discussed earlier, a fluorine-based component aids in the removal of etch residues left behind by preceding RIE steps but can cause bond pad corrosion if the bond pads are not subsequently cleaned to remove fluorine residue. By removing the photoresist in a separate step and subsequently performing a wet clean to remove fluorine traces before the bond pad protective layer is formed, the risk of fluorine induced bond pad corrosion can be mitigated.

[0029] Turning now to Figure 6, therein is shown a partial cross sectional view of an integrated circuit system 600 in accordance with an alternative embodiment of the present invention. The integrated circuit system comprises a substrate 601 including a top metal layer 612 and an overlying bond pad 620 embedded within an interlayer dielectric 610. A via 630 contacts a lower surface of the top metal layer 612 while the bond pad is attached to the opposed upper surface of the top metal layer 612. The via 630 may be connected to an underlying

interconnect or circuit components (not shown). Although not illustrated in Figure 6, the substrate may also comprises a plurality of active and passive devices formed below the top metal layer 612 and interconnects linking some of the devices to the top metal layer 612. The interconnects comprise metallic lines and vias embedded in one or more layers of dielectric material. The bond pad is conventional in the art and may comprise metals such as aluminum, aluminum-copper or alloys thereof. Alternatively, other conductive materials may also be used and the bond pad may also be a laminate structure made up of additional layers of material such as copper, titanium, titanium nitride or combinations thereof.

[0030] A first composite layer is provided over the interlayer dielectric 610 and bond pad 620. In the presently illustrated embodiment, the first composite layer comprises a lower Titanium (Ti) layer 640 proximate the bond pad 620 and interlayer dielectric 610 followed by an intermediate Titanium Nitride (TiN) layer 650 overlying the Ti layer 640 and on the uppermost portion of the first composite layer, a silicon nitride layer 660 formed over the TiN layer 650. The silicon nitride layer 660 serves as a passivation layer that protects underlying components of the integrated system from external contaminants such as moisture and mechanical damage. In alternative embodiments, other materials such as but not limited to silicon oxynitride and polyimide may also be used as a passivation layer in addition to or as a replacement of silicon oxide/nitride.

[0031] An opening 670 is created through the first composite layer so as to allow access to a portion of the bond pad top surface. This is necessary so that bonding connections such as ball bonds may be subsequently formed to the bond pad 620.

[0032] As shown in Figure 6, a bond pad protective layer 680 is formed over the top surface of bond pad 620 and the edges of the titanium layer 640 and titanium nitride layer 650 are also covered by a sidewall protective layer 690. The protective layers 680 and 690 help to protect the bond pad from corrosion. In one embodiment, the protective layer 680 is an oxide layer grown over the bond pad 620 while the edges of the titanium and titanium nitride layers

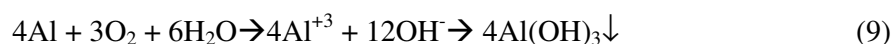
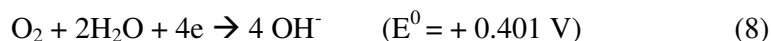
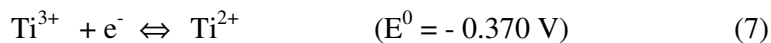
640 and 650 are oxidized to form a sidewall protective layer 690 composed of titanium oxide and titanium oxynitride. In a preferred embodiment, the bond pad is composed of aluminum copper or alloys thereof and the oxide layer 680 grown over the bond pad is aluminum oxide (Al_2O_3).

[0033] A possible reason for bond pad corrosion is due to the formation of an electrochemical cell when two electrochemically dissimilar metals are placed in contact. When the electrochemical cell is exposed to water (for example, when an IC is rinsed in water during processing steps subsequent to bond pad formation or moisture in the atmosphere), water acts as an electrolyte, which facilitates the occurrence of galvanic corrosion. During galvanic corrosion, one of the metals acts as an anode that loses electrons and metal ions while the other metal acts as a cathode that gains electrons. With reference to the example shown in Figure 6, two electrochemical cells may be formed in this embodiment. The first electrochemical cell is the one arising from the use of an aluminum-copper bond pad 620. As discussed earlier, the electrochemical differences between aluminum and copper (illustrated in equations (1) and (2)) result in the formation of an electrochemical cell where aluminum corrodes preferentially with respect to copper when the metals are exposed to moisture or water. In particular, aluminum loses electrons and aluminum ions by reacting with OH^- ions in water to form aluminum hydroxide (illustrated in equations (3) and (4)) while copper acts as a cathode that gains electrons.

[0034] The second electrochemical cell is formed between aluminum from the bondpad and titanium from the Ti/TiN layers 640 and 650. When the aluminum-titanium electrochemical cell is exposed to water or moisture, aluminum having a more negative electrical potential acts as an anode thus losing electrons and metal ions while titanium acts as a cathode that gains electrons. The electrical potential differences between aluminum and titanium are shown in equations (5) and (6). Specifically, aluminum corrodes preferentially with respect to titanium

by reacting with OH⁻ ions in water to form aluminum hydroxide (Al(OH)₃) as shown in equations (8) and (9).

[0035] Galvanic Corrosion (Al-Ti)



[0036] Galvanic corrosion of the bond pad 620 resulting from the electrochemical cell formed between aluminum and titanium can be avoided by providing a sidewall protective layer of titanium oxide/titanium oxynitride 690 at the edges of the titanium/titanium nitride layers 640 and 650, respectively, and a bond pad protective layer 680 of aluminum oxide formed over the surface of the bond pad. The bond pad protective layer of aluminum oxide 680 protects the aluminum-copper bond pad from being exposed to moisture or water and hence the resultant corrosive reaction which follows due to the aluminum-copper electrochemical cell.

[0037] In one embodiment, the protective layers 680 and 690 may be formed via a plasma process involving oxygen or oxygen based gases. During the plasma process, the chamber is preferably maintained at a chamber temperature of 200°C or more so that moisture trapped at the edges of the bond pad may be removed concurrently with the oxide growth. In alternative embodiment, the protective layers 680 and 690 may be grown thermally in a high temperature oxidation process. Preferably, the aluminum oxide (Al₂O₃) layer 680 grown over the bond pad is between 50 to 55 angstrom. Alternatively, other values of aluminum oxide layer thickness which are sufficiently thick to act as a barrier to water while still allowing the successful formation of electrical contacts to the top surface of the bond pad may also be used.

[0038] Similar to the embodiment described in relation to Figures 2-5, the oxide layers 680 and 690 are only grown after the removal of the photoresist masking layer for patterning the first composite layer (640, 650 and 660) and a wet solvent clean process to remove any remaining etch residue and polymer left behind by the first composite layer RIE. This sequence of steps is critical as the plasma strip and wet solvent clean facilitate the removal of any contaminants such as etch and photoresist residue that may inhibit the growth of a uniform aluminum oxide (Al_2O_3) protective layer on the surface of the bondpads. A non-uniform Al oxide layer may leave some portions of the bond pad surface less protected and more vulnerable to galvanic corrosion. Furthermore, separating the photoresist removal and protective layer formation steps also makes it possible to introduce a fluorine-based component into the photoresist removal step. As discussed earlier, a fluorine-based component aids in the removal of etch residues left behind by preceding RIE steps but can cause bond pad corrosion if the bond pads are not subsequently cleaned to remove fluorine residue. By removing the photoresist in a separate step and subsequently performing a wet solvent clean to remove fluorine traces before the bond pad protective layer is formed, the risk of fluorine induced bond pad corrosion can be mitigated.

[0039] The preferred embodiment of the invention is illustrative of the invention rather than limiting of the invention. It is to be understood that revisions and modifications may be made to methods, materials, structures and dimensions of a semiconductor structure while still providing a semiconductor that fall within the scope of the included claims. All matters hitherto set forth herein or shown in the accompanying drawings are to be interpreted in an illustrative and non-limiting sense.

What is claimed is:

CLAIMS

1. A method of fabrication an integrated circuit comprising:
providing a substrate with a bond pad formed thereover, the bondpad having a top surface for the formation of bonding connections;
providing a passivation layer over the bondpad;
forming a masking layer over the passivation layer;
etching the passivation layer in accordance with the masking layer to form a patterned passivation layer with an opening that exposes a portion of the top surface of the bond pad;
removing the masking layer; and
forming a bond pad protective layer on the exposed top surface portion of the bond pad after removing the masking layer.
2. The method according to claim 1, wherein the bond pad protective layer comprises an oxide.
3. The method according to claim 1, wherein the masking layer comprises photoresist.
4. The method according to claim 3, wherein the masking layer is removed by a plasma strip process.
5. The method according to claim 4, wherein the plasma strip process comprises a combination of a first oxygen containing gas chemistry and an etch residue removal chemistry for removing etching residues arising from the step of etching the passivation layer.

6. The method according to claim 5, wherein the etch residue removal chemistry comprises a fluorine-based gas chemistry.
7. The method according to claim 1, further comprising cleaning the substrate to remove etching residues after removing the masking layer and before forming the bond pad passivation layer.
8. The method according to claim 7, wherein cleaning the substrate comprises using a wet solvent clean process.
9. The method according to claim 8, wherein at least one of the chemical solvents EKC-265, Aleg310 or NE-111 is used the wet solvent clean process.
10. The method according to claim 1, wherein the bond pad comprises an aluminum copper based alloy.
11. The method according to claim 8, wherein the bond pad protective layer is composed of aluminum oxide.