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## METHOD OF FABRICATING AN ALUMINUM PLUG USING SELECTIVE CHEMICAL VAPOR DEPOSITION

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The invention relates in general to a metallization process for the fabrication of semiconductor integrated circuits (ICs). In particular, the invention relates to a method of fabricating an aluminum plug for ICs by performing a vacuum thermal annealing treatment prior to a chemical vapor deposition (CVD) procedure, resulting in improved deposition selectivity

#### Description of the Related Art

Sputtering is a technique that is widely used in the fabrication of semiconductor IC devices, for depositing aluminum to form interconnects in the device circuitry. Due to the fact that sputtering is a physical vapor deposition (PVD) procedure, resulting in generally poor step coverage compared to that provided by a CVD procedure, it is not suitable for IC fabrication at the sub-micron level. If sputtering were utilized in sub-micron device fabricating procedures, undesirable results such as poor uniformity in thickness and voids in the deposited aluminum layer would arise. In particular, when recessions, such as holes, in the device substrate are small in cross-section and are deep, metallization may not be effectively achieved down to the bottom of the recessed portion. In such a situation, electrical connection to the underlying conductive region would be incomplete or absent

In order to provide background for the description of the invention, an aluminum deposition layer formed using a conventional sputtering procedure is briefly examined, with reference to FIG. 1 of the accompanying drawings. Essentially, a substrate 10 is used as the basis for fabrication of semiconductor components for an IC device. For clarity, the entire IC device is not shown. Rather, only a portion of the conductive region 12, such as a metal or a metal silicide layer of the exemplified semiconductor component, is schematically shown in the drawing. An insulating layer 14, such as a thermal silicon dioxide layer, a borophosphosilicate glass (BPSG) layer, or a tetraethoxysilane (TEOS) layer, is formed over the surface of the substrate 10. Photolithography and etching procedures are then utilized to form a contact opening 16 in the insulating layer 14



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exposing the conductive region 12 of the semiconductor component being fabricated. A sputtering procedure is then conducted to deposit an aluminum layer 18 over the insulating layer 14, filling the space inside the contact opening 16 and connecting to the conductive region 12, thereby forming the interconnect for the fabricated semiconductor component.

5 However, as the feature size of semiconductor devices is reduced, this conventional metal sputtering procedure for forming the metallization interconnect inevitably becomes less effective. When the dimensions of the contact opening 16 are reduced as a result of device miniaturization, the deposited aluminum layer 18 suffers deteriorated step coverage conditions, as well as uneven layer thickness. Voids 15 may  
10 even appear in the opening 16. All these factors render the performance characteristics of the device thus fabricated less controllable and often unacceptable. When the space in the contact opening 16 is reduced to a certain level, the sputtered metal may not even reach the bottom of the opening hole at all.

To solve the problem, as shown in FIG. 2, instead of directly depositing the  
15 aluminum layer over the surface of the insulating layer 14 and in the contact opening 16 formed therein, frequently a tungsten plug 17 is first formed inside the contact opening 16 by a selective CVD procedure, followed by aluminum layer deposition over the surface of the insulating layer 14 using a conventional sputtering procedure.

However, fabrication of additional tungsten plugs in contact openings for  
20 semiconductor components represents an increase in overall manufacturing costs. Further, the use of a tungsten plug is disadvantageous, as it has an electrical conductivity that is only about one-third that of aluminum. Efforts thus have been devoted toward developing process techniques using CVD procedures for depositing aluminum, that are suitable for semiconductor devices featuring fabrication resolution on the level of 0.25  $\mu\text{m}$  and less.

25 When a CVD procedure is utilized in depositing aluminum layers, triisobutylaluminum (TIBA) or dimethylaluminum hydride (DMAH) is typically used as the precursor. TIBA is difficult to use, as it requires a relatively high temperature (about 160 to 170  $^{\circ}\text{C}$ ) to vaporize because of its lower vaporization pressure. DMAH, on the other hand, although relatively easier to vaporize because of its inherently higher  
30 vaporization pressure, also causes the deposited aluminum layer to have carbon-containing

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impurities that reduce the electrical conductivity of the deposited aluminum layer. This is because DMAH has a strong carbon-aluminum covalent bond in its molecular structure.

Gladfelter and M. G. Simmonds of the University of Minnesota proposed a method for depositing aluminum using a CVD procedure by utilizing a dimethylethylamine alane (DMEAA) compound as the precursor. As shown in FIG. 3, because DMEAA has a coordinate covalent bond between the nitrogen and aluminum atoms, featuring a bonding energy gap that is smaller than the conventional covalent bonds, its vaporization temperature is relatively lower, at about 90 °C. The resulting deposition aluminum layer would thus have a much lower concentration of impurities. Based on these outstanding results, the present inventor proposed a DMEAA-related semiconductor device fabricating process in SSDM, p. 634, 1994 as well as in VMIC, p. 362, 1994. The selectivity characteristics with respect to different substrate materials, however, was not investigated in those disclosures.

### SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a method for fabricating an interconnect in a semiconductor IC device that results in a continuous, reliable electrical connection.

The invention provides an improved method of fabricating an aluminum plug in a selective CVD procedure that includes the following steps. First, a semiconductor component is formed in a substrate having an insulating layer formed over the surface thereof. The insulating layer has a contact opening that exposes a conductive region of the semiconductor component. Then, a vacuum thermal annealing treatment is implemented on the device substrate. Dimethylethylamine alane (DMEAA) is utilized as a precursor for depositing an aluminum layer over the surface of the substrate in a CVD procedure conducted at a substrate temperature not higher than 250 °C, for fabricating an aluminum plug in the contact opening. The aluminum plug is selectively deposited over the surface of the exposed conductive region in the contact opening while relatively not deposited over the surface of the insulating layer.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features, and advantages of the invention will become apparent by way of the following detailed description of the preferred but non-limiting embodiment. The description is made with reference to the accompanying drawings in which

5       FIG. 1 schematically shows a cross-section of a metallization interconnect fabricated using a conventional aluminum sputtering-deposition process.

FIG. 2 schematically shows a cross section of a metallization interconnect fabricated using a conventional selective CVD process for depositing a tungsten plug.

FIG. 3 shows the molecular structure of precursor DMEAA utilized in a fabrication  
10       process in accordance with a preferred embodiment of the invention.

FIG. 4 shows the aluminum layer growth rate plotted as a function of the substrate temperature during the process of deposition.

FIG. 5 shows the purity of the aluminum layer formed using a CVD procedure, as determined using an Auger electron spectroscopy process;

15       FIG. 6 shows plots of deposition selectivity for aluminum deposited over different materials at different temperatures using a CVD procedure;

FIG. 7 shows a comparison of deposition selectivity, before and after a thermal annealing treatment, for aluminum deposited over different materials at different temperatures using a CVD procedure; and

20       FIG. 8 schematically shows a cross section of an aluminum plug fabricated in accordance with a preferred embodiment of the invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

25       A preferred method of fabricating aluminum plugs for metallization of semiconductor devices in selective CVD procedures is described with reference to FIG. 8 of the drawings

First, a substrate 20 is provided as the basis for fabrication of semiconductor components for an IC device. For clarity, only a portion of the conductive region 22, such as a metal or a silicide layer of the exemplified semiconductor component, is schematically  
30       shown. An insulating layer 24, such as a thermal oxide layer or a borophosphosilicate glass (BPSG) layer, is formed over the surface of the substrate 20. Photolithography and

etching procedures are then utilized to form a contact opening 26 in the insulating layer 24 exposing the conductive region 22 of the semiconductor component being fabricated

Then, a vacuum thermal annealing treatment is performed on the device wafer at this stage by heating the wafer to a temperature of about 450 °C for about 30 minutes. Afterwards, DMEAA is utilized as a precursor for performing a CVD procedure to deposit an aluminum layer 28. The substrate temperature is controlled to be no higher than 250 °C, in order to achieve excellent deposition selectivity. In other words, under the above-described conditions, aluminum can be deposited with high selectivity, only on the conductive region 22 inside the contact opening 26, not on the surface of the insulating layer 24. An aluminum plug 28 having a structural configuration such as the one schematically depicted in FIG. 8 is thus formed. Then, a conventional sputtering procedure can follow to form the interconnects above the insulating layer 24. Because the invention is not directed toward this phase of fabrication, subsequent steps will not be elaborated herein.

Thus, because the method of the invention for fabricating aluminum plugs in a selective CVD deposition procedure makes use of DMEAA as a precursor, more easily-controlled fabricating conditions are available for forming the aluminum deposition. This is because, as mentioned above, DMEAA has a coordinate covalent bond between the nitrogen and aluminum atoms, featuring a bonding energy gap that is smaller than conventional covalent bonds. That smaller bonding energy gap results in a higher vaporization pressure, so that its vaporization temperature is relatively low, at about 90 °C. The resulting aluminum plugs have a low level of impurities and feature electrical resistance characteristics comparable to aluminum depositions formed by conventional sputtering procedures.

The vacuum thermal annealing treatment performed before implementing the CVD procedure for depositing the aluminum serves to greatly improve the deposition selectivity between the insulating layer and the conduction layer over the surface of the substrate. Because of this outstanding selectivity, the method of the invention is suitable for fabricating contact plugs such as aluminum plugs, and in particular, for integrated circuit device fabricating procedures requiring a high level of integration. To demonstrate the

superiority of the method of the invention, several tests and corresponding analyses were conducted, with the following results

In the first test, a CVD procedure for depositing aluminum was performed, using DMEAA as the precursor. The aluminum layer growth rate plotted as a function of the substrate temperature during the deposition process is shown in FIG. 4. The aluminum was deposited in two CVD procedures, utilizing DMEAA as a precursor, at respective process ambient pressures of 100 and 200 mTorr. The data collected and presented in FIG. 4 shows that the growth-rate/substrate-temperature relationships at the two selected pressures were basically the same, with the growth rate generally increasing as the substrate temperature rose. Calculation results show that the surface reaction activation energy is about 0.75 eV, comparable to the bonding energy of aluminum-nitrogen atoms in the molecule. This indicates that the breaking up of the aluminum-nitrogen bond is the key step for selective aluminum deposition using the CVD procedure with DMEAA as the precursor. DMEAA is more suitable than conventional precursors for this selective aluminum deposition because it has a smaller covalent bonding energy.

In another test, an aluminum layer deposited using the above-mentioned CVD procedure was the subject of Auger electron spectroscopy, resulting in the corresponding analysis data shown in FIG. 5. Essentially, FIG. 5 plots data representing the purity of the aluminum layer formed by the CVD procedures of the invention, as obtained in the Auger electron spectroscopy. The Auger data shows that the deposited aluminum has a very high level of purity, with rare carbon or oxygen impurity atoms barely present in the deposited layer. Analysis of the specimen shows that the layer has a resistance of about  $3.0 \mu\Omega/\text{cm}$ , comparable to that found in layers formed using the conventional sputtering deposition procedures.

A third test for aluminum deposition selectivity for the method of the invention was conducted. For this test, aluminum was deposited over the surface of a conduction layer, as well as on insulating layers of a variety of different materials at different process temperatures. FIG. 6 shows the aluminum deposition selectivity recorded for this test. As shown in the drawing, aluminum particles were measured as they were deposited over the surface of four insulating layers composed of different materials, including thermal oxide (Th-OX), tetraethoxysilane (TEOS), borophosphosilicate glass (BPSG), and oxide formed

by a plasma-enhanced CVD procedure (PEOX). Basically, the deposition selectivity deteriorated as the deposition temperature increased. In other words, aluminum particles were easily deposited over the surfaces of both the conduction and insulating layers at high process temperatures, while, when the process temperature was maintained at a lower level, the same insulating layers gathered considerably fewer aluminum particles than did the conduction layer.

A fourth test was conducted wherein an additional vacuum thermal annealing treatment was performed, the remainder of the test proceeded according to the third test procedure described above. The vacuum thermal annealing treatment procedure was conducted at a temperature of about 450 °C and was sustained for about 30 minutes. The test results are plotted in FIG. 7, which shows the aluminum deposition selectivity improvement, before and after the vacuum thermal annealing treatment, as the aluminum is deposited over different materials using the CVD procedure. As clearly shown in the plot, aluminum deposition selectivity (deposition over the conduction layer rather than the insulating layer) improved for the CVD procedure when a vacuum thermal annealing treatment was performed first. In particular, the selectivity was shown to be best for the Th-OX insulating layer, followed by the BPSG layer, and then by the PEOX layer. This selectivity ranking could have been based on the fact that PEOX is a material that absorbs more water molecules than does Th-OX. There would therefore be fewer —OH bonds in the Th-OX material than in the PEOX. When the vacuum thermal annealing treatment is performed prior to deposition, water is removed. Therefore, while aluminum particles deposit smoothly over the surface of the conduction layers, fewer aluminum particles are deposited over the surface of PEOX insulating layers, and even fewer on the Th-OX layers.

The invention has been described by way of example and in terms of a preferred embodiment, but the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements. The appended claims, therefore, should be accorded the broadest interpretation so as to encompass all such modifications and similar structures.

What is claimed is:

- 1           1           A method of fabricating an aluminum plug using a selective chemical vapor  
2 deposition procedure comprising the steps of:  
3           forming a semiconductor component in a substrate having an insulating layer  
4 formed over the surface thereof, the insulating layer having formed therein a contact  
5 opening exposing a conductive region of the semiconductor component;  
6           performing a vacuum thermal annealing treatment on the substrate, and  
7           depositing an aluminum layer over the surface of the substrate in a chemical vapor  
8 deposition procedure utilizing dimethylethylamine alane as a precursor and performed at a  
9 substrate temperature not higher than 250 °C, for fabricating an aluminum plug in the  
10 contact opening and in contact with the conductive region, the aluminum plug being  
11 selectively deposited over the surface of the exposed conductive region while not being  
12 deposited over the surface of the insulating layer.
- 1           2.           The method of claim 1, wherein the vacuum thermal annealing treatment is  
2 performed at a temperature of about 450 °C and is sustained for about 30 minutes.
- 1           3.           The method of claim 1, wherein the insulating layer is a thermal oxide layer.
- 1           4           The method of claim 1, wherein the insulating layer is a  
2 borophosphosilicate glass layer.
- 1           5.           The method of claim 1, wherein the insulating layer is a plasma enhanced  
2 chemical vapor deposited oxide layer.
- 1           6.           A method of fabricating an aluminum plug, comprising the steps of:  
2           forming a contact opening in an insulating layer over a substrate to expose a  
3 conductive region in the substrate;  
4           performing a vacuum thermal annealing treatment on the substrate, and

5 performing a chemical vapor deposition procedure at a substrate temperature not  
6 exceeding 250 °C using dimethylethylamine alane as a precursor, to deposit an aluminum  
7 layer on the exposed conductive region in the contact opening

1 7. The method of claim 6, wherein the vacuum thermal annealing treatment is  
2 performed at a temperature of about 450 °C and is sustained for about 30 minutes.

1 8. The method of claim 6, wherein the insulating layer is a thermal oxide layer

1 9. The method of claim 6, wherein the insulating layer is a  
2 borophosphosilicate glass layer.

1 10. The method of claim 6, wherein the insulating layer is a plasma enhanced  
2 chemical vapor deposited oxide layer.