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IMPROVED PLUG FILLING TECHNIQUE

BACKGROUND OF THE INVENTION

(1) FIELD OF THE INVENTION

The invention relates to semiconductor integrated circuit technology in general, more particularly to the problem of filling high aspect ratio holes with conductive material.

(2) DESCRIPTION OF THE PRIOR ART

Referring to FIG. 1, a semiconductor substrate (most commonly silicon), including conducting line 2 (seen head-on in the figure) has been covered by insulating layer 3. Opening (or hole) 4 has been formed in 3 and extends all the way down to the surface of conductor 2. The aspect ratio of hole 4 is defined as the ratio of its depth H to its diameter W . Aspect ratios in excess of about 2:1 are considered to be high aspect ratios.

Hole 4 was formed so as to allow electrical contact to be

made between a conductive layer 5, on the upper surface of 3, and conductive layer 2. Thus it becomes necessary to fill, or plug, hole 4 with a suitable conductive material.

Aluminum, widely used as a conductive material in integrated circuits, is also the material usually used to provide the filler plug. The preferred method for depositing the aluminum inside hole 4 has been sputtering because it allows the film properties to be tightly controlled (through adjustment of processing conditions. Conventional sputtering -- placing a silicon substrate a short distance below an aluminum target, has been found to be unsuitable for plug filling because a very thick layer has to be built up on the main surface before the hole can be plugged.

The reason for this can be seen by referring once more to FIG. 1. Although aluminum atoms leave the surface of target 10 over a wide range of angles relative to the surface 10, only those atoms that arrive at the silicon substrate at normal, or near normal, incidence, such as those following paths 6 or 7, will be able to reach the bottom of hole 4. All other atoms from the target end up on the surface of layer 3 so that, by the time hole 4 has been filled, layer 5 will have grown to a thickness that is much greater than desired.

In the invention of Lee et al. (U.S. Patent 5,401,675 Mar 1995) this problem has been solved by the interposition of collimating grid 11 between the target and the substrate. Because of the grid's presence, most material that originates at target 10 is caught by the collimator, only atoms following paths similar to 6 or 7 (in FIG. 1) being able to pass. Thus, the deposition rates at the surface of 3 and at the bottom of hole 4 end up approximately the same.

While this approach to the problem is effective in equalizing the two deposition rates, it has the major disadvantage of significantly reducing both of said rates. For example, as described in the Lee patent, the deposition rate was reduced by a factor of more than 20 when a collimating grid, intended for use with a 2:1 aspect ratio hole, was employed. This happens because atoms leaving the surface of 10, at angles corresponding (for example) to path 9 that would normally be capable of reaching the bottom of the hole, are unable to contribute to the overall deposition rate, being blocked by the collimating grid 11.

The present invention overcomes this major disadvantage of Lee et al.'s invention by eliminating the grid and, instead, adjusting the target-to-substrate distance during the deposition process. Grant et al. (U.S. Patent 5,358,615 Oct 1994) teaches

how conditions may be changed in the course of a sputter-deposition operation but their invention is concerned with how to improve the adhesion of thin films, not how to plug holes. Furthermore, the separation distance between target and substrate is not changed during the operation.

SUMMARY OF THE INVENTION

It has been an object of the present invention to provide a method and apparatus for filling high aspect ratio holes in semiconductor substrates (such as silicon) with a material such as aluminum.

A further object of the present invention has been to provide a method for filling holes in a substrate without causing a drop in the deposition rate of the hole filling material.

Yet another object of the present invention has been to provide a method for filling holes in a substrate without causing an excessive buildup of the hole filling material on surfaces outside of said holes.

These objects have been achieved by initially depositing a

seed layer of the hole filling material (such as aluminum) by means of 'long throw' sputtering, i.e. target and substrate are kept a substantial distance apart during sputtering. This causes most of the sputtered atoms to arrive at the substrate surface at normal angles of incidence thereby resulting in uniform coating of the holes' interiors without, at the same time, causing an excessive buildup of material on the other surfaces of the substrate.

Once the seed layer is in place, the target-to-substrate distance is reduced to a value that is typical for conventional sputter-deposition. In addition, the temperature of the substrate is raised to at least 400°C and sputtering is reinitiated. Under these conditions, effective filling of the holes can now occur.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the problem solved by the present invention as well as a solution available in the prior art.

FIGs. 2 and 3 illustrate the apparatus of the present invention as well as the associated methodology.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Aluminum, when deposited onto a surface that is at a temperature greater than about 400 °C, will flow along the surface of deposition to a sufficient degree to, for example, enter and fill a hole in a substrate, such as hole 4 in FIG. 1. This makes it possible to fill holes at reasonable rates without producing excessively thick layers elsewhere.

The 'hot aluminum' process just described will, however, not work unless a seed layer of oxide-free aluminum is already present on the surface in question. Without such a seed layer aluminum will not stick to a surface that is at the aforementioned high temperature.

Referring now to FIG. 2, sputtering chamber 21 is shown, together with aluminum target 22 and substrate holder 23. Target 22 is connected to the outside of chamber 21 by means of gas-tight moveable shaft 25, while substrate holder 23 is similarly set up via gas-tight moveable shaft 26.

Vacuum port 27, on one side of sputtering chamber 21, allows the latter's interior to be evacuated following which a sputtering gas 28, such as argon, is admitted at a controlled rate so as to establish and maintain a pressure within the

chamber between about 1.5 and 9 millitorr. At this point, substrate holder 23 and target 22 are at their maximum distance of separation, one from another. Said maximum separation distance is between about 5 and 20 cm. for a target diameter between about 11.5 and 15.5 inches. More generally, we have found that the ratio of separation distance to target diameter should be between about 0.15:1 and 0.5:1 for a 15.6 inch target and between about 0.18:1 and 0.7:1 for an 11 inch target.

D.C. sputtering is now initiated by applying a voltage of about 20 kW, preferably in conjunction with a magnetron source, and is allowed to proceed for from about 10 seconds to about 1 minute at a pressure between about 1.5 and 9 millitorr. Because of the large target-substrate distance, most of the aluminum atoms will arrive at the surface of silicon wafer (or substrate) 24 at normal, or near normal, incidence, all others ending up on the walls of the sputtering chamber. Thus, by sputtering under the conditions and for the time specified, a suitable seed layer, between about 1,500 and 2,500 Angstroms thick, can be formed on the interior side-walls and bottoms of any holes in the surface of 24 without an excessive buildup elsewhere.

Referring now to FIG. 3, we proceed to the next step. Without breaking vacuum, either target 22 or substrate holder 23 is moved along gas-tight moveable shafts 25 or 26 respectively so

that they come closer together, until their separation distance has been reduced to between about 4 and 6 cm. More generally, they are moved until the separation distance to target diameter ratio has been reduced to between about 0.13:1 and 0.15:1 for a 15.6 inch target or to between about 0.14:1 and 0.18:1 for an 11 inch target. In addition, heat is applied to substrate holder 23 so that silicon wafer 24 is raised to a temperature of at least 400 °C.

Sputtering is now resumed at a power level of about 4 kW and a pressure between about 1.5 and 3 millitorr and allowed to continue for from about 0.5 to 4 minutes until all holes are filled, additional material being deposited to a thickness between about 3,000 and 4,000 Angstroms. A wide variation in the aspect ratios of the holes that are to be filled can be tolerated since there is no excessive build-up of aluminum on the surfaces outside of the holes.

While the invention has been particularly shown and described with reference to this preferred embodiment, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. A method for filling a high aspect ratio hole in a semiconductor wafer comprising:

a) providing a sputtering chamber that includes a moveable aluminum target and a moveable, heatable substrate holder;

b) adjusting said target and said substrate holder to their maximum separation distance;

c) placing said semiconductor wafer on said substrate holder;

d) filling said sputtering chamber with a gas at a first low pressure;

e) sputtering a first layer of material from said aluminum target onto said semiconductor wafer for a first period of time;

f) moving the aluminum target and the substrate holder, along with the semiconductor wafer, so as to reduce the separation between them to a lesser separation distance;

g) filling said sputtering chamber with a gas at a second low pressure and heating the substrate holder, thereby raising the temperature of the semiconductor wafer; and

h) then sputtering a second layer of material from said aluminum target onto said semiconductor wafer for a second period of time.

2. The method of claim 1 wherein said maximum separation distance is between about 6 and about 20 cm.



3. The method of claim 1 wherein said lesser separation distance is between about 4 and about 6 cm.
4. The method of claim 1 wherein the temperature to which the semiconductor wafer is raised in step (g) is at least 400 °C.
5. The method of claim 1 wherein the semiconductor comprises silicon.
6. The method of claim 1 wherein said gas comprises argon.
7. The method of claim 1 wherein said first period of time is between about 10 seconds and about one minute.
8. The method of claim 1 wherein said second period of time is between about 0.5 and about 4 minutes.
9. The method of claim 1 wherein said first gas pressure is between about 1.5 and about 9 millitorr and said second gas pressure is between about 1.5 and about 3 millitorr.
10. The method of claim 1 wherein the thickness of said first layer of material is between about 1,500 and about 2,500 Angstrom units.



11. The method of claim 1 wherein the thickness of said second layer of material is between about 3,000 and about 4,000 Angstrom units.

12. An apparatus for filling a high aspect ratio hole in a semiconductor wafer comprising:

a sputtering chamber having first and second opposite ends;

an aluminum target, including a magnetron, inside said sputtering chamber, connected to the first end of the sputtering chamber;

a substrate holder, inside said sputtering chamber, coaxial with said aluminum target, connected to the second end of the sputtering chamber and maintaining a separation distance from said aluminum target and capable of supporting said semiconductor wafer;

gas-tight means for changing said separation distance;

means for evacuating said sputtering chamber;

means for admitting a gas into said sputtering chamber in controlled amounts; and

means for heating said substrate holder.

0 13. The apparatus of claim 12 wherein said separation distance is adjustable to be between about 4 and about 20 cm. for a target diameter between about 11 and about 15.6 inches.



14. The apparatus of claim 12 wherein said gas comprises argon.

15. The apparatus of claim 12 wherein said heating means is capable of raising the temperature of the substrate holder to at least 400°C.

16. The apparatus of claim 12 wherein said gas-tight means for changing said separation distance further comprises:

a vacuum-sealed shaft for moving said target and magnetron;
and

a vacuum-sealed moveable shaft for moving said substrate holder.



ABSTRACT

IMPROVED PLUG FILLING TECHNIQUE

A method and associated apparatus are described for filling high aspect ratio holes in a substrate with a material such as aluminum. Initially a seed layer of the hole filling material is laid down by means of 'long throw' sputtering, i.e. target and substrate are kept a substantial distance apart during sputtering. This causes most of the sputtered atoms to arrive at the substrate surface at normal angles of incidence thereby resulting in uniform coating of the holes' interiors without, at the same time, causing an excessive buildup of material on the other surfaces of the substrate. Once the seed layer is in place, the target-to-substrate distance is reduced to a value that is typical for conventional sputter-deposition. In addition, the temperature of the substrate is raised to at least 400 °C and sputtering is reinitiated. Under these conditions, effective filling of the holes can now occur.

FIGURE 1 IS SUGGESTED FOR PUBLICATION

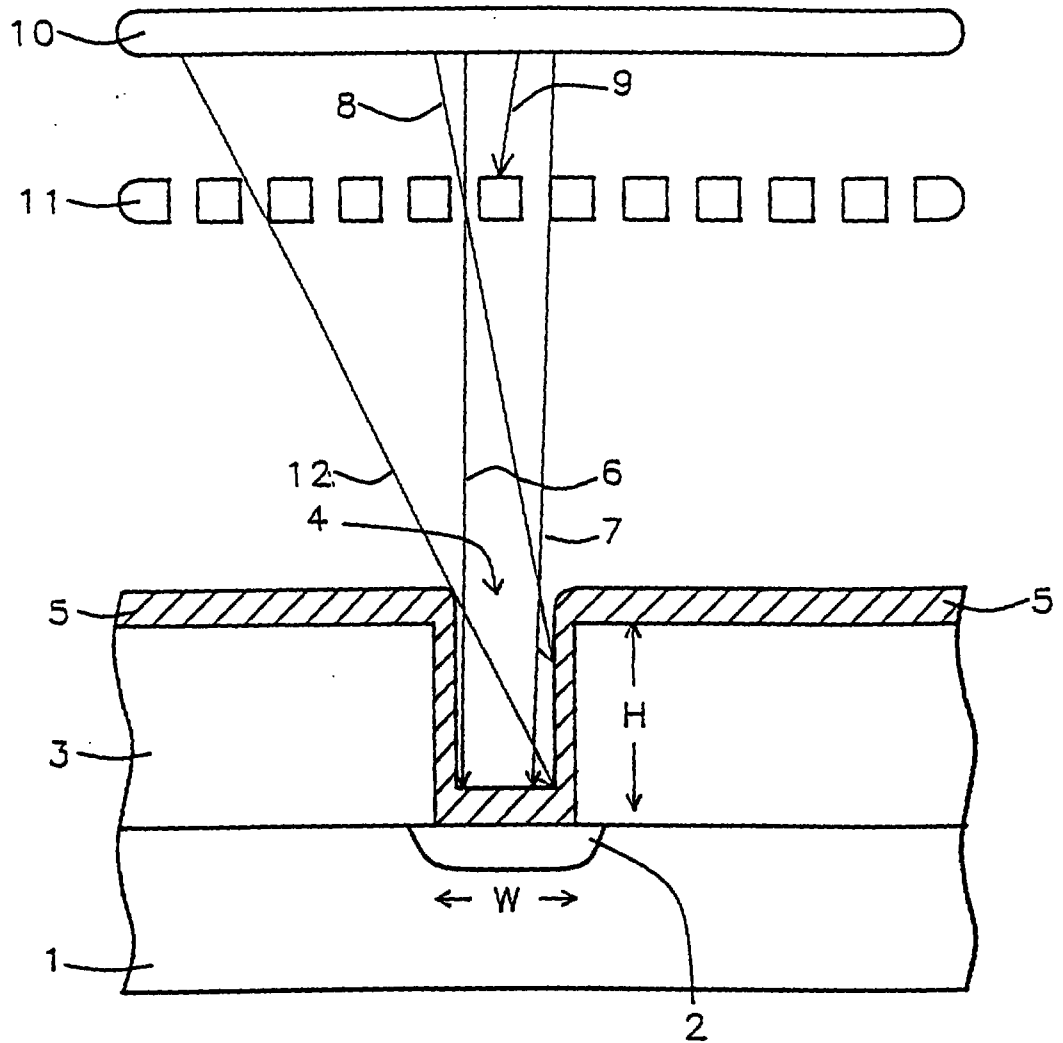


FIG. 1 - Prior Art

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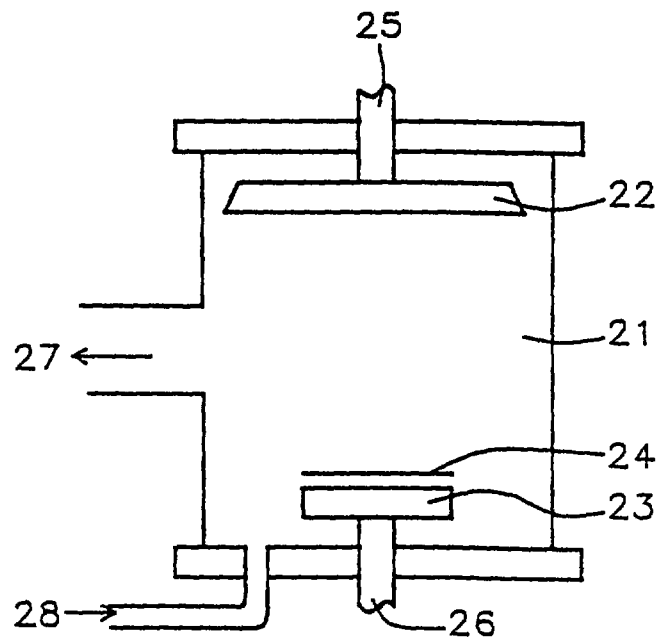


FIG. 2

