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ALLOY METALLIZATION

This invention relates in general to a method and structure for metallizing a silicon substrate and more specifically to a method for providing a layer of silicon-aluminium alloy on a silicon substrate and the metallisation so provided.

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In the fabrication of silicon semiconductor devices including both discrete devices and integrated circuits, aluminium metallization is often used for making contact to device regions and for interconnecting between devices. Many of those semiconductor devices are characterized by two main features with which the aluminium metallization process must be compatible. First, the surface topography of the device typically exhibits large, near vertical steps (often as much as 2 micrometers or more in height) which the metallization must cover without cracking or significant thinning. Second, doped regions in the silicon substrate which the metallization must contact electrically are often very shallow, i.e., 1-2 micrometers or less in depth.

To be compatible with the first of these features and to provide a high integrity coating over the large steps, the metallization is typically deposited at an elevated substrate temperature. The elevated temperature of the device substrate, typically in the range of about 200-300 degrees centigrade, imparts a higher surface mobility to the atoms of the metallization film, thereby improving the step coverage. The second feature, namely the need to contact shallow doped regions, can result in yield loss or reliability problems when the device is subjected to elevated temperatures during additional processing of the semiconductor device after the application of the metallization.

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The elevated temperature steps are a required part of the device processing; for example, to achieve low resistance ohmic contacts to the doped regions and to reduce the density of interface states, a sintering process at about 450 degrees centigrade is required after the metallization has been deposited. During the sinter process the aluminium chemically reduces any native oxide present in the contact areas of the silicon surface. Additionally, most devices are subjected to similar or even higher temperatures during the application of an overlying passivation layer and/or during the assembly of devices into packaged units. If pure aluminium metallization is used, silicon diffuses out of the substrate and into the aluminium during the high temperature step. Enough silicon diffuses into the aluminium to attempt to satisfy the solid solubility limit of silicon in aluminium at the elevated temperature. The quantity of silicon which diffuses out of the silicon substrate at each silicon-aluminium contact depends upon the area of the contact, the temperature encountered, and the volume of aluminium in proximity to the contact region. Simultaneously with the silicon diffusion, aluminium diffuses or drops into vacancies left by the silicon. In the typical process the depth of penetration of aluminium into the silicon substrate is on the order of 1-2 micrometers. Therefore, if the depth of the doped silicon region which is contacted is less than the 1-2 micrometer penetration depth of the aluminium, the danger exists that the junction will be shorted out as the aluminium makes contact to both the doped region and the underlying substrate.

The conventional solution to problems engendered by this second feature is to include silicon in the device metallization as it is applied to the device substrate. Since the amount of silicon removed from contact regions is determined by the solid solubility of silicon in the aluminium, using aluminium which already contains a concentration of silicon at least equal to the solid solubility limit at the highest temperature encountered during or subsequent to the metal deposition process minimizes the quantity of silicon dissolved from the contact region.

Usually 1-2 percent by weight of silicon in aluminium is used. This amount satisfies the solubility requirement for temperatures up to 577 degrees centigrade, the silicon-aluminium eutectic temperature.

5 This above-related solution however, is itself the source of a further serious problem. The solid solubility of silicon in aluminium is dependent upon temperature. To solve the shorting problem, an amount of silicon is added to the aluminium to satisfy the solubility limit at the highest temperature the substrate may
10 encounter. At temperatures below that highest temperature, such as at the deposition temperature and especially at room temperature, however, the silicon-aluminium system is supersaturated with silicon. This results in the precipitation of pure silicon from the metallization layer if sufficient time is
15 allowed for equilibrium to be achieved. The time to reach equilibrium is a function of the mean migration distance over which a silicon atom must diffuse to effect precipitation. The diffusivity of silicon in aluminium is sufficiently high at 200 degrees centigrade that the mean migration distance is in excess
20 of 1 micrometer (the typical metallization thickness) if only three minutes are allowed to achieve equilibrium. It has been found that the silicon precipitation preferentially nucleates at the interface between the metallization and the substrate. Because of this preference, large silicon precipitates (known in
25 the semiconductor industry as freckles) are found adhered to the substrate surface in those regions of the surface from which the metallization is removed during subsequent metal patterning. That is, at temperatures for which the metallization is supersaturated with silicon, the excess silicon migrates to the substrate surface
30 where it is exposed as freckles left behind by the etching of the aluminium.

A number of difficulties result from the formation of silicon precipitates or freckles. When acid etchants are used to pattern
35 the conventional silicon-aluminium alloy film the etch rate of the bottom part of the film, i.e., the silicon rich portion, is significantly less than the etch rate of the top part of the film i.e., the silicon rare portion.

The difference in etch rate results in a significant lateral etching of the top part of the film as the slower etching bottom portion is etched through. This is a particularly significant problem where the metallization has to cover steep steps on the substrate since at these locations the metallization already tends to have a reduced thickness. The phenomenon of lateral etching at a substrate step, usually referred to as "notching", is a significant yield and reliability problem.

The characteristic of alloy films of having a slower etch rate at the bottom than at the top causes particular problems when wafers are acid etched in batches. Detection of the end point of the etching is not easy to determine because of the residual silicon left on the substrate.

After patterning the metallization, a passivating layer of glass or nitride is typically chemical vapor deposited over the substrate. The presence of freckles on the substrate causes the formation of large globules of the passivating material. These globules present a difficult surface for subsequent layers of photoresist to cover with good integrity. Also, it is difficult to rinse thoroughly and dry the substrate surface which is covered with either freckles or passivation globules; solvents, etchants or water trapped by the freckles or globules on the substrate surface cause problems with the reliability of the device.

In the event of misprocessing during either the deposition or patterning of the metallization, it may be necessary to etch off all of the metallization film and to redeposit a fresh layer. The presence of freckles from the first metallization is then compounded by the freckles resulting from the second metallization. Attempting to remove the freckles prior to the second metallization through use of either a wet chemical or plasma defreckle etch also etches the exposed silicon contacts and is therefore undesirable.

Finally, the presence of freckles on the substrate surface between metallization tracks is cosmetically undesirable. The freckles also prevent the close optical examination of underlying layers during defect analysis.

In view of the foregoing, a need exists for an improved metallization system which overcomes the above-mentioned and other shortcomings of the prior art metallization process.

5 The present invention seeks to provide an improved method for metallizing a silicon semiconductor substrate in which at least one of the above mentioned shortcomings of the know metallization process is mitigated.

10 BRIEF SUMMARY OF INVENTION

15 In accordance with one aspect of the invention, there is provided a method for metallizing a silicon semiconductor substrate having a surface topography exhibiting at least one step over which the metallization has to pass to contact a silicon surface portion of the substrate, the method including the steps of;

20 forming a layer of aluminium on said surface portion at a first elevated temperature which is sufficiently high to provide suitable coverage of the step; cooling said substrate to a second temperature lower than said first temperature; and forming at said second temperature a layer of silicon-aluminium alloy on said layer of aluminium, the second temperature and the thickness of the layer of
25 aluminium being chosen so as substantially to prevent the migration of silicon through the layer of aluminium to form precipitates at the silicon surface portion.

30 BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 illustrates, in cross section, a portion of a metallized semiconductor device;

35 Fig. 2 illustrates, in plan view, a portion of a metallized semiconductor device;

Figs. 3-5 illustrate process steps for metallizing a semiconductor device in accordance with the invention; and;

Fig. 6 illustrates the diffusivity of silicon in aluminium as a function of temperature.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1 illustrates in cross-section, a portion of an metallized semiconductor device 9 in accordance with the invention. The portion of the device shown includes a semiconductor substrate 10 which can be, for example, P type silicon. An N type region 12 is formed in the P type substrate forming a PN junction 14. A layer of insulator 16 overlies the top surface of the substrate. An opening 17 in the insulator exposes a portion 18 of the silicon substrate. Insulator 16 can be, for example, a layer of silicon dioxide having a thickness of, say, two micrometers. The edges of opening 17 may be defined by fairly steep edges 22 of the insulator. A metallization layer 20 is provided over the surface of insulator 16 and makes electrical contact to the exposed portion 18 of the silicon substrate. Some difficulty is encountered in maintaining the thickness of metallization layer 20 as it traverses steep edges 22, and, in fact, some thinning of the metallization layer may occur at 24.

FIG 2. illustrates, in plan view, a portion of a semiconductor circuit showing two metallization runs 26 and 27 which are positioned on the surface of an insulator 16. The two metallization runs make contact to an underlying silicon semiconductor substrate through openings 28,29 respectively.

In accordance with the invention a metallization process is provided which minimises the amount of thinning of the metallization runs as they pass over steep steps such as illustrated at 22 (in FIG 1). The metallization process also minimizes the amount of silicon diffusion out of the silicon substrate into the metal film and the amount of diffusion of the metal film material into the silicon. The improved metallization process is achieved without the formation of freckles, for example, on the portion 31 of insulator layer 16 between the metal runs 26 and 27.

The metallization process in accordance with the invention is a two-step process illustrated in FIGS. 3-5. FIG.3 illustrates again in cross-section, a contact area of a semiconductor device. An opening 17 through a thick insulating layer 16 exposes a surface portion 18 of an underlying silicon substrate. The extremities of the opening 17 are bounded by steep insulator sidewalls 22. It should be noted that in typical semiconductor processing a thin layer 33 of native oxide exists on the exposed surface of the silicon substrate. Thin layer 33, which may only be a few nanometers in thickness, grows quickly on the silicon surface even at room temperature when the surface is exposed to air. It is the presence of this thin insulating layer which makes a sintering step necessary to ensure a low resistance contact between the aluminium metallization and the underlying silicon. At a sintering temperature of about 450 degrees centigrade the aluminium reduces the oxide layer allowing intimate contact between the aluminium and silicon. The presence of this thin layer, however, also prevents the migration of silicon into the aluminium and of aluminium into the silicon at temperatures below about 300 degrees centigrade.

FIG.4 illustrates the first of the two steps in the metallization process according to the invention. A layer 35 of pure aluminium is deposited on the exposed surface of the semiconductor device covering thick insulating layer 16 as well as depositing in opening 17 to cover the sidewalls 22 and the interface oxide 33. To ensure adequate coverage of the steep sidewalls, the first deposition of pure aluminium is done at an elevated temperature. Preferably the first deposition is done at a temperature of above 200 degrees centigrade and below 300 degrees centigrade. The elevated temperature imparts a higher surface mobility to the aluminium atoms and thus improves the step coverage. The thickness of the pure aluminium film should be about 40-75% of the total final intended film thickness. The deposition of aluminium can be carried out by any of the normal deposition techniques such as by vacuum evaporation or by sputtering.

In either type of deposition the substrate is in a controlled ambient preferably an inert ambient or vacuum during and following the deposition. The term "pure aluminium" is herein used to mean aluminium substantially free from silicon. The pure aluminium may be alloyed with small amounts of other elements such as copper, chromium or the like. Preferably the first layer is substantially all aluminium.

Following the depositing of the pure aluminium layer, the silicon substrate remains in the controlled ambient and the substrate temperature is allowed or forced to drop to a temperature in the range of about room temperature to about 150 degrees centigrade. The temperature is chosen such that the silicon diffusivity is sufficiently low that silicon cannot migrate through the previously deposited pure aluminium film in sufficient quantities to allow formation of freckles at the metal substrate interface. Preferably the substrate temperature is lowered to a temperature of about 100 degrees centigrade. At this lower temperature the second step of the metallization process is carried out. As illustrated in FIG. 5 a second layer 37 of silicon-aluminium alloy is deposited again either by evaporation or sputtering over the pure aluminium film to bring the total thickness of the two films to the final desired thickness. The second alloy film contains about 1-2 percent by weight of silicon. Following the second deposition, the substrate is further cooled to room temperature and then removed from the deposition apparatus.

FIG. 6 illustrates the diffusivity of silicon in a thin film of aluminium as a function of temperature. From the graph it can be seen that the diffusivity of silicon at 100 degrees centigrade is lower than that at 200 degrees centigrade by a factor of about 40. It is this lower diffusivity that prevents freckle precipitation at the substrate-metal interface in the process according to the invention.

In contrast, if both films, the first film of pure aluminium and the second film of silicon-aluminium alloy, are evaporated at the elevated temperature necessary to achieve good step coverage, the high diffusivity of silicon will allow precipitation of the silicon as the film is being deposited as well as while the substrate is being cooled subsequent to the deposition. This effect is also observed if the prior art technique of depositing an aluminium-silicon alloy film at a single elevated temperature is employed. At a temperature of 200 degrees centigrade the mean migration distance of silicon is 1.13 micrometers if only 3 minutes is allowed to achieve equilibrium i.e. in only 3 minutes at 200 degrees centigrade silicon will diffuse entirely through the thickness of an aluminium layer having a nominal thickness of 1 micrometer. In the process in accordance with the invention, however, at the lower temperature encountered during and subsequent to the second deposition the decreased diffusivity of silicon in the aluminium prevents the diffusion of silicon to the substrate metal interface and the consequent formation of silicon precipitates at that interface. Some silicon does diffuse into the first layer during the second layer deposition and during subsequent high temperature processing, but the first pure aluminium layer having a thickness of 40-75% of the total film thickness prevents the migration of sufficient silicon to the interface to cause precipitation.

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Following the deposition of the second layer of silicon-aluminium alloy, processing of the device substrate proceeds in normal fashion. The double metallization layer is photolithographically patterned to provide metal interconnections. The etching of the double layer metallization is uniform and reproducible without significant etch narrowing of the top of the aluminium lines because there is no high concentration of silicon i.e., a silicon rich portion, in the bottommost portion of the film.

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Passivation glass is applied over the surface of the substrate including the patterned metallization without the formation of passivation globules because there are no silicon freckles to nucleate the globules.

The lack of passivation globules improves the coverage and adhesion of photoresist during the patterning of the passivation layer. The removal of the photoresist layer and subsequent rinsing of the devices is made easier by the uniform surface free of globules. A sintering step to ensure good contact between the aluminium metallization and the underlying substrate is carried out either before or after the passivation deposition.

No dissolution of silicon is observed after sintering when metal is removed from the sintered samples and the contact areas examined. The reason no contact dissolution is observed is believed to result from the different rate at which two processes occur during the temperature rise in the sintering process.

The two processes are (1) a very rapid diffusion of the silicon in the uppermost film and through the total film thickness to satisfy the increasing solubility limit as the temperature rises and (2) the reduction of the native oxide in the contact area by the aluminium in the film. The activation energy for the oxide reduction step is high enough so that the oxide remains in place and migration of silicon out of the substrate is impeded until a significant amount of silicon redistribution has occurred between the two film regions.

Thus it is apparent that there has been provided, in accordance with the invention, a new and improved metallization process and structure which achieves the objects and advantages set forth above. While the invention has been described in relation to certain embodiments thereof it is not intended that the invention be limited to these illustrative embodiments. Those skilled in the art will appreciate that variations and modifications in the process are possible and it is intended that such variations and modifications be included in the invention as defined by the appended claims.

CLAIMS

1. A method for metallizing a silicon semiconductor substrate
5 having a surface topography exhibiting at least one step over which
the metallization has to pass to contact a silicon surface portion of
the substrate, the method including the steps of;
forming a layer of aluminium on said surface portion at a
first elevated temperature which is sufficiently high to provide
10 suitable coverage of the step; cooling said substrate to a second
temperature lower than said first temperature; and forming at said
second temperature a layer of silicon-aluminium alloy on said layer of
aluminium, the second temperature and the thickness of the layer of
aluminium being chosen so as substantially to prevent the migration of
15 silicon through the layer of aluminium to form precipitates at the
silicon surface portion.
2. The method of claim 1 wherein the layer of aluminium has a
thickness between 40 and 75 percent of the total thickness of the
20 layer of aluminium and the layer of silicon-aluminium together.
3. The method of claim 1 or 2 wherein said first elevated
temperature is in the range 200 degrees centigrade, to 300 degrees
centigrade.
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4. The method of any preceding claim wherein said first
elevated temperature is 200 degrees centigrade.
5. The method of any preceding claim wherein said second
30 temperature is in the range ambient temperature to 150 degrees
centigrade.
6. The method of claim 5 wherein said second temperature is
100 degrees centigrade.



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7. The method of any preceding claim wherein said layer of aluminium and said layer of alloy are formed by vacuum evaporation or sputtering.
- 5 8. The method of claim 7 wherein said step of cooling said substrate is carried out in vacuum or controlled inert environment.
9. The method of any preceding claim wherein said silicon-aluminium alloy contains about 1-2 percent by weight of
10 silicon.
10. The method as claimed in any preceding claim wherein the substrate is a silicon semiconductor device and the method further includes the steps of;
- 15 patterning said layer of silicon-aluminium alloy and said layer of pure aluminium to form a desired pattern of metallization on said silicon device; and sintering said silicon device and said pattern of metallization.
- 20 11. A method of metallizing a silicon semiconductor substrate substantially as herein described with reference to and as shown in Figs. 3-5 of the drawings.
12. A method of metallizing a silicon semiconductor device
25 substantially as herein described with reference to and as shown in Figs. 3-5 of the drawings.
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