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COMPLETE SPECIFICATION

Ohmic Contacts for Semiconductor Devices

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to ohmic contacts for transistors, integrated circuits, or the like, and more particularly to the triode sputtering of multilayer ohmic contacts to semiconductor devices.

Ohmic contacts to semiconductor devices must be composed of materials which have good chemical, electrical, thermal, and mechanical properties when applied to semiconductor surfaces. While problems in making contacts exist for all semiconductors, the selection of a contact material or materials is particularly important when the semiconductor is silicon, as in planar transistors and integrated circuits where silicon is at present most commonly used.

As a consequence, therefore, it is desirable to utilise a contact material or materials to silicon semiconductor devices, particularly planar silicon semiconductor devices of the type having an oxide or insulating coating overlying the silicon surface except in the actual contact areas, which adhere well both to the silicon material and the overlying oxide, which do not undesirably penetrate the semiconductor material so as to degrade the device itself, which provide ohmic and low resistance contact to the silicon regions, and which lend themselves to manufacturing techniques

compatible with other processes used on the devices.

In accordance with these objects, a particularly advantageous multilayer ohmic contact system has been developed which includes a first thin film comprised of molybdenum and an overlying second thin film comprised of gold, this particular contact system being described and claimed in United Kingdom Patent Specification No. 1104804. While this particular contact system has been observed to have substantial advantages over others, the present day method for applying these various thin films to the surface of the semiconductor wafer, namely by evaporation, has presented some problems which have prevented the utilisation of this contact system to its full potential. For example, the method for defining the lead and interconnection pattern involves the initial deposition of the metal layers over the entire oxidized semiconductor slice, followed by a series of photographic masking and etching techniques which selectively remove the metal layers except in the desired pattern of the leads and interconnections. To avoid the peeling or undercutting of the metallic films during these etching operations, it is preferred that the molybdenum film adhere tightly to the oxide coating, and that the overlying gold layer adhere tightly to the molybdenum film. In addition, it is desirable to physically isolate the overlying gold from the bare silicon material so as to avoid undesirable alloying therewith, and the consequent degradation of the junction regions. This latter requirement necessitates that the molybdenum layer be continuous and substantially free of pinholes and imperfections. While these results have been achieved,

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to some extent with the use of conventional evaporation techniques, for example, of the molybdenum and gold layers, it has been found that on a very high production basis, existing techniques for depositing these thin film or layers result in devices having very low yields.

Accordingly, the present invention involves a deposition technique, referred to as triode sputtering, to deposit the various thin metallic films.

The invention provides a method for depositing a multilayer ohmic contact upon a substrate of semiconductor material including depositing a thin film of molybdenum on the substrate by sputtering and depositing a thin film including gold on the film of molybdenum by sputtering in which platinum or aluminium is present on the surface of the substrate during the deposition of the film of molybdenum whereby the adhesion of the molybdenum film to the semiconductor substrate is improved.

Particular features of an embodiment of the present invention include the upward sputtering of the various metal films, the simultaneous sputtering of platinum with gold by using a sputtering cathode composed of platinum and gold rather than pure gold and the addition of hydrogen into an inert (argon) sputtering atmosphere to eliminate the undesirable formation of oxides. Among the advantages realised by these techniques have been a significant improvement in the adhesion of the sputtered molybdenum to the semiconductor surface and the silicon oxide, a continuous molybdenum film which, for all practical purposes is free of any pinholes, and metallic films of substantially uniform resistivity.

The novel features believed characteristic of this invention are set forth in the appended claims. The invention itself, however, as well as other objects and advantages thereof, may best be understood by reference to the following detailed description of illustrative embodiments, read in conjunction with the accompanying drawings, wherein:

Figs. 1-4 are sectional views of the various steps in the fabrication of an N-P-N transistor utilising a deposition technique of the present invention for the application of the ohmic contacts and interconnections,

Fig. 5 is a cross-sectional view of a portion of a semiconductor wafer in which an integrated circuit is formed utilising deposition techniques and a contact system of the present invention, and

Fig. 6 is a representation of one form of apparatus used in practicing the invention.

With reference to Fig. 1, there is shown a semiconductor wafer 10 having a transistor formed therein including base and emitter regions 11 and 12, respectively, the remainder of the wafer 10 providing the collector

region. The transistor is formed by conventional planar techniques, using successive diffusions with silicon oxide masking. This process leaves an oxide coating 13 on the top surface of the wafer, this coating having a stepped configuration due to the successive diffusion operations. For high frequencies, the geometry of the active part of the transistor is ordinarily extremely small, the elongated emitter region 12 being perhaps 0.1 to 0.2 mil (0.0002 inch) wide and less than a mil long. Holes 14 and 15 are then provided within the oxide layer 13 for the base and emitter contacts respectively. Typically, the wafer 10 is merely a small undivided part of a larger slice of silicon, perhaps one inch in diameter and eight mils thick, the slice being scribed and broken into individual wafers or dice after the contacts are applied. After various cleaning operations to prepare the surface of the oxide and the semiconductor material for the contacts, the transistor device of Fig. 1 is now ready to have the multilayered contact system deposited in accordance with the process of this invention.

Before such depositing, however, it has been observed that the formation of a sintered platinum-silicide deposit in the contact areas prior to the deposition of the thin molybdenum film improves the mechanical and ohmic contact of molybdenum to the semiconductor surface. Consequently, after the final oxide removal exposing the base and emitter contact areas, one or two microinches of platinum are evaporated onto the entire slice located in a high vacuum and at a substrate temperature of approximately 250°C. The coated slice is then placed within a quartz tube furnace in a nitrogen atmosphere and heated for 20 minutes at approximately 700°C, this heating causing a sintering at the platinum-silicon interface. The slice is then boiled in aqua regia to remove the platinum from the oxide area but leaving sintered platinum-silicide deposits 17 and 18 in the base and emitter contact areas respectively, as shown in Fig. 2.

Referring to Fig. 6, there is depicted one form of triode sputtering apparatus utilised for depositing the metallic ohmic multilayer contact in accordance with the invention. The apparatus comprises a stainless steel turntable 30 having precision-milled slots or grooves 31 in which the silicon slices 10 with the platinum-silicide contacts 17 and 18 thereupon are placed. Above the turntable 30 is a bank of quartz infrared heaters as the lamp 33 tilted at a specific angle (approximately 20°), these functioning to heat the slices 10 to any desired temperature and to hold the slice temperature at the selected point with a fair degree of precision. A suitable temperature control, including a thermocouple and a feedback arrangement (not shown) is provided for this latter purpose. A loose fit-

ting stainless steel disk 32 is placed onto the backside of each slice to provide uniform heat transfer.

The "heart" of the triode sputtering apparatus are the cathodes 35 and 35' (formed of the metal to be deposited), anodes 36 and 36' (usually formed of molybdenum), and cathodic filaments 37 and 37' (usually of tungsten). In addition, there is positioned a tungsten coil 39 for evaporating a charge 40 of gold. A shutter 41 which may be pivoted over either the cathodes 35 and 35' or over the evaporation coil 39 is mounted beneath the turntable 30 as shown. The turntable 30 may be rotated at a suitable rate by a combination of motor and gear drive connected thereto. All of the components described are mounted within a bell jar or chamber 50 mounted on a base plate 52, all of the electrodes being electrically isolated from the base plate 52 by feedthrough collars 53 fabricated of glazed ceramic for example. An opening 55 in the base plate 52 is connected to a vacuum pump for evacuating the chamber. Another opening 56 is provided for the introduction of the sputtering atmospheric gas mixture 60 in accordance with the invention.

Since the sputtering rate and texture of the deposited films are somewhat influenced by the pressure of the sputtering chamber, an electronic servo-driven flow controller is strongly recommended to hold the chamber pressure to the correct range. The voltages for the cathodic filaments, cathodes and anodes can be quickly switched from one set of electrodes to the other by means of a ganged switch (not shown) for sputtering the various layers of the invention. A circular magnet 58 surrounding the bell jar 50 may be utilised if desired to create an internal magnetic field which is used to concentrate the glow discharge formed.

The silicon slices 10 with the platinum-silicide contacts 17 and 18 (as shown in Fig. 2) are loaded face down in the grooves of the stainless steel turntable 30, covered with the disks 32, and the turntable is then rotated at a constant speed of approximately 30 rpm or greater. The bell jar 50 is evacuated to a pressure below 5×10^{-6} Torr and the infrared lamps 33 are energised to heat the slices to approximately 200°C. A gas mixture 60 composed substantially of an inert gas such as argon, krypton, or xenon flows into the evacuated chamber through the opening 56 to establish a chamber pressure of approximately 2×10^{-5} Torr. It is presently desirable to utilise argon as the inert gas since it is presently available in high purity at a reasonable cost. Krypton and xenon, being of higher mass, are of particular interest if economically available. As will subsequently be described, the gas flow 60 does not have to be composed entirely of argon but as a particular feature of the process may actually be a mixture of

argon and hydrogen (H_2) gas, the hydrogen gas providing a reducing atmosphere which substantially eliminates the formation of undesirable oxides on the various surfaces.

The tungsten filament 37 is then heated to incandescence to emit electrons. These electrons are then attracted with considerable velocity to the positively charged anode 36. During their trip, they collide with argon molecules in the chamber, thereby producing a glow discharge of positively charged argon ions above the cathode plate 35. A very strong negative voltage is then applied to the cathode plate 35 which consequently attracts these positively charged argon ions. The ions strike the surface of the metal cathode 35 with tremendous kinetic energy, this energy being transferred to the cathode, "sputtering" metal atoms of the cathode plate from its surface to the silicon slices 10. Therefore, when the cathode plate 35 is of molybdenum, a thin film 20 of molybdenum, shown in Fig. 3, is deposited by sputtering over the entire surface of the oxide mask 13 and within the apertures 14 and 15 upon the platinum-silicide contact surfaces 17 and 18, respectively.

In similar manner, the cathode plate 35' may be formed of gold, and when the cathodic filament 37', anode 36', and cathode 35' are energised as above, a thin film 21 of gold may be triode sputtered upon the molybdenum layer 20.

However, the cathode 35' need not be entirely of gold but may be either of a platinum-gold alloy or a gold cathode which has a portion of its surface area covered with platinum. This allows a simultaneous sputtering of platinum and gold to provide a layer 21 of platinum-gold rather than one of pure gold. It was observed that when small amounts of platinum were sputtered simultaneously with the gold, there was a substantial improvement in the adhesion of the resulting layer 21 to the molybdenum film. For example, tests were run to determine the amount of force required to "pull" the layer 21 from the molybdenum film 20 when the cathode 35' had the following percents (by weight) of platinum (and consequently the same percentage composition of the sputtered layer 21) covering its surface:

% of Pt on Surface of Cathode	Force Required	
0	5 grams	120
0.1	8 grams	
2.0	20 grams	
5.0	24 grams	
10.0	24 grams	

It was concluded therefore that by using a composition of 95% gold—5% platinum for the layer 21 instead of pure gold, there is almost a 400% increase in adhesion to the

molybdenum film 20. In addition, the resulting layer 21 was found to be smooth and continuous, preventing the oxidation of the underlying molybdenum film during any subsequent high temperature operations. Furthermore, the sheet resistivity of the platinum-gold layer 21 was found to be substantially uniform over its entire surface area.

Thereafter as the next step, a gold layer 22 is deposited by evaporation upon the platinum-gold film 20 by energising the coils 39 to evaporate the charge 40 of gold. Gold wires may then be bonded to the layer 22 for external connections. In summary therefore, the optimum process steps of the present invention include the triode sputtering of the molybdenum film, the triode sputtering of a platinum-gold film, and the evaporation of an overlying gold layer. If desired, a shutter 41 shown in Fig. 6 may be pivoted over the cathodes or over the evaporation coil for a short time prior to the actual deposition of each layer to prevent the deposition of any foreign particles that may be upon either of the cathode or coil surfaces.

It has been observed that there appears to be a tendency for an oxide film to form upon the platinum-silicide surfaces, and upon the thin film of molybdenum, due to the presence of oxygen within the sputtering chamber. These oxides "skins" undesirably increase the total resistance of the resulting multilayer contact, as well as detrimentally decreasing the adherence of each of the thin films to the other. In addition, the presence of the oxygen within the chamber often causes an oxide to form on the molybdenum anodes. As a consequence, and as another specific feature of the present invention, hydrogen gas is incorporated with the argon gas of the flow 60 to provide a reducing atmosphere within the chamber 50 which thereby prevents the oxidation of the various metallic surfaces. For example, samples were sputtered in hydrogen-argon atmospheres ranging from pure argon to a 10% hydrogen-90% argon mixture, the latter mixture providing particularly good results.

It was determined that by placing the silicon slices above the electrodes, as depicted and sputtering upward, it was possible to substantially reduce or eliminate any particles or "flakes" of metal. In the particular case of molybdenum, a molybdenum film was produced having a substantially uniform grain structure.

The triode deposition of the various metal films is dependent upon the various process parameters. For example, in one particular example, when the cathodes 35 and 35' were shaped in the form of a segment of a circle of six-square-inch surface area, the following conditions were maintained:

Cathodic filament voltage: 12 volts AC

Cathodic filament current: 40 amps

Anode voltage: +50 volts DC

Anode current: 5 amps

Cathode voltage: -1200 volts DC

Cathode current: 100 milliamps

Chamber pressure: 2×10^{-3} Torr

Substrate temperature: 200°C

Rate of rotation of turntable: 30 rpm

When the above conditions were maintained, the molybdenum film was sputtered at a rate of approximately 0.20 micro-inches per minute, and the 5% platinum-95% gold layer at a rate of approximately 0.11 micro-inches per minute. Investigation of various combinations resulted in the determination that the optimum advantages may be achieved with a first thin film of 10 micro-inches sputtered molybdenum, a second thin film of 2 microinches sputtered platinum-gold, and 26 microinches of evaporated gold. In this manner, the technical advantages of the triode sputtered films are achieved while taking advantage of the ordinarily shorter deposition time of the final overlying evaporated gold layer.

With the deposition of the films 20, 21 and 22 completed, the slices are removed from the chamber 50 for the selective removal of the metallic coatings by conventional photographic and etching techniques to define the individual expanded contacts. Thus the emitter contact 24 and the base contact 25 are formed as illustrated in Fig. 4. A suitable etching solution for selectively removing the gold layer 22 and the platinum-gold layer 21 is an alkaline cyanide, while nitric acid may be utilised in the etching of the molybdenum layer 20 where it is undesired. Contact to the collector may then be effected, for example, by mounting on a conductive base.

Referring now to Fig. 5, a portion of an integrated circuit structure is shown in section which comprises a P-type silicon wafer 70 having a transistor formed on the left hand end by a diffused N-type collector 71, a P-type base region 72 and N-type emitter region 73. On the right hand side is a resistor being provided by a P-type diffused region 75 ordinarily formed simultaneously with the base region of the transistor, the resistor being isolated from the transistor by the isolation region 74. Thereafter holes are cut in the oxide coating 69 upon the surface of the wafer where the transistor contacts and the resistors contacts are to be made, and the previously described process is used to apply a triode sputtered molybdenum coating 77, a triode sputtered platinum-gold film 78, and an overlying gold layer 79, these metal coatings being selectively removed to produce the desired pattern of contacts and interconnections. Thus, for example, the collector 71 is connected to one end of the resistor by an interconnection 80 which ex-

tends over the oxide. A typical integrated circuit would include in the same semiconductor wafer many transistors and resistors of the type seen in Fig. 5, rather than one of each. Of course, the platinum-silicide deposits may be made in the various contact areas as before.

Utilising the above-described process significant improvements have been achieved. Due to the increased adherence of the molybdenum film to the oxide coating and the platinum-gold film to the molybdenum film (thus avoiding undercutting during the various etching operations), and due to the continuous pinhole free nature of the molybdenum layer (thus preventing the undesirable contact between the gold and silicon materials), substantial improvements in yields were observed during high rates of production. For example, one line of integrated circuits using the contact system and the deposition technique of the present invention has resulted in a percentage improvement in yield in excess of 40%. Furthermore, triode sputtering is analogous to an elemental triode vacuum tube, and offers a means for closely controlling the process by regulating the voltages and currents of the filament, anode, and cathode electrodes.

The technique described above not only produces a continuous molybdenum film substantially free of pinholes, but also one which results in the molybdenum layer tightly adhering to the overlying protective oxide coating, and an overlying gold or gold-alloy film tightly adhering to the molybdenum film. The technique produces a novel multilayer contact and interconnection system which adheres well to silicon and to silicon oxide surfaces without reacting unfavourably with either, which can be used with available photoresist masking and etching procedures, and which forms an ohmic and low resistance electrical contact to the silicon material.

While the above-described process has suggested the initial formation of sintered platinum-silicide deposits in the contact areas prior to the sputtering of the molybdenum film, in some situations it is desirable to avoid this step. For example, the selective diffusion of gold into the semiconductor wafer prior to fabrication is often utilised to lower the carrier lifetime therein. During the sintering of the platinum, the heat produced often causes precipitation and redistribution of the gold impurities with corresponding detrimental effects on the device characteristics. To avoid this difficulty a very thin layer (approximately 200 Å) of evaporated aluminium deposited onto heated (600°C) silicon can be used in place of the sintered platinum material.

Various other modifications of the disclosed processes, may become apparent to persons skilled in the art without departing from the

scope of the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A method for depositing a multilayer ohmic contact upon a substrate of semiconductor material including depositing a thin film of molybdenum on the substrate by sputtering and depositing a thin film including gold on the film of molybdenum by sputtering in which platinum or aluminium is present on the surface of the substrate during the deposition of the film of molybdenum whereby the adhesion of the molybdenum film to the semiconductor substrate is improved.

2. A method according to claim 1, in which a film of platinum is deposited on the substrate by evaporation prior to the deposition of the film of molybdenum.

3. A method according to claim 2, in which the substrate is silicon and the substrate is heated after the deposition of the film of platinum and before the deposition of the film of molybdenum, so that the platinum forms a film of sintered platinum silicide, the molybdenum being deposited on the film of platinum silicide.

4. A method according to claim 3, in which the substrate is covered with a film of silicon oxide, except for the or each area of the substrate when an ohmic contact is to be formed, prior to the substrate being coated with the film of platinum, and after heating to form sintered platinum silicide, the substrate is treated with aqua regia to remove the superfluous platinum.

5. A method according to claim 1, in which a film of aluminium is deposited by evaporation on to the substrate prior to the deposition of the film of molybdenum.

6. A method according to any preceding claim, in which platinum is also present during the deposition of the film including gold, thereby to improve the adhesion of the film including gold to the molybdenum film.

7. A method according to claim 6, in which the material from which the film including gold is sputtered includes a proportion of platinum.

8. A method according to claim 7 in which the material from which the film including gold is sputtered includes 5% by weight of platinum.

9. A method according to any preceding claim, in which the substrate is positioned above the discharges during sputtering.

10. A method according to any preceding claim, in which the sputtering is carried out in an atmosphere containing a minor percentage of hydrogen.

11. A method according to claim 10, wherein the atmosphere is composed of approximately 90% argon and 10% hydrogen by volume.

tends over the oxide. A typical integrated circuit would include in the same semiconductor wafer many transistors and resistors of the type seen in Fig. 5, rather than one of each.

5 Of course, the platinum-silicide deposits 81 may be made in the various contact areas as before.

Utilising the above-described process significant improvements have been achieved. 10 Due to the increased adherence of the molybdenum film to the oxide coating and the platinum-gold film to the molybdenum film (thus avoiding undercutting during the various etching operations), and due to the continuous pinhole free nature of the molybde- 15 num layer (thus preventing the undesirable contact between the gold and silicon materials), substantial improvements in yields were observed during high rates of production. 20 For example, one line of integrated circuits using the contact system and the deposition technique of the present invention has resulted in a percentage improvement in yield in excess of 40%. Furthermore, triode sput- 25 tering is analogous to an elemental triode vacuum tube, and offers a means for closely controlling the process by regulating the voltages and currents of the filament, anode, and cathode electrodes.

30 The technique described above not only produces a continuous molybdenum film substantially free of pinholes, but also one which results in the molybdenum layer tightly adhering to the overlying protective oxide coat- 35 ing, and an overlying gold or gold-alloy film tightly adhering to the molybdenum film. The technique produces a novel multilayer contact and interconnection system which adheres well to silicon and to silicon oxide surfaces 40 without reacting unfavourably with either, which can be used with available photoresist masking and etching procedures, and which forms an ohmic and low resistance electrical contact to the silicon material.

45 While the above-described process has suggested the initial formation of sintered platinum-silicide deposits in the contact areas prior to the sputtering of the molybdenum film, in some situations it is desirable to avoid this 50 step. For example, the selective diffusion of gold into the semiconductor wafer prior to fabrication is often utilised to lower the carrier lifetime therein. During the sintering of the platinum, the heat produced often causes precipitation and redistribution of the gold 55 impurities with corresponding detrimental effects on the device characteristics. To avoid this difficulty a very thin layer (approximately 200 Å) of evaporated aluminium deposited onto heated (600°C) silicon can be used in 60 place of the sintered platinum material.

Various other modifications of the disclosed processes, may become apparent to persons skilled in the art without departing from the

scope of the invention as defined by the 65 appended claims.

WHAT WE CLAIM IS:—

1. A method for depositing a multilayer ohmic contact upon a substrate of semiconductor material including depositing a thin 70 film of molybdenum on the substrate by sputtering and depositing a thin film including gold on the film of molybdenum by sputtering in which platinum or aluminium is present on the surface of the substrate during 75 the deposition of the film of molybdenum whereby the adhesion of the molybdenum film to the semiconductor substrate is improved.

2. A method according to claim 1, in which 80 a film of platinum is deposited on the substrate by evaporation prior to the deposition of the film of molybdenum.

3. A method according to claim 2, in which 85 the substrate is silicon and the substrate is heated after the deposition of the film of platinum and before the deposition of the film of molybdenum, so that the platinum forms a film of sintered platinum silicide, the molybdenum being deposited on the film 90 of platinum silicide.

4. A method according to claim 3, in which the substrate is covered with a film of silicon oxide, except for the or each area of the substrate when an ohmic contact is to 95 be formed, prior to the substrate being coated with the film of platinum, and after heating to form sintered platinum silicide, the substrate is treated with aqua regia to remove the superfluous platinum. 100

5. A method according to claim 1, in which a film of aluminium is deposited by evaporation on to the substrate prior to the deposition of the film of molybdenum.

6. A method according to any preceding 105 claim, in which platinum is also present during the deposition of the film including gold, thereby to improve the adhesion of the film including gold to the molybdenum film.

7. A method according to claim 6, in which 110 the material from which the film including gold is sputtered includes a proportion of platinum.

8. A method according to claim 7 in which the material from which the film including 115 gold is sputtered includes 5% by weight of platinum.

9. A method according to any preceding claim, in which the substrate is positioned 120 above the discharges during sputtering.

10. A method according to any preceding claim, in which the sputtering is carried out in an atmosphere containing a minor percentage of hydrogen.

11. A method according to claim 10, 125 wherein the atmosphere is composed of approximately 90% argon and 10% hydrogen by volume.



12. A method according to claim 8 with or without the features of claims 9, 10 and 11, in which the thin film including gold deposited on the film of molybdenum consists of approximately 95% gold and 5% platinum.

13. A contact and lead arrangement for a semiconductor device of the type including a silicon wafer having a region adjacent the one face thereof with a PN junction between such region and other silicon of the wafer extending to said one face beneath a silicon oxide coating, the coating defining a small opening over said region, the contact and lead arrangement comprising a first triode sputtered film of molybdenum on a film of sintered platinum silicide or aluminium in ohmic contact with said region in said opening of the silicon oxide coating, the triode sputtered film of molybdenum extending from said opening out over said silicon oxide coating in direct contact therewith and over the edge of said junction to a position spaced from said region of said one face, and a second triode sputtered film including gold overlying said film of molybdenum.

14. An arrangement as claimed in claim 13, in which the second sputtered film consists of platinum and gold.

15. An arrangement as described in claim 13, including a layer of evaporated gold overlying said second triode sputtered film of platinum and gold.

16. An arrangement as described in claim 13, wherein said second triode sputtered film is comprised of 95% gold and 5% platinum by weight.

17. A method of forming multilayer ohmic contacts on a substrate of semiconductor material substantially as herein described with reference to the accompanying drawings.

18. A contact and lead arrangement for a semiconductor device substantially as herein described with reference to Figures 1 to 5 of the accompanying drawings.

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