

PATENT SPECIFICATION

(11) 1 342 486

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- (21) Application No. 50483/70 (22) Filed 23 Oct. 1970
 (31) Convention Application No. 85358
 (32) Filed 25 Oct. 1969
 (31) Convention Application No. 87072
 (32) Filed 30 Oct. 1969 in
 (33) Japan (JA)
 (44) Complete Specification published 3 Jan. 1974
 (51) International Classification C23B 9/00; H01L 7/02
 (52) Index at acceptance
 C7B 13 15B 2F
 H1K 217 353 416 41Y 422 441 521 52Y 530 612 615 616 618
 61Y
 H1R 2A1V 2A3P 2AX 2D



(54) IMPROVEMENTS IN OR RELATING TO ELECTRICAL CONNECTIONS

(71) We, NIPPON ELECTRIC COMPANY, LIMITED, a Company duly organized and existing under the laws of Japan and having its executive office at 7—
 15, Shiba Gochome, Minato-ku, Tokyo-to, Japan, 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 methods of producing electrical connections in semiconductor devices.

An aluminum selective etching method has been widely employed for forming electrical connections. This method is such that aluminum is evaporated to the surface of a substrate made of semiconductor, insulator or conductor covered with an insulating film, photoresist is applied to the aluminum film for masking, and the aluminum film excepting the areas which are to become the electrical connections is removed by etching. According to this method, however, it has been often the case that the thickness of the aluminum film becomes uneven, etching is not uniform due to inhomogeneous etching liquid, and an accurate control of the shape of the electrical connections is difficult.

An object of the invention is to provide a method for producing a highly reliable semiconductor device in which electrical connection to the device is made easily and at a high accuracy.

According to the present invention a method of producing an electrical connection in a semiconductor device comprises the steps of forming an insulating film on a semiconductor substrate, forming openings in said insulating film at locations where electrical connection with said semiconductor substrate is desired, de-

positing a film of an anodizable material on said insulating film and in said openings, converting by anodic oxidation a surface layer of said film of anodizable material into a porous oxide film, providing a masking member on selected areas of the surface of said oxide film, said selected areas excluding the areas above respective openings, and using the masking member to perform a selective anodic oxidation of said film of anodizable material, thereby to leave a plurality of conductive paths of anodizable material each isolated from the others by anodized oxide of the anodizable material and each contacting the substrate through an opening and serving as an electrical connection, the selective anodic oxidation including the step of converting the surface of said film of the anodizable material except for portions under said masking member into a non-porous oxide film.

A selective anodic oxidation technique has been proposed in the specification of the copending British patent application No. 1,276,745 in place of the conventional selective etching method to afford a highly reliable multi-layer interconnection structure of a semiconductor device.

However, by the process of the prior art technique in which a part of the deposited aluminum surface is directly covered with photoresist, it is sometimes the case that the edge of photoresist does not stand the anodizing treatment and thus permits oxide growth beneath the photoresist. This is supposedly attributable to the heat of reaction due to the chemical process of anodization. In order to overcome this difficulty, the initial formation of a thin aluminum oxide film on the entire surface of the deposited aluminum is introduced in one embodiment of this invention. Thus, by the addition of a new step to the prior art, the

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shape of conducting paths or wiring channels can be so formed that it corresponds faithfully to the intended pattern. Furthermore, the aluminum oxide film initially formed on the entire surface of the deposited aluminum layer enables the selective anodization of the aluminum layer with a high forming voltage. In detail, the electric field due to the forming voltage employed during the selective anodization is distributed both onto the initially formed aluminum oxide film and onto the photoresist mask formed on the initially formed aluminum oxide film. Therefore, the electric field applied to the photoresist mask is effectively weakened, and it becomes possible to make a forming voltage higher than that employed in the prior art process. Thus, non-porous aluminum oxide can be selectively formed at a high forming voltage. This means the improvement in resistivity of the non-porous aluminum oxide as a mask against the formation of porous aluminum oxide in the following step, which is to the great advantage of the process.

Furthermore, an experimental result has indicated that photoresist adheres more steadily to the anodized aluminum surface than to the aluminum surface itself. So photoresist is desirably applied not on the immediate aluminum surface as in the prior art but on the anodized surface of aluminum as in this present invention to secure its adhesion.

With all these advantages combined, a process is provided which enables accurate wiring pattern formation more securely than the formerly proposed art in the specification of the copending British patent application 1,276,745 by introducing the initial formation of the anodized oxide on the entire surface of the deposited aluminum.

Additionally, if the deposited aluminum surface is changed into oxide by anodization prior to the photoresist process as in the present invention, it becomes chemically stable in a given atmosphere as well as mechanically resistant against any possible scratches. Thus, a whole structure can be set aside without any fear of aluminum degradation only if it has undergone this stage. Then it is ready to be processed to the next stage of photoresist application at any time. This increases the efficiency in production.

It is noted that other anodizable metals, or film-forming metals, such as tantalum, niobium and titanium may be used instead of or together with aluminum.

The invention will now be described by way of example with reference to the accompanying drawings, in which:—

Figures 1, 2(a), 3, 4, 5(a), 6, 7, 8(A), 9 and 10(A) are sectional views and Figures 2(B),

5(B), 8(B) and 10(B) are plan views, illustrating in sequence the processes for producing a semiconductor device according to this invention.

Figures 1 to 10 are to illustrate a preferred production method of a semiconductor device embodying this invention. The surface of a N-type semiconductor substrate 101 (Fig. 1) provided with specific PN junctions and covered with a silicon oxide film 102 is coated with photoresist (not shown), and the silicon oxide film 102 is selectively removed by etching whereby an opening 103 communicated directly with the semiconductor substrate 101, and openings 104 and 105 communicated with the base region and emitter region respectively are disposed as shown in Figures 2(a) and 2(B). An aluminum film 106 of 1.5 microns thickness is evaporated uniformly on the surface of the semiconductor substrate 101 as shown in Figure 3. Then the first anodizing process is applied to the whole surface of the aluminum film 106 whereby a porous aluminum oxide film 107 of about 0.1 micron thickness is formed as shown in Figure 4. To form this porous aluminum oxide film 107, it is desirable that a wafer is immersed in 10% chromic acid solution, with the constant forming voltage of 10 volts applied for ten minutes.

Then, a photoresist 108 is applied to the surface of the wafer, to cover the areas excepting the areas 110', 111' and 109' where an emitter electrode, a base electrode, and a communicating channel with the width of 3 microns are to be formed, respectively, as shown in Figures 5(A) and 5(B). Using the photoresist 108 as the mask, the second anodizing treatment is applied thereto whereby a non-porous aluminum oxide layer 112 is formed in the region having no photoresist, as shown in Figure 6. In this second anodizing process, a forming solution of ethylene glycol saturated with boric acid ammonium is used at a constant forming voltage. It is desirable that the forming voltage is 80 volts and the forming time is about 15 minutes, which results in the non-porous aluminum oxide film of about 0.1 micron thick.

Then, the photoresist 108 is removed by the use of remover. Using said non-porous aluminum oxide 112 as the mask, the third forming process is applied thereto whereby all the aluminum portion excepting the area covered with the non-porous aluminum oxide 112 is converted into a porous aluminum oxide 113, as shown in Figure 7. The third forming process is done using 2% dilute sulphuric acid solution at normal temperature, with the constant forming voltage of 20 volts applied to the wafer. In this embodiment, the areas excepting those masked are converted into

aluminum oxide in 10 minutes and, about 15 minutes later, the communicating channel 109 is converted into aluminum oxide 113, as shown in Figures 8(A) and 14(B).

Finally, the treatment for forming non-porous aluminum oxide is done whereby stable non-porous aluminum oxide is formed on the sides of aluminum electrodes 110 and 111, as shown in Figure 9.

In this final process, constant current forming is done first. When the forming voltage reaches the sum of the breakdown voltage of the collector junction and the voltage of 100 to 150V, the constant current forming is switched to constant voltage forming. This voltage forming is done for 30 to 60 minutes. In this process, the non-porous aluminum oxide film does not grow to more than a certain definite thickness even after a long period of time since the thickness achieved is dependent only on the forming voltage. In this embodiment, the non-porous aluminum oxide film was observed grown to about 0.2 micron thickness.

After the above process, openings 114 through which external lead is to be connected is disposed in the desired area, and thus the formation of electrode is completed. (Refer to Figs. 10(A) and 10(B).)

The electrode of the semiconductor device produced according to the foregoing method has highly accurate shape. In addition, the periphery of the electrode is covered with chemically stable aluminum oxide and, consequently, a highly reliable semiconductor can be obtained. Another noteworthy feature of this invention is that the electrode formation can be automatically controlled and thus the productivity can markedly be increased.

The prior art anode-oxidation technique has not been applicable when forming NPN transistor because of polarity problem in the anode forming process. More specifically, the anode-oxidation method is such that a wafer to which a positive forming voltage is applied is immersed in the forming solution to apply selective anode-oxidation on the aluminum film whereby the aluminum film excepting the areas which are to become the electrodes is converted into aluminum oxide which is an insulating material. Thus the electrodes are formed. The most important point of this method is that the forming current is supplied from the substrate through more than one adjacent electrodes.

The forming current is supplied both from the aluminum-evaporated film side and from the substrate side. The current from the aluminum-evaporated film side is gradually reduced as anode-oxidation progresses, and is finally stopped. Therefore, in order to perfectly isolate the adjacent electrodes from each other, it is necessary to supply the

forming current from the substrate side through the electrode.

Nevertheless, in the NPN transistor, the forming voltage applied to the N-type substrate is applied reversely to the collector junction and, hence, the forming current can neither be supplied from the base electrode or emitter electrode. In short, it is impossible to perfectly isolate the electrodes from each other according to the prior art.

In the semiconductor device having the structure in which the forming voltage is prevented by the PN junction and is not applied directly to the electrode regions as in the NPN transistor, an opening is disposed in the silicon oxide film (which is to serve as the mask in the selective anode-oxidation process) to communicate directly with the substrate not by way of the PN junction, and a current communicating channel having a specific narrow portion is provided to connect the electrodes, as illustrated in the embodiment. In this structure, the forming voltage is applied to more than one adjacent electrodes directly from the substrate via the communicating channel, anode-oxidation continues even after the unmasked aluminum film has been converted into aluminum oxide, and the forming current is kept supplied from the substrate until the narrow portion of the communicating channel is anode-oxidized from its side and converted into aluminum oxide. When thus the forming current stops, the anode-oxidation stops automatically.

In other words, the invention permits forming the electrode automatically at a high accuracy regardless of small variation in the forming voltage if only the width of the most narrow portion of the communicating channel is accurately defined.

In the above embodiments, the forming current is supplied both from the aluminum-evaporated film and from the substrate. The forming current supplied from the aluminum-evaporated film may serve to make the anodizing time fast, but is not necessarily needed. In other words, the anodization can be carried out without the forming current supplied from the aluminum-evaporated film, so long as the forming current is supplied from the substrate. The current supply from the substrate is necessary to make it sure that no aluminum is left unoxidized between adjacent electrodes. One aspect of the present invention provides means for supplying the forming current from the substrate to those portions 110, 111 which are to be finally insulated from a major part of the substrate 101. Such means is the narrow connection channel 109 which is converted into oxide finally after having played its role as a

path of the forming current from the major part of the substrate to the portions to be insulated, from the mentioned part of the substrate.

5 The invention makes it possible to realize a method of producing semiconductor devices in such manner that the forming current is supplied to an electrode, which corresponds to the junction whose break-down voltage and punch-through voltage
10 are lower than the forming voltage or the junction whose leakage current is large, by way of such junction even after the communicating channel through which the current flows from the substrate has been
15 vanished, and the anode oxidation process is continued until the whole electrode is converted into aluminum oxide. During this process, it is possible to reject automatically the semiconductor elements with defective
20 junction by setting the forming voltage at a value to be sufficient to continue anode-oxidation.

25 While a specific embodiment of the invention has been described in detail, it is particularly understood that the invention is not limited thereto or thereby.

The method described above is also described in our co-pending application No 30 29026/73 (Serial No. 1,342,487) which is divided in the present application.

Having regard to the provisions of section 9 of the Patent Act attention is directed to the claims of the said copending application.

35 WHAT WE CLAIM IS:—

1. A method of producing an electrical connection in a semiconductor device, comprising the steps of forming an insulating film on a semiconductor substrate,
40 forming openings in said insulating film at locations where electrical connection with said semiconductor substrate is desired, depositing a film of an anodizable material on said insulating film and in said openings,
45 converting by anodic oxidation a surface

layer of said film of anodizable material into a porous oxide film, providing a masking member on selected areas of the surface of said oxide film, said selected areas excluding the areas above respective openings, and
50 using the masking member to perform a selective anodic oxidation of said film of anodizable material, thereby to leave a plurality of conductive paths of anodizable material each isolated from the others by
55 anodized oxide of the anodizable material and each contacting the substrate through an opening and serving as an electrical connection, the selective anodic oxidation including the step of converting the surface of said film of the anodizable material
60 except for portions under said masking member into a non-porous oxide film.

2. A method as claimed in claim 1, wherein the selective oxidation includes the steps of removing said masking member and thereafter converting by anodic oxidation
65 said film of anodizable material not covered with said non-porous oxide film into an oxide film.

3. A method as claimed in claim 1 or 2, in which said anodizable material is aluminum.

4. A method as claimed in any of the preceding claims, in which said masking member is formed of a photoresist.

5. A method of producing an electrical connection in a semiconductor device substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

6. A semiconductor device having an electrical connection produced therein by the method claimed in any one of the preceding claims.

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6. A semiconductor device having an electrical connection produced therein by the method claimed in any one of the preceding claims.

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