

PATENT SPECIFICATION

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(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 33—
 5 1, 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
 10 and by the following statement:—

This invention relates to methods of producing electrically conductive paths or substrates.

15 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
 20 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
 25 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.

30 An object of this invention is to provide a new and improved method of easily and securely producing a conducting path for electrical connection.

35 According to the present invention a method of producing electrically conductive paths on a substrate comprises the steps of coating a conductive surface of said substrate with an insulating film, forming at
 40 least one opening in said insulating film, depositing a film of an anodizable material over said insulating film, said film of the anodizable material being electrically connected through each opening with said

substrate, and performing anodic oxidation 45 of a selected area of said film of the anodizable material to leave a plurality of electrically conductive paths of said anodizable material, said conductive paths being isolated from one another by the
 50 anodized oxide of said anodizable material, at least one of said conductive paths being electrically connected through one of the openings with said substrate, and said step of performing an anodic oxidation including
 55 the step of supplying an anodizing current from said substrate through at least one opening to said film of the anodizable material.

It is noted that other anodizable metals, 60 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:— 65

Figures 1(A), 2, 3(A), 4 and 5(A) are sectional views and Figures 1(B), 3(B) and 5(B) are plan views, illustrating in sequence a preferred process for fabricating the wiring substrate embodying this invention; 70 and

Figures 6, 7(A), 8, 9, 10(A), 11, 12, 13(A), 14 and 15(A) are sectional views and Figures 7(B), 10(B), 13(B) and 15(B) are plan views, illustrating in sequence the processes for producing a semiconductor device according to another embodiment of this invention. 75

Figures 1 to 5 illustrate a preferred process for producing a wiring substrate according to this invention. In this embodiment, a plate 21 of conductive material with coating of thin insulating film 22 is used as the insulating substrate. Selective etching is applied to the insulating film 22 which covers the surface of the substrate 21 comprising a conductive material whereby 80 85

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an opening 23 to communicate directly to the conductive material 21 is disposed in a predetermined area of the substrate, as shown in Figures 1(A) and 1(B). Then an aluminum thin film 31 is evaporated to the surface of the substrate 21 as shown in Figure 2 and is subject to a first anodizing process to form a porous aluminium oxide film. In the process of forming this porous aluminium oxide film it is desirable to use 10% chromium trioxide dissolved in water, with a constant forming voltage of 10 volts applied for 10 minutes. Then, the surface of thus-formed aluminum oxide film 32 excepting area 34 which is to become the wiring channel and also excepting area 35 which is to establish electric connection between the wiring channel and the opening 23 are covered with photoresist 33 as shown in Figures 3(A) and 3(B), and a second anodization is processed. In this second anodizing process a non-porous aluminium oxide film is formed by using a solution of ethylene glycol saturated with ammonium borate, a constant forming voltage of 80 volts being applied for 15 minutes. Then the photoresist is removed. The non-porous aluminum oxide film 37 formed by the second anodizing process is used as the mask in converting all the aluminum therearound into porous aluminum oxide 36. In this process, an anodizing voltage is applied both to the aluminum film 31 and to the conductive material 21. The anodizing current is supplied both from the aluminum-evaporated film 31 and from the substrate 21. The current from the aluminum-evaporated film stops when the unmasked aluminum is converted into aluminum oxide which is an electrically insulating material (Refer to Figure 4).

As long as the current from the substrate 21 flows in the wiring channel 34 through the connection channel 35 anode-oxidation continues. Anode-oxidation in this area is automatically stopped, when the narrowest part of the connection channel 35 is completely anode-oxidized into aluminum oxide and thus the anodizing current is no more supplied to the wiring channel 34. (Refer to Figures 5(A) and 5(B). In this manner, the invention permits formation of the wiring channel automatically at a high accuracy regardless of small variation in the anodizing voltage if only the width of the narrowest part of the connection channel is accurately determined beforehand.

In the above described production process, the substrate 21 may be so arranged that the surface of a flat plate made of an insulating material is coated with a metal film such as aluminum film, and the surface of the metal film is coated with an insulating material such as silicon dioxide. Where such an insulating plate coated with a metal film

is substituted for the conductive substrate 21, the metal film serves as a path of the anodizing current which is in turn supplied to a material to be anodized through an opening formed in the insulating film coating the metal film.

The wiring structure comprising the wiring layer having wiring channels and insulating films formed by the process as illustrated in the foregoing embodiment includes the increment of volume due to the chemical conversion of aluminum into aluminum oxide. In spite of such volume increment, the surface of this wiring substrate is markedly flat in comparison with that of the conventional wiring substrate having the wiring channels formed by selective etching or printing process. Since the wiring channels according to this invention are firmly protected by the aluminum oxide, the wiring substrate having such wiring layer is well protected from scratches or failures caused by deposit of dust during its production process.

This invention is particularly featured by the effect that raised or hollow portions are not produced on the surface of the wiring substrate after installation of an additional wiring layer and therefore this wiring structure can be applied to multilayer wiring substrate having more than two layers without losing high reliability.

Figures 6 to 15 are to illustrate a preferred production method of a semiconductor device embodying this invention. The surface of a N-type semiconductor substrate 101 (Fig. 6) 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 7(A) and 7(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 8. 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 9. 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 10(A) and 10(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 11. 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 12. 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 13(A) and 13(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 14.

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. 15(A) and 15(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 last 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.

5 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
10 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
15 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
20 invention provides means for supplying the forming current from the substrate to those portions 34, 110, 111 which are to be finally insulated from a major part of the substrate 21, 101. Such means is the narrow connection channel 35, 109 which is converted
25 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
30 substrate.

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
35 corresponds to the junction whose breakdown voltage and punch-through voltage 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
40 current flows from the substrate has been 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
45 junction by setting the forming voltage at a value to be sufficient to continue anode-oxidation.

50 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.

55 The methods described above are also described in our copending application No. 50483/70 (Serial No. 1342486), on which the present application is divided.

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

WHAT WE CLAIM IS:—

65 1. A method of producing electrically conductive paths on a substrate, said method comprising the steps of coating a conductive surface of said substrate with an

insulating film, forming at least one opening in said insulating film, depositing a film of an anodizable material over said insulating film, said film of the anodizable material being electrically connected through each
70 opening with said substrate, and performing anodic oxidation of a selected area of said film of the anodizable material to leave a plurality of electrically conductive paths of said anodizable material, said conductive
75 paths being isolated from one another by the anodized oxide of said anodizable material, at least one of said conductive paths being electrically connected through one of the openings with said substrate, and said step
80 of performing an anodic oxidation including the step of supplying an anodizing current from said substrate through at least one opening to said film of the anodizable material.
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2. The method of claim 1, further comprising the step of converting a part of said one of said conductive paths into an oxide of said anodizable material to divide said one of said conductive paths into two portions,
90 one of said portions being still capable of being supplied with the anodizing current from said substrate and the other of said portions being incapable of being supplied with the anodizing current from said substrate.
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3. The method of claim 2, in which said part of said one of said conductive paths is narrower in width than the remainder of said one conductive path.
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4. The method of any of claims 1 to 3, in which said substrate is formed of a conductive material.

5. The method of any of claims 1 to 3, in which said substrate comprises a plate of an insulating material and a metallic film coating one surface of said plate.
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6. The method of any of claims 1 to 3, in which said substrate is formed of a semiconductor.
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7. The method of claim 4 or 5, further comprising the steps of, before said step of performing an anodic oxidation, converting by anodic oxidation a portion of the thickness of said film of the anodizable material into a porous oxide film and forming a mask pattern on the surface of said oxide film.
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8. The method of claim 7, in which said step of performing an anodic oxidation further includes the step of converting the surface of said film of the anodizable material except for a portion under said mask pattern into a non-porous oxide film.
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9. The method of claim 8, further comprising the steps of removing said mask pattern and thereafter converting by anodic oxidation said film of the anodizable material not covered with said non-porous oxide film into an oxide film.
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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.

5 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
10 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
15 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
20 forming current from the substrate to those portions 34, 110, 111 which are to be finally insulated from a major part of the substrate 21, 101. Such means is the narrow connection channel 35, 109 which is converted
25 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.

30 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
35 corresponds to the junction whose breakdown voltage and punch-through voltage 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
40 current flows from the substrate has been 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
45 the semiconductor elements with defective junction by setting the forming voltage at a value to be sufficient to continue anode-oxidation.

50 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.

55 The methods described above are also described in our copending application No. 50483/70 (Serial No. 1342486), on which the present application is divided.

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WHAT WE CLAIM IS:—

65 1. A method of producing electrically conductive paths on a substrate, said method comprising the steps of coating a conductive surface of said substrate with an

insulating film, forming at least one opening in said insulating film, depositing a film of an anodizable material over said insulating film, said film of the anodizable material being electrically connected through each opening with said substrate, and performing
70 anodic oxidation of a selected area of said film of the anodizable material to leave a plurality of electrically conductive paths of said anodizable material, said conductive
75 paths being isolated from one another by the anodized oxide of said anodizable material, at least one of said conductive paths being electrically connected through one of the openings with said substrate, and said step
80 of performing an anodic oxidation including the step of supplying an anodizing current from said substrate through at least one opening to said film of the anodizable material.

85 2. The method of claim 1, further comprising the step of converting a part of said one of said conductive paths into an oxide of said anodizable material to divide said one of said conductive paths into two portions,
90 one of said portions being still capable of being supplied with the anodizing current from said substrate and the other of said portions being incapable of being supplied with the anodizing current from said substrate.

95 3. The method of claim 2, in which said part of said one of said conductive paths is narrower in width than the remainder of said one conductive path.

100 4. The method of any of claims 1 to 3, in which said substrate is formed of a conductive material.

105 5. The method of any of claims 1 to 3, in which said substrate comprises a plate of an insulating material and a metallic film coating one surface of said plate.

110 6. The method of any of claims 1 to 3, in which said substrate is formed of a semiconductor.

115 7. The method of claim 4 or 5, further comprising the steps of, before said step of performing an anodic oxidation, converting by anodic oxidation a portion of the thickness of said film of the anodizable material into a porous oxide film and forming a mask pattern on the surface of said oxide film.

120 8. The method of claim 7, in which said step of performing an anodic oxidation further includes the step of converting the surface of said film of the anodizable material except for a portion under said mask pattern into a non-porous oxide film.

125 9. The method of claim 8, further comprising the steps of removing said mask pattern and thereafter converting by anodic oxidation said film of the anodizable material not covered with said non-porous oxide film into an oxide film.
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10. The method of any of claims 1 to 7, in which said anodizable material is aluminum, tantalum, niobium, or titanium.

5 11. The method of any of claims 1 to 9, in which said anodizable material is aluminum.

12. The method of any of claims 7 to 9, in which said mask pattern is formed of a photoresist.

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