

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,179,876

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COMPLETE SPECIFICATION

Resistors for Integrated Circuits

We, RCA CORPORATION, formerly known as RADIO CORPORATION OF AMERICA, a Corporation organized under the laws of the State of Delaware, United States of America, of 30, Rockefeller Plaza, City of State of New York, 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 improved resistors for integrated circuits and, more particularly, to resistors of the type made by diffusing an impurity of one conductivity type into a semiconductor body of opposite conductivity type.

At present, integrated circuits which comprise a number of active and passive circuit elements fabricated in and on a single crystal semiconductor wafer, have resistors of either one of two main types. One of these types is made by evaporating a shaped layer of metal on a part of the semiconductor body covered with an insulating film. The second type is made by diffusing an impurity capable of producing one conductivity type into a semiconductor body of a second conductivity type. In making the second type resistor, an opening of desired length and width is made in a protective masking coating which covers the semiconductive body. The impurity is either evaporated from a vacuum source, or derived by decomposition of a gaseous compound and deposited on the surface of the body within the opening and then diffused into the body at a particular temperature and time. The value of resistance thus obtained is a function of the initial concentration of impurity at the surface of the body, the length and width dimensions of the diffused region and of the time and temperature of

diffusion. The resistance value also depends upon the particular impurity being used.

Although the diffused type of resistor has proved to be satisfactory for commercial uses, it has certain undesirable limitations and disadvantages. The resistance values are not as reproducible as desired. For high values of resistance considerable room is taken up on the semiconductor wafer where space is at a premium. And, since the resistors are usually made at the same time as the base diffusion of the bi-polar transistors, where these are also present in the circuit, a compromise must be accepted in what would be more desirable parameters of each. If the surface concentration of impurities of the resistor is low, the temperature coefficient of resistance of this element may be undesirably high. So the diffusion step which forms both the transistor base regions and the resistors is adjusted to keep the sheet resistance at a low enough value to obtain resistors having good temperature characteristics even though the transistor base regions may then not have optimum resistivity for their own purpose.

Briefly, the resistor of the present invention includes a first diffused region of a first type conductivity having a predetermined depth, in a body of semiconductor material of a second type conductivity. Ohmic contacts are made to spaced apart portions of this first region. A second region of the second type conductivity is diffused into the first region between the contacts but separated therefrom. The second region is floating and extends only partly through the depth dimension of the first region. Since there are no contacts to the second region, there is no current flow through it and current does not pass from the first region into the second region because a P-N junction between the regions prevents such flow. The dimensions

[Price 5s. 0d.]

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of the second region are selected to adjust the effective depth of the first region and this aids in accurately adjusting its resistance value to some desired amount.

In the drawings:

Figure 1 is a top plan view of a part of a typical monolithic integrated circuit showing a resistor of the present invention in an early stage of fabrication;

Figure 2 is a section view taken along the line 2-2 of Figure 1;

Figure 3 is a graph showing variation in concentration of conductivity type-determining impurity with depth, in a typical diffusion step illustrated in Figures 1 and 2;

Figure 4 is a plan view, similar to that of Figure 1, showing a completed resistor of the invention;

Figure 5 is a section view taken along the line 5-5 of Figure 4, and

Figure 6 is a graph like that of Figure 3 showing impurity profile concentrations after the completion of diffusion of a second impurity in making a resistor of the present invention.

Referring now to the drawing wherein like parts are designated with the same numerals, a resistor of the present invention is usually made as part of an integrated circuit. The circuit may be made in a substrate which comprises, (Figure 2) for example, a P substrate 2 of single crystal silicon on which are grown successive epitaxial layers 4 and 6 of N+ and N type silicon, respectively, to form a body of one conductivity type.

In order to provide an island portion 8 of the N type top layer 6 which is isolated from other circuit components, a P+ diffused region 10 is provided which completely encompasses the lateral periphery of the isolated N region 8.

As shown in Figures 1 and 2, a first step in making a resistor comprises forming a P+ diffused region 12, which may be of elongated configuration, having enlarged terminations 14, in the isolated N region 8. In order to reduce costs it is desirable that this diffusion step be carried out at the same time as that used in forming the base P+ region of any N-P-N transistors (not shown) which may be present elsewhere in the circuit.

As shown in Figure 3, the P type impurity concentration, represented by the area 15 under the curve B, in the diffused region 12, is highest in the area of the surface junction between the isolated region 8 and the diffused region 12, and decreases in the regular manner with increasing depth within the semiconductor layer. At a depth of about 2.4 microns the P type impurity concentration drops below the N type background doping level, represented by the area 17 beneath line A. Therefore, the P+ region 12

effectively terminates at 2.4 microns depth even though P type impurities are diffused below this level.

This single diffusion step is representative of the manner in which diffused resistors have previously been made in integrated circuits. Resistance value can be varied by varying the length and width dimensions of the region, by varying the initial impurity concentration as the impurity is deposited on the surface of the body, and by varying the time and temperature of diffusion. However, these variations have certain practical limits.

Although higher resistance values can be obtained by increasing the length of the diffused region, this takes up valuable surface space needed for other components and adds to the circuit cost.

And, although higher resistance values can also be obtained by reducing the width of the region 12, this is also of limited value because, as the width of the region becomes less, irregularities in dimension due to unavoidable mask imperfections and variations have a relatively greater effect on the resistance actually obtained. Thus allowable tolerances in resistance are exceeded in a larger percentage of circuits and more circuits must be scrapped.

This leaves impurity surface concentrations and time and temperature of diffusion as possible variables to utilize. However, these variables are also of limited utility and flexibility. If the concentration of impurities is kept low in order to get high values (say 1,000-2,000 ohm per square) of resistance, the actual doping level achieved is very difficult to control. Minor variations in amount of impurity deposited cause wide variations in resistance of the doped region. Therefore, using only a single diffusion, it has been difficult to fabricate resistors of relatively high value without sacrificing some other desirable feature such as small area.

Another aspect of the single diffusion problem is that it is desirable, for economic reasons, to diffuse in the resistor regions at the same time as steps used in making some other circuit component. From a cost standpoint it is therefore attractive to diffuse a P type resistor at the same time as the P type base of an N-P-N transistor. However, it has often proven difficult to compromise between the resistance value desired in the resistor and the resistance value desired in the transistor base, with the consequence that one or both suffered.

The next step in making an improved resistor is illustrated in Figures 4 and 5. A second N+ diffused region 16, is formed between the terminal ends 14 of the P+ diffused region 12 by diffusing N-Type impurities into a part of the surface of region 12 between but not in contact with the enlarged end portions 14. The N+ region 16

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may overlap the boundaries between the regions 8' and 12. The depth to which the second diffused region 16 extends will always be less than the depth of the first diffused region 12 so as to leave a controlled partial layer 12' of the region 12 in its original conductivity type. The resistor effectively now comprises the terminal portions 14 and the thinned-down central portion 12'. Metal contacts 18 are made to the terminal portions 14.

The second diffused region 16 is preferably made at the same time as the N+ emitter regions, and possible also N+ collector contacts, are made. Current does not flow through the N+ region 16 since it is floating and is separated by a P-N junction from the rest of the resistor which is connected in circuit through contacts 18.

The depth of the region 16 can be used to control the residual resistance of the layer 12' since the thickness of layer 12' is varied thereby.

The improved resistor has a number of advantages over single diffusion types. One of these is that high resistance values can be achieved using only high concentration diffusion steps. Concentration of the impurity decreases rapidly with depth beneath the surface of a semiconductor and by utilizing mostly that part of the diffused region at the greatest depths, the resistance of the completed resistor is high relative to the resistance obtainable from that part of the diffused region near the surface through which the diffusion is made.

It is also possible to carry out the P+ diffusion step in making the resistors at the same time as the P+ parts of the P type bases of N-P-N transistors are fabricated. Many N-P-N transistors have P+ base portions to reduce base resistance in order to make better ohmic contact to the base.

Resistance values of the resistors can also be accurately controlled to close tolerances. At higher impurity concentrations, depths of penetration and impurity concentration profiles are accurately predictable. Therefore, not only wide variations in resistances are possible but accurate and predictable values as well.

Example 1

Using a silicon single crystal body having the layered construction of Figure 5, the top N layer 6 had a resistivity of 0.45 ohm-cm. The top surface of the assembly was covered with a protective layer of silicon dioxide (not shown in the drawing). By conventional photoresist and etching techniques openings were etched in the oxide layer where resistors and P+ portions of transistor base regions were desired and boron was deposited on the exposed silicon surface by passing BBr₃ over the surface for 60 minutes at 975°C. This provided a surface boron

concentration having a sheet resistance, R_s , of 25 ohms/square.

The oxide layer was then removed with hydrofluoric acid and a fresh oxide layer grown in steam for 30 minutes at 1000°C.

An opening (not shown) was then made in this second oxide layer to deposit more P type impurity to make a P type base region portion of a transistor. BBr₃ was passed over the opening, this time for 60 minutes at 915°C.

An additional diffusion step was then carried out by heating the assembly to a temperature of 1100°C for 150 minutes. This resulted in regrowth of oxide in previously-made openings and this step, together with previous heating steps, formed a P+ region 12 with enlarged terminal portions 14 as shown in Figures 1 and 2.

A new opening was made through the oxide layer where the second diffused region 16 of the resistor was desired and where the emitters (not shown) of any N-P-N transistors were desired.

Phosphorous was deposited in the new openings by passing POCl₃ thereover for 17 minutes at 1050°C. This was then followed by a re-oxidation step at 940°C for 45 minutes, which also caused further penetration of the N+ layer 16.

Finally, openings were made in the oxide layer over the terminal portions 14 and metal pads 18 were deposited by evaporation. Excess metal was removed with removal of photoresist that had been put down to define the openings.

The double impurity concentration profile which resulted is shown graphically in Figure 6. The original N layer 6 had a uniform N-type impurity concentration of about 10^{18} atoms/cm³ as indicated by line A of the graph. The profile of the P+ diffusion is shown as the curve B, having a surface concentration of 10^{19} atoms/cm³ and tapering off to 10^{16} atoms/cm³ at depth of 2.4 microns. It should be understood that the P type impurity penetration continues beyond this depth but has no effect on the resistor below about 2.4 microns where the P type concentration falls below the background N type concentration. The profile of the N+ diffusion is shown as the curve C, having a surface concentration of 10^{21} atoms/cm³ and tapering to about 7×10^{18} atoms/cm³ at 1.5 microns in depth where it drops below the concentration of the P type impurity. Like the P+ diffusion, the N type impurities continue to penetrate below 1.5 microns but are masked by the P type impurities below this depth. The area D in Figure 6, which is the area under Curve B not overlapped by Curve C, is the part which is of interest with respect to the resistor represented by region 12' of Figures 4 and 5. The dotted line E, within area D, represents the profile

of the actual net concentration of P type impurities in the region 12'. In this example, the resistivity of the resistor was 1,030 ohms/sq.

Example 2

In this example processing was the same as in Example 1 except that, after the first P+ deposition, the oxidation step in steam was continued for 45 minutes instead of 30 minutes. The completed resistor had a resistance of 1,260 ohms/square.

Example 3

In this example processing was also the same as in Example 1 except that, after the first P+ deposition, the steam oxidation was continued for 90 minutes instead of 30 minutes. The completed resistor had a resistance of 2,120 ohms/square.

Example 4

Processing was the same as Example 1 except that the initial P+ deposition was for 60 minutes at 1025°C and the following steam oxidation was for 120 minutes at 1000°C. P+ penetration was 3.0 microns and N+ penetration was 1.8 microns. The finished resistor had a resistance of 1,400 ohms/square.

Example 5

Processing was the same as Example 1 except that the initial P+ deposition was for 60 minutes at 1050°C and the following steam oxidation was for 120 minutes at 1000°C. Resistance of the finished resistor was 320 ohms/square. P+ penetration was 3.7 microns and N+ penetration was 1.8 microns.

Example 6

In this Example all processing was like that of Example 1 except that the initial P+ deposition was for 60 minutes at 1075°C and subsequent steam oxidation was for 120 minutes at 1000°C. The resistance of the finished resistor was 80 ohms/square. P+ penetration was 3.9 microns and N+ penetration was 1.2 microns.

Almost any value of resistance within wide limits can be obtained by varying the conditions of P+ deposition and diffusion. If all the steps involving heating of the unit can be kept constant from one batch operation to the next except certain ones left flexible for purposes of obtaining varia-

tions in resistance, a high degree of accuracy is possible.

WHAT WE CLAIM IS:—

1. A method of making a resistor including forming in a portion of a semi-conductor body of one type conductivity, a first region of opposite type conductivity, said region having predetermined length, with and depth, and said region having a certain resistance value between two points at which there are formed contacts of said resistor, and effectively reducing said depth over at least a part of said length between said points such that said resistance value is increased.

2. A method as claimed in Claim 1, wherein said reduction in depth is accomplished by diffusing an impurity into said region such that a portion thereof is converted to said one type conductivity.

3. A method as claimed in Claim 1 or 2, including diffusing a first impurity into said body from a surface thereof so as to form the first region of opposite type conductivity therein, and diffusing a second impurity into said body so as to form a second region of said one type conductivity, said second region being disposed within said first region but having a depth less than that of said first region.

4. A resistor made by the method as claimed in Claim 1, 2 or 3 including a body of semiconductor material of one type conductivity, a first region of opposite type conductivity having predetermined thickness disposed within said body, ohmic contacts to spaced apart portions of said region, and a second region of said one type conductivity disposed within said first region between but separated from said contacts so that in use it is arranged to be electrically floating, said second region extending only partly through said thickness of said first region.

5. A micro-circuit comprising in combination the resistor of Claim 4, and a plurality of interconnected circuit components disposed within said body.

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PATENTS ACT 1949

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Reference has been directed, in pursuance of Section 8, of the Patents Act, 1949, to Specification No. 1,081,646.

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18 November 1970

R 127781/1

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4. A resistor made by the method as claimed in Claim 1, 2 or 3 including a body of semiconductor material of one type conductivity, a first region of opposite type conductivity having predetermined thickness disposed within said body, ohmic contacts to spaced apart portions of said region, and a second region of said one type conductivity disposed within said first region between but separated from said contacts so that in use it is arranged to be electrically floating, said second region extending only partly through said thickness of said first region.

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PATENTS ACT 1949

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