

March 5, 1963

P. ROBINSON

3,080,481

METHOD OF MAKING TRANSISTORS

Filed April 17, 1959

2 Sheets-Sheet 2

Fig. 2.



Fig. 3.

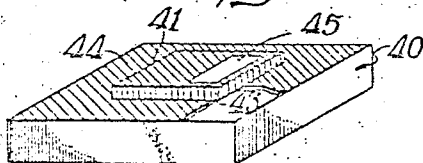


Fig. 4.

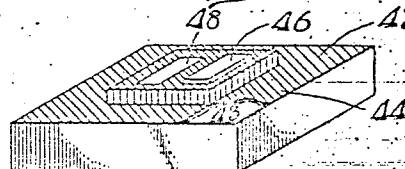
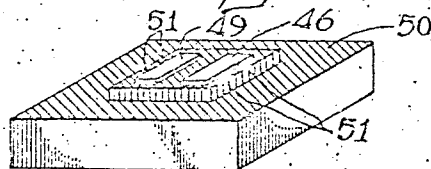


Fig. 5.



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3,080,481

METHOD OF MAKING TRANSISTORS

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Filed Apr. 17, 1959, Ser. No. 867,247

4 Claims. (Cl. 250-83.3)

The present invention relates to the manufacture of transistors and, more particularly, to the apparatus and the method for making a transistor body.

Junction transistor devices are made up of a base of semiconductive material on which is placed electrodes of opposite conductivity material. Rapid production of transistors and other semiconductive devices presents problems in reproducibility and accuracy.

It is an object of this invention to provide a semiconductor device which is made by subjecting a body to a beam of electrodes.

It is another object of this invention to provide a technique for the preparation of transistor bodies in a simple manner which accurately reproduces identical completed transistors.

These and other objects of this invention will become more apparent upon consideration of the following description taken together with the accompanying drawing in which:

FIGURE 1 is a diagrammatic section of apparatus for making a semiconductive device;

FIGURE 2 is a side section of a semiconductive device created by the technique of this invention with portions of the original body removed;

FIGURE 3 is a perspective of a transistor during preparation according to the technique of this invention;

FIGURE 4 is a perspective of the transistor of FIGURE 3 under a further step of preparation; and

FIGURE 5 is a perspective of the transistor.

This invention, in general, provides a means and method for producing a transistor or a semiconductive device through the action of a focused beam of electrons on a body to cause the body to be made into a transistor. The transistor is formed by a succession of treatment steps.

Referring to FIGURE 1, there is shown an apparatus for treatment of a semiconductive body. The apparatus uses an electron beam generated in any convenient manner from an electron beam source indicated at 10. Such a source can, for example, be of the type described in British Patent No. 714,613. It provides a beam which is focused so that it converges at the site of a body shown at 11 in FIGURE 1. The body 11 is held in an encircling positioning ring or sheet 14 on a raised mounting platform 16 in a base 17. As shown, the ring 14 holds the body 11 in the electron beam. An electrical lead 15 is attached to the ring 14 and the lead 15 is connected into the electron beam circuit. A good electrical contact is provided between the body 11 and the ring 14. The ring can have its inner edges flanged as indicated at 12 to provide a contact against the body 11 is pressed and held in position.

The raised platform 16 has tapered side walls 18 which form the shape of a column and which provide an airtight joint with a correspondingly shaped skirt of a chamber-forming inverted cup 19 placed over the side walls 18. The seal is improved by lubrication with a sealing material such as the silicon type of joint grease conventionally used in chemical apparatus. The cup 19 may be made of glass or metal. The upper wall of the cup 19 is formed with an opening 21. The opening 21 permits the electron beam from the source 10 to pass to the body 11. As shown in FIGURE 1, the wall 20 is shaped in a recessed form so as to lie adjacent to the body 11

and approaches the upper surface of the body 11. This places the opening 21 preferably close to the body 11.

The cup 19 is also provided with duct fittings 22 and 23 to provide for evacuation of the chamber 24 within the cup 19. In this manner, the control of the ambient atmosphere in the chamber 24 and around the body 11 is effected. Gases may be evacuated from the chamber 24 and gases or other material may be introduced into the chamber 24. This provides a means for controlling the type of activity that goes on in the chamber 24 and adjacent the body 11.

A second inverted cup 25 may be positioned over the cup 19 and, thus, provide a second chamber 26. The cup 25 is provided with an opening 27 for the passage of the electron beam from the source 10. Similarly to cup 19 and its chamber 24, the cup 25 was provided with a duct 28 for introducing and removing material into and out of the chamber 26. A third cup 29 may also be provided to form a third chamber 30.

All of the cups 19, 25 and 29 have slanted side walls at the same angle as side walls 18. Thus, the cups are removable and interchangeable. Similarly, all of the cups are provided with an opening for permitting the passage of the electron beam from the source 10. The joints between the walls of the adjacent cups are airtight as described above so that the apparatus can have chambers with various sorts of material within them through which the electron beam is passed.

The base 17 contains a device 31 for measuring X-ray emanations. This device 31 is any satisfactory equipment having sensitivity to X-rays such as a SCINTILLOMETER. The measuring device has a sensitive surface which is as close as possible to the body 11, preferably directly in contact with the body 11. On the other hand, the platform 16 is composed of material that does not readily absorb X-rays. Suitable vitreous materials such as sodalime glass, thermally resistant borosilicate glasses, or low alkali silica are suggested. Even the phosphate glasses are suitable for this purpose. It is preferred that the metals used in forming the parts of the apparatus be of a low atomic number such as aluminum, magnesium, titanium, iron and so forth. It will be understood that suitable plastics are useful such as phenol formaldehyde or even high molecular weight polyethylene.

In this invention, a semiconductive device and, more particularly, a transistor may be formed by mounting a body of suitable semiconductive material in the cup 19 and subjecting it to the action of the electron beam. The electron beam may be employed to remove portions of the semiconductive material, to apply electrodes to the semiconductive material and to otherwise transform the semiconductive material into a completed transistor. This action on the semiconductive material may all take place without removing the semiconductive material from its position in the flange 12 within the chamber 24. The apparatus of FIGURE 1 is adapted to cooperate with this treatment of the semiconductive material. The chamber 24 can be evacuated by suction pumps connected to the ducts 22 and 23. This evacuation can serve to remove a vapor from the chamber 24 and also to lower the pressure within the chamber and, thus, make the electron beam projected into the chamber more effective.

In the operation of the apparatus of FIGURE 1 for the treatment of the semiconductive material and the formation of the transistor, the electron beam is switched on and focused by adjustment to give a desired beam impingement on the semiconductive material. This beam impingement is similar to that described in my U.S. Letters Patent No. 2,883,544 issued April 21, 1959. As described in the co-pending application, the beam penetrates into the chamber 24 and can be used to attack, modify and

adapt semiconductive material positioned in the chamber 24.

The pressure maintained in the chamber 24 is controllable and may be any desired pressure from atmospheric down to an extremely high vacuum such as 0.01 micron. Also pressures above atmosphere may be produced within the chamber 24. In this connection, the weight of the upper part of the apparatus serves to permit raising of the pressure within the lower chamber. The cup 19 also may be clamped in the side wall in order to be held down when containing a raised pressure.

The cups 25 and 29 are employed to isolate the chamber 24 from the ambient atmosphere around the apparatus. Openings 27 are provided through these cups, but these openings are maintained as small as possible so as to assist in the isolation of the interior of chamber 24 from the remainder of the atmosphere through the intercession of cups 25 and 29.

Further gases generated within the chamber 24 are retained within the chamber and prevented from reaching the electron beam source. Here again, the apertures 27 are kept as small as the use of the device will permit so that such undesirable gases are restricted in escape from the chamber 24. Further, in cases of very reactive gases, it may be necessary to use at least one additional cup, for example, cup 37, in order to satisfactorily retain the gases within the apparatus and to guard against escape.

The electron beam source is produced according to the conditions set forth in my U.S. Letters Patent No. 2,883,544 issued April 21, 1959. This electron beam is introduced into the apparatus through the openings 27 and penetrates into the chamber 24. The electron beam can be focused and can be aimed within the chamber 24. Such focusing and aiming is shown in the above-identified British Patent No. 714,613. In this operation, the body of semi-conductive material which is to be made into a transistor or other semiconductive material is mounted in the place provided within chamber 24. The body is then subjected to treatment by the electron beam more fully described below. After the steps of treatment, the transistor is completed and removed from the chamber 24. In order to carry out this treatment, suction pumps attached to the ducts 22 and 23 will create a reduced pressure in the chamber or remove gases produced in the chamber. The ducts 22 and 23 may be used to introduce gases into the chamber in order to achieve the desired finished transistor product.

The electron beam source is used to produce a number of phenomena within the chamber such as polymerizing a gas, applying a mask to the surface of a transistor, removing the mask, evaporating leads and electrodes on the semiconductor and removing the excess material from the leads and the electrodes. The electron beam source is preferably operated at a potential of at least 15,000 or 20,000 volts and possibly higher. An electron beam current can be produced which will cause the semiconductive body to evaporate under the impingement of the beam on the semiconductive material. For example, at a potential of 50,000 volts, the electron beam current of a few milligrams will be sufficient to evaporate a germanium body. This evaporation can be carried on in such a way as to rapidly remove portions of the body and, thus, change its shape. The action of the beam on the semiconductive body can be determined by the measurement of the X-ray output. The amount of removal achieved in a given period of operation over predetermined circumstances can be established and from such standards a specific procedure developed for creating a desired product. X-ray measurement readings can then be used to monitor the treatment of the semiconductive body; the steps of this procedure can be programmed into an automatic operation.

Bodies of either type of semiconductive material may be treated in this procedure, and n-type or p-type semiconductive devices and transistors may be provided. It

will be understood, however, that with various types of materials, the conditions and procedures may be varied to give the desired results.

The treatment of the semiconductive material, according to this invention, includes subjecting the semiconductor to other action in addition to evaporation. The semiconductive material may have a protective surface applied by polymerizing a gas in the chamber 24 for deposit on the semiconductive body. Electrodes and leads may be deposited on the semiconductive body by condensation. The electrodes may be microalloyed into a semiconductive body and the protective mask may be removed along with excess electrode material. The chamber 24 may hold a gas which, when subjected to the electron beam, will result in the application of a mask to the semiconductive material. Similarly, vapors may be created within the chamber 24 and deposited on the semiconductive material. In the removal steps of burning off protective films from the semiconductive materials or evaporating semiconductive material away from the semiconductive body, the chamber can be evacuated through the ducts 23 or 22 so as to provide a disposal of the removed material.

The electron beam is created and focused by the means and method described in my U.S. Letters Patent No. 2,883,544 issued April 21, 1959, filed December 19, 1955.

A transistor structure may be created with the method of this invention by applying the electron beam against the surface of a semiconductive body as described above. Referring to FIGURE 2, a body 40 of a semiconductive material is shown in vertical cross-section to be made up of a semiconductive material on a nickel base, the semiconductive material is a p-type conductivity substance having an upper surface of an n-type conductivity material. The body 40 is shown in solid outline with a mesa 41. At the two sides of the mesa 41, there is shown in dotted lines a portion of the semiconductive body 40 removed according to the process of this invention by the electron beam evaporation and the apparatus of FIGURE 1. The removed portions 42 of the body 40 are the result of the volatilization of the semiconductive material by direct evaporation. To effect this evaporation, the body 40 is positioned in the sheet 14 within the chamber 24, under a reduced atmosphere having a pressure low enough to cause the electron beam to be projected against it without undue loss of efficiency. Suction pumps on the outlet ducts 22 and 23 evacuate the chamber 24. The electron beam from the beam source 10 strikes the body 40 and is focused by previous adjustment to give the desired beam impingement. An electron beam source operates at a sufficiently high potential so that the effect of its impingement on the semiconductive material of the body 40 results in an evaporation of the semiconductive material by directing the beam against the portions 42. These side portions are removed from the body 40 as indicated by the broken line sectioning.

After removal of the portions 42 and the creation of a mesa 41 on the body 40, the body 40 is subjected to the next step of transistor manufacture. Referring to FIGURE 3, the view shows the mesa-formed upper surface 43 of the body 40. This surface 43 is covered according to this invention with a protective skin 44 as indicated by the partial covering shown in FIGURE 3. The covering 44 partly broken away in FIGURE 3 covers the top of the body 40 so as to protect it against subsequent depositions. In laying down the protective covering 44, an area 45 is left uncovered to permit the subsequent reception of a transistor electrode. The protective covering 44 is applied by deposition of a suitable film from a vapor in the chamber 24 of FIGURE 1, in which the body 40 is positioned. The deposition is achieved by the polymerization of a suitable vapor such as pump oil, ethyl-silicate, styrene or other suitable monomer. The monomer, when heated with the electron beam, polymerizes to a deposit.

The ethyl-silicate forms a solid silicate. The deposition of the coating 44 takes place in the area of the surface 43 struck by the electron beam. This provides an accurate control of the laying down of the coating 44 and permits the creation of an uncoated area 45.

After the formation of the coating 44 on the upper surface 43 of the body 40, elemental aluminum is positioned in the chamber 24 and subjected to the impingement of the electron beam. This electron beam impingement causes evaporation of the aluminum to a vapor. The aluminum vapor then condenses when it contacts the surface of the semiconductor and covers area 45 to fill the area with a deposit of the electrode material directly on the semiconductor material in an accurate pattern. It is a feature of this invention that, when depositing an electrode of an alloy metal, the evaporation by electron beam avoids any preferential of melting of one of the alloy elements with the result that the entire electrode metal substance is evaporated and transferred to the surface of the body 40.

After deposition of the electrode 46 on the body 40, the protective layer 44 is removed along with excess electrode matter overlying the protected areas of the body 40. The removal of the protective surface is achieved by burning off the covering film and the excess electrodes material under the impingement of the electron beam.

FIGURE 4 illustrates the next step which is a modified repetition of the first step of protective coating deposition. In the second protective coat deposition, the deposited coat is applied to the surface 43 as shown in FIGURE 4. A partly broken away coat 47 is shown applied to the surface 43 so as to cover the top of the body 40. In practice, this coat 47 completely covers the surface 43, except for the electrode 45 and an area 48 reserved for the other electrode. The coat 47 is created in the same manner as the coat 44. As the surface 43 is completely covered, the chamber 24 is evacuated and a source of aluminum metal is evaporated by striking it with the electron beam. An aluminum vapor is created which depositing on the area 48 causes a deposition of a second electrode on the mesa 41. Subsequently, a coating 47 and the excess electrode metal are removed from the mesa 41 and the surface 43 to leave the mesa 41 with two electrodes 46 and 49.

The electrodes 49 and 46 are then microalloyed onto n-type conductivity material of the mesa 41. The microalloyed step is carried out by focusing the electron beam on the respective electrodes to heat the deposited electrode metal and cause it to melt and to alloy into the mesa 41. The transistor is now ready to receive the leads.

The finishing step is illustrated in FIGURE 5. Prior to applying the leads, the upper surface 43 is once again covered with a final protective coat 50 and is laid down on surface 43 by polymerization or other suitable deposition of a solid film on the surface 43. The final protective coat 50 does not cover the electrodes 46 and 49 which remain uncovered and exposed.

Finally, leads 51 are deposited over the coat 50. As shown in FIGURE 5, the leads 51 extend from their respective electrodes and are laid down in lines running from the microalloyed electrodes 46 and 49 over the protective coat 50 laterally to the edge of the upper surface 43. Thus, the transistor is provided with electrodes 46 and 49 and leads 51 leading to the electrodes. The rest of the conventional transistor structure is suitably provided. Further, the transistor is provided with a protective coat 50 remaining on the upper surface 43.

As set forth in my co-pending application mentioned above, the volatilization in the process of this invention can be aided so that the formation of the transistor does not rely on volatilization alone. The material can be made to undergo chemical changes that facilitate volatilization. For example, the chamber 24 may be provided with a gas such as oxygen or a halogen. Under the heat-

ing effect of electron beam impingement, the locally heated material upon which the beam is focused will react with the gas. This reaction leads to conversion to more volatile materials. Thus, the semiconductive bodies susceptible to this process can be acted upon more quickly or more effectively by the use of such gases. A pressure of 1 mm. of chlorine, for example, will speed up the removal of the semiconductive material for a given electron beam intensity and without any appreciable effect on the X-ray variations produced. In forming transistors of silicon, this acceleration is particularly desirable as this material is more refractory than other materials in semiconductive bodies. Where reactive gases such as chlorine or fluorine are used, the apparatus must be accordingly protected in its exposed portions by a covering of suitably resistant materials. Glass or tantalum are suggested as available materials showing resistance to exposure to chlorine or other halogens except fluorine. For protection of the apparatus parts from fluorine, known resistant plastics such as Bakelite or polytetrafluoroethylene are suggested or highly resistant metals such as nickel. The pressure in the chamber 24 may be maintained at any desired level as described by ranging from atmospheric pressure or higher down to a vacuum such as 0.1 micron.

The successive steps of preparation of a semiconductive device by this invention can be controlled by automatic means. Thus, the control can be made subject to automatic operation and a semiconductive body transformed into a completed transistor by successive automatic treatments in one location with a plurality of operations. It will, thus, be seen that one of the advantages obtained by this invention is automation of transistor manufacture. Further, the automatic operation provides means for high speed treatment with the successive steps following each other in rapid succession. The sensitivity of the control possible as a result of this invention enhances this advantage of speed. The progress of the treatment of the semiconductive body is followed by the output of the X-ray treatment. As the apparatus is standardized by adaptation to bodies having specific characteristics, the X-ray measurement readings may be charted to provide the automatic control which is necessary to automation. The invention is particularly effective with bodies of germanium.

The X-ray sensitivity measurement means may be positioned at any point where it can effect an accurate measurement of the treatment of the semiconductive body and the activity which is taking place on the body surface. The platform 16 and the sheet 14 may be arranged to grip the semiconductive body in various ways to adapt it to the treatment and to the X-ray measurement. Further, the carriage of the semiconductive body can have mobility so as to turn the semiconductive body over and carry out the treatment on opposite faces of the body.

Various adaptations of this invention may be had within the spirit thereof. For example, the mask of the protective covering 44 may be made up of a film deposited from a suitably polymerizable vapor which may be subsequently burned off under the electron beam. The film is formed by impinging the electron beam on the semiconductor in the presence of the vapor. While pump oil, ethyl silicate and styrene monomer have been disclosed as providing vapors which are polymerizable to form the desired protective covering, masks may be made up of other materials having the same reaction under the impingement of the electron beam on a semiconductive body.

Another advantage of this invention is the completion of evaporation of the depositing metal which forms the electrodes. When an alloy is used to form the electrodes, the evaporating beam, on striking the metal source, evaporates the entire alloy source; and, thus, there is no selection in the material transferred and condensed as an electrode. These advantages, in addition to the accurate

control referred to above, make the invention particularly useful in the manufacture of semiconductive devices. In view of the adaptability of this invention to various types of construction and the materials, it will be understood that the above-described embodiments have been set forth for the purpose of illustration and that it is intended that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

This application is a continuation-in-part of my U.S. Letters Patent No. 2,883,544 issued April 21, 1959, filed December 19, 1955.

What is claimed is:

1. A process for making a semiconductive device including the steps of projecting a focused beam of electrons against a portion of a semiconductive body in the presence of polymerizable vapor, polymerizing the vapor at the body surface to form a protective layer on the surface of the semiconductive body, projecting the focused beam of electrons against a metal-containing body, volatilizing an electrode metal from said metal-containing body to form a metallic vapor adjacent the surface of the semiconductive body, condensing the volatilized metallic vapor on the body and subsequently removing the protective film and the condensed metal from the surface of the body.

2. A process as claimed in claim 1 for making a semiconductive device including the step of providing an area of said body surface free of said protective layer, condensing the volatilized metallic vapor on said unprotected area, and subsequently removing the protective film and the condensed metal from the area of the body surface covered by the protective layer.

3. A process for forming a semi-conductive body comprising the steps of projecting a focused beam of electrons against a portion of the body to generate X-rays and cause the portion to become heated and to be volatilized away, introducing a polymerizable vapor into the region of the semiconductive body, polymerizing a film of the

vapor on the remaining surface by said volatilization, measuring the intensity of the X-rays that are generated in the same direction that the beam of electrons is projected, and controlling the beam projection by the measured intensity of the X-rays.

4. A process for making a semiconductive device including the steps of projecting a focused beam of electrons against a portion of a semiconductive body in the presence of a corrosive gas, heating the impinged portion of the body and volatilizing the impinged portion of the body to generate X-rays, shifting the position of the semiconductive body to project the focused beam of electrons against a different portion of the body, repeating the volatilization of the impinged portion, shifting the position of the semiconductive body in the focused beam, projecting the focused beam of electrons against a third portion in the presence of polymerizable vapor, polymerizing the vapor at the body surface to form a protective layer on the surface of the semiconductive body, providing an area of said body surface free of said protective layer, projecting the focused beam of electrons against a metal-containing body adjacent the surface of the semiconductive body, volatilizing an electrode metal from said metal-containing body to form a metallic vapor adjacent the surface of the semiconductive body, condensing the volatilized metallic vapor on said unprotected area and subsequently removing the protective film and condensed metal from the area of the body surface covered by the protective layer by moving the body under the focused beam of electrons.

References Cited in the file of this patent

UNITED STATES PATENTS

2,662,957	Eisler	Dec. 15, 1953
2,771,568	Steigerwald	Nov. 20, 1956
2,778,926	Schneider	Jan. 22, 1957
2,860,251	Pakswar et al.	Nov. 11, 1958
2,883,544	Robinson	Apr. 21, 1959

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,080,481

March 5, 1963.

Preston Robinson

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 19, for "electrodes" read -- electrons --;
line 58, after "against" insert -- which --; column 5, line
25, for "electrodes" read -- electrode --; column 8, line
17, after "of" insert -- a --.

Signed and sealed this 1st day of October 1963.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

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Commissioner of Patents

UNITED STATES PATENT OFFICE
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