

April 21, 1959

P. ROBINSON
TRANSISTOR MANUFACTURE
Filed Dec. 19, 1955

2,883,544

FIG. 1

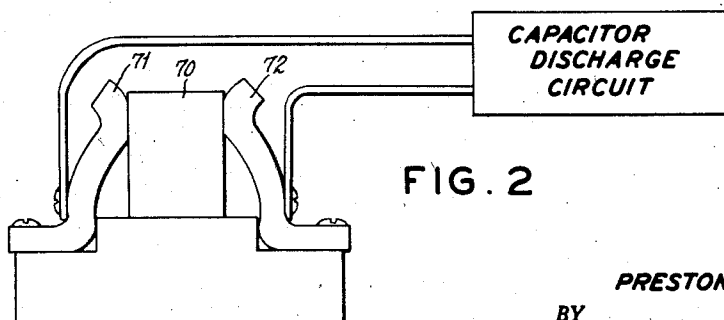
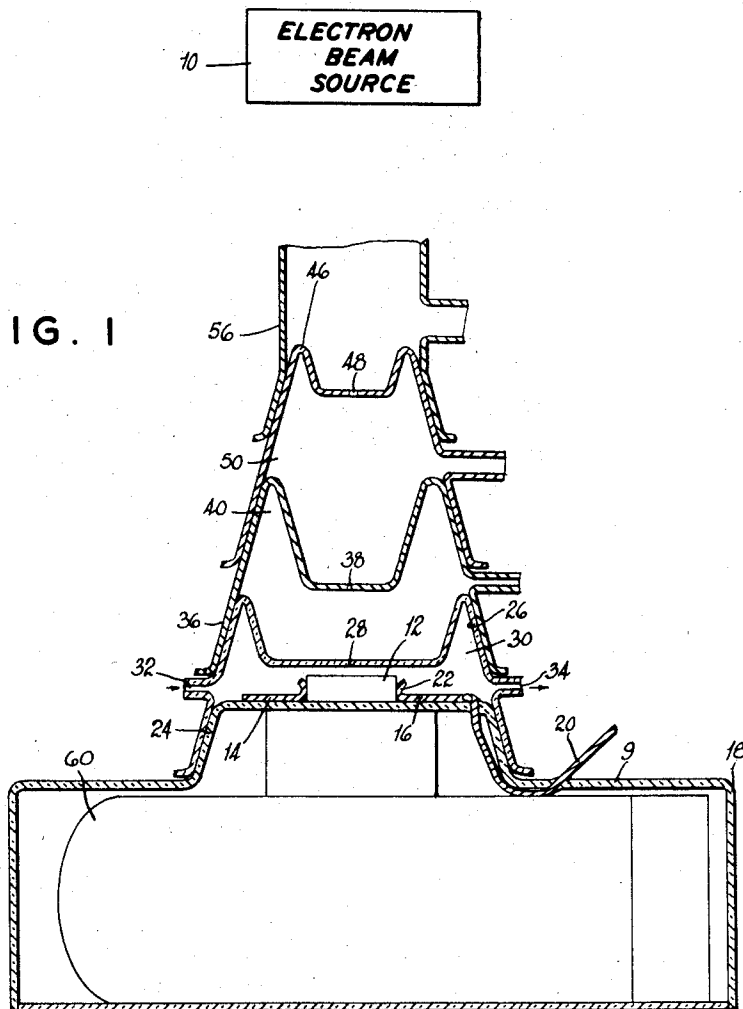


FIG. 2

INVENTOR.
PRESTON ROBINSON
BY
Connolly and Kutz
HIS ATTORNEYS

1

2,883,544

TRANSISTOR MANUFACTURE

Preston Robinson, Williamstown, Mass., assignor to Sprague Electric Company, North Adams, Mass., a corporation of Massachusetts

Application December 19, 1955, Serial No. 553,893

5 Claims. (Cl. 250—49.5)

The present invention relates to the manufacture of transistors, more particularly to techniques for suitably shaping and forming transistor bodies.

Among the objects of the present invention is the provision of new techniques for preparing transistor bodies in a relatively simple manner, as well as novel apparatus therefor.

The above as well as additional objects of the present invention will be more clearly understood from the following description of several of its exemplifications, reference being made to the accompanying drawings wherein:

Fig. 1 is a more or less diagrammatic sectional view of a portion of an apparatus for providing cavities in a transistor body; and

Fig. 2 is a diagrammatic illustration of a different technique for forming a transistor body.

According to the present invention a transistor body can be readily provided with an accurately located cavity by subjecting it to a focussed beam of electrons so as to cause a localized portion of the body to become heated and volatilized away. The depth of the transistor body below the cavity is conveniently indicated by causing the electron beam to generate X-rays and measuring the X-rays that penetrate through this depth.

The transistor body itself can be made and remelted for purification or junction formation by passing through the body a high intensity momentary surge of current such as in a condenser discharge.

Referring now to Fig. 1, there is here shown a cavity-providing apparatus which uses an electron beam generated in any convenient manner, indicated by the block 10. Such a source can be, for example, of the type shown in British Patent No. 714,613, and provides a beam which is focussed so that it converges at the site where the cavity is to be provided. The transistor body is shown at 12 as held in an encircling positioning ring or sheet 14 on a raised mounting platform 16 of a box-like base 18. As shown, the ring 14 can be made of metal with an electrical lead 20 secured to it as by welding or soldering, and extending out through any convenient location for insertion in the electron beam circuit. To improve the electrical contact between the transistor body 12 and the ring 14, the ring can have its inner edge flanged, as indicated at 22 for example, to provide a spring-like contact against which the body is pressed when mounted in position.

In the construction of Fig. 1, the raised platform 16 has side walls 24 that taper outwardly from the top to the bottom of the platform and are in the shape of a cone which is accurately ground to provide an air-tight joint with the correspondingly shaped skirt of a chamber-forming inverted cup 26. To minimize leakage of gas through the joint, it should be lubricated or coated with a sealing material such as the silicone type of joint greases that are conventionally used in chemical apparatus. Cup 26 can be made of glass or metal and has an opening 28 through which the focussed electron beam passes to the

2

transistor body 12. The wall of the cup in which the opening 28 is located can be recessed so that it approaches the upper surface of the transistor body. As pointed out in the above-mentioned British patent, the distance from the opening 28 to the top of the transistor body should be held down to a relatively small dimension, preferably not over a few millimeters, where the chamber 30 formed by cup 26 is not kept under extremely high vacuum. Tubular duct fittings 32, 34 are also shown as sealed to the cup 26 so as to provide passageways for evacuating and/or introducing material into chamber 30.

A second inverted cup 36 can be positioned over cup 26 so as to provide a second chamber 40. Cup 36 can also have a perforation shown at 38 for the passage of the electron beam. The illustrated construction also includes a third cup 46 forming a third chamber 50 and also having a beam-passing aperture 48. Each of the cups can be provided with tubular connectors, as shown.

The joints between the walls of the adjacent cups can be made interchangeable so that some or all of the cups can be removed and the remainder reassembled to provide an air-tight sealed construction. On the uppermost cup the lower end 56 of the electron beam source, or of the container holding the source, can be fitted in a correspondingly jointed manner.

Within the base 18 there is mounted an X-ray measuring apparatus such as a scintillometer diagrammatically indicated at 60. For optimum X-ray sensitivity, the scintillometer or other measuring instrument that is used, has its sensitive surface brought as closely as possible to the transistor body 12 as by being positioned directly against the lower surface of raised platform 16. It is also advantageous to make platform 16 of material that does not absorb X-rays very readily. Ordinary soda lime, thermally resistant borosilicate glasses or low alkali silica, or even the phosphate glasses are suitable for this purpose. Metals can also be used, preferably of the low atomic number type, such as aluminum, magnesium, titanium, iron or the like. Plastics such as the phenol-formaldehyde or similar hard types, or even polyethylene, can be used. The cups can also be made of any of the above materials.

The apparatus of Fig. 1 is used in the manner indicated in the above-identified British patent, the transistor body being mounted in place and the assembled apparatus subjected to a pressure low enough for the electron beam to be projected without undue loss of efficiency. For this evacuation one or more suction pumps can be connected to the various cup outlet duct connectors. The electron beam can then be switched on, preferably with the focusing previously adjusted to give the desired beam impingement. Where ring 14 is used as a connector, it can be connected as a suitable second or final anode and can be maintained at ground potential if desired. The electron beam source is preferably operated at a potential of at least 15,000 or 20,000 volts with respect to the accelerating anodes since higher voltages are more effective in causing the electron beam to generate X-rays on striking the transistor body.

At a potential of 50,000 volts the electron beam current of a few milliamperes will be sufficient to cause a germanium transistor body to rapidly develop a cavity by evaporation of the germanium at the impingement site. This cavity can have an exceedingly narrow width, of the order of $\frac{1}{10}$ of a millimeter or somewhat larger. The progress of the cavity formation as it penetrates into the transistor body is readily followed by the output of the X-ray measurement. Where essentially the same type of transistor body is used with a uniform electron beam, the apparatus can be standardized by trial runs in which the X-ray measurement readings are charted against the

depth of the transistor body beneath the bottom of the cavity.

Silicon-type transistor bodies can also be provided with cavities the same way. It is preferred, however, to use a more intense beam current with silicon inasmuch as the X-ray generation is not as efficient as with germanium, and silicon furthermore has a higher volatilization temperature.

Instead of relying on volatilization caused by direct evaporation of the transistor material, the material can also be made to undergo chemical changes that facilitate volatilization. By way of example, chamber 30 can be arranged to hold a gas such as oxygen or a halogen so that the heating effect of the electron beam impingement will cause the locally heated material to react with the gas and be converted to more volatile materials. A pressure of 1 millimeter of chlorine, for example, in this chamber will speed up the penetration of the cavity without any appreciable effect on the X-ray variations. Such acceleration is particularly desirable with the more refractory materials such as silicon. Where reactive gases such as chlorine or fluorine are used, it is advisable to have all parts of the apparatus, exposed to such gases, of suitably resistant materials. Glass or tantalum make good materials for exposure to chlorine or any of the halogens except fluorine. Plastics like Bakelite or polytetrafluoroethylene or resistant metals such as nickel, can be used with fluorine.

The pressure maintained in the chamber 30 can be kept at any desired level, from atmospheric pressure or higher down to extremely high vacuums such as 0.1 micron. For superatmospheric pressure, arrangement should be provided to make sure the high pressure does not blow the cup 26 away from the platform. The weight of the upper portion of the apparatus might be sufficient for this purpose, but clamps holding down the side wall of the cup can also be used. As shown in the above-identified British patent, the desired gas can be supplied from one of the duct connectors such as 32, preferably through a needle-type valve which can be adjustable, if desired. At the same time as the gas is admitted, evacuation can be applied through the other duct, although this is not necessary where the pressure in the chamber 30 is maintained at or above atmospheric.

Cups 36 and 46 are used principally to keep any gases generated or present in chamber 30 from reaching the electron beam source too freely. For this purpose apertures 28, 38 and 48 are kept as small as practicable, with evacuation applied to chambers 40 and 50 as well as to the electron beam-supplying portion of the apparatus 56. The lower the pressure in chamber 30 the fewer additional cups 36 or 46 are needed. However, where very reactive gases such as fluorine are present in chamber 30, it is desirable to use at least one additional cup even when the pressure in chamber 30 is low.

In order to make the electron beam source more adaptable under conditions where it can be exposed to corrosive gases, the electron-emitting portion which usually contains a hot cathode, should have the cathode made of a more resistant metal such as platinum. If desired, the heating of the hot cathode can also be shielded from the corrosive influences as by using an induction heater mounted externally of the beam source so that it is not exposed to the same atmosphere. Alternatively, where the usual type of electric resistance heater is mounted within the cathode, this heater can be made readily replaceable, either by itself or with the cathode.

A cold cathode, that is one not dependent upon a separate source of heat, can also be used to generate the desired electrons.

The electron beam can be focussed as by the arrangement shown in the above-identified British patent, or any other suitable magnetic or electrostatic focussing device. For example, permanent types of focussing arrangements can be used and the permanent magnet ar-

range can be of the so-called "periodic" type as described in the Mendel et al. article in the Proceedings of the Institute of Radio Engineers, volume 42, pages 800-810, May 1954. The cups 26, 36 and 46 can also be used to assist in focussing as well as in accelerating the beam, where these cups include electrically conductive portions. These portions can then be connected in the focussing and/or accelerating circuit.

Cavities in transistor bodies are of considerable value in providing surface portions that are very close together. For use at high frequencies, for example, it is desirable to have junctions or electrodes no further apart than 1 or 2 mils. By using a cavity-providing technique as described above, it is possible to prepare semiconductor bodies thick enough to be easily handled, yet with a cavity having a depth such that the distance from the bottom of the cavity to the opposite surface has the desired small thickness. Alternatively, the semiconductor body can initially have a PN junction, as described in U.S. Patent No. 2,631,356, for example, and the cavity penetration can be controlled to where it approaches the barrier by a predetermined short distance, such as 1 or 2 mils.

After the cavity is formed, it is usually desirable to insert an electrode so that it contacts the semiconductor body at the bottom of the cavity. Where the cavity is relatively narrow, the electrode can be inserted in the form of a fine wire which can be welded in place by the passage of a suitable electric current. If the welding causes the lower end of the wire to melt into the cavity away from the outer portions, an external wire can then merely be soldered to the molten part of the electrode after it has solidified. On the other hand, a fresh electrode can be inserted and welded to the previously melted electrode portion. The connection of the electrodes is sometimes more rapidly effected when the cavity is made relatively wide, e.g. up to about 10 mils or more in transverse dimension. A cavity of such width is made by shifting the electron beam or by moving the semiconductor target body slightly in the target zone and causing the electron beam to cover the desired area. It can also be made by adjusting the electron beam so it is not as sharply focussed and covers the desired area without requiring the target shifting.

Where the transistor body has no junction or only one junction, the electrode should include a doping ingredient such as gallium or arsenic so as to change the type of electrical conductivity of the transistor body portion adjacent the cavity. Two cavities can also be provided in the same or adjacent or opposite surfaces of the transistor body, each carrying an electrode with appropriate types of doping ingredients. For more complex types of transistors where more than three electrodes are involved, a suitable arrangement of the cavities and electrodes can be made.

Fig. 2 shows another aspect of the present invention by which a semiconductor body can be remelted, as for example to purify it or to form a junction in it. For this purpose the body which is shown at 70 is connected in a capacitor discharge circuit as by means of friction contacts 71 and 72. These contacts should be made of a material which is inert to the semiconductor when the semiconductor is molten. Platinum is a suitable material for germanium, and carbon electrodes with silicon. The electrodes should be pressed against the semiconductor body to establish a firm contact. When a capacitor of a thousand microfarads is discharged through the discharge circuit, the semiconductor body melts very rapidly. Inasmuch as the body might have a resistance of up to 100 ohms or even more, the charging voltage of the capacitance should be high enough to pass an appreciable surge current. A 500 voltage charging potential is suitable with a 5 gram body presenting 100 ohms resistance.

The semiconductor can either be completely melted by

the discharge surge, or the discharge can be adjusted so that only a selected portion of the body, such as its upper part, is melted. By placing the contacts 71, 72 against the desired portion, as illustrated in Fig. 2 for example, the upper part of the body can be melted and the molten material will remain supported by the lower portion of the body where the entire mass of semiconductor is relatively small, such as 2 to 10 grams or less. With such an arrangement it is desirable to make sure that the contacts are not permitted to move together close enough to cause the molten portion to be squeezed out of place. The entire melting operation only takes a fraction of a second, and the resulting melt resolidifies a few seconds later.

This technique can be used to prepare a junction by starting with a germanium crystal, for example, which has a high concentration of N-type or donor-type impurity such as arsenic along with a lower concentration of P-type impurity as gallium. Inasmuch as an impurity such as arsenic shows a much lower segregation upon freezing of the molten material than gallium, gallium will be deposited in large amounts as the solidification commences, forming a discrete P-layer with a sharp boundary against the unmelted N-type body. As the solidification continues, the conductivity of the depositing solid will change from P to N, not as an abrupt but rather gradual transition. To prepare a single junction crystal the diffused junction portion can be removed by cutting away of the surface until the P-region is reached. For an N-P-N crystal of abrupt junctions, the initial solidification is followed by further doping of the remainder of the melt with an N-impurity as arsenic or antimony.

Two separate junctions can also be provided in a single semiconductive body by carrying out a remelting operation at two different portions.

A single capacitor-discharge circuit can be used to melt a multiplicity of bodies connected in parallel or series. The current surge of the capacitor discharge is so rapid that the electrical connection between the body and its contacts will carry all the fusing current needed before the fusion actually takes place and surface tension effects cause the molten material to withdraw from the contacts, thereby breaking the discharge circuit.

The melting and solidification technique of Fig. 2 can advantageously be combined with the electron beam process. After resolidification of a melted semiconductor body portion, the final solidification zone containing the diffused junction can be removed by volatilization through electron beam impingement. For such removal the electron beam or target body can be shifted to cause the volatilization to take place over the desired area.

Advantages can also be obtained by combining the capacitor-discharge assembly of Fig. 2 with the electron beam system of Fig. 1, as by using separate contacts to hold the body 12 in the target zone. The melting and resolidification can then be carried out and promptly followed by electron beam treatment to remove the undesired semiconductor portion. Furthermore, after the undesired zone is removed, a cavity can then be provided in the upper portion of the remaining semiconductor body, as described above. All of these operations can be carried out without moving the semiconductor body except for the slight shifting needed to make sure the beam impingement will cause the desired zone removal. A simple form of adjustable carriage mechanism, as shown in the above-identified British patent, is suitable for such shifting.

For use in conjunction with X-ray intensity measurements, the carriage can be arranged to grip the semiconductor support 16 from only one side of the beam-projection site, so that no unnecessary material is interposed in the X-ray measurement path. Alternatively, the carriage

can have the X-ray measuring apparatus built in directly underneath a support for the semiconductor body. This assembly can then be moved as a unit. The carriage can also be arranged to turn the semiconductor body over, as for example when melting and resolidification, and/or cavity drilling, are to be carried out on opposite faces of the body.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed:

1. A process for making cavities in a semiconductor body, the steps of projecting a focussed beam of electrons against a portion of the body to generate X-rays and cause the portion to become heated and be volatilized away, measuring the intensity of the X-rays that are generated in the same direction that the beam of electrons is projected, and terminating the beam projection when the measured intensity shows a predetermined thickness of the semiconductor.

2. A cavity-producing apparatus having an electron beam-producing structure for projecting an X-ray generating focussed electron beam at a target zone, support structure for holding in the target zone a body in which a cavity is desired, and X-ray intensity measuring elements just beyond the target zone connected to measure the intensity of the X-rays generated by the beam at the bottom of the cavity it creates in the target body.

3. The combination of claim 2 in which the support structure includes a pair of electrical contacts connected in a capacitor discharge circuit.

4. A process for treating a semiconductor body comprising the steps of connecting the body in a capacitor discharge circuit by contacts that are positioned to heat only the upper portion of the body, discharging a charged capacitor through the circuit to pass a current sufficient to melt the upper part of the body, permitting the body to resolidify, projecting a focused beam of electrons against a portion of the upper part of the body in such a manner as to generate X-rays and to cause the portion to be volatilized, measuring the intensity of the X-rays that are generated in the same direction as the projection of electrons, and terminating the projection when the measured X-ray intensity shows a predetermined thickness of semiconductor.

5. A process for treating a semiconductor body comprising the steps of connecting the body in a capacitor discharge circuit by contacts that are positioned to heat only the upper portion of the body, discharging a charged capacitor through the circuit to pass a current sufficient to melt the upper part of the body, permitting the body to resolidify, projecting an electron beam against the upper part of the body in such a manner as to volatilize the surface of the body, projecting a focused beam of electrons against a portion of the upper part of the body in such a manner as to generate X-rays and to cause the portion to be volatilized, measuring the intensity of the X-rays that are generated in the same direction as the projection of electrons, and terminating the projection when the measured X-ray intensity shows a predetermined thickness of semiconductor.

References Cited in the file of this patent

UNITED STATES PATENTS

1,180,047	Kobert	Apr. 18, 1916
2,145,724	Horsley	Jan. 31, 1939
2,503,075	Smith	Apr. 4, 1950

FOREIGN PATENTS

714,613	Great Britain	Sept. 1, 1954
---------	---------------	---------------

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,883,544

April 21, 1959

Preston Robinson

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

Column 3, line 22, after "such" insert -- as --; line 74, after "permanent" insert -- magnetic --; column 4, line 72, for "voltage" read -- volt --.

Signed and sealed this 8th day of September 1959.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,883,544

April 21, 1959

Preston Robinson

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

Column 3, line 22, after "such" insert -- as --; line 74, after "permanent" insert -- magnetic --; column 4, line 72, for "voltage" read -- volt --.

Signed and sealed this 8th day of September 1959.

(SEAL)

Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON
Commissioner of Patents