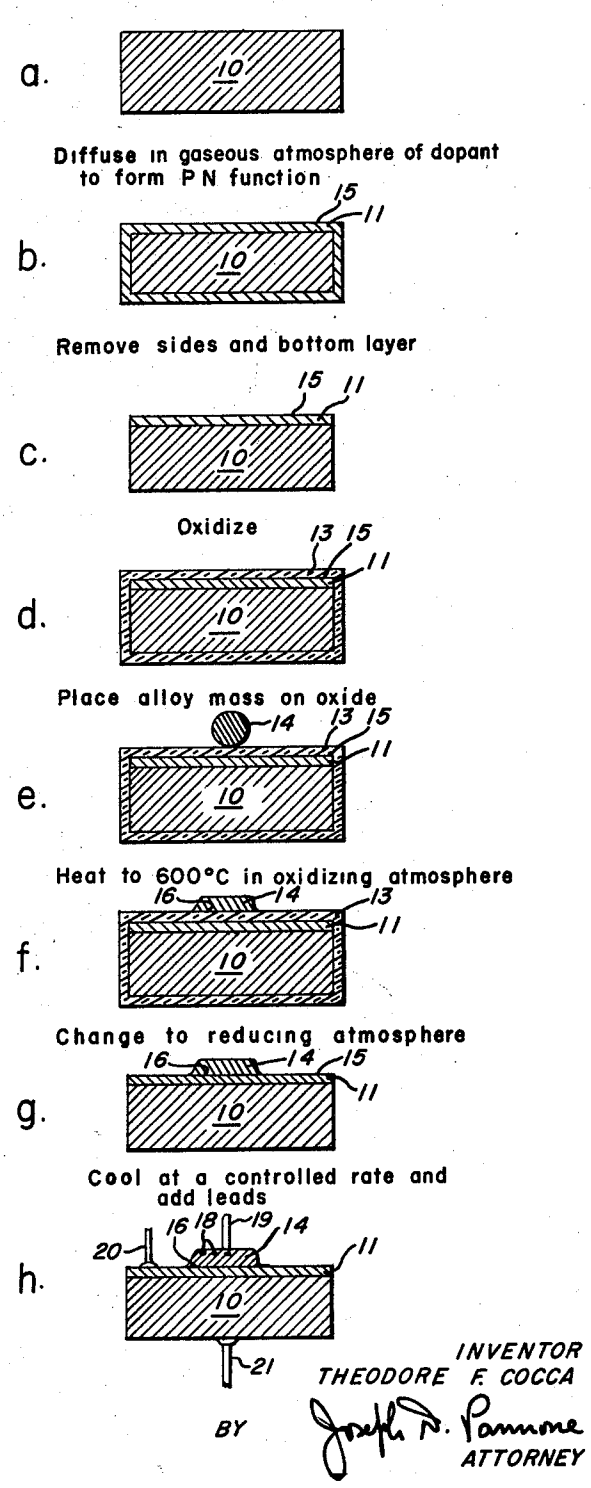
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METHOD OF FUSING MATERIAL AND THE LIKE

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FIG. 1



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FIG. 2

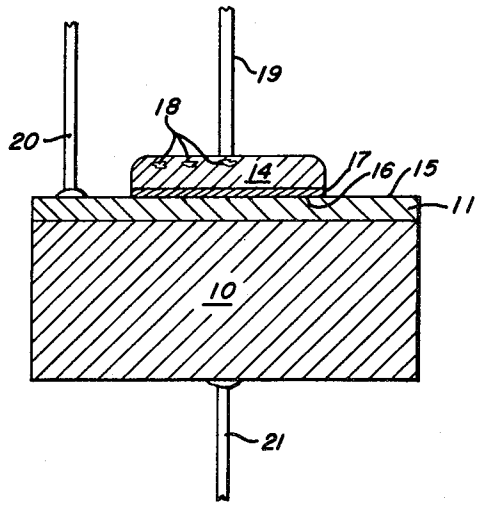
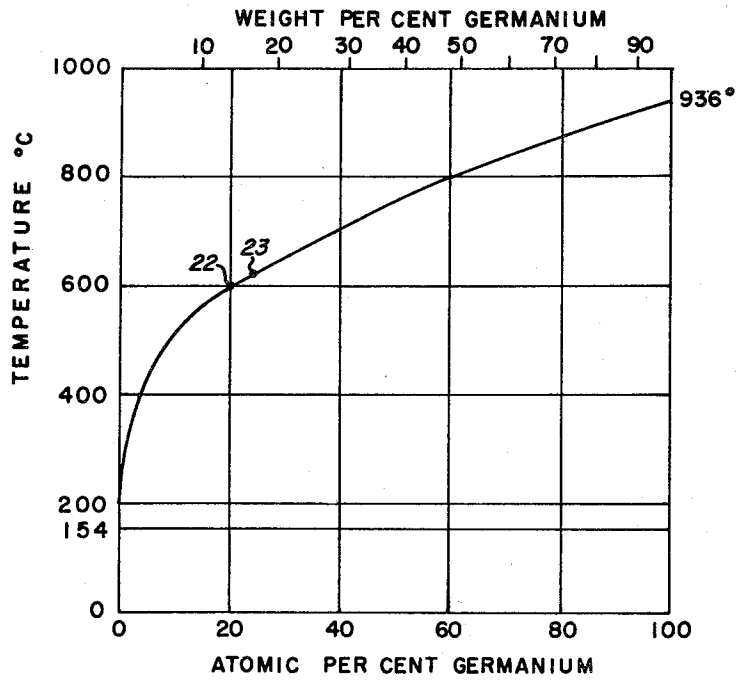


FIG. 3



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METHOD OF FUSING MATERIAL AND THE LIKE

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This invention relates generally to coatings, and more particularly to a novel method of separating a plurality of materials until it is desired that they be brought into contact.

In a number of processes it is desirable that two or more reactive materials be separated until certain predetermined conditions are met at which time the reactive materials are brought into contact and fused together. This method is particularly useful in the production of semiconductive devices.

A particular embodiment of the invention comprises an alloy element or mass comprising semiconductive material dissolved in a metal which is a solvent for, and capable of doping said semiconductive material said mass being placed on a body of corresponding semiconductive material which has been treated to produce an oxide coating thereon. The alloy mass could also be composed of a solvent material, one or more doping materials, and the semiconductive material. The assembly of alloy mass and the coated semiconductive body is then heated by suitable means to a desired preassigned temperature in an oxidizing atmosphere. When the desired temperature is reached, the atmosphere is changed to a reducing one which removes the oxide coating from the semiconductive body and allows the alloy mass to come directly in contact with the semiconductive body and fuse thereon. The entire assembly is then treated as to reduce its temperature while still maintaining the reducing atmosphere and a P-N junction is thus formed at the interface of the alloy element and the semiconductive body. This P-N junction could function, for example, as an emitter junction in a completed transistor device.

The above described alloy mass is composed of a metal which is solvent for the semiconductive material and which may also be a dopant for said material. Such an alloy mass can be, for example, indium supersaturated at an assigned firing temperature with the basic semiconductive material of the body for example, germanium. The amount of semiconductive material contained in the alloy element should preferably be greater than that which would be dissolved at the preassigned firing temperature so that an excess of undissolved semiconductive material remains in the alloy element after alloying to the material. The assembly is then heated to liquify the alloy mass. Upon liquification, there is dissolved in the alloy mass almost completely the semiconductive material contained therein; but, because of the oxide coating or layer between the alloy mass and the semiconductive body, no wetting of the surface of the semiconductive body occurs. Since it has been found that oxide coatings on some semiconductive bodies act as selective masks against diffusion into the semiconductive body of only some donor and some acceptor impurities but allow other impurity elements to pass therethrough, it is thus important that the doping materials used be so selected as to be masked by the oxide layer. It has been found that in the case of indium, the oxide layer acts as a complete mask. If the oxide coating was not present on the surface of the body during the heating process, then the alloy mass would not only penetrate into the semiconductive base material but also would not result in the formation of a planar junction. After the alloy element has liquified and dissolved completely the semiconductive material contained therein, the atmosphere is changed to a reducing one which removes the oxide layer

and allows the alloy mass to come directly in contact with the semiconductive chip and fuse thereon. It is to be understood that the term fuse is used herein to mean a tight adherence of one mass to another. That is, the semiconductive material dissolved in the alloy mass deposits out on the surface of the body and utilizes that surface as a seed for crystal growth, forming a continuous single crystal extending into the regrown region contained within the alloy mass without any distinguishable crystal boundary. This occurs when the alloy element is supersaturated with semiconductive material at the preassigned alloying temperature. Thus no penetration by the alloy mass into the semiconductive body occurs; but, rather, the semiconductive material dissolved in the alloy mass deposits out on the surface of the semiconductive body to form a regrown region on the surface. Since there is an excess of semiconductive material in the alloy mass it remains saturated with semiconductive material and no penetration of the chip can occur. As the entire assembly is reduced in temperature, while maintaining the reducing atmosphere, the regrown region continues to grow forming a P-N junction at the interface of the alloy element in the semiconductive body. Thus, during cooling, there is formed at the surface of the body a zone or regrown region which exhibits electrical characteristics determined by the type of conduction carrier centers of the solvent metal or dopant employed in the alloy mass.

The above described process may also be used to form planar P-N alloy junctions whose penetration into the semiconductive body is controlled with a high degree of precision. It has been found that the type and degree of penetration of an alloy junction in a semiconductive body depends upon the degree of saturation of the alloy mass with semiconductive material of the same type as that of the body and upon the temperature of the alloy mass and the semiconductive body at the time they are brought into contact. If an alloy mass is not saturated with semiconductive material, then at the time that it comes into contact with a semiconductive body penetration will take place and the amount of penetration will depend upon the amount of semiconductive material that can be dissolved in the alloy mass. The temperature of the alloy mass and semiconductive body at the time they are placed in contact determines whether or not the junction formed is a planar one. It has been found that if the alloy mass and the semiconductive body are placed in contact before heated to the temperature at which the alloy liquifies then a non-planar junction is formed in the semiconductive body. However if the oxide coating described above is placed between the alloy mass and the semiconductive body during or before the heating process and removed only after the alloy mass becomes liquid, then when the alloy mass contacts the surface of the semiconductive body, a precisely controlled planar penetrating junction will be formed in the semiconductive body.

The features of the invention, together with further objects and advantages thereof, will be more clearly and fully understood as the following description proceeds, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatical representation of a flow sheet depicting the fabrication of a diffused alloy semiconductive device.

FIG. 2 is an enlarged section elevation of a diffused alloy transistor, formed in accordance with this invention.

FIG. 3 is a temperature solubility curve for germanium and indium.

Referring now to the drawings, and more particularly to FIG. 1 thereof, there is shown in FIG. 1–*a* a semicon-

ductive chip comprising a body of semiconductive material **10** preferably composed of P-type germanium or silicon. However, the principles of the present invention are not limited to the use of germanium or silicon, but are intended to include any material of the class known as semiconductives, which may have their electrical conductivity characteristics altered by the inclusion of a conductivity type determining impurity element therein. In addition to germanium and silicon, other semiconductives include silicon carbide, and the so-called intermetallic compounds formed from the metallic elements of groups III and V of the periodic table according to Mendelyeev. For example, these may include indium antimode, indium phosphide, indium arsenide, gallium antimode, etc.

It will be noted that since the above-mentioned intermetallic compounds are composed of materials which separately are considered as impurity elements when introduced into materials selected from group IV of the periodic table. The intermetallic compounds therefrom may be N-type or P-type, depending upon their degree of unbalance in the atomic proportion of the material constituting the body.

As an example, a P–N junction may then be formed in a P-type germanium body **10** by any diffusion process well known in the art. Accordingly, the body **10** is, in FIG. 1–*b*, shown as having a diffused N-type region **11** which may, for example, be at a depth of .0001" from the top surface **15** of the chip. This region **11** constitutes the base region of the completed device of FIG. 1–*h*, while the adjacent region of P-type material constitutes the collector. After diffusion, as shown in FIG. 1–*c*, the sides and bottom layer of N-type material are removed by any convenient method such as lapping. The body **10** is then placed in a solution of 15% hydrogen peroxide (H_2O_2) for approximately 30 seconds to result in an oxide layer on the surface of the body **10** as shown in FIG. 1–*d*. Other means of oxidizing the surface may also be utilized. It has been found that an oxide layer approximately 2000 angstroms thick appears to be suitable for the impurity dopant used in this example. The body is then removed from the solution and dried by any convenient heat source for approximately 15 minutes. Following this oxidation, an alloy mass **14**, which is supersaturated as regards the preassigned firing temperature with semiconductive material corresponding to the material of the chip, is placed on the oxide layer **13**, as shown in FIG. 1–*e*, and the entire assembly heated in an atmosphere of oxygen to the preassigned firing temperature of 600° C. The alloy mass **14** is composed of a composition of 75 atomic percent indium and 25 atomic percent germanium, and the indium as may be seen in FIG. 3, is saturated for a temperature of 610° C. but supersaturated for a temperature of 600° C.

In general, the preassigned firing temperature should, preferably, be such that the alloy element **14** liquifies but should preferably be below that temperature at which the alloy element **14** was prepared and below which any additional semiconductive material can be dissolved in the alloyed element.

The alloy element **14**, when placed upon the oxide layer **13** and heated to 600° C., melts. This temperature should preferably be maintained for approximately 15 to 30 minutes, after which the atmosphere is changed to a reducing atmosphere of hydrogen to remove the oxide layer **13** so that the alloy mass **14** contacts and wets the surface **15** of the semiconductive body **10** without dissolving any other material from the body **10**. This occurs because the alloy element **14** has dissolved within itself all of the germanium which it can hold at the temperature to which it is heated and is incapable of dissolving any germanium from the surface of the body **10** when placed in contact therewith as ordinarily happens in the prior art fusion alloy processes. The semiconductive material contained in the alloy mass **14** begins to deposit out on the surface of the body **10** to form the regrown region **17** but the alloy mass **14** continues to be saturated since it then dissolves the previously undissolved semiconductive body **10**, but will contain atoms of the solvent material which dopes the regrown region **17** so that the conductivity of the regrowth region **17** is opposite to that of the region **11** and a P–N junction **16** is formed. As the body **10** is treated to reduce its surface temperature, this regrowth region **17** continues to form and a nonpenetrating planar rectifying junction **16** is formed at the interface **15** of the alloy element **14** and the germanium body **10**. The surface temperature of the body **10** is preferably cooled at a rate of 100° C. per hour until the surface temperature falls below 350° C. It has been determined that if the assembly is cooled too rapidly, then a non-planar junction will be formed and some penetration of the semiconductive body **10** can occur. Leads **19**, **20**, and **21** are then attached to the body by means well known to the art. The completed PNP transistor may then be encapsulated in any manner well known to the art. This completes the description of a specific example of a method of practicing this invention.

The preassigned firing temperatures described above should preferably be such that the alloy element **14** liquifies but should preferably be below that temperature which the alloy element **14** was prepared, and below which any additional semi-conductive material can be dissolved in the alloy element. It is desirable that the alloy mass **14** be supersaturated with semiconductive material for the temperature at which the heating or firing takes place. When the alloy mass **14** is thus supersaturated with semiconductive material, there will be still undissolved semiconductive material contained within alloy mass **14** when it liquifies.

The junction **16** is formed in the lower portion of the regrown region **17** and in line with the top surface **15** of the body **10** due to the fact that no penetration into the body **10** takes place. The alloy mass **14** is, as described above, composed of an impurity material which will impart the desired electrical conductivity type to the regrown region adjacent the material of the body and contains a controlled amount of semiconductive material which is the same as that composing the body.

Consequently, the regrown region **17** comprises the germanium which was originally contained in the alloy mass **14** and is doped with indium as to make it P-type, and no penetration into the surface **15** of the chip takes place. In this way, the danger of punching through the diffused region **11**, by attempting to alloy an impurity material onto the surface **15** of the body **10**, wherein during such alloying process, a portion of the surface of **15** of the body **10** being dissolved into a liquid state by the impurity material is avoided.

FIG. 2 shows the transistor formed by this method. The body **10** has a diffused layer **11** situated therein with a P–N junction **16** formed by the alloy mass **14** coming in contact with the surface **15** of the body **10**. As shown in FIG. 2, small particles of germanium **18** still remain in the frozen alloy dot **14**, after it has cooled to the point of becoming a solvent. Thereafter, an emitter lead **19**, a base lead **20**, and a collector lead **21**, may be attached to the device as shown by means well known in the art. Following the attachment of the above leads, the unit may be encapsulated in a standard transistor case and a completed PNP transistor of the diffused alloy type is formed.

FIG. 3 is a temperature solubility curve for the alloy element **14**. For various desired firing temperatures, the composition of the alloy element **14** may be varied in accordance with this chart to assure the alloy element **14** is always supersaturated with semiconductive material. For example, if as above, it is desired that the firing temperature be at 600° C. (point **22** in FIG. 3) then a supersaturated solution of indium could contain approximately 25% germanium per atomic number or 13% by weight as designated by point **23** on the curve in FIG. 3. Therefore, for any selected firing temperature, it is necessary

that the alloy mass be one which is supersaturated at a temperature higher than that of the firing temperature, so that the alloy mass will always be supersaturated with semiconductive material in the furnace at the oxide surface of the presassigned firing temperature. For other combinations of elements, other solubility charts would of course be utilized.

It can thus be seen that an improved method of making semiconductive devices has been provided, in which nonpenetrating alloy mass may be used to form regrown regions with no penetration into the semiconductive chip itself, thereby enabling the production of devices having extremely narrow base regions.

It is to be understood that the above described arrangements and techniques are but illustrative of the application of the principles of the invention. Numerous other arrangements and procedures may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. The method of producing a P–N junction on a germanium semiconductive body which comprises the steps of oxidizing a germanium semiconductive body, placing a mass composed of 25 atomic percent germanium and 75 atomic percent indium on said oxidized body, heating to 600° C. in an oxidizing atmosphere, maintaining said temperature for at least 15 minutes, changing said atmosphere to a reducing one, maintaining said reducing atmosphere at a predetermined time and temperature to remove the oxide on said body and lowering the semiconductive surface temperature below 350° C. at a rate of 100° C. per hour, to form a substantially planar nonpenetrating P–N junction on said germanium semiconductor body.

2. The method of making a semiconductor device comprising the steps of coating a surface of a semiconductor body with an oxide, depositing on the coated surface of said body an alloy mass comprising a supersaturating quantity of semiconductor material of the same type as said body in a metal which is a solvent therefor and which has a melting point lower than the melting point of said body, heating said body and said alloy mass in oxidizing atmosphere to a temperature above the melting point of said mass but below the melting point of said body, changing said oxidizing atmosphere to a reducing atmosphere to remove said oxide coating, and reducing the temperature of the body and mass to form on the surface of the body a regrown region having a nonpenetrating P–N junction at the interface between said mass and said body.

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