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3,279,964

METHOD FOR CONTINUOUS GAS DIFFUSION

Original Filed July 31, 1961

4 Sheets-Sheet 1

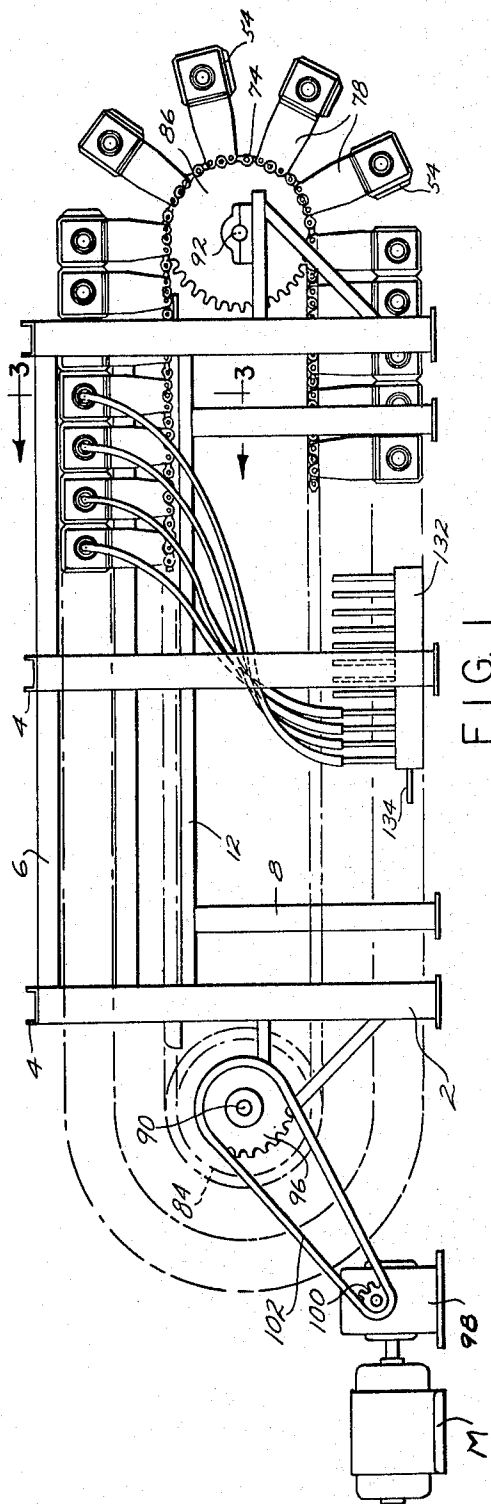


FIG. 1

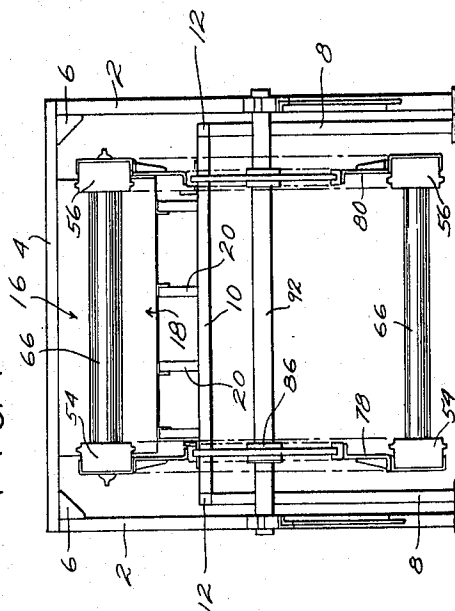


FIG. 2

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4 Sheets-Sheet 2

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4 Sheets-Sheet 3

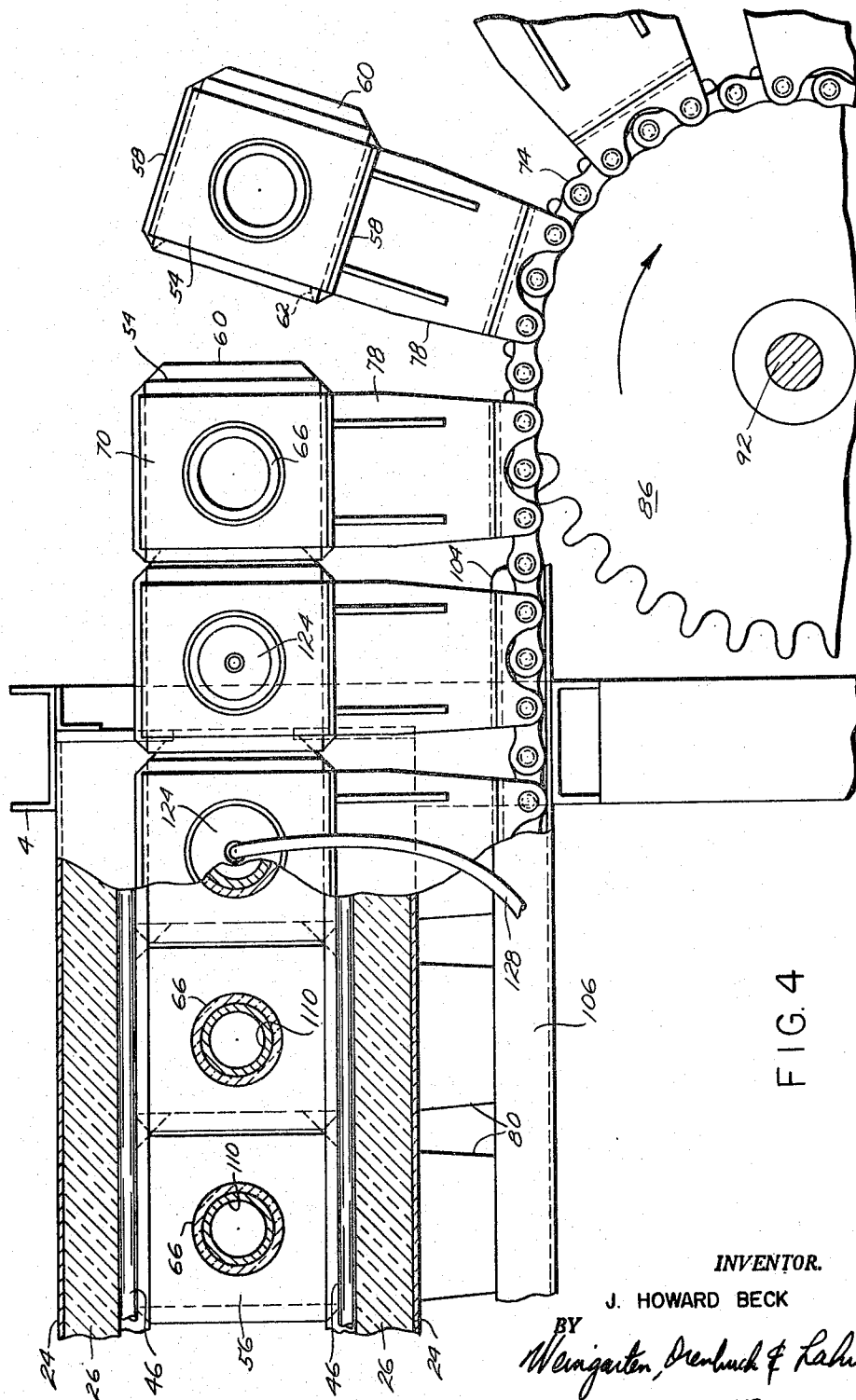


FIG. 4

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4 Sheets-Sheet 4

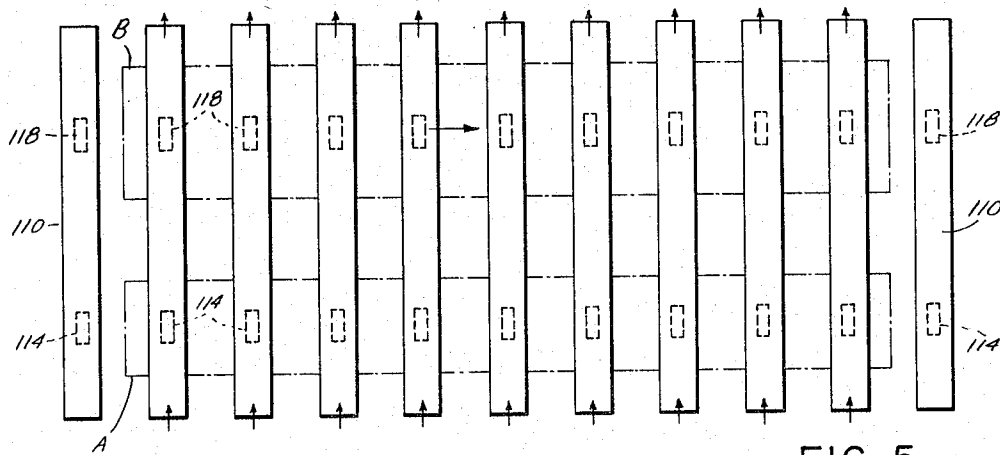


FIG. 5

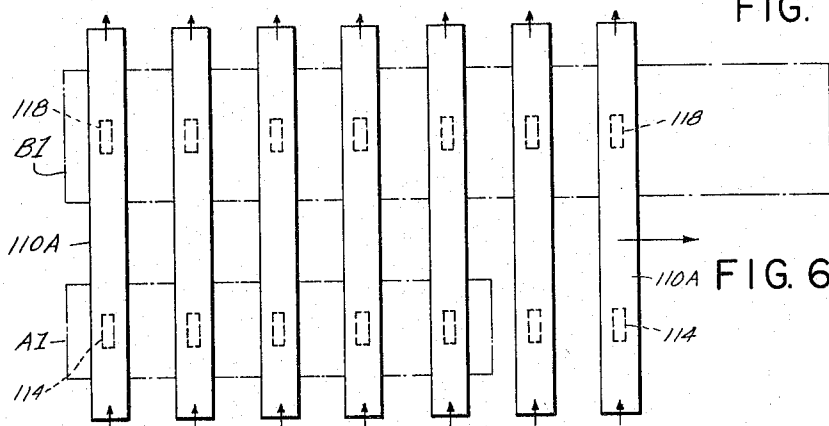


FIG. 6

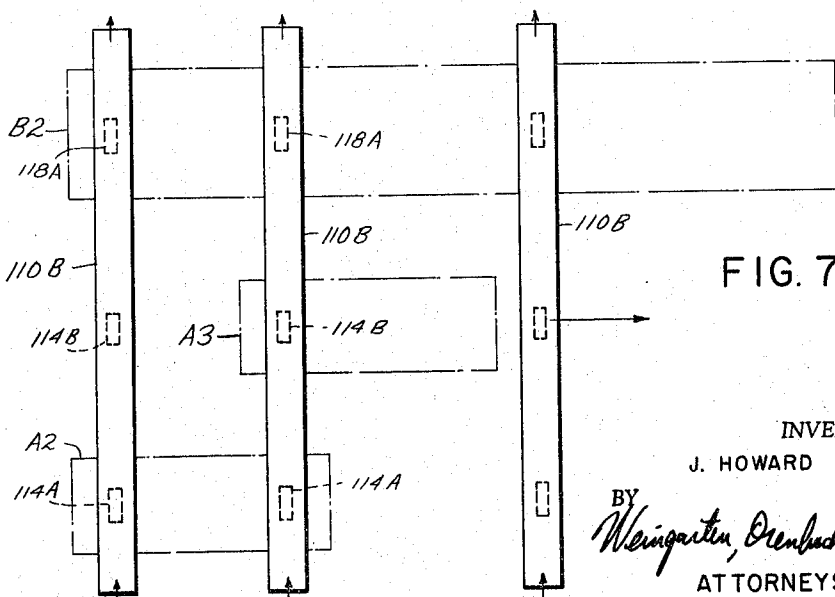


FIG. 7

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3,279,964

METHOD FOR CONTINUOUS GAS DIFFUSION

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Continuation of application Ser. No. 247,707, Dec. 27, 1962, which is a division of application Ser. No. 127,932, July 31, 1961, now Patent No. 3,193,267. This application June 3, 1965, Ser. No. 461,127

6 Claims. (Cl. 148—189)

This application is a continuation of my copending patent application, Serial No. 247,707, filed December 27, 1962, now abandoned, entitled Method for Continuous Gas Diffusion, which in turn is a division of my copending application, Serial No. 127,932, filed July 31, 1961 now Patent No. 3,193,267, entitled Apparatus for Continuous Gas Diffusion.

This invention relates to gas diffusion and more particularly to a gas diffusion furnace and process for use by the semiconductor industry.

One of the chief methods of making semiconductors is by gaseous diffusion of impurities. In this type of construction, a crystal of semiconductor material such as silicon and a source, i.e., a mass of impurity such as antimony, are sealed together in a quartz tube and the complete assembly heated in a furnace to a very high temperature in the order of about 1200° C. At this temperature, the impurity is in the form of a gas which diffuses into the surface of the crystal, thereby forming P- or N-type layers. The reaction time is usually in the range of 16 to 36 hours. An advantage of this technique is the ability to form very large, flat junctions, i.e., diffused layers, of controlled thicknesses. However, heretofore it has not been feasible to execute this technique on a continuous basis because of the inability to achieve strict diffusion control, a prerequisite to obtaining diffused layers of precise thicknesses. Basically, the extent of diffusion depends on three factors: (1) the concentration of impurity, (2) heating time, and (3) temperature. The first two variables are easily controlled, but temperature presents a problem. Not only does the rate of diffusion vary with temperature, but in addition, the rate of change is not linear but a complex exponential function. Hence a flat temperature profile is required. Because of this temperature problem and also because of the belief that it is difficult to maintain the atmosphere free of undesired contaminants, continuous furnaces have been considered unfeasible for gaseous diffusion and batch furnaces have been used instead. Some consideration has been given to making a continuous diffusion furnace wherein the quartz tube containing the semiconductor crystal and the source is moved along its own longitudinal axis through the furnace. However, this approach is not feasible. Proper diffusion requires that the concentration of the gaseous impurity be maintained at a predetermined value. This is achieved by precisely controlling the temperature to which the source is heated. If the temperature varies, the concentration of the gaseous impurity will go up or down and, therefore, the final product will be affected. An attempt to move the quartz tube axially through any sort of continuous furnace at one point or another will cause a change in the temperature of the source and crystal. Thus, for example, when the tube is entering the furnace, some vapor will enter the crystal before the crystal has attained full diffusion temperature, but the rate of diffusion at this point would be smaller than desired. On the other hand, as the tube progresses toward the exit end of the furnace, the source will be overheated. If the source is an alloy, overheating will decompose it. If the source is a single element, overheating will produce an excessive concentration of impurity vapor and also a

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different partial pressure. In either case, the overheating will cause uncontrolled and uncomputable diffusion.

Although batch furnaces do permit precise control of the thickness of a diffused layer, they have certain important drawbacks such as (1) low production, (2) excessive handling, (3) high labor requirements, and (4) furnace deterioration. In normal batch furnace operation, the furnace is cooled down between batches. This repeated cooling causes rapid deterioration of the furnace, particularly of the heating elements. In addition to cost of replacement, heater deterioration causes uneven heating which in turn prevents normal operation.

Accordingly, the object of this invention is to provide a diffusion furnace which is capable of continuous operation with precise diffusion control.

A further object is to provide a novel method of diffusing impurities into the surfaces of semiconductor crystals.

A more specific object of this invention is to provide a continuous diffusion furnace which provides quality control equal to that of a batch furnace yet is free of the disadvantages of a batch furnace. In a continuous diffusion furnace embodying the present invention, diffusion is carried out on a precisely controlled temperature flat, thereby yielding diffused layers of precise thicknesses. This is achieved by providing separate heating zones for the source and crystal and moving them solely through their own zones. The source and crystal are supported in a heating tube which is mounted at 90° to its path of movement, simultaneously through two heating zones. As viewed in cross-section, a furnace constructed according to the present invention comprises two separate furnace sections, appropriately described as source heater and diffusion heater, which are precisely controlled at different temperatures. A conveyor transports successive quartz tubes through the furnace, each quartz tube containing a source of impurity to be vaporized and a crystal which is to be doped by diffusion of the impurity. The impurity is vaporized in the source heater and diffuses into the crystal in the diffusion heater. In the practice of this invention, the quartz tubes may be closed off by a hermetic seal or they may be adapted for circulation of an inert carrier gas.

Other objects and many of the attendant advantages of the present invention will be readily appreciated as the invention becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a side view of a continuous diffusion furnace embodying the present invention;

FIG. 2 is an end view of the same furnace;

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 1;

FIG. 4 is an enlarged fragmentary side view, partly in section, of the same furnace;

FIG. 5 is a schematic plan view of the same furnace as employed for closed tube operation;

FIG. 6 is a schematic plan view showing the invention as applied to open tube operation; and

FIG. 7 is a schematic plan view showing how the invention is applied to a double diffusion process.

Referring now to FIGS. 1 and 2, the furnace is mounted on upper and lower metal supporting frames. The upper frame is made of uprights 2, cross bars 4, and longitudinal beams 6. The lower frame is made up of uprights 8, crossbars 10, and beams 12. The furnace itself comprises a top body section 16 attached to the undersides of crossbars 4 and a bottom body section 18 supported by a plurality of beams 20 mounted on crossbars 10.

As seen in FIGS. 3 and 4, each furnace section comprises an outer metal case 24 by which it is attached to the frame and a ceramic liner 26 attached to the metal case. The top and bottom furnace sections are mirror

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images of each other, having opposed side edges flanges 32, 34, 36, and 38 and opposed longitudinal dividing ribs 40 and 42, respectively. The two sections 16 and 18 define a furnace interior which is divided by ribs 40 and 42 into two parallel, longitudinally extending heating chambers A and B. It is to be observed that the two body sections are in parallel spaced relation with each other so that heating chamber A is open at edges 32 and 34 and heating chamber B is open at edges 36 and 38 and both chambers are open at their ends. In addition, chamber A communicates with chamber B. Mounted in both chambers at the top and bottom thereof are longitudinally extending electrical heater rods 46 and 48 which, when energized by a suitable source, serve to heat the chambers to desired temperatures. Chamber A and heater rods 46 together constitute a source heater. Chamber B and heater rods 48 together constitute a diffusion heater.

The edge flanges 32 and 34 are provided with identical grooves 50 which serve as guide tracks for a plurality of movable ceramic carriages 54. Edge flanges 36 and 38 have identical grooves 52 for a like plurality of identical movable ceramic carriages 56. Each carriage is of rectangular block configuration having identical tongues 58 at two opposite sides, a similar tongue 60 at a third side, and a slot 62 at the fourth side. Each slot 62 is sized to receive a tongue 60 of another seal 54. The tongues 58 are sized to make a snug but slidable fit in grooves 50 and 52. The carriages 54 and 56 are arranged in pairs, being attached to opposite ends of a plurality of identical open ceramic carrier tubes 66. The outer diameter of these tubes is slightly less than the distance between ribs 40 and 42, being just large enough to substantially block off any convection currents between chambers A and B but small enough to be movable longitudinally along the space between the ribs.

The carriages 54 and 56 are partially encased in metallic collars 70 and 72 which are connected to a pair of endless chains 74 and 76 by identical bracket members 78 and 80, respectively. Chain 74 is mounted on suitable sprockets 84 and 86 attached to a pair of shafts 90 and 92 journaled at opposite ends of the frame. Although not fully shown, it is to be understood that chain 76 is mounted on identical sprockets. Mounted on shaft 90 is a second sprocket 96 which is driven from a motor M through a gear reducer 98, a drive sprocket 100, and a chain 102. It is to be noted that the chains have an upper run traveling over the bottom crossbars 10 and a lower run traveling under the same crossbars. Mounted on the crossbars 10 and extending longitudinally of the furnace are two guide rails 104 and 106 which support the upper runs of chains 74 and 76. The vertical length of the brackets 78 and 80 is such that with the chains riding on the guides 104 and 106, the carriages 54 and 56 are supported at the elevation required to allow their ribs 58 to ride in grooves 50 and 52.

When the motor M is operating, the carriages and the ceramic carrier tubes 66 will be driven by brackets 78 and 80 in an endless path in the direction shown in FIG. 1. Tubes 66 and carriages 54 and 56 will enter the furnace at one end and will exit at the opposite end. During the travel through the furnace, the tubes will be supported in a horizontal plane by the carriages 54 and 56. The carriages 54 (and also the carriages 56) will engage each other while they are in the furnace. In this connection, it is to be observed that the brackets 78 and 80 are spaced along the chains 74 and 76 a distance such that the tongues 60 on one carriage will be fully disposed within the slot 62 of the preceding carriage while the tubes 66 are moving along within the furnace. When the ribs 60 are disposed within the slots 62, carriages 54 and 56 effectively seal off the spaces between flanges 32, 34 and 36, 38, respectively, thereby completing the side walls of the furnace. The side walls may be

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considered as made up of the flanges 32, 34, 36, and 38 and the carriages 54 and 56. On leaving the interior of the furnace, the carriages move away from each other as they travel around sprockets 86 and re-engage each other after they have passed around the sprockets 86. The spacing movement is repeated as the carriages negotiate the turn from the lower to the upper run. This spacing is advantageous, making it easier to insert and remove materials from the ceramic carrier tubes 66 as described hereinafter. Loading and unloading is also facilitated by the speed at which the chains travel. The chain speed is relatively slow so as to allow tubes 66 to be within the furnace for a substantial interval, e.g., 22 to 36 hours, depending upon the particular diffusion process to be executed.

The ceramic tubes 66 function as carriers for quartz heating tubes of the kind used heretofore in diffusion processes. These quartz tubes may be of various types. For example, they may be fully sealed off, either permanently or by removable end caps for so-called "close tube operation." The permanent type is useable only once since it must be broken open in order to remove its contents. Alternatively, the quartz tubes may also be provided with end openings for so-called "open tube operation" wherein a gas is circulated through the tubes to promote diffusion or out-diffusion. The quartz tubes 110 shown in FIGS. 1-4 are of the latter type.

In practice, each quartz tube 110 functions to contain (1) a boat 112 within which is a source of impurity 114 which is to be diffused into a semiconductor material and (2) a boat 116 within which is stacked a plurality of thin wafers or disks 118 of a crystal semiconductor. The boat 112 is disposed within the quartz tube 110 in a position such that when the quartz tube is transported through the furnace by a carrier tube 66, the source 114 will travel through chamber A. Boat 116 is positioned so that it will travel through chamber B.

At this point, it is to be observed that the heater rods 46 are controlled (by means not shown) so that chamber A will have a temperature sufficient to cause vaporization of the source 114. On the other hand, the heater rods 48 are controlled so as to produce in chamber B a temperature at which the vaporized impurity will diffuse into the surfaces of the crystal wafers 118. In a typical case, chamber A will have a temperature of 300° C., and chamber B will have a temperature of 1200° C. As each quartz tube is transported along within the furnace, the impurity in boat 112 will vaporize, and then, due to its own vapor pressure or to the influence of a carrier gas, the vaporized impurity will envelop the crystalline wafers 118 and diffuse into their surfaces.

As seen in FIG. 3, each quartz tube 110 is provided at its opposite ends with removable end caps 124 and 126 having small tubular extensions to which may be connected flexible hoses 128 and 130, respectively. As seen in FIG. 1, hoses 128 are attached to a suitable inlet manifold 132 which is coupled by a tube 134 to a gas supply (not shown). Although not shown, it is to be understood that flexible hoses 130 are connected to an outlet manifold of similar construction located on the opposite side of the furnace. The function of hoses 128 and 130 and the manifolds to which they are attached is to permit an appropriate inert gas such as argon to be circulated through the quartz tubes (in the direction of the small arrows in FIG. 5) at a suitable rate for the purpose of facilitating diffusion. The gas promotes distribution of the vaporized impurity throughout the quartz tubes and also helps control its concentration, thereby helping to provide precise diffusion control. The hoses 128 and 130 are attached to the quartz tubes immediately after they are inserted in the carrier tubes 66 but before the tubes enter the furnace. As indicated in FIG. 5, the carrier gas is made to circulate as soon as the tubes enter the furnace and is cut off after they leave the furnace. The hoses are removed after the tubes have left the furnace.

The quartz tubes are removed after they have been transported out of the furnace but before passing through any substantial angle about sprockets 86. Because of the slow speed of the conveyor chains, the quartz tubes have adequate time to cool before being removed from the carrier tubes.

Although the use of a carrier gas is most beneficial, the factor which is primarily responsible for attainment of precise diffusion control is the provision of the two parallel heater chambers A and B. With this arrangement, the source is vaporized at a relatively constant rate since it is exposed only to the temperature in heater chamber A which is maintained substantially constant throughout its length. Moreover, diffusion of the impurity into the crystal proceeds at an even, predictable rate and for the time duration of the crystal's travel through the furnace since the crystal is exposed only to the temperature in chamber B which is maintained substantially fixed throughout its length at the desired level. Accordingly, the furnace will operate equally with closed tubes, in which case, the flexible hoses 128 and 130 are not required. In this connection, it is to be noted that in any closed tube operation, the partial pressure of the impurity itself promotes contact with the crystal wafers, the vaporized impurity being present in sufficient quantity to assure super-saturation of the surfaces of the wafers. However, as a consequence of the super saturation condition, it is often necessary to transfer the wafers to another furnace to execute out-diffusion. The latter may be defined as the process of boiling off excess impurity from the wafers. In out-diffusion, it is customary to pass an inert carrier gas over the heated crystal for the purpose of flushing away excess impurity as it is released by heating of the crystal. A noteworthy advantage of the furnace shown in FIG. 1 is that it may also be used for a straight out-diffusion process. Of course, such use does not require operation of the source heater. For out-diffusion, hoses 128 and 130 will circulate the inert carrier gas through the quartz tubes in the same manner described previously in connection with straight diffusion.

FIGS. 6 and 7 illustrate still other variations of the same invention. In FIG. 6, gas is circulated through the quartz tubes 110A continuously while they are in the furnace. However, the source heater chamber A1 is illustrated as shorter than the diffusion heater chamber B1. At this point, it is to be noted that the two chambers may actually be of different lengths. Alternatively, they may have the same physical lengths, but the effective length of chamber A from a heating standpoint may be restricted by shortening the heater rods 46 so that they terminate a substantial distance from the end of the furnace. As a consequence, vaporization and diffusion of the impurity will be stopped when the tubes reach a predetermined point along the length of chamber B, and thereafter, since the wafers are still being heated in chamber B, excess impurity absorbed by the crystal will diffuse out and be flushed away by the carrier gas.

FIG. 7 illustrates how the furnace also may be used for a double diffusion process. Here the furnace is provided with two source heater chambers A2 and A3 and a single diffusion heat chamber B2. Each quartz tube 110B contains three boats, two of which contain two different sources of impurity 114A and 114B and the third of which contains crystal wafers 118A to be doped. Because the effective upstream end of chamber A3 is downstream of the upstream ends of chambers A2 and B2, source 114A will vaporize and start to diffuse before source 114B, the latter will vaporize and start to diffuse before diffusion of impurity from source A2 has ceased. Out-diffusion occurs with the cooperation of the carrier gas for a prescribed period of time after diffusion of impurity from source 114B has ended.

Of course, it is not necessary to carry out double diffusion precisely as described in connection with FIG. 7. Thus, for example, chambers A2 and A3 could be ar-

ranged so as to start vaporization of sources 114A and 114B at spaced intervals or substantially simultaneously and to terminate them simultaneously or in prearranged time sequence.

It is to be noted that it is not necessary to fully seal off the sides of the heater chambers in the manner accomplished by the carriages 54 since the amount of heat which can be lost through the openings therein is not great. These openings are not large, the outer diameter of the carrier tubes 66 usually being in the order of 2½ inches. Moreover, simple inexpensive radiation shields may be positioned along the furnace sides to minimize heat loss.

The present invention has many important advantages. For one thing, it makes possible furnaces which can be used for single or multiple diffusion and also for out-diffusion, either as a separate operation or as the final phase of a diffusion process. With respect to diffusion, it is to be noted also that different quartz tubes may have different sources of impurities and also different kinds of semiconductor material, whereby different products may be produced in the same furnace. Moreover, furnaces constructed as described above are capable of producing junction layers of precisely controlled thicknesses, while at the same time achieving greater production than is possible in batch furnaces. Further advantages of the foregoing type of construction are that it is capable of being built with existing materials and utilizing conventional quartz tubes. Also important to note is that the life of the heating elements is much greater than it is in the case of a batch furnace since it is not necessary for furnaces of the type described to be repeatedly cooled down as are batch furnaces. It is also recognized that the invention may be utilized for processes wholly unrelated to the manufacture of semiconductors.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is to be understood, therefore, that the invention is not limited in its application to the details of operation or of construction and arrangement of parts specifically described or illustrated, and that within the scope of the appended claims, it may be practiced otherwise than as specifically described or illustrated.

What is claimed is:

1. A continuous diffusion process for doping a crystal wafer with a selected impurity comprising the steps of providing at least partially juxtaposed first and second fixed elongated heating zones having substantially parallel longitudinal axes with said first heating zone at a temperature suitable for vaporization of said impurity and with said second heating zone at a temperature suitable for diffusion of the vaporized impurity into said crystal wafer, inserting a mass of said impurity and said crystal wafer into a heat resistant tube with said tube in transverse relation to said longitudinal axes of said heating zones and with said mass of impurity and said crystal wafer in alignment with said axes of said first and second zones, respectively, continuously advancing said tube in a direction parallel to said longitudinal axes though both of said zones at a selected speed while maintaining the aforesaid transverse relationship whereby during the transverse time of said tube at said selected speed said impurity vaporizes at said temperature of said first zone and diffuses into said crystal wafer at said temperature of said second zone.

2. The process as defined by claim 1 and further including the step of flowing a gas through said tube during its transverse of said zones in a manner causing the gas to flow from the region of said first zone to the region of said second zone to facilitate migration of said vaporized impurity to said crystal wafer.

3. The process as defined by claim 2 wherein said first zone is arranged to terminate longitudinally in the direction of advance before termination of said second zone

in the same direction, and continuing the flow of said gas through said tube after it has progressed beyond said first zone and while it is within said second zone to accomplish out-diffusion of excess impurity from said crystal wafer.

4. A continuous diffusion process for doping a crystal wafer with first and second selected impurities comprising the steps of providing at least partially juxtaposed first, second and third fixed elongated heating zones having substantially parallel longitudinal axes with said first and second heating zones at first and second temperatures suitable for vaporization of said first and second impurities, respectively, and with said third heating zone at a temperature suitable for diffusion of the vaporized impurities into said crystal wafer, inserting masses of said first and second impurities and said crystal wafer into a heat resistant tube with said tube in transverse relation to said longitudinal axes of said heating zones and with said first and second masses of impurities and said crystal wafer in alignment with said axes of said first, second and third zones respectively, continuously advancing said tube in a direction parallel to said longitudinal axes through all of said zones at a selected speed while maintaining the aforesaid transverse relationship, flowing a gas through said tube during its transverse of said zones in a manner causing gas flow from the region of said first zone across the region of said second zone and to the region of said third zone to facilitate migration of said vaporized first and second impurities to said crystal wafer, whereby during the transverse time of said tube at said selected speed said first and second impurities vaporize at said temperatures of said first and second zones and diffuse into said crystal wafer at said temperature of said third zone.

5. A continuous diffusion process for doping a semiconductor crystal wafer with a selected impurity comprising the steps of placing said semiconductor wafer in a heat resistant tube, placing a mass of said selected impurity into said tube in spaced relationship with said crystal wafer, continuously passing a carrier gas through said tube, the direction of flow of said carrier gas being

from said impurity to said crystal wafer, arranging said tube for movement transversely of first and second elongated heat zones with said impurity in the region of said first heat zone and said semiconductor wafer in the region of said second heat zone, maintaining said first elongated heat zone at a temperature in the vicinity of 300° C. and said second elongated heat zone at a temperature in the vicinity of 1200° C., continuously moving said tube transversely of its own longitudinal axis at substantially constant speed through said first and second elongated heat zones while retaining said impurity in the region of said first heat zone and said semiconductor wafer in the vicinity of said second heat zone and maintaining the flow of said carrier gas therethrough, whereby during said movement of said tube said impurity vaporizes at said temperature of said first heat zone and diffuses into said semiconductor wafer at the temperature of said second heat zone, and arranging said speed of movement of said tube with reference to the length of said elongated heat zones to provide sufficient time to achieve doping of said crystal wafer.

6. The process as defined by claim 5 wherein said first heat zone is arranged to terminate in the direction of movement of said tube prior to termination of said second heat zone in the same direction, whereby during movement of said tube as aforesaid heat is removed from said mass of impurity prior to removal of heat from said semiconductor wafer while continuing the flow of said carrier gas, whereby vaporization of said impurity is discontinued while said crystal wafer remains in said second heat zone with the flow of carrier gas thereover to accomplish out-diffusion of excess impurity from said semiconductor wafer.

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