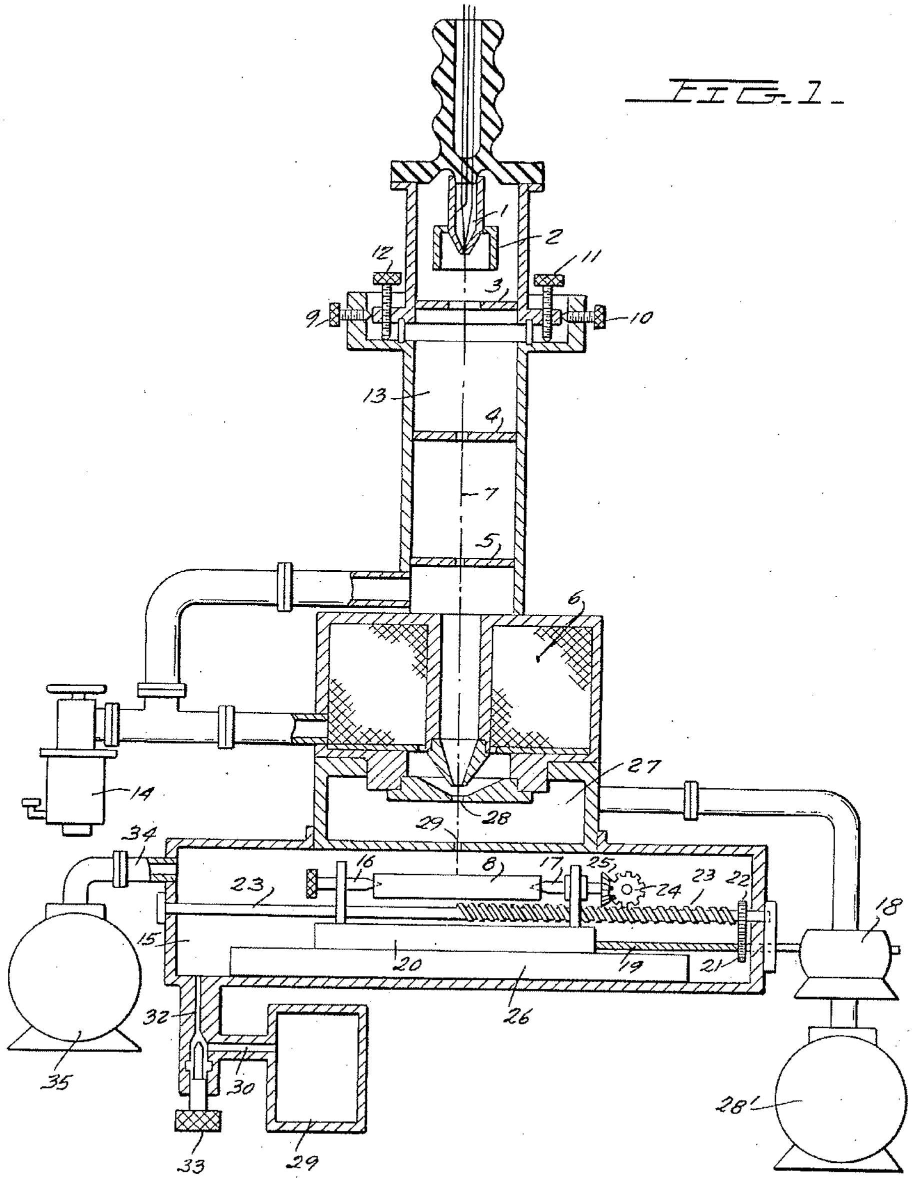
Jan. 17, 1961 K. H. STEIGERWALD 2,968,723

MEANS FOR CONTROLLING CRYSTAL STRUCTURE OF MATERIALS

Filed April 11, 1957

3 Sheets-Sheet 1

FIG. 1



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3 Sheets-Sheet 2

FIG. 2

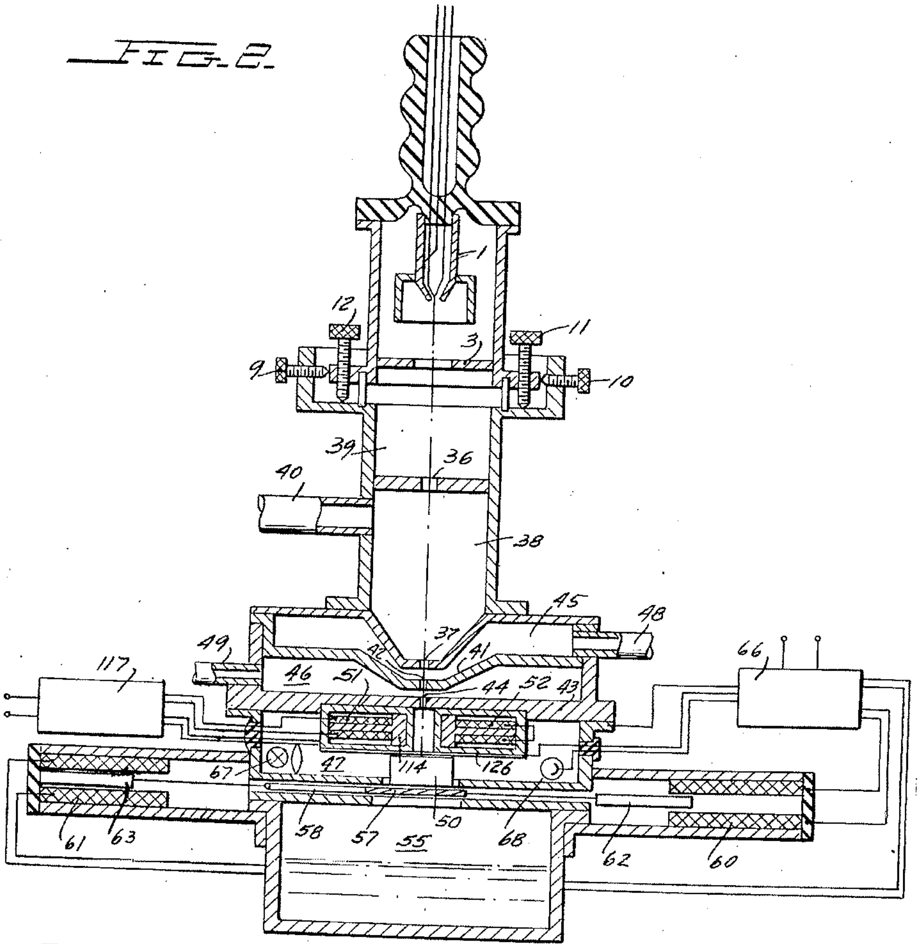


FIG. 4

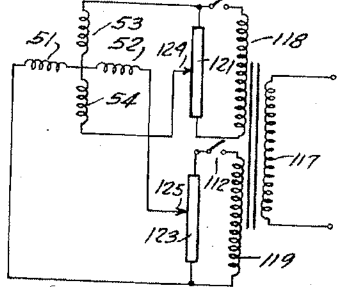


FIG. 7

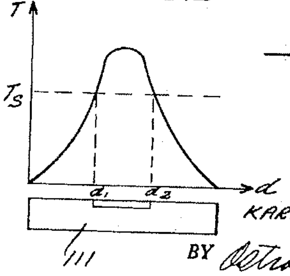
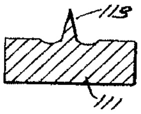


FIG. 8



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3 Sheets-Sheet 3

FIG. 5.

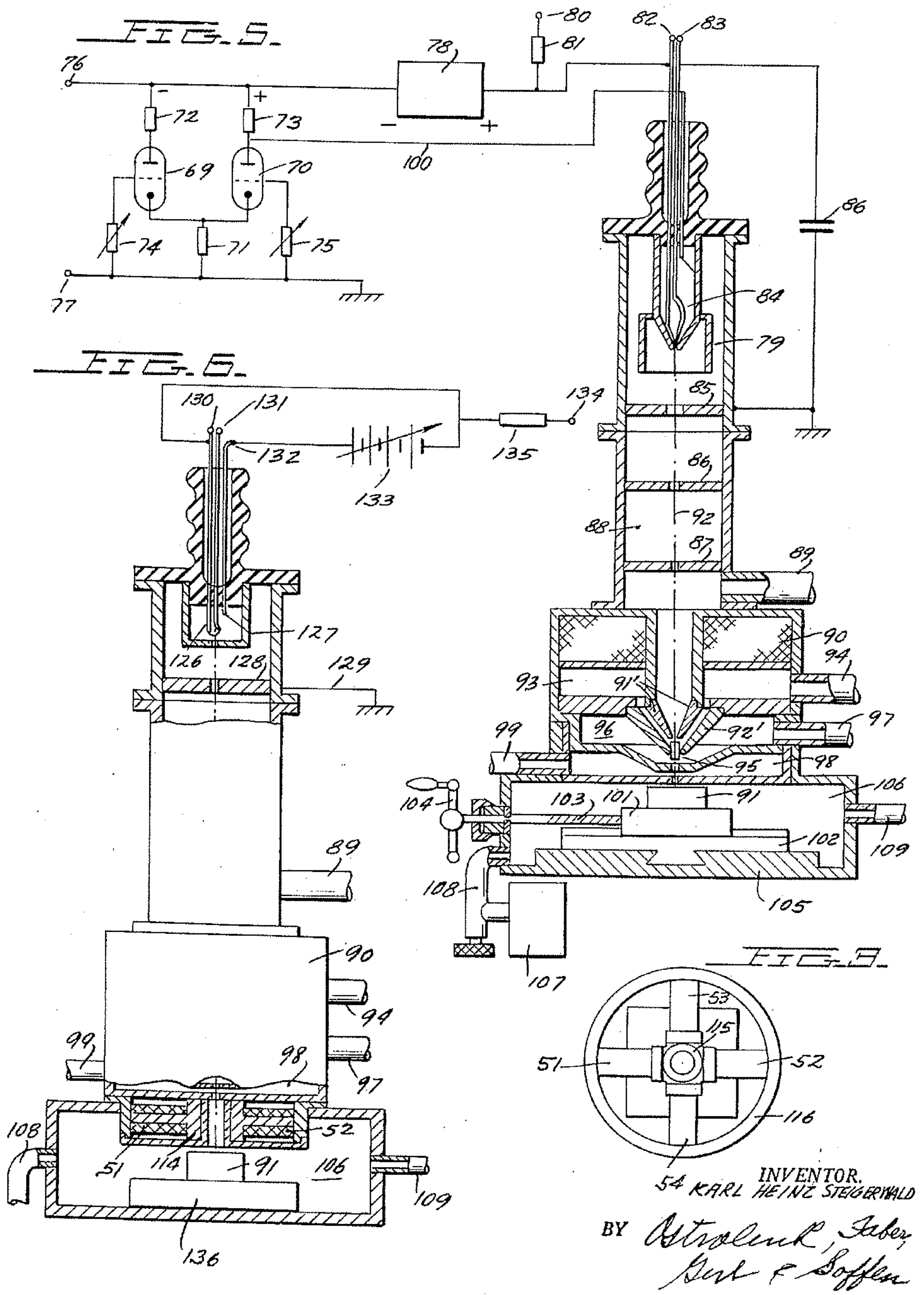
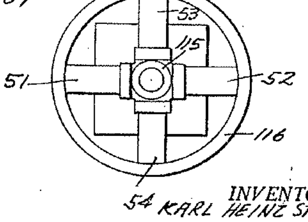


FIG. 6.

FIG. 3.



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MEANS FOR CONTROLLING CRYSTAL STRUCTURE OF MATERIALS

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Filed Apr. 11, 1957, Ser. No. 652,239

10 Claims. (Cl. 250—49.5)

This application is a continuation in part of my co-pending application Serial No. 258,673, filed November 28, 1951 now U.S. Patent No. 2,793,282 and is specifically directed to the use of a beam of charged particles as a heat source for controlling the crystalline structure of materials.

The use of a beam of charged particles, such as electrons, as a heat source has been set forth in my co-pending application Serial No. 640,828 filed February 18, 1957 entitled Electron Beam Means for Initiating Chemical Reactions while my above noted co-pending application Serial No. 258,673 shows the use of a beam of charged particles for producing small spherically shaped objects. That is, the material which is to be shaped into a sphere is exposed to an electron beam at the focus point of the electron beam. The kinetic energy of the electrons is transferred to the material which then becomes quickly heated to its melting point and forms a molten globule. The surface tension of the molten globule draws it into a spherical shape and it is thereafter cooled while maintaining this spherical shape.

It is further possible as set forth in the above noted application Serial No. 258,673 to suddenly increase the intensity of the electron beam to such a point that the object upon which the electron beam is focused will explode and form a number of smaller objects of the desired spherical shape.

The primary object of the instant invention is to direct charged particles at a material so that the crystalline structure of the material is controllably altered.

The material being worked may or may not be positioned at the focused point of a beam of charged particles, such as electrons, which act as a flexible means for producing localized heat in the material. For example, in the treatment of specific areas, it is possible to increase or decrease or vary the electron density so as to localize thermal operations in a manner not possible heretofore.

One particular advantage lying in the use of a focused beam of charged particles is that small discrete areas of the material to be worked are subjected to rapid temperature changes due to the kinetic energy of the focused electron beam with substantially no effect on areas of the material adjacent to the cross-sectional area of the electron beam impinging upon the material. By not heating the surrounding portions of the material as well as not heating the containers holding the material, no impurities are produced during recrystallization of the area of the material which has been heated. This feature is of great importance in the manufacture of semi-conductor devices such as germanium and silicon diodes and transistors.

My novel system has further application in the surface hardening of materials wherein only an extremely thin surface layer of a material may be re-crystallized to a more desirable crystalline structure. Thus the electron beam and work piece may be moved relative to one another so that the area upon which the electron beam is focused at any instant is rapidly heated to a predetermined temperature whereupon the beam moves to an adjacent area and the previously heated area is quickly cooled. By scanning the entire surface of the material, it is clear that by adequate control of the electron beam intensity and scanning time, a surface layer of predetermined thickness may be altered in any desired manner.

If desired, this re-crystallization process may take place in a gaseous atmosphere with the utilization of the structures set forth in my co-pending application Serial No. 640,828, which gaseous atmosphere could be at any required pressure and of a nature which does not chemically combine with the heated material. Conversely, the chemical atmosphere could be of the type which would chemically combine with the surface layer to be formed so as to offer some desired physical characteristic to the re-crystallized surface.

Accordingly, a primary object of my invention is to provide a novel method for controlling the crystalline structure of a material.

Another object of my invention is to utilize charged particles as a heat source for heating discrete areas of a material to cause a change in the crystalline structure of the heated areas.

Another object of my invention is to provide a novel system for surface hardening a thin surface layer of a material which utilizes a focused electron beam as a heat source.

As has been above mentioned, my novel system for controlling the crystal structure of materials has important applications in the field of semi-conductor devices. This is because my novel system may utilize a focused heat source which can raise the temperature of a small well-defined area of a material within a very short time and portions of the material adjacent the area having its temperature raised will be relatively unaffected by the application of heat. Therefore, in applying my novel invention to a diode or transistor device of either germanium or silicon material, the crystal structure of any portion of the material may be controllably altered without affecting adjacent portions of the material.

Hence in a semi-conductor device of the above noted type, the conductivity of any particular portion of the device may be controlled by bringing that portion to a temperature which could cause melting thereof. The re-crystallization of that portion may then take place at such a rate that the impurities which control the conductivity are controllably disbursed in view of the difference in melting temperatures between the impurities and the semi-conductor material itself. That is, the concentration of impurities can be sharply controlled by controllably melting and re-crystallizing the material so that the impurities will be concentrated at some desired region in the semi-conductor material.

This is advantageous over the normal heat means presently employed where the temperature gradient from the most penetrated portion of the germanium to the exterior has only a small slope as compared to the temperature gradient when electron beams are employed as in my novel invention where the temperature gradient is quite steep. Because of the smaller slope in the former case, those impurities which tend to migrate to the hotter regions will have a longer and more difficult travel than is true where electrons are employed for heat. In the latter case, because of the steeper temperature gradient, these particular impurities would tend more easily to arrive at the hotter regions. Thus there will be at least in that portion of the crystal which has been treated, a region of substantially greater purity and a sharp definitive concentration of impurities.

Another useful application of my novel crystalline control system in the manufacture of semi-conductor devices lies in the formation of a small protruding point at any desired location of the material, which point could serve to accept terminal members for allowing connection to the semi-conductor device. This process depends upon the novel use of a focused electron beam whereupon the temperature distribution across the area of the electron beam is higher in the central portion than it is in the external portions of the focused area of the beam. Therefore, by focusing the beam on a point at which it is desired to produce a protruding tip, the material of the small discrete area is heated to the melting point at its center while portions radially displaced from the central portions are not heated to the melting point. The material within the molten range will then form the protruding tip.

That is, as the molten material cools in the circumferential outer regions, the contraction following such cooling causes the central portion to move outwardly in the form of a tip. This process continues on as successive inner layers are cooled and contact, causing the center to take on a conical shape.

Accordingly, an important object of my invention is to provide a novel crystal structure control system for controlling the properties of semi-conductor materials.

Another object of the present invention is the control of the distribution of the impurities in any materials such as semi-conductors.

Another object of my invention is to utilize a focused electron beam as a heat source for controlling the crystal structures of discrete areas of semi-conductor materials.

A still further object of my invention is to provide a novel method for producing a protruding point on the surface of a semi-conductor material.

As may be seen in my co-pending application Serial No. 640,828, the intensity of the focused beam of charged particles applied to any particular area of a material may be controlled by either controlling the intensity of the beam of charged particles in a continuous or intermittent manner or by causing a relative motion between the charged particle beam focus and the material to be heated. Since the crystalline structure of a body is in part determined by the rate of cooling, it follows that any heat control method can be used to control crystal structure.

When rapid cooling or quenching is required in some particular application, I have provided novel means whereby the material which is to have its crystalline structure controlled is first heated in accordance with this novel invention and is thereafter immersed in a quenching fluid. This process can be made automatic with the use of photoelectric means wherein radiations emitted from the heated area are impinged upon a photoelectric cell which energizes control equipment when the radiations indicate that a predetermined temperature has been reached. The control equipment then either moves the material being worked into a quenching fluid or, if desired, could bring the quenching fluid directly into contact with the material being heated with the material retained in its heating position.

Accordingly, another important object of my invention is to provide means for controlling the application of a heat source comprised of a focused beam of charged particles to a material for controlling the crystalline structure of the material.

Another object of my invention is to controllably alter the crystalline structure of material by controlling the length of time that a focused beam of charged particles is impinged upon any given area of a material.

Still another object of my invention is to control the crystalline structure of a material by means of a focused beam of charged particles wherein heat intensity control means comprising means for causing relative motion between the focused point of the beam of charged particles and the material to be heated are provided.

Another object of my invention is to provide means for controlling the intensity of a beam of charged particles utilized in controlling the crystalline structure of a material.

A further object of my invention is to provide means for causing a controlled intermittent energization of an electron beam which is utilized for controlling the crystalline structure of a material positioned at the focus point of an electron beam.

A still further object of my invention is to provide means for causing quenching of a material after it is heated by a focused electron beam.

A further object of my invention is to provide photoelectric means for automatically causing the quenching of a heated material by a quenching fluid after the material has been brought to a predetermined temperature by a focused beam of charged particles.

These and other objects of my invention will become apparent from the following description when taken in conjunction with the drawings, in which:

Figure 1 shows one embodiment of my novel invention wherein the crystalline structure of the surface of the material to be worked is so altered with respect to the core of the material.

Figure 2 shows a second embodiment of my invention wherein means are provided for moving the beam of charged particles with respect to the material to be worked and further shows automatic means for quenching the heated material.

Figure 3 shows the deflecting structure utilized in the embodiment of Figure 2 for controlling the position of the charged particle beam.

Figure 4 shows an electrical connection diagram for the structure of Figure 3.

Figure 5 shows an embodiment of my novel invention wherein the work material is movable with respect to the beam of charged particles and further shows electronic control means for intermittently energizing the charged particle beam.

Figure 6 shows my novel system in conjunction with a conventional type of electron beam production system.

Figure 7 shows the temperature distribution across the cross-sectional area of a focused charged particle beam and therefore illustrates the temperature distribution of a portion of the surface of a work piece which is heated in the focus of the charged particle beam.

Figure 8 shows a semi-conductor crystal having a point produced thereon due to the temperature distribution set forth in Figure 7.

Referring now to Figure 1 which shows one manner in which a focused electron beam can be utilized as a heat source for controlling the crystalline structure of a material, the electron gun system is generally comprised of a cathode **1**, a Wehnelt cylinder **2**, and an anode **3**. Two apertures **4** and **5** are positioned below the anode **3** and serve to reduce the scattering of the electron beam so that a narrow bundle is achieved at the output. By means of an electromagnetic lens **6**, the beam of charged particles **7** may be focused on the surface of a metal cylinder **8** which is to have the crystalline structure of its surface controlled in accordance with my novel invention.

The beam producing system proper may be adjusted by means of the screws **9**, **10**, **11** and **12** which control the alignment of the beam. The complete electron gun system is housed in chamber **13** which is kept under a high vacuum by means of a diffusion pump **14**.

The electron beam producing system described above is particularly capable to supply a beam of electrons which are focused at a remote point and is completely described in my U.S. Patent No. 2,771,568 issued November 20, 1956, and reference is made thereto for further details regarding this electron gun structure. It is to be clearly noted, however, that any electron gun structure could be utilized, the only important thing being that a beam of focused electrons is provided to operate as a heat source. Furthermore, the use of an electron beam is set forth herein for illustrative purposes only and a beam of positive or negative ions could be utilized as well as a beam of negative electrons.

The material which is to have its surface characteristic controlled in accordance with my novel invention is shown as the metal cylinder 8 which is rotatably mounted between pivot members 16 and 17 within a chamber 15. More specifically, a motor 18 is connected to rotate spindle 19 which is connected to displace table 20 in a direction perpendicular to the axis of the electron beam 7.

A gear 21 is coaxially connected to spindle 19 and is positioned to engage gear 22 which is coaxially fastened to worm 23, whereby rotation of gear 22 effects rotation of the worm 23. The worm 23 then engages gear member 24. Gear member 24 is a bevel gear and engages a cooperating bevel gear 25 which is connected to rotate the spindle 17 which is one of the pivotal mounting points of the work material 8.

In operation, by energizing motor 18, spindle 19 will rotate to cause the table 20 to be moved in a direction perpendicular to the axis of the electron beam at a predetermined rate. Since the mounting members of pivotal mounting members 16 and 17 are fastened to table 20, the work material 8 will be translated in this perpendicular direction with the table 20. Furthermore, since rotation of spindle 19 causes a rotation of worm gear 23, through the cooperating gears 21 and 22, the bevel gear 24 (which is pivotally mounted on a structural member not shown but is movable with the table 20) drives bevel gear 25 to cause a rotation of the work material 8.

Accordingly, the single drive motor 18, when energized, will cause the work material 8 to thread past the focused point of electron beam 7. By properly coordinating the vertical displacement speed of table 20 and the angular velocity of work material 8, the entire surface of cylinder 8 may be swept past the focus point of the charged particle beam.

At any one instant, the particular area of the work material 8 which is exposed to the charged particle beam will be heated to a predetermined temperature. This area will thereafter be removed from the focused charged particle beam and will be rapidly cooled. In this manner the crystal structure of each discrete area will be exposed to the beam and will be heated and thereafter rapidly cooled.

By way of example, the cylinder 8 could comprise a cylinder of steel having a diameter of 2 cm. and a length of 5 cm. Cylinder 8 may be rotated at a speed of 5 revolutions per second and the table 20 may be displaced at a speed of 5 mm. per second. When the cross section of the charged particle beam at its focus point is approximately 1.1 mm., the entire surface of cylinder 8 may be exposed to the charged particle beam within ten seconds.

By then making the beam current intensity approximately 10 milliamperes with an accelerating voltage of sixty thousand volts, it has been found that the discrete surface areas exposed to the beam of approximately twenty microns thickness are heated to 1200° C. during the operating process. That is to say, the surface material is raised to 1200° C. only when that particular area is exposed to the electron beam. The cooling of the individual heated surface elements after being taken away from the focused electron beam occurs so quickly that the crystalline structure is altered in a manner that would be obtained by quenching the material so as to achieve an extremely hard thin surface layer.

It is important to note that during this process, the entire cylinder is heated to an average temperature of only 150° C.

Clearly, the surface thickness of the hardened layer as well as the hardness of the layer may be easily controlled by altering any combination of accelerating voltage, beam current, and the time during which a particular area is exposed to the focused electron beam, this time being determined by the angular velocity of the work material as well as the rate of displacement of the work table.

In many cases it may be desirable to expose cylinder 8 to the crystal structure control beam 7 with the surface of the material exposed to a gaseous atmosphere which may be at any pressure. This gaseous atmosphere could be chemically inert with respect to the material being heated or, if desired, the gas could have some chemically reducing effect which would enhance the hardening of the surface work piece.

As has been set forth in my U.S. Patent No. 2,793,281, issued May 21, 1957, one or more intermediate pressure chambers may be utilized to isolate the low pressure of an electron beam producing system from the higher pressure of the gaseous atmosphere exposed to the material to be worked while still preventing interference of the electron beam low pressure system from the high pressure gaseous atmosphere.

This system is set forth in Figure 1 as comprising the intermediate pressure chamber 27 which contains apertures 28 and 29 wherein the distance between the two openings 28 and 29 which are in registry with the electron beam 7 and the area to be heated on the surface of the material 8 are kept smaller than the mean free path of the gas molecules contained therein. The pressure within intermediate pressure chamber 27 is controlled to be intermediate between the pressure within the electron beam producing system and the work material chamber by means of a vacuum pump 28′.

The gaseous atmosphere is supplied to the work material chamber 26 from a tank 29′ which is connected to the pressure chamber through a conduit 30, control valve mechanism 33 and conduit 32. A conduit 34 then connects vacuum pump 35 to pressure chamber 26 whereby pressure and gas flow within the chamber 26 may be controlled by valve mechanism 33.

While Figure 1 shows my novel invention with the use of a single intermediate pressure chamber, it is to be understood that any desired number of intermediate pressure chambers may be utilized. By way of example, Figure 2 which shows a second embodiment of my novel invention utilizes a first and second intermediate pressure chamber. In Figure 2, two apertures 36 and 37 are positioned below the anode 3 to limit the scattering of the electron beam. The vacuum chamber 38 is connected to a high vacuum pump (not shown) through the conduit 40 and in this manner is kept at a hard vacuum.

The aperture 37 is in the center of a conically shaped extension of one wall of the high vacuum enclosure and is positioned adjacent a similar conical partition 41 which includes an aperture 42. A further partition 43 which contains an opening 44 is positioned beneath partition 41.

In this manner (as is more fully described in copending application Ser. No. 640,828), a first and second intermediate pressure chamber 45 and 46 respectively are created with their apertures in alignment with the charged particle beam and the work material. That is to say apertures 37, 42 and 44 will allow the electron beam access to the actual work chamber 47 which contains the material to be worked.

The intermediate pressure chamber 45 is connected to a vacuum pump (not shown) through the conduit 48 and in this manner may be kept at some desired pressure. The intermediate pressure chamber 46 is connected to a second vacuum pump (not shown) through the conduit 49 whereby the pressure of this intermediate chamber is kept at some predetermined pressure.

As was the case in the single intermediate pressure chamber of Figure 1, the adjacent aperture of the various intermediate pressure chambers are spaced at a distance from one another which is less than the mean free path of the gas molecules within the intermediate pressure chamber.

Accordingly, the material 50 which is to have its crystalline structure controlled by the heat of the focused electron beam may be positioned in any desired gaseous atmosphere of any desired pressure by utilizing the above described intermediate pressure chamber system which isolates the vacuum system of the electron gun and its surrounding gaseous atmosphere.

Figure 2 also differs from Figure 1 in the manner in which relative motion between the electron beam and the work material surface is obtained. That is, in Figure 1 this relative motion was achieved by maintaining the beam position steady and moving the work material. Figure 2 shows a manner in which the work material may be held rigid and relative motion is achieved by deflecting the beam in accordance with the beam-deflecting system set forth in my copending application Ser. No. 258,672.

In Figure 2 the deflecting system which is further shown in Figures 3 and 4 includes four energizing coils **51**, **52**, **53** and **54**, respectively.

As is best seen in Figure 3, which is a top view of the magnetic control structure, coils **51** and **52** are wound on diametrically opposite magnetic pole pieces while coils **53** and **54** are 90° displaced from coils **51** and **52** and are wound on similar protruding magnetic pole pieces. Each of the pole pieces have their inner ends terminated adjacent a non-ferro-magnetic ring **115** while their outer ends are terminated in ring **116** of ferro-magnetic material which closes the magnetic lines of flux of each of the pole pieces.

One manner in which the control windings **51** through **54** may be connected is set forth in Figure 4 wherein A.-C. power is connected to the primary winding **117** of a transformer having secondary windings **118** and **119**. Winding **118** is connected through a switch **120** and across a potentiometer **121** while winding **119** is connected through switch **122** to potentiometer **123**.

A tap **124** then connects coils **53** and **54** in series with one another for controllable excitation from transformer winding **118** while coils **51** and **52** are connected in series and are energized through transformer winding **119** through tap **125**.

By adjustably varying taps **124** and **125** the current flowing through the deflecting coils **51** and **54** may be regulated. By way of example, if the two taps are so adjusted that the current flowing through coils **51** and **52** is the same as the current flowing through coils **53** and **54** and if a phase quadrature voltage is applied to the two potentiometers **121** and **123**, the magnetic field created by coils **51** through **54** will cause the charged particle beam to describe a circle on the surface of material **50** of Figure 2. By adjustably controlling the excitation of coils **51** through **54**, it is therefore seen that any desired pattern of surface heating of the surface of work material **50** may be achieved to thereby achieve any predetermined hardening pattern of that surface.

When it is necessary to harden a relatively thick surface layer of a material such as material **50** of Figure 2 it is possible that the small areas of the surface which have been exposed to the heating effect of the electron beam consecutively cannot be cooled quickly enough to obtain the required quenching by heat exchange with the remaining material.

A similar problem arises in heating a volume of material which constitutes a substantially large portion of the entire body itself. In such construction, it is not possible to rely on the unheated portion to conduct away the heat at the desired high rate. To allow rapid quenching, I have provided a novel means for bringing the heated object into a cooling medium whereby rapid quenching is achieved. This structure is set forth in Figure 2 and comprises the chamber **55** which is positioned below the work chamber **47**. The work material **50** is positioned on a plate **57** which has a recess **58** therein. A first and second coil **60** and **61** respectively, having movable cores **62** and **63** are coupled to the plate **57** by any desired flexible coupling means. Thus when the cores **62** and **63** are in the left hand position shown in Figure 2, the solid portion of plate **57** is positioned beneath the object to be worked **50**. When, however, coil **60** is energized as will be described hereinafter, the plate **57** will be moved to the right whereby aperture **58** will be moved into registry with work material **50** and work material **50** will drop through the aperture **58** and into the cooling medium within chamber **55**.

Clearly, the winding **60** could be manually energized to allow quenching of the heated surface of material **50** to proceed. However, it may be more desirable to have the time of quenching determined by automatic means which would be more accurate than would a human operator.

This automatic quenching means is seen in Figure 2 and comprises the photocell **126** which is contained within the base plate of the deflecting system of coils **51** through **54**. The light emanating from the heated surface of work piece **50** falls on this photocell to cause energization thereof. Since the light emanating from the heated surface of work material **50** is a function of the temperature of that surface, the output voltage of photocell **126** will also be related in some manner to the temperature of the surface of work material **50**. By connecting the output voltage of photocell **126** to relay **66** which could be of any well known type, the relay may be operated on a predetermined input voltage to cause energization of winding **60** of the electromagnet control system whereby core **62** will be pulled into the solenoid coil **60** and the work material **50** will drop through aperture **58** and into the quenching fluid. Hence the heated surface of work material **50** will be quenched once this surface reaches a predetermined temperature.

In order to reset the plate **57** to receive a new work piece a light source **67** and a second photocell **68** may be provided wherein the work material **50** is interposed between these two elements so as to normally block the impingement of light source **67** upon photocell **68**. When, however, plate **57** is moved to the left and work piece **50** is dropped, photocell **68** is energized by light from the light source **67** to reenergize relay **66** in such a manner that coil **60** is deenergized and coil **61** is energized. With the energization of coil **61**, plunger **63** will be pulled into the solenoid coil **61** to thereby reposition platform **57** for the reception of a new work piece.

One application of my novel invention which requires the use of additional quenching means of the type set forth in Figure 2 utilizes a work material **50** which is a steel member having a length of 10 cm., a width of 3 cm. and a thickness of 1 cm. A beam current of intensity of ten milliamperes at an acceleration voltage of 100,000 volts is utilized and the work piece is scanned for approximately ten seconds by a charged particle beam having a diameter of 5 mm.

For this purpose, a control voltage is applied to deflecting coils **51** and **52** at a frequency of 50 cycles per second while a control voltage having a frenquency of 600 cycles per second is applied to deflecting coils **53** and **54** whereby the individual traces of the charged particle beam overlap on the surface of the steel work material so as to completely cover the surface. With this combination of parameters, a surface layer having a thickness of forty microns is heated to 1200° C. and it was found that in order to achieve sufficient cooling for the desired surface hardening, it was necessary to utilize the additional quenching of a cooling fluid as set forth in Figure 2.

While the structures of Figures 1 and 2 have utilized heat control means which includes structures for causing relative motion between the beam of charged particles and the surface to be heated, it is to be understood that heat control could be also obtained through an intermittent energization through either a gradual control of the beam current intensity or through an intermittent control of the beam current.

Certain other advantages are provided by causing intermittent beam control since the heating of the material does not continuously vary from one area to an adjacent area but is applied to a first area and is thereafter turned off and then applied to a second discrete area. Hence, the cooling of the first area is unaffected by the heating of the second area. Furthermore, with the use of intermittent energization of the beam, it is easier to obtain a variable heating effect along the surface of the body which is to be worked. In this manner, various structural differenecs may be taken into consideration when heating a body as for example, when heating a body having a sharp edge to which less heat should be applied to obtain a predetermined hardening.

One manner in which the beam current could be intermittently controlled is set forth in Figure 5 and is based on the intermittent control system set forth in my above noted application Serial No. 640,828. More specifically, Figure 5 shows a beam control system which in essence comprises a multivibrator type of control where the multivibrator includes triodes **69** and **70** which have a common cathode resistor **71**. The plates of each of triodes **69** and **70** are connected through plate resistors **72** and **73** respectively which are terminated at terminal **76** while their grids are connected through adjustable grid resistors **74** and **75** which, along with common cathode resistor **71**, are connected to the grounded terminal **77**.

In operation, adjustment of the grid resistor **74** will regulate the length of time during which the electron beam is turned off and grid resistor **75** will control the length of time that the beam is turned on. The voltage input for the multivibrator system is applied across terminals **76** and **77** and regulation of this voltage will regulate the intensity of the electron beam impulses.

Terminal **76** is also connected to a D.-C. biasing voltage source **78** where the polarity of this source is indicated in the figure. This voltage biases the grid potential of Wehnelt cylinder **79** to some predetermined point while the high voltage supply is connected at terminal **80** and through the protective resistor **81**. Terminals **82** and **83** have voltage sources applied thereacross for supplying the heater current of cathode **84**.

Since terminal **82** is also connected to the high voltage supply **80**, the potential of the Wehnelt cylinder **79** will be maintained at a potential difference with regard to cathode **84** which is determined by the potential of the D.-C. bias **78**. By way of example, if the high voltage supply at terminal **80** is minus 50,000 volts while the voltage of D.-C. bias **78** is 400 volts, the Wehnelt cylinder **79** will be normally maintained at a potential difference of minus 400 volts with respect to cathode **84** which is normally sufficient to suppress the energization of the electron beam. When, however, plate current flows through tube **70**, a positive impulse is applied to the Wehnelt cylinder **79** over conductor **100** so as to unblock the electron beam and cause the initiation of a beam impulse. By controlling grid resistors **74** and **75** in an appropriate manner the duration of time during which the tube **70** conducts may be adjustably controlled whereby the initiation of the electron beam impulse is similarly controlled.

It is to be noted that a condenser **86** is connected between terminal **82** and anode **85** which is connected to ground potential. This condenser charges during an impulse pause and is discharged during the initiation of an impulse to thereby give a clearly defined electron impulse current as has been described in my co-pending application Ser. No. 640,828.

The remaining electron beam producing structure is similar to that hereinbefore described and includes diaphragms **86** and **87** which have apertures therein for limiting the scattering of the electron beam. The chamber **88** within which the electron gun system is housed is connected to a vacuum pump through conduit **89** and is kept at a high vacuum.

As was the case in Figure 1 and as is described in my co-pending application Ser. No. 640,828, the electron beam **92** may be focused by an electromagnetic lens **90**. This electromagnetic lens is designed to have upper pole shoes **91'** and lower pole shoes **92'** which form an intermediate pressure chamber **93** which is kept at a predetermined pressure by vacuum pump means connected to the conduit **94**.

A small hollow tube **95** is introduced into the lower pole shoes **92'** as was described in my co-pending application Ser. No. 640,828 wherein the small aperture of tube **95** which is sufficient only to pass the small diameter of the focused electron beam and offers relatively high resistance to the passage of gas molecules which attempt to flow into the lower pressure region of lower pressure chamber **93**. A further intermediate pressure chamber **96** is positioned below pressure chamber **93** and is maintained at a predetermined temperature through the conduit **97** which is attached to some suitable vacuum pump means.

A still further intermediate pressure chamber **98** is positioned below chamber **96** and is maintained at a predetermined pressure by vacuum pump means connected to conduit **99**. The material **91** which is to have the crystalline structure of its surface controlled in accordance with the instant invention is positioned on a table **101** which may be moved on a further table **102** by a spindle **103** which is rotatable by means of the crank **104**. The table **102** is in turn movable with respect to the bottom **105** of the work chamber **106** by means of a dove-tailed guide. It is to be noted that for allowing this type of movement that the spindle **103** may be translated through a slotted arrangement in the left hand wall of chamber **106**. In order to move table **102** there is a similar spindle and crank arrangement to the spindle and crank **103** and **104** respectively which is not seen in the figure.

Since the direction of displacement of the two tables **101** and **102** is perpendicular to one another, it is possible to position the surface of material **91** in any desired manner with respect to the beam **92**.

If it is desired to work the surface of material **91** in the presence of an inert gas or in the presence of a chemically active gas, the gas may be supplied from a container **107** through a conduit **108** and into the chamber **106**. Chamber **106** is also connected to an exhaust pump (not shown) through conduit **109**.

In the embodiment of Figure 5 the temperature control is achieved by causing the electron beam to be impinged upon the material to be worked in an intermittent manner. Therefore, the material is first heated and when the beam is turned off there is ample time for the heat to be rapidly conducted to adjacent portions of the material which were not subjected to the electron beam, and adequate quenching of the small area which has been heated may result.

By way of example, it is possible to harden the point of a phonograph pick-up needle by impinging an electron beam upon the tip of the needle for 1×10^{-6} seconds with a beam current intensity of 10 milliamperes at an accelerating voltage of 80,000 volts.

In another application of the device in Figure 3, a germanium crystal may be placed in the position of material **91** whereby the crystalline structure and distribution of impurities of the crystal are controlled.

By way of example, with an impulse duration of 10^{-3} seconds, a beam intensity of 0.2 milliampere, and an accelerating voltage of 50,000 volts a small area of about 50 microns in diameter may be heated to 1,000° C. to a depth of approximately 10 microns.

As is well known, this control of conductivity is essential in the manufacture of semi-conductor devices such as transistors. If desired, any area of any desired configuration could be melted, as set forth above, by appropriate control of crank **104** and the impulsing system.

Figure 6 sets forth a still further embodiment of my invention wherein heat control is obtained through a continuous control of the charged particle beam intensity. In Figure 6 the electron gun structure is of the conventional type and comprises a cathode **126**, a Wehnelt cylinder **127**, and an anode **128**. The anode high voltage supply for accelerating the charged particle beam is connected at terminal **134**. The filament of the cathode **126** is heated by a voltage source (not shown) which is connected across terminals **130** and **131**. A variable voltage source **133** is then connected in series with the Wehnelt cylinder **127**, a protective resistor **135**, and a high voltage supply **134**.

Thus, the high voltage supply connected to terminal **134** can be of the order of 50,000 volts while the voltage source **133** could be of the order of **300** volts. Hence, the cathode **126** would be at a potential of minus 50,000 volts while the Wehnelt cylinder **127** is at a potential of minus 50,300 volts. Clearly, by regulating the voltage source **133** it is possible to vary the intensity of the charged particle beams supplied by the electron gun structure from some conduction value to a cut-off point.

The work chamber **106** of Figure 6 which could be similar to that set forth in either of Figures 2 or 5 is shown as including a table **136** in Figure 6 which supports the work material **91**. In order to achieve relative motion between the electron beam or charged particle beam and the work material **91** an electromagnetic deflecting system of the type set forth in Figure 2 is provided.

In operation, the object **91** could be a germanium crystal which is scanned by a charged particle beam having a diameter of ½ millimeter. The beam current intensity may be ½ of a milliampere and an accelerating voltage of 50,000 volts with the beam moving relative to the work material at a speed of 1 centimeter per second. With this set of parameters it has been found that the scanned surface layer is heated to approximately 1,000° C. and is thereby melted as this is above the melting point of germanium. In this manner the conductivity of the surface layer may be controlled in some defined manner.

It is to be noted that by changing the parameters above recited that any type of material could be utilized. Thus, silicon which has a higher melting point than germanium could be worked upon in a similar manner.

It is also to be noted that a plurality of objects could be positioned in the place of the single object **91** of Figure 6 wherein each of the objects are scanned in turn by the deflecting system.

The temperature distribution across the diameter of the focused charged particle beam has been found to be that set forth in Figure 7. More specifically, Figure 7 shows that the central portion of the cross-sectional area of the beam has a higher temperature than do the outward portions, as is to be expected.

In radiating a germanium crystal such as the crystal **111** of Figure 8 with a charged particle beam having the temperature distribution set forth in Figure 7, the intensity of the electron beam may be so controlled that the temperature t_s of Figure 7 is the melting point of the crystal **111**. Thus, by applying this beam to the crystal **111** it is seen in Figure 7 that only the region between diameters $d1$ and $d2$ is brought to the melting point while the external portions are maintained in their solid state. In this way any contamination of the crystal by heating of other material adjacent to the crystal is completely avoided and possibilities of external contamination of the crystal are substantially reduced.

If, in the use of the embodiment of Figure 6, the beam is first applied to a material such as germanium crystal

111 of Figure 7 so that only the central portions of the focused beam will cause melting in the crystal and the beam intensity is fully reduced so as to cause a controlled cooling of the molten material, a point, such as the point **113** of Figure 8, has been found to grow on the crystal. This point is symmetrical and may be advantageously used in the connection of an electrode.

Furthermore, the material of point **113** and its surrounding areas contain a higher impurity concentration because of the diffusion of impurities to the portion which is at a higher temperature whereby, for example, the conductivity or any other property of the tip is easily controlled.

By way of example, in using the device as set forth in Figure 6, wherein a charged particle beam of 0.2 millimeter in diameter and a beam intensity of 0.2 milliampere and an acceleration voltage of 50,000 volts is impinged on the crystal for approximately 1 second, and thereafter decreased to cut-off in approximately 10 seconds, a point is formed on the original germanium crystal. If desired, this process may be so controlled that after the original point is formed, a second point may be formed on an adjacent portion so as to form any desired uplifted or embossed pattern on the crystal.

Although I have described preferred embodiments of my novel invention, many variations and modifications will now be obvious to those skilled in the art, and I prefer therefore to be limited not by the specific disclosure herein but only by the appended claims.

I claim:

1. The method of controlling the crystalline structure of a material; said method comprising the steps of positioning the material to have its crystalline structure controlled in a predetermined position, directing a beam of charged partcles at said material and focusing said beam of charged particles on a predetermined cross-sectional area portion of said material as defined by the cross-sectional area of said beam of charged particles bringing the said predetermined portion of said material to a predetermined temperature, and thereafter controllably affecting the application of said focused beam of charged particles to said predetermined portion of said material to allow a predetermined controlled decrease in the temperature of said heated predetermined portion to control the recrystallization of said predetermined portion in a predetermined manner.

2. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of said material until a surface portion of said material defined by the cross-sectioned area of said beam of charged particles impinging thereon is brought to a predetermined temperature and thereafter varying the relative position of said focused beam with respect to said material surface whereby said beam moves over a predetermined surface area of said material; the relative motion between said beam and said surface of said material being controlled to permit a predetermined controlled cooling of any heated discrete area of said surface area when said charged particle beam is removed to another discrete area during said scanning process to produce a thin surface hardened shell.

3. The method of controlling the crystalline structure of a material; said method comprising the focusing of a beam of charged particles to act as a heat source on a portion of said material whereby the cross-sectional area of said material defined by the cross-sectional area of said beam of charged particles is brought to a predetermined temperature and thereafter affecting the application of said focused beam of charged particles to said portion to allow a predetermined controlled decrease in the temperature of said portion to control the recrystallization of said portion in a predetermined manner by controlling the intensity of said beam of charged particles in a predetermined manner.

4. The method of controlling the crystalline structure of material; said method comprising the focusing of a beam of charged particles to act as a heat source on a portion of said material whereby the cross-sectional area of said material defined by the cross-sectional area of said beam of charged particles is brought to a predetermined temperature and thereafter affecting the application of said focused beam of charged particles to said defined area to allow a predetermined controlled decrease in the temperature of said heated area to control the recrystallization of said area in a predetermined manner by controlling the intensity of said beam of charged particles by intermittently energizing and cutting off said beam of charged particles applied to said predetermined area.

5. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of a material to have its crystalline structure controlled and retaining said focused beam of charged particles on a predetermined surface area of said material until said predetermined surface area is brought to a predetermined temperature and thereafter cooling said predetermined area in a predetermined controlled manner to controllably affect the crystalline structure of said predetermined area in a predetermined manner.

6. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of said material until a surface portion of said material defined by the cross-sectional area of said beam of charged particles impinging thereon is brought to a predetermined temperature and thereafter moving said beam of charged particles to a position removed from said area brought to said predetermined temperature to permit a controlled decrease in temperature of said area to control the recrystallization of said area.

7. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of said material until a surface portion of said material defined by the cross-sectional area of said beam of charged particles impinging thereon is brought to a predetermined temperature and thereafter moving said material with respect to the focal point of said focused charged particle beam to permit a predetermined decrease in the temperature of the portion of said material which was brought to said predetermined temperature to permit a controlled recrystallization of said portion.

8. The method of controlling the crystalline structure of material; said method comprising the focusing of a beam of charged particles to act as a heat source on a portion of said material whereby the cross-sectional area of said material defined by the cross-sectional area of said beam of charged particles is brought to a predetermined temperature and thereafter affecting the application of said focused beam of charged particles to said defined area to allow a predetermined controlled decrease in the temperature of said heated area to control the recrystallization of said area in a predetermined manner by controlling the intensity of said beam of charged particles by intermittently energizing and cutting off said beam of charged particles applied to said predetermined area, and thereafter causing relative motion between said focused beam of charged particles and said material to apply said focused beam at a different portion of said material.

9. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of a material to have its crystalline structure controlled and retaining said focused beam of charged particles on a predetermined surface area of said material until said predetermined surface area is brought to a predetermined temperature and thereafter cooling said predetermined area in a predetermined controlled manner to controllably affect the crystalline structure of said predetermined area in a predetermined manner by bringing a quenching medium into contact with said material.

10. The method of controlling the crystalline structure of a material comprising the steps of focusing a beam of charged particles to act as a heat source on the surface of a material to have its crystalline structure controlled and retaining said focused beam of charged particles on a predetermined surface area of said material until said predetermined surface area is brought to a predetermined temperature and thereafter cooling said predetermined area in a predetermined controlled manner to controllably affect the crystalline structure of said predetermined area in a predetermined manner by moving said material into a quenching medium when the said portion of the surface area of said material reaches a predetermined temperature.

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