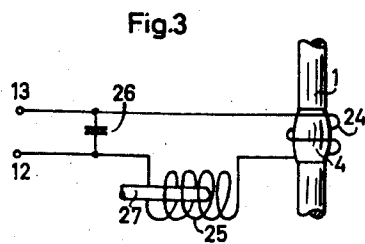
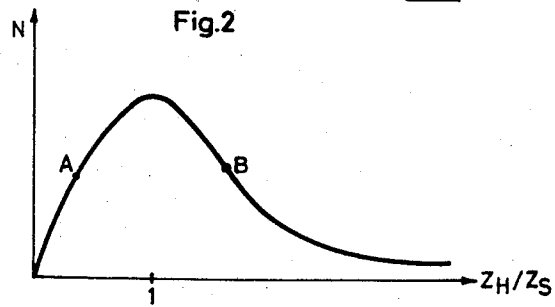
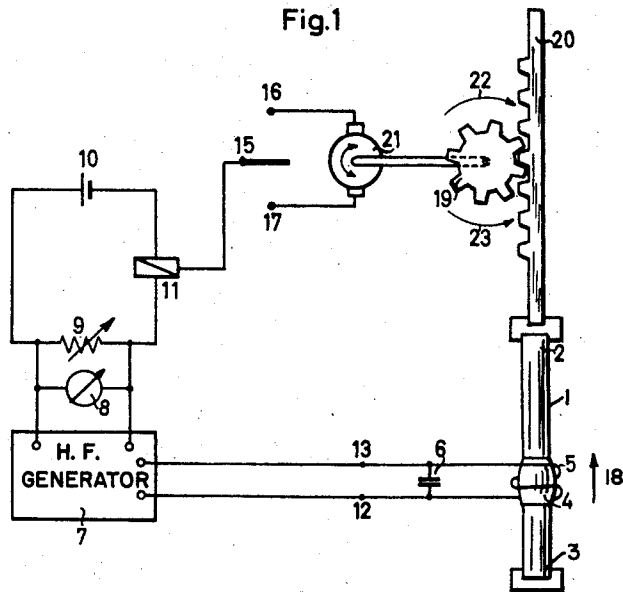


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PROCESSING SEMICONDUCTOR RODS

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## PROCESSING SEMICONDUCTOR RODS

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This invention relates to the processing of semiconductor rods and is particularly concerned with automatic thickness regulation incident to zone drawing applied to semiconductor rods.

C. Theurer has described a method of zone drawing of semiconductor rods, especially silicon rods, comprising holding a silicon rod at its opposite ends, and drawing a molten zone produced by inductive heating through the medium of a high frequency coil, axially of the rod. Such method is employed for purifying semiconductor material and for producing mono-crystalline semiconductor rods.

The invention proposes a method of and a device for producing incident to zone drawing a mono-crystalline semiconductor rod of defined thickness, that is, of a thickness which remains uniform within a desired range.

In accordance with the invention, the current fed from a high frequency current source to the coil surrounding the semiconductor rod, which changes with changing thickness of the rod, is utilized for controlling the operation of a device adapted to change the spacing between the holding means for the semiconductor rod, such device moving the holding means respectively toward and away from each other, until the current flowing in the high frequency coil again assumes the desired value.

The high frequency coil is in accordance with the invention very short as compared with the length of the semiconductor rod. It is advantageous but not absolutely necessary to employ the high frequency coil for the control of the thickness of the semiconductor rod at the same time for the heating of the molten zone. If desired, a separate coil supplied from a separate high frequency generator, may be used for the thickness regulation.

The various objects and features of the invention will be brought out in the course of the description which will be rendered below with reference to the accompanying drawings, in which

Fig. 1 shows the principles underlying the operation;

Fig. 2 indicates the power  $N$  delivered by the generator depending upon the ratio of the load resistance  $Z_H$  to the output resistance of the transmitter  $Z_S$ ; and

Fig. 3 illustrates a feature of the heating system.

In Fig. 1, numeral 1 indicates a semiconductor rod, for example, a silicon rod which is held at its ends 2 and 3. In the illustrated example, the high frequency coil 5 also serves for the heating of the zone 4. This entire arrangement is contained in a quartz tube (not shown) in a protective gas atmosphere. A supporting field coil may be provided for additionally increasing the molten zone. The supporting field coil and the high frequency coil 5 are arranged so that they can be moved along the rod at a given speed. For example, if the molten zone is moved in the direction indicated by the arrow 18, the device for compressing and stretching the rod during the zone drawing will in accordance with the invention be arranged at the end of the semiconductor rod indicated by numeral 2. The device is generally always arranged at the end

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of the rod which solidifies last because, in such a case, faults occurring in the crystal grid due to the compression and stretching of the rod can be eliminated by the successive melting zone, resulting in rods exhibiting good crystal perfection.

A capacitor 6 may be disposed in parallel with the high frequency coil 5 for compensating the inductive characteristic impedance thereof, resulting in the advantage that the high frequency generator 7 has to supply only the effective operating current for the heating effect and the ohmic losses of coil 5 and capacitor 6, which is much less than the current normally flowing through the coil.

The oscillating circuit formed by the coil 5 and the capacitor 6, which is detuned as against the interior transmitter oscillating circuit of the generator, is coupled capacitively or inductively to the transmitter oscillating circuit. The coupling is thereby so loose that the system generator-heating circuit will oscillate with one frequency even responsive to a further detuning of the heating circuit caused by thickness variations of the semiconductor rod.

The high frequency current flowing in the coil 5 induces in the part of the semiconductor rod surrounded thereby, a voltage which produces a current the magnetic field of which opposes the field produced by the coil. This part of the semiconductor rod can therefore be compared with a coil winding. As is known, the coupling factor of such coil arrangement is a function of the geometric dimensions of the coils and proportional to the diameter of the inner coil. Therefore, if the thickness of the semiconductor rod changes during the operation according to the invention, the coupling factor and therewith the resistance  $Z_H$  of the heating circuit, measured across the terminals 12, 13, will likewise change. This load variation effects a variation in the anode current which is indicated by the instrument 8. A definitely determined magnitude of the anode current will accordingly correspond to a definite thickness of the rod.

The variable resistor 9 is at the start of the operation so adjusted that an anode current corresponding to the desired rod thickness causes a voltage drop at such resistor, which is equal to the voltage delivered by the battery 10, so that the polarized relay 11 will be in a normal position with the contact spring 15 positioned as shown. If the thickness of the semiconductor rod and therewith the anode current of the generator change in the course of the operation, the relay 11 will energize, causing the contact 15 to establish engagement with contact 16 or contact 17, depending upon the direction in which the current change took place. Closure of the circuit over one or the other of these contacts 16 or 17 will effect operation of motor 21 to actuate by way of a suitable gear (not shown) a toothed wheel 19 for the purpose of moving the ratchet 20 so as to effect either compression or stretching of the semiconductor rod depending upon the direction of rotation of the toothed wheel 19.

Fig. 2 shows the power  $N$  delivered by the generator depending upon the ratio of the load resistance  $Z_H$  to the output resistance of the transmitter  $Z_S$ . The delivered power as is known, is upon matching, that is,  $Z_H = Z_S$ , greatest. In the method according to the invention, the load resistance  $Z_H$  is such, for example, that the power delivered by the generator at the thickness of the semiconductor rod which is to be maintained by the regulation corresponds to that indicated at point A, the operation being accordingly within the ascending branch of the curve.

It will be appreciated from previous explanations that the coupling factor will become smaller for a rod becoming thinner, that is, the coupling between the high frequency coil and the part of the semiconductor represent-

ing a coil winding, will become looser and  $Z_H$  will accordingly become greater. It is apparent from Fig. 2 that the matching will then improve, that is, the delivered power and therewith the anode current, will increase. However, when the semiconductor rod becomes thicker, 5 resulting in tighter coupling,  $Z_H$  and also the anode current will become smaller.

The load resistance  $Z_H$  may also be such as to permit working within the descending branch of the curve, about 10 at the point B, that is, the power N delivered by the generator and therewith the anode current will become smaller when the rod becomes thinner and  $Z_H$  increases. In order to obtain thickness regulation in the desired direction, the relay 11 must be oppositely poled as compared with the operation which utilizes the working point A 15 in the ascending branch of the curve.

If the working point is along the ascending branch of the curve, the anode current indicated by the instrument 8 will rise when the rod becomes thinner. The relay 11 must be poled so that it closes, for example, the contact 20 16 to cause operation of the motor 21 so as to rotate the toothed wheel 19 in the direction of the arrow 22, resulting in compression of the semiconductor rod, that is, in reducing the spacing between the ends 2 and 3 for an interval until the anode current has again the desired 25 value, causing the relay 11 to restore with the contact spring 15 in the normal position shown.

When the rod becomes thicker, the anode current will become lower and relay 11 will operate its contact 15 30 to engage contact 17, causing the motor 21 to rotate the toothed wheel 19 in the direction of the arrow 23, resulting in stretching of the semiconductor rod until the anode current again assumes the desired value to effect restoration of the relay 11.

The heating system shown in Fig. 3 is connected when 35 it is desired to change the thickness of the semiconductor rod during the drawing. In addition to the high frequency coil 24 which surrounds the semiconductor rod 1, there is provided a second coil 25 in series therewith. The characteristic impedance of these two coils can again be 40 compensated by means of a capacitor 26. The inductance of the coil 25 may be varied, for example, by immersion into or withdrawal from the coil 25, of a metallic member 27, thereby affecting the operatively effective 45 load resistance of the system between the terminals 12 and 13 and therewith the anode current and the thickness of the semiconductor rod.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent. 50

We claim:

1. In the art of zone drawing semiconductor material, wherein a rod of highly pure semiconductor material is held at its opposite ends by holding means therefor, and wherein a molten zone, produced by inductive heating 55 through the medium of a high frequency coil surrounding said rod, is moved axially of said rod, the improvement which consists in utilizing the current supplied from a high frequency current source to the coil surrounding said rod, which current changes with changing thickness of the rod, for controlling the operation of a device adapted to vary the spacing between said rod-holding means, said device being operative to move said rod-holding means 60 respectively together and apart to effect compression and stretching of the semiconductor rod until the current flowing in said high frequency coil assumes a desired value.

2. In the art of processing highly pure semiconductor rods by the use of apparatus including means for holding a semiconductor rod to be processed at the opposite ends 70 thereof, and wherein a zone of said rod is melted by inducting heating through the medium of a high frequency coil surrounding said rod, said molten zone being moved axially of said rod, a method of automatically regulating the thickness of the molten zone to maintain the thickness

of the rod substantially uniform, said method comprising utilizing the current supplied to said high frequency coil from a high frequency current source, which current changes with changing thickness of said molten zone, for causing a force to be applied to said rod-holding means so as to vary the spacing therebetween for the purpose of respectively stretching and compressing said semiconductor rod, thereby maintaining the molten zone at a desired thickness and consequently causing a current to flow in said high frequency coil which is of a magnitude corresponding to the desired thickness of the semiconductor rod.

3. A method according to claim 2, wherein said high frequency coil is short as compared with the length of said semiconductor rod.

4. A method according to claim 2, wherein said force is applied at the end of said semiconductor rod which solidifies last.

5. A method according to claim 2, wherein said high frequency coil is in circuit with said high frequency current source to provide for increased current flow from said high frequency current source responsive to decreasing thickness of the molten zone.

6. A method according to claim 2, wherein said high frequency coil is in circuit with said high frequency current source to provide for decreased current flow from said high frequency current source responsive to decreasing thickness of said molten zone.

7. A method according to claim 2, wherein a capacitor is disposed in parallel with said high frequency coil.

8. A method according to claim 2, wherein the oscillating circuit of said high frequency current source is detuned with respect to the oscillating circuit of said high frequency coil, said circuits being relatively loosely 45 coupled over a coupling member.

9. A method according to claim 2, comprising connecting a further coil in series with said high frequency coil and changing the inductance of said further coil by displacement of a metallic member relative thereto, for the purpose of changing the thickness of the semiconductor rod during the processing thereof.

10. In apparatus for processing highly pure semiconductor rods including means for holding a semiconductor rod to be processed at the opposite ends thereof and having a high frequency coil which surrounds said semiconductor rod and which is supplied with current from a high frequency source to effect melting of a zone along said rod by inductive heating thereof, which zone is moved axially of said rod, an arrangement for automatically regulating the thickness of said semiconductor rod during the processing thereof, comprising a device for varying the spacing between said rod-holding means to effect respectively stretching and compressing of said rod, operating means for said device, control means for governing said operating means, and circuit means controlled by the current supplied by said high frequency source to said high frequency coil, which current changes with changing thickness of said molten zone, for governing the actuation of said control means.

11. A structure and cooperation of parts according to claim 10, wherein said high frequency coil is short as compared with the length of said semiconductor rod.

12. A structure and cooperation of parts according to claim 10, wherein said device for varying the spacing between said rod-holding means cooperates with said rod at the end thereof which solidifies last.

13. A structure and cooperation of parts according to claim 10, wherein said high frequency coil is in circuit with said high frequency current source to provide for increased current flow from said source responsive to decreasing thickness of said molten zone.

14. A structure and cooperation of parts according to claim 10, wherein said high frequency coil is in circuit with said high frequency current source to provide for

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decreased current flow from said source responsive to decreasing thickness of said molten zone.

15. A structure and cooperation of parts according to claim 10, comprising a capacitor connected in parallel with said high frequency coil.

16. A structure and cooperation of parts according to claim 10, wherein the oscillating circuit of said high frequency current source is detuned with respect to the oscillating circuit of said high frequency coil, and a coupling member for relatively loosely coupling said oscillating circuits.

17. A structure and cooperation of parts according to claim 10, in combination with means for changing the thickness of the semiconductor rod during the processing thereof, comprising a further coil connected in series with said high frequency coil, and a metallic member disposed for immersion into and withdrawal from said further coil to change the inductance thereof.

18. A structure and cooperation of parts according to claim 10, wherein said control means comprises a relay connected to the anode circuit of said high frequency current source for governing the actuation of said operating means to control the operation of said device to effect

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compressing or stretching of said semiconductor rod responsive respectively to decrease and increase of the thickness of said molten zone.

19. A structure and cooperation of parts according to claim 18, wherein said operating means comprises a reversible motor for controlling said device in two directions of motion thereof, and circuit means governed by said relay for controlling the directional rotation of said motor depending upon variations of the anode current of said high frequency current source.

20. A structure and cooperation of parts according to claim 19, comprising a capacitor and a resistor connected in series with said relay.

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