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[56]

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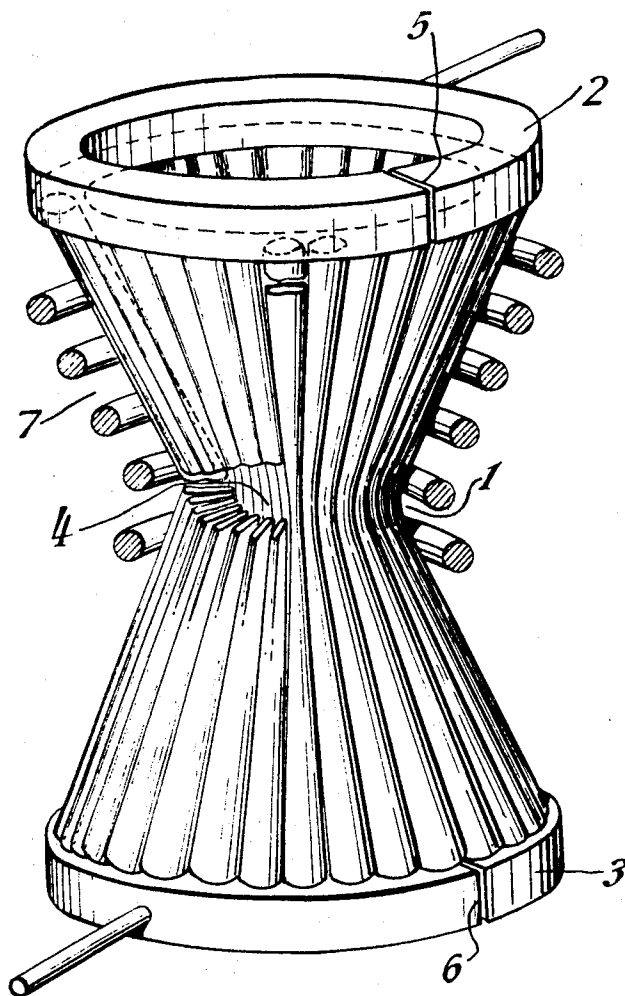
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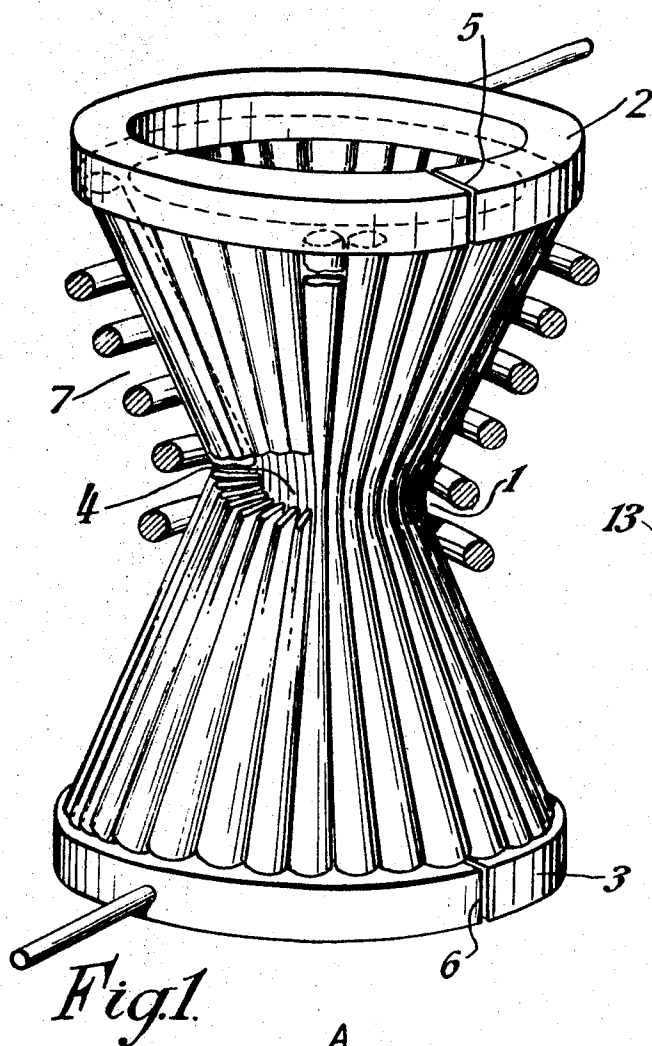
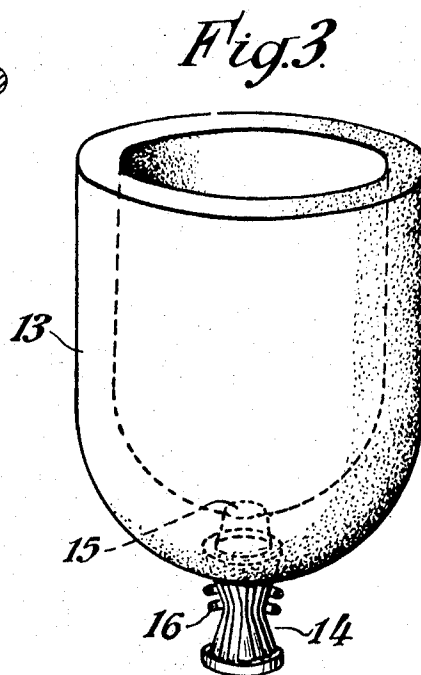
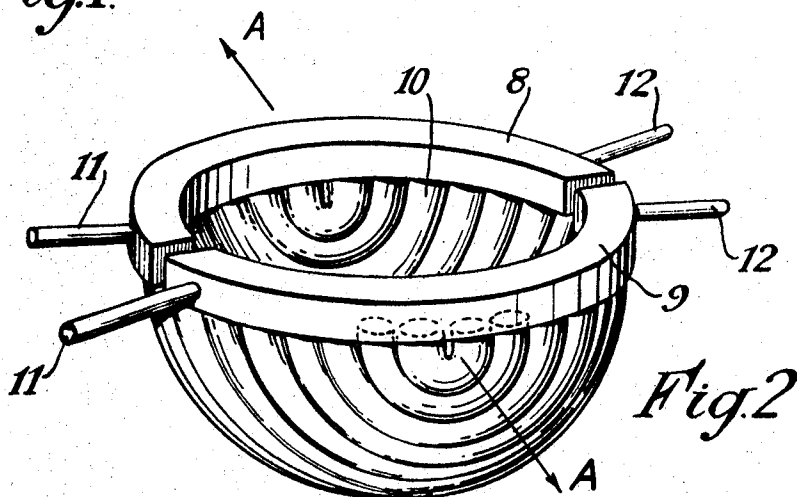
[54] TREATMENT PROCESS

5 Claims, 3 Drawing Figs.

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	219/75, 266/33, 263/52
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	H05b 5/12
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	10.49, 10.79; 13/27

ABSTRACT: This invention relates to that method of processing charges of electrically conducting or semiconducting material by fusing the charge in a crucible by means of induction heating effects induced in the charge by a working coil surrounding the crucible. The invention is characterized in that the crucible is provided with a pouring aperture in the base thereof and that the charge is supported above the pouring aperture in the crucible at least during the fusing thereof by means of electromagnetic forces induced in the charge by the working coil. Preferably the crucible is a liquid-cooled crucible of an electrically conducting material (i.e. is fabricated from a cage of water-cooled copper tubes).





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TREATMENT PROCESS

This invention relates to an improved method of processing a molten charge of an electrically conducting or semiconducting material which has particular reference to the production of ultra high purity materials.

According to the invention, a method of processing a charge of an electrically conducting or semiconducting material which method comprises fusing the charge in a crucible by means of induction heating effects induced in the charge by a working coil surrounding the crucible, is characterized in that the crucible is provided with a pouring aperture in the base thereof and that the charge is supported above the pouring aperture in the crucible at least during the fusing thereof by means of electromagnetic forces induced in the charge by the working coil.

The employment of electromagnetic forces to both levitate and heat molten charges has already been proposed but heretofore it has not been appreciated that such levitating forces can be employed to support a complete charge in a crucible having an aperture in its base and thereby to permit "bottom pouring" of the crucible contents when the heating cycle is completed, merely by removing, or at least reducing, the electromagnetic field.

In the production of highly pure materials (e.g. high tensile alloys or semiconductor materials) the avoidance of sources of contamination is of prime importance. Typically, such materials are melted in induction furnaces with a vacuum, or an atmosphere of a chemically inert gas, surrounding the charge, the surrounding atmosphere or vacuum being maintained by a refractory, air-impermeable container in which the crucible (and sometimes also the working coil) is placed.

If the charge is not to be allowed to solidify in the crucible (with consequent problems of removal after it has solidified) means must be provided to pour the melt from the crucible while maintaining the surrounding atmosphere or vacuum. The crucible can be tipped within the container, but this requires a larger container than is otherwise desirable. The "bottom pouring" technique has the advantage that it can be very simply employed but heretofore has suffered from the serious disadvantage that the plug used to close the pouring aperture represents a source of contamination which militates against the production of the highest purity materials.

We have now discovered that by simple empirical design of the crucible and its shape and disposition relative to a working coil, a charge can be supported in molten condition within an open-bottomed crucible so that bottom pouring can be effected merely by removing or at least reducing the levitating and heating electromagnetic field.

The invention lends itself particularly to use with liquid-cooled, electrically conducting crucibles where the crucible has a concentrating effect on the electromagnetic field enabling molten charges of several kilograms to be processed by the method of the invention.

The size of the pouring aperture should be chosen with regard to the power input and frequency of the working coil as well as the density, resistivity and surface tension of the charge to ensure that the horizontal cross section of the lowest region of the fused charge in the crucible is large enough to avoid "current cancellation" arising therein.

The crucible will normally taper in the downward direction towards the pouring aperture, but the geometric form of this taper has not been found to be critical. Thus crucibles of part spherical or part conical form can be employed. A preferred shape for a liquid-cooled, electrically conducting crucible is double frustoconical (i.e. a diabolo shape) with a semiangle of between 25° and 45°. The preferred semiangle varies depending on the same parameters already mentioned with regard to the critical size of the pouring aperture and can best be determined empirically.

In order to permit circulating currents to flow in a conducting crucible, it is necessary to ensure that complete encircling electrically conducting paths are not available in the crucible. This can easily be arranged in practice by splitting the crucible

in a vertical plane and although we prefer to maintain the split portions of the crucible in the same relative positions throughout the heating and pouring operations, it will be appreciated that the pouring action can be facilitated by a separation of the split portions of the crucible to increase the size of the pouring aperture.

The crucible can be of refractory nonconducting material, in which case the levitation effect necessary to retain the charge therein until pouring is commenced can be provided by a concentrator (e.g. a liquid-cooled cage of copper tubes) disposed below the pouring aperture of the refractory crucible. The concentrator then serves as a "magnetic valve" preventing flow through the pouring aperture until the valve is "opened" by removing the levitating electromagnetic field produced thereby.

Where the initial charge is of granular material (the individual granules of which may be so small that current cancellation occurring therein prevents the generation of a levitating force) it may be necessary to obturate the pouring aperture until at least partial fusion of the charge has occurred. For this purpose a liquid cooled plug can be employed, the plug being removed at the earliest opportunity to minimize the risk of contamination from this source.

Alternatively a split crucible may be employed, the parts of which can be moved together at the commencement of a heating operation (to prevent unfused particles falling from the bottom of the crucible) and then opened after fusing has occurred to define a pouring aperture greater than the critical size, electromagnetic levitation than being relied upon to retain the molten charge in the crucible until pouring is required.

Any convenient receptacle can be employed to collect the molten charge when pouring occurs.

Three embodiments of crucible suitable for employment in the method of the invention are illustrated, by way of example in the accompanying drawing, in which:

FIG. 1 shows a cage of tubes with a fixed pouring aperture,

FIG. 2 shows a cage of tubes, openable to increase the dimension of the pouring aperture, and

FIG. 3 shows a conventional "hot" crucible with a magnetic valve defined by a cage of tubes similar to that shown in FIG. 1.

The crucible illustrated in FIG. 1 shows a double-conical array of tubes 1 linking an upper header 2 and a lower header 3. The array of tubes defines gaps therebetween which are too small to allow molten material (e.g. silicon, tungsten or titanium) to flow out of the upper portion of the crucible (i.e. the portion between the upper header 2 and a pouring aperture 4). The upper and lower headers are split at 5 and 6, respectively, to break the path for shorting currents to flow therearound. Water is fed to the crucible through one header and removed from the crucible via the other so that water flows through each tube to keep the entire crucible well below the melting point of the metal from which it is made (e.g. copper, silver or silver-plated copper). A helical working coil 7 surrounds the upper portion of the crucible and extends a short distance below the pouring aperture. The diameter of the turns of the coil 7 vary from turn to turn to maintain a substantially constant working clearance between the turns and the adjacent wall of the crucible. The precise disposition of the turns of the coil are chosen such that levitating field is produced in the vicinity of the aperture 4 which is strong enough to support the molten charge. The aperture 4 is typically some 5 mm. to 25 mm. in diameter.

The crucible shown in FIG. 2 comprises two semicircular upper headers 8 and 9 each supporting an approximately part spherical array of tubes 10. Each header has a water inlet 11 and a water outlet 12. The two parts of the crucible are mounted for controlled relative movement in the directions of the arrows A when pouring is desired. The working coil (not shown) surrounds the crucible and serves to fuse and levitate a molten charge of electrically conducting material contained therein. The gaps between the tubes of each part and the ad-

jacent tubes of the two parts, in their position of closest approach are too small to allow loss of material from the crucible.

FIG. 3 shows a conventional "hot" crucible 13 (e.g. of refractory oxide material or graphite) with a cage 14 of cooled tubes disposed below a pouring aperture 15 therein. A working coil 16 (which may be in series with the main heating coil (not shown) of the crucible) surrounds the cage 14 and prevents flow of molten charge through the aperture 15 until pouring is required.

EXAMPLE 1

A crucible as shown in FIG. 1 constructed from 34 copper tubes 1 of an outside diameter of one-quarter inch and a wall thickness of around 0.020 inch. The crucible was some 5 inches long between the headers 2 and 3, had a maximum internal diameter of 3 inches and a pouring aperture 4 of an internal diameter of one-half inch. (The tubes 1 were flattened in the vicinity of the pouring aperture and alternately staggered slightly, the diameter of the pouring aperture being measured around the inner surface of the alternate tubes closest to the vertical axis of symmetry of the crucible).

Seven hundred grams of a tungsten ingot was placed in the upper part of the crucible and melted by the application of some 80 kilowatts at a frequency of 350 kilocycles applied to the working coil 7. The tungsten fused into a ball (of approximately the size of a golf ball) which remained in the upper part of the crucible. When the HF power was turned off the spherical shape of the molten material disappeared and the molten tungsten poured through the aperture 4 into a mold placed below the crucible.

EXAMPLE 2

A crucible similar to that shown in FIG. 1 being a scaled-up version of that described in example 1, was used for melting a 20 kg. ingot of tungsten. The crucible was some 12 inches long with a maximum inside diameter of some 9 inches and a pouring aperture 4 of about 1 inch. The tubes 1 were of a wall thickness of 0.050 inch.

The working coil was fed with 50 kilowatts of HF energy at 3—4 kilocycles and when the ingot melted it formed a roughly spherical ball some 4¼ inches in diameter. Bottom pouring was achieved by turning off the HF power.

What we claim is:

1. A method of processing a charge of an electrically conducting or semiconducting material which method comprises fusing the charge in a crucible by means of induction heating effects induced in the charge by a working coil surrounding the crucible, characterized in that the crucible is provided with a pouring aperture in the base thereof and that the charge is supported above the pouring aperture in the crucible at least during the fusing thereof by means of electromagnetic forces induced in the charge by the working coil.

2. A method as claimed in claim 1, in which the crucible is a liquid-cooled crucible of an electrically conducting material.

3. A method as claimed in claim 2, in which the crucible is fabricated from a cage of water-cooled copper tubes.

4. A method as claimed in claim 3, in which the cage of tubes is of diabolo shape with the pouring aperture located at the narrowest part of the crucible.

5. A method as claimed in claim 1, in which the crucible is housed in an air-impermeable container which also encloses a mold below the crucible to receive the poured charge.

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