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APPARATUS FOR GROWING SINGLE CRYSTALS

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FIG. 1

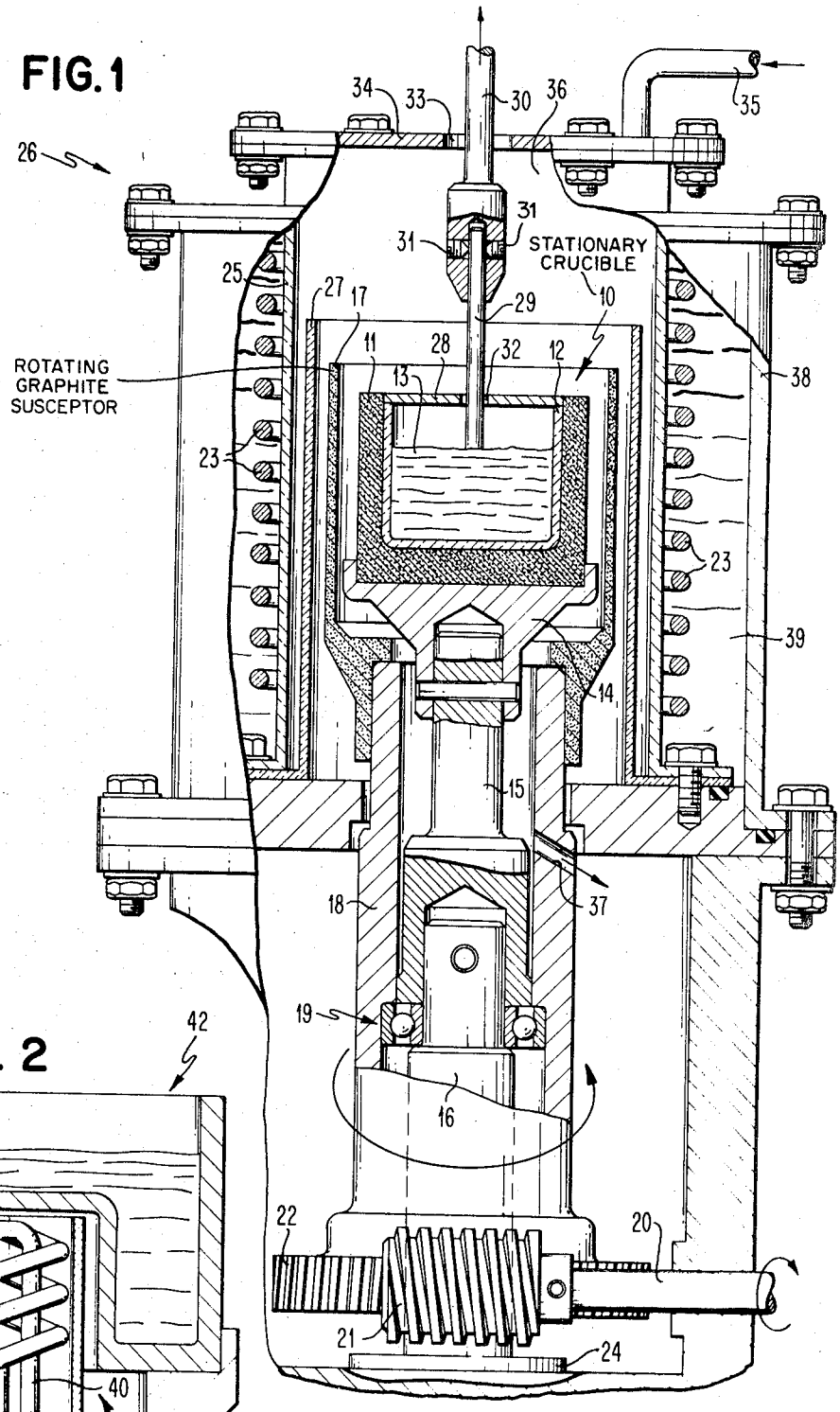
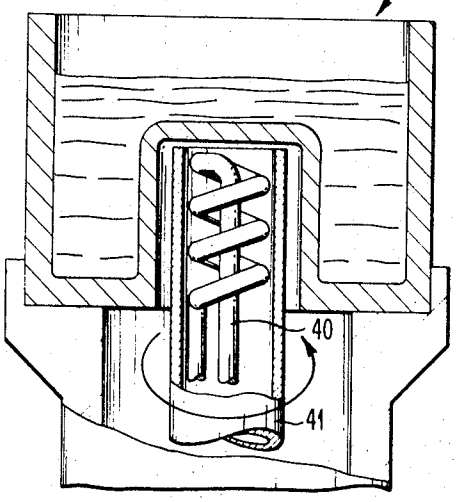



FIG. 2




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# APPARATUS FOR GROWING SINGLE CRYSTALS

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## ABSTRACT OF THE DISCLOSURE

Apparatus for the growth of single crystals by Czochralski-type crystal pulling, in which the crystal is pulled from a melt contained in a central crucible which is heated by RF induction. The crucible is surrounded by an annular member of an electrically conductive refractory material which is coaxial with the crucible and rotatable about the common axis. The RF induction heat is generated in the rotating annular member by a coil encircling the member and this heat is transferred uniformly to the central crucible.

## BACKGROUND OF THE INVENTION

### Field of the invention

The present invention relates to improved apparatus for the production of single crystal materials. Crystals of semiconductor material such as silicon and germanium, extensively used in the production of solid state electronic components, are grown in such apparatus.

### Description of the prior art

The most commonly used method for the growth of such single crystals of semiconductor materials is the well-known Czochralski method in which a charge of hyperpure silicon from which the single crystal is to be grown is placed in a quartz-lined graphite crucible. If a doping impurity is to be added to the crystal, it is added to the silicon in the crucible during the growth. The crucible and its charge are placed within a quartz housing and a controlled, inert atmosphere is provided. RF induction coils which encircle the crucible induce heat in the graphite crucible. The charge temperature of the apparatus is stabilized at just above the melting point of the silicon. Then, a seed crystal, which is a small, highly perfect and oriented crystal of silicon, is dipped into the molten silicon. The seed is permitted to melt partially to remove any surface imperfections which may have arisen in its preparation. The seed is then very slowly withdrawn from the melt. Conventionally, the seed is rotated while it is being withdrawn so that the crystal produced is cylindrical. The finished crystal is typically about 1"–1½" in diameter and 8" to 10" long. Growth of single crystals by this method is commonly known as crystal pulling.

After the cylindrical crystal has been grown, it is sawed into thin slices commonly referred to as wafers. These thin wafers are then subjected to a conventional series of epitaxy, masking, diffusion, and metallization steps required to produce the desired microelectronic components or integrated circuits.

While RF induction heating is most commonly used in crystal pulling apparatus, other heating such as resistance heating has also been utilized. In resistance heating, the crucible is heated by means of an encircling resistor element from which heat is transferred to the crucible instead of by the RF induction of heat in the crucible.

In order to obtain accurate crystal growth, it is necessary to have uniform temperature distribution at each



cross-sectional level in the melt. Difficulty has been encountered in maintaining such a uniform temperature distribution at each level. This was believed to be primarily due to a lack of exact concentricity between the encircling heating element or coil and the enclosed crucible.

One approach which has been utilized to provide such uniform temperature distribution at each level is by the rotation of the crucible containing the melt within the coil or heating element. This exposes portions of the crucible and the melt at a given level to identical thermal conditions which results in a uniform temperature distribution at that level. Unfortunately, rotation of the crucible and melt causes vibrations in the melt which tend to introduce lattice dislocations or disruptions in the crystal being grown. While vibration-caused imperfections are a general problem in all processes in which the melt is rotated, they represent a particularly serious problem in crystal growing processes in which elongated dendritic crystals are being grown. Dendrites or flat ribbon-like crystals are made by pulling crystal seeds from a supercooled melt at a higher rate of speed than conventional cylindrical crystals are pulled. In the growth of crystals of this structure, rotation of either of the crystal or melt is not possible. Because of the small thickness of these ribbon-like crystals, the surface tension will not withstand the shear forces of rotation, and the crystal separates from the melt to end further growth. Consequently, it is standard practice to pull dendritic crystals from a melt in a stationary crucible. On the other hand, because dendritic crystals are pulled from a super-cooled melt, it is highly important that a uniform temperature distribution is maintained at each level in the melt and particularly in the super-cooled upper level of the melt from which the crystal is being pulled. In crystal-pulling apparatus utilizing a stationary crucible, a uniform temperature distribution at each level is very difficult to maintain, and excessive thermal gradients develop, particularly in peripheral regions adjacent to the crucible walls. Such pheripheral temperature conditions render it extremely difficult to maintain the melt in a super-cooled condition because spurious nucleation points arise in these peripheral regions causing the melt itself to crystallize at the crucible sidewalls.

## SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a uniform crystal-pulling apparatus in which each level of the melt has a uniform heat distribution.

It is a further object of this invention to provide such uniform temperature distribution in apparatus having a stationary crucible.

It is a still further object of the present invention to provide crystal-pulling apparatus for the production of uniform crystals having a minimum of dislocations or other imperfections.

It is yet another object of this invention to provide crystal-pulling apparatus for the production of dendritic crystals having a minimum of dislocations or other imperfections.

It is an even further object of this invention to provide apparatus insuring a uniform temperature distribution at each level in the melt without any attendant increase in dislocations or other crystal disruptions.

It is an additional object of this invention to provide for uniform temperature distribution at each melt level in RF induction heated crystal-pulling apparatus.

The apparatus of the present invention achieves uniform temperature distribution without attendant crystal dislocations by utilizing, in combination with the crucible,

an axially rotatable annular member made of an electrically conductive refractory material which is adjacent to and coaxial with said crucible. The apparatus further includes means for rotating said annular member independently of said crucible member and means for heating the annular member whereby the rotating annular member transfers heat uniformly to all areas at a given melt level in the crucible.

The crucible, annular member and heating means are preferably coaxial with the annular member disposed intermediate the crucible and the heating means. For best results in semiconductor crystal pulling, the crucible is centrally disposed surrounded by the rotatable annular member which is, in turn, encircled by the heating means. The heating means is preferably an induction coil, e.g., RF induction, which induces heat in the rotatable annular member. The rotatable member is preferably made of graphite.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description and preferred embodiments of the invention as illustrated in the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial, longitudinal, sectional view of a preferred embodiment of the crystal-pulling apparatus of the present invention.

FIG. 2 is a diagrammatic, partial, sectional view of another embodiment of the apparatus of this invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a preferred embodiment of the apparatus of the present invention. The apparatus is arranged for the growth of dendritic crystals. However, it may be readily utilized for the growth of cylindrical crystals merely by utilizing a conventional, rotatable pulling rod of a slightly different design. Crucible **10**, comprising graphite body **11** and quartz liner **12**, contains a melt **13** of hyperpure silicon. The crucible is affixed to pedestal **14** on stationary shaft **15** which is mounted on shaft **16** supported on base **24**. Pedestal **14** and shafts **15** and **16** may be suitably made of graphite. Annular member or susceptor **17**, made of an electrically conductive refractory material, which in the present structure is graphite, is affixed to rotatable shaft sleeve **18**. Sleeve **18** is rotatable about stationary shaft **16** by means of bearing coupling **19**. The rotational motion of sleeve **18**, and consequently of annular susceptor **17**, is provided by a motor (not shown) which rotates drive shaft **20**, the rotation of the drive shaft being transmitted to rotatable sleeve **18** by means of mating worm gears **21** and **22**.

The crucible is heated by means of induction heating coil **23** disposed so as to encircle rotating annular susceptor **17**. Control means, not shown, supply an alternating RF current to induction coil **23**. The coil induces heat in rotating susceptor **17** which is uniformly transferred to crucible **10** to provide a uniform heat distribution at each level in melt **13**. The induction effect of coil **23** upon rotating susceptor **17** is not interfered with by either walls **25** of housing **26**, or by heat shield **27**. While the walls and the heat shield are between coil **23** and rotating susceptor **17**, they are made of a dielectric material such as quartz and consequently, they do not affect the induction heating of susceptor **17**. Housing **26** acts to maintain controllable temperature and atmospheric conditions during the crystal-pulling operation, and heat shield **27** aids in temperature control by preventing the loss of heat by outward radiation from the crucible.

In the growth of dendritic crystals, the temperature of the melt is readily controllable to provide an initial uniform temperature a few degrees above the melting point. Then, the current of the coil **23** is reduced so that the temperature of the melt drops, within five to ten seconds, to a level below the melting temperature, and preferably, the melt is supercooled 5° to 15° C. A crucible cover **28**, closely fitting on the top of crucible **10**, may be provided to maintain a low thermal gradient above the melt neccessary in the pulling of dendritic crystals. Seed crystal **29** is fastened to pulling rod **30** by screw means **31**. The crystal passes through aperture **32** in cover **28** into melt **13**. The pulling rod **30** is actuated by a conventional crystal-pulling mechanism, not shown, which controls its upward movement at a selected uniform rate, ordinarily at a rate of from ¼″ to 4″ per minute. The pulling rod is withdrawn through aperture **33** in cover **34** of housing **26**. A suitable protective atmosphere is introduced through conduit **35** into enclosure **36** within housing **26**. The atmosphere circulates around the crucible through the space between shaft **15** and sleeve **18** and out through vent **37**. In the growth of crystals from a silicon melt, the atmosphere is preferably an inert gas such as nitrogen, helium or argon. Other atmospheres may also be utilized. Depending on the crystal material being produced, the protective atmosphere may comprise helium, or a reducing gas such as hydrogen, or mixtures of hydrogen and nitrogen. In some cases, the space around the crucible may be evacuated to a high vacuum in order to insure crystals free of any gas contamination. During a lengthy and continuous crystal-pulling operation, wall **25** may display a tendency to become undesirably overheated. Such overheating causes the devitrification of the quartz. This tendency may be readily compensated for by enclosing the coil in a jacket **38** and filling the region enclosed by the jacket with a liquid coolant **39** such as water. This structure acts as a heat exchanger which keeps wall **25** below its devitrification temperature.

The significant feature of the apparatus described above is that annular susceptor **17** is rotated throughout the crystal-pulling operation to provide a uniform heat distribution in the melt. While the crucible is preferably stationary during the pulling of crystals of semiconductor materials, particularly during the pulling of dendritic crystals, there still are some crystal-pulling processes in which the dislocation tolerances are sufficiently liberal to permit the utilization of apparatus having a rotating crucible. In such apparatus, the heat distribution may be even further enhanced by the incorporation of the rotating annular susceptor.

The coil, the rotating susceptor and the crucible are preferably coaxial; i.e., the axes of the inner circumference of the annular rotatable susceptor and of the coil are coincident with the crucible axis. While in the preferred embodiment for semiconductor crystal pulling described herein, the crucible is centermost and the coil outermost, it should be clear that the reverse disposition of coil-rotating susceptor and crucible would still provide the advantages of this invention in uniform temperature distribution within the melt. Such an alternative embodiment is shown in FIG. 2 in which central heating coil **40** is surrounded by rotating annular graphite susceptor **41**, the coil and susceptor providing a central core enclosed by stationary crucible **42**.

While rotating annular susceptor **17** has been described as being made of graphite, any electrically conductive refractory material which is capable of withstanding the temperatures encountered, e.g., up to 2000° C., without decomposition or deformation may be used. Such refractory materials include other forms of carbon such as pyrolitic graphite, as well as refractory materials such as molybdenum, tantalum, tungsten.

Heat shield **27** and cylinder walls **25** are preferably made of quartz. However, they may be made of any other refractory dielectric material such as silica, alumina or magnesia.

While the preferred embodiment of the present invention has been described with respect to induction heating, it should be clear that apparatus would still be operable

under the principles of this invention if a resistance element were used in place of the induction coil. In such an embodiment, the rotating susceptor would insure the uniform transfer and distribution to the crucible of the heat generated by the resistance element. Where such a resistance element is utilized, the element must, of necessity, be disposd proximate to the rotating susceptor and not separated from the susceptor by walls **25** and heat shield **27** if the coil is in the preferred embodiment shown in FIG. 1.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

**1.** A furnace comprising:
a central crucible member,
an axially rotatable, annular member of electrically conductive refractory material coaxial with said crucible surrounding said crucible member,
means for rotating said annular member independently of said crucible member, and
means for applying heat to said annular member.

**2.** The furnace to claim **1** wherein said heating means are external to said annular member.

**3.** A furnace comprising:
a central crucible member,
an axially rotatable, annular member of electrically conductive refractory material coaxial with said crucible surrounding said crucible member,
means for rotating said annular member independently of said crucible member, and
an induction coil for heating said annular member encircling said annular member.

**4.** The furnace of claim **3** wherein said annular member is made of graphite.

**5.** The furnace of claim **3** wherein said crucible member is stationary.

**6.** A furnace comprising:
a stationary central crucible,
an adjacent axially rotatable annular susceptor coaxial with said crucible surrounding said crucible,
means for rotating said susceptor independently of said crucible member, and



an induction coil for heating said susceptor encircling said susceptor.

**7.** The furnace of claim **6** wherein said susceptor is made of graphite.

**8.** The furnace of claim **6** wherein said induction coil is a radio frequency induction coil.

**9.** Apparatus for the growth of single crystals comprising:
a stationary central crucible for holding the melt from which the crystal is grown,
an adjacent axially rotatable, annular graphite susceptor coaxial with said crucible,
means for rotating said susceptor independently of said crucible member,
an induction coil for heating said susceptor encircling said susceptor, and
means for pulling crystal from the melt along the axis of said crucible.

**10.** The furnace of claim **6** wherein said induction coil is a radio frequency induction coil.

**11.** A furnace comprising:
a cylindrical crucible member,
an axially rotatable cylindrical member of electrically conductive refractory material adjacent to and coaxial with said crucible member,
means for rotating said rotatable member independently of said crucible member, and
an induction coil coaxial with said rotatable member.

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