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SILICON CRYSTAL GROWING

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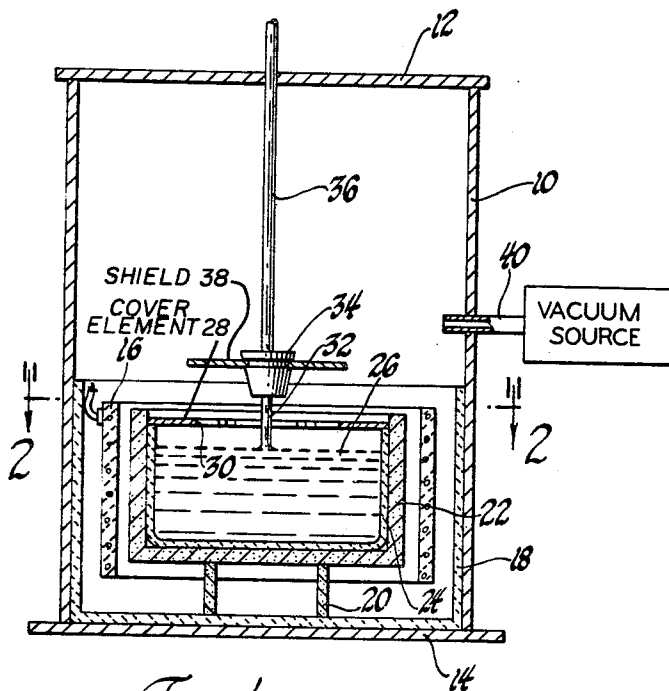


Fig. 1

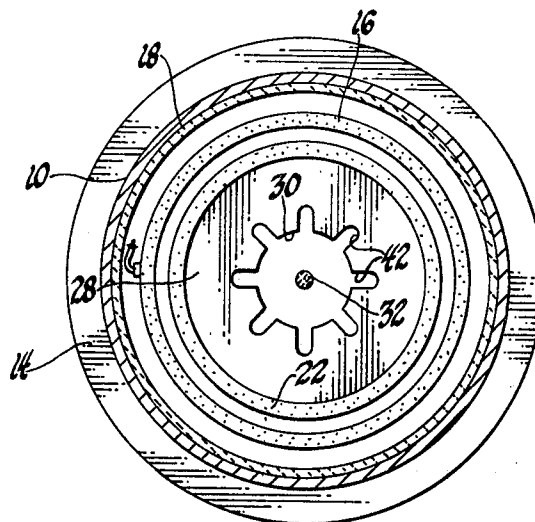


Fig. 2

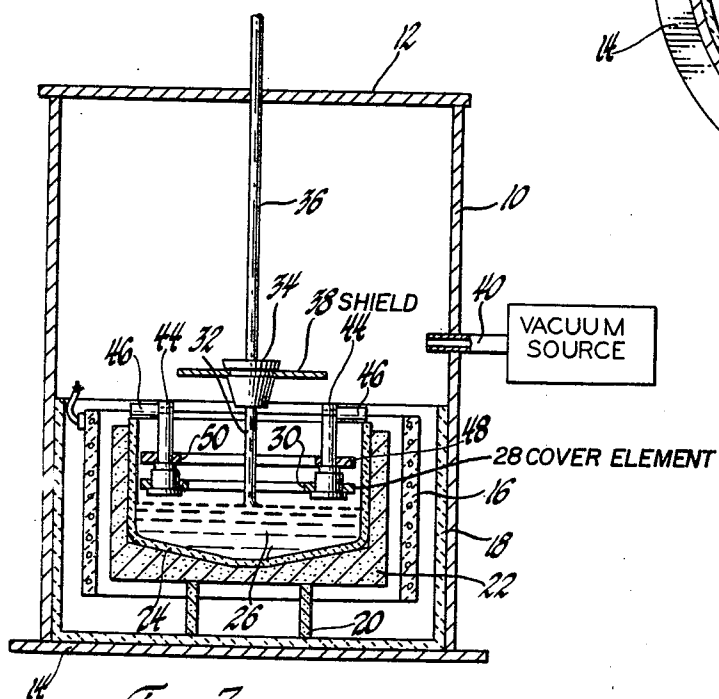


Fig. 3

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SILICON CRYSTAL GROWING

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ABSTRACT OF THE DISCLOSURE

An apparatus for growing semiconductor monocrystals under vacuum conditions that eliminates the twinning problem previously inherent to growth under vacuum conditions. The apparatus suppresses melt evaporation and inhibit solid particles of evaporated melt from forming in the crystal growing environment and dropping back into the melt adjacent the crystal growing interface.

This invention relates to crystal growing and more specifically to an improved process and apparatus for growing monocrystals of a semiconductor, such as silicon, under vacuum conditions.

For various reasons, it has long been preferred to grow monocrystals of certain semiconductors, such as silicon, under vacuum conditions; that is, extremely low pressures, rather than in a protective atmosphere. However, I have found that when growing a monocrystal under such low pressure conditions, appreciable deleterious evaporation of the molten metal from which the crystal is grown can occur. If the melting point temperature of the semiconductor involved is especially high, as is the case for silicon, melt evaporation becomes excessive and produces deleterious results.

I have found that excessive melt evaporation in silicon is one of the principal causes of "twinning" while the crystal is being grown. Twinning is the formation of another differently oriented growth site on a crystal being grown, resulting in the subsequent growth of two crystals in one body instead of one. It appears that evaporation of the melt is so significant that semiconductor vapors condense and solidify in cooler regions of the crystal growing apparatus and form particles which subsequently drop back down into the melt. These particles migrate to the crystal growing interface while still solid, attach themselves to the crystal, and produce a new site upon which further crystal growth can proceed. When this occurs, further crystal growth produces two crystals, instead of one, in the same semiconductor body being grown. In such event, the crystalline body must be remelted and the crystal growing process started all over again.

Accordingly, it is an object of this invention to provide an improved process and apparatus which inhibits "twinning" of a semiconductor crystal as it is being grown.

A further object of the invention is to provide a process and apparatus for inhibiting semiconductor melt vapors from condensing, solidifying and forming particles which fall back into the melt to interfere with the desired crystal growing process.

A still further object of the invention is to provide a process in which evaporation of the semiconductor melt during crystal growth is inhibited.

Still another object of the invention is to provide an apparatus for inhibiting evaporation of the melt during crystal growth and for inhibiting particles which may happen to form from deleteriously entering the melt during crystal growth.

Other objects, features and advantages of the invention will become more apparent from the following de-

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scription thereof in connection with the drawing, in which:

FIG. 1 is a schematic sectional view of a vacuum crystal growing apparatus showing a preferred embodiment of the invention;

FIG. 2 shows a plan view of the crucible cover shown in FIG. 1; and

FIG. 3 shows a schematic sectional view of another embodiment of the invention shown in FIG. 1.

Briefly, the invention comprehends both a process and apparatus for growing semiconductor monocrystals under vacuum conditions so as to inhibit deleterious introduction of solid semiconductor particles into the melt during crystal growth. In its broadest sense, the invention comprehends maintaining any evaporated melt in a vapor state while the vapor is located in any place where it can condense, solidify, and form solid particles which can drop back down into the melt during the crystal growth process. More specifically, it comprehends both a process and an apparatus for actually inhibiting evaporation of the melt during crystal growth.

One might consider that the broader objects of the invention would be achieved by simply putting a cover over the crystal growing melt so that any particles forming above the cover would fall onto the cover and not be introduced into the melt. However, this is not, per se, significantly effective. It does not stop formation of such particles under the cover, which particles can cause as much of a problem as those forming above it. Hence, an objective would be to prevent formation of the particles at all. This can be achieved by maintaining the entire crystal growing furnace at a sufficiently higher temperature to prevent solid particle formation. While this would be effective, I do not consider it to be presently commercially practical to carry out. It is costly to heat the entire furnace to such a high temperature, and it involves achieving a fairly critical heat field balance to avoid melting the freshly grown crystal. Thus, while helpful, this technique only allows one to compensate for an existing problem. It does not control the cause of the problem; namely, evaporation of the semiconductor melt.

I have found that I can very effectively suppress evaporation of the melt by establishing and maintaining a high semiconductor partial pressure over the surface of the melt during the crystal growing process. By inhibiting semiconductor evaporation, fewer particles can actually form to interfere with the crystal growing process. Further, if this evaporation is inhibited by a melt cover element through which the crystal is pulled from the melt, those particles which do happen to form will not be able to deleteriously enter the melt since they will fall onto the melt cover rather than directly into the melt.

An apparatus for accomplishing this result is shown in connection with FIG. 1. A vacuum furnace having a stainless steel vertical wall 10 with steel end plates 12 and 14 contains a graphite resistance heater 16. A cylindrical quartz heat reflector 18 is disposed between heater 16 and furnace wall 10. Resting on a graphite support 20 on bottom end plate 14 is a graphite crucible 22 having a quartz crucible liner 24. A molten semiconductor melt 26 is shown within crucible liner 24. A crucible cover element 28 rests on the upper edge of crucible liner 24. Cover 28 has a central aperture 30 therein through which a semiconductor monocrystal is pulled from the melt. The monocrystal forms by progressive unicrystalline solidification on a seed crystal 32 held by seed holder 34 which, in turn, is connected to a crystal pulling mechanism (not shown) via shaft 36. Shaft 36 passes through the furnace upper end plate 12. Suitable seals (not shown) are associated with shaft 36 and the upper end plate 12 to insure satisfactory vacuum conditions will prevail within the furnace.

Passage 40 in the furnace side wall 10 communicates with an appropriate vacuum source to establish the appropriate vacuum conditions within the furnace. Seed holder 34 has a horizontal shield element 38 which initially cooperates with melt cover 28 to shield the cover aperture 30 during the critical initial phases of starting crystal growth on the small diameter seed crystal, before crystal diameter is increased to almost the cover aperture diameter.

The cover element must be sufficiently hot to prevent solidification of the melt onto its lower surface. This temperature should, therefore, not be significantly below the melt temperature, which is approximately at the melting point temperature of the semiconductor. For silicon, the cover temperature should be at least 1000° C. It is preferred that the cover temperature not exceed appreciably 1400° C. for silicon to avoid ancillary problems such as remelting the freshly grown crystal, maintaining melt temperature, etc. A most convenient means by which the cover member can be maintained at an appropriate temperature is by using the melt heat field. In this manner the cover temperature will not be appreciably below that of the melt and no particles will form on the cover to drop back into the melt. Moreover, since those molecules which do escape from the surface of the melt will not appreciably lose any energy as they strike the relatively same temperature cover, they will remain in the vapor state between the cover and the melt surface to establish a sufficiently high partial pressure to suppress further evaporation from the melt. Hence, one establishes an equilibrium on melt evaporation, effectively suppressing further evaporation. Of course, some molecules actually do gradually escape through the cover aperture, but do not present much of a problem, if any. Moreover, if the boule being grown is only slightly smaller than the cover aperture, comparatively little loss by evaporation even occurs.

As previously indicated, it is desirable to use the melt heat field to maintain the cover at the desired temperature, avoiding the necessity of a separate heat source and separate temperature control. In order to enjoy the benefit of the melt heat field, the cover should be placed initially as close to the surface of the melt as possible without contacting it. This close spacing has an ancillary benefit in that it reduces the volume between the cover element and the surface of the melt into which the melt can evaporate. Hence, the closer this spacing, the more effective one can inhibit melt evaporation. I prefer to use a fixed position cover and avoid the practical problems attendant with one that is movable and maintained a fixed distance from the melt surface as the melt surface drops during growth. Best results are obtained with the apparatus shown in FIG. 1 when the initial cover distance above the melt surface is not greater than approximately 1/4 inch.

The crucible opening 30 is preferably only large enough to allow the crystal being grown to pass through. This will help sustain the equilibrium established and also reduce the chance of any particles which may happen to form outside the crucible to fall into the melt. However, one must be able to observe the crystal growing interface in order to monitor and control the crystal growing process. Hence, I prefer to use a crucible cover having one or more slots 42 radially extending from the cover opening, as shown in connection with FIG. 2. A plurality of these slots will facilitate viewing the crystal from any angle. The diameter of the circular aperture, however, need only be sufficiently larger than the diameter of the crystal to be grown, so that the crystal can pass through.

In practicing my process, one essentially grows the crystal in the normal and accepted practice for pulling a monocrystal from a semiconductor melt, such as by the Czochralski technique. In such a process, the semiconductor melt is maintained at about the melting point temperature of the semiconductor. A seed crystal is then lowered into contact with the melt and the melt precipitates onto the seed crystal. A monocrystalline body is

formed in this manner by progressive monocrystalline solidification of the melt on a monocrystalline seed.

In accordance with the invention, then, a small, narrow seed crystal 32, shown in FIGS. 1 and 2, is lowered into contact with the melt, and melted back slightly to insure a good surface contact between the crystal and the melt. In this initial step the shield 38 on seed holder 34 will be located just above the cover aperture 30, to supplement the effect of the cover at this especially critical phase of crystal growth. Since the crystalline body or boule which is to be grown is substantially larger in cross-sectional dimensions than the seed crystal, the aperture at this point is substantially larger than the seed crystal. Consequently, during this initial period of crystalline growth the supplementary shield on the seed holder cooperates with the cover to suppress evaporation loss, and particle entrance into the melt, through the cover aperture.

As is the normal practice, melt back of the seed crystal is achieved by increasing melt temperature slightly. The temperature is then reduced and the seed crystal is slowly raised out of the melt at a rate commensurate with the rate of monocrystalline solidification on the end of the seed in contact with the melt. Melt temperature and pulling rate are then adjusted to obtain the desired monocrystalline boule. The crystal may or may not be rotated during crystal growth, as one prefers. Also, as is the normal practice, the crystal growing furnace is evacuated before heating is commenced. Evacuation to a maximum pressure of 3×10^{-6} torr is normally practiced. However, using the principles of this invention, one can now evacuate to even lower pressures, if one so chooses, to obtain an even higher quality crystal and still not encounter the normal problems associated with growing crystals under extremely low pressure conditions. An abnormally low pressure can be employed in the preferred embodiment of my invention since the invention effectively suppresses evaporation even at the lower pressures.

A further embodiment of the invention is shown in connection with FIG. 3, in which there is shown essentially the same type of apparatus as shown in connection with FIG. 1. However, in FIG. 3 the crucible cover element 28 does not itself rest on the crucible liner 24. Cover element 28 is suspended over the melt by a plurality of support elements 44, each of which has a radially extending arm 46 which rests on the upper edge of the crucible liner 24. A further feature of this composite assembly crucible cover is that it has a heat shield 48 above the cover element 28. This double element cover assembly is preferred in those situations where radiation from the upper surface of the cover element 28 produces too great a heat loss to remain in the preferred temperature range. In such instance, the heat shield 48, being spaced somewhat above the cover 28, reflects heat back to the cover to maintain the latter at a higher temperature. The aperture in the cover element 28 is circular in this embodiment, not slotted. In such instance the aperture 50 of the heat shield 48 must be somewhat larger than cover aperture 30 to facilitate viewing of the crystal growing interface. However, as shown in connection with FIGS. 1 and 2, both of these elements can be slotted and, in such instance, the apertures of both the cover element 28 and heat shield 48 can be of essentially the same diameter; that is, only slightly larger than the boule which is to be produced.

It is to be appreciated that this invention has been described in connection with certain specific examples thereof, but that no limitation is intended thereby except as defined in the appended claims. For example, while the invention has been described in connection with a graphite crucible having a quartz liner, it may also be practiced using an ingot of silicon in which a molten puddle is formed serving as the melt. In such instance, the ingot serves as the crucible and the molten portion serves as a melt. Analogously, the heat field need not necessarily be produced by resistance heating but can be produced

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by any suitable means, such as induction heating, electron beam heating or the like.

I claim:

1. An improved apparatus for growing silicon crystals under vacuum conditions comprising: a housing, means for evacuating said housing, a container for a silicon crystal growing melt in said housing, means for maintaining said melt at a crystal growing temperature, means including a seed holder for pulling a single crystal boule from said melt by progressive monocrystalline solidification of said melt onto a seed crystal at a seed-melt interface, a cover member for said melt container having an aperture therein substantially larger than said seed crystal and only slightly larger than the boule to be produced, means for maintaining said cover at a temperature which inhibits evaporation of said silicon from said melt, and inhibits solid particles of evaporated melt from condensing thereon, solidifying and dropping back onto the surface of said melt adjacent the seed-melt interface, and a cover aperture shield supported by said seed holder for complementing the action of the cover during initial phases of crystal growth before the crystal boule is enlarged to approximately aperture size.

2. The apparatus as defined in claim 1 wherein the

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melt cover aperture is generally circular and has at least one crystal-melt interface viewing slot radially extending therefrom, and the cover aperture shield extends over the cover aperture and the viewing slot.

3. The apparatus as defined in claim 1 wherein said melt container cover is a composite assembly of at least two closely spaced upper and lower annular molybdenum elements having generally circular apertures therein and the aperture in the upper element is somewhat larger than the aperture in the lower element to facilitate viewing of the crystal growing interface.

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