

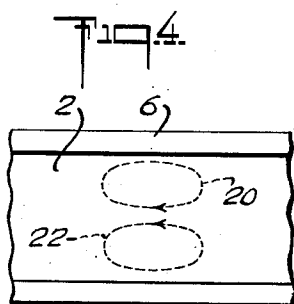
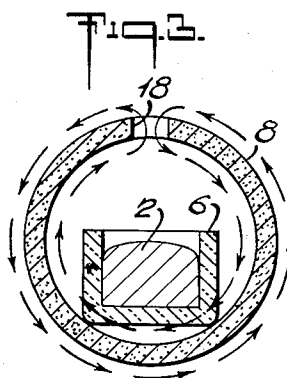
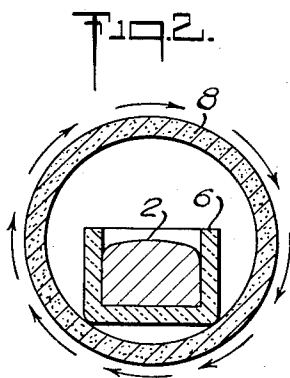
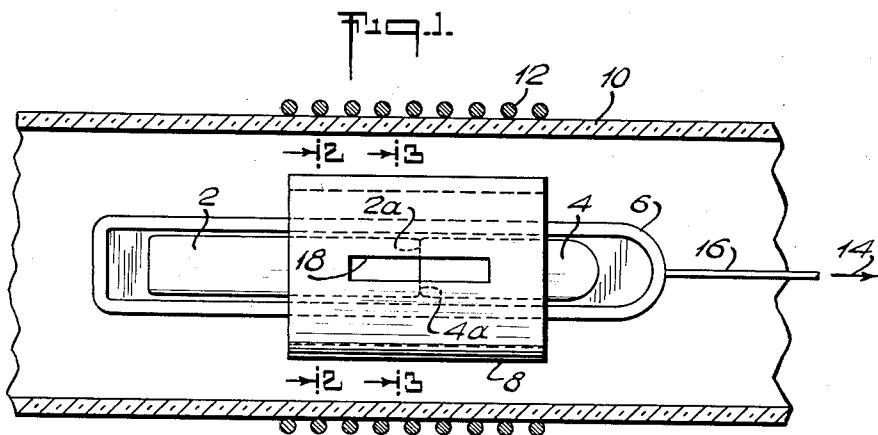
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IMPROVEMENT IN APPARATUS FOR GROWING SINGLE CRYSTALS

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## IMPROVEMENT IN APPARATUS FOR GROWING SINGLE CRYSTALS

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2 Claims. (Cl. 219—10.65)

The present invention relates to crystal growth and more particularly to a method of, and means for, growing single crystals of germanium, silicon, or the like, for solid state devices such as transistors and crystal diodes. Solid state devices of this general type require crystals that have been grown with controlled amounts of specific impurities or additives therein, which additives, for most satisfactory results, should be uniformly distributed throughout the crystal. For convenience, and because at the present time most transistors and crystal diodes are of germanium, the invention will be described with particular reference to such semi-conductor. It will be understood that the invention, in its broadest aspects, is not limited to any particular semi-conductor material. The invention is applicable wherever it is desired to produce a single crystal with additive material uniformly distributed therein.

Crystals grown by processes presently in wide use are not of uniform composition throughout and hence when such crystals are cut into small pieces for use as transistors or diodes, the characteristics of the resulting devices differ widely. In one such process one end of a purified solid block of germanium is placed adjacent a crystal seed with a measured amount of the donor or acceptor material sandwiched between the seed and block. A graphite ring in a neutral atmosphere is inductively heated by radio frequency currents while a shallow vessel of quartz or the like carrying the sandwich of seed and block is pulled slowly through the ring to fuse the abutting ends of block and seed and to cause the growth of a single crystal from the seed during solidification in the cooler zone beyond the ring. The added material, which tends to remain in the heating zone, becomes distributed in the molten charge as the result of thermal diffusion. Thus, temperature variations and other factors, such as the relative specific gravity of the additives and of the germanium affect the final disposition of the additive in the crystal.

If the material, while in the heating zone, is subjected to interacting high frequency magnetic fields, more uniform distribution of the added impurities in the grown crystal is obtained and consequently semi-conductor devices of more uniform electrical characteristics can be made from such a crystal. The interacting fields apparently cause the molten germanium and impurities carried thereby to circulate in closed paths and thus in effect provide a stirring action which tends to distribute the added material uniformly through the germanium.

Subjugation of the molten materials to the interacting high frequency fields may be simply effected by providing in the graphite ring a strategically placed longitudinal slot which, over the length thereof, changes the distribution of the high frequency current paths and produces complex mutual coupling between regions in the ring and regions in the ring and melt.

For a better understanding of the invention, reference may be had to the accompanying drawing, of which—

Fig. 1 is a diagrammatic plan view, partly in section,

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of an improved single crystal growing apparatus embodying the invention;

Figs. 2 and 3 are vertical sectional views taken on the lines 2—2 and 3—3, respectively, of Fig. 1 with current paths shown by arrows; and

Fig. 4 is a diagram illustrating typical movements induced in the molten material by the interacting high frequency fields.

In Fig. 1 a solid block 2 of germanium which has been previously purified by known methods, and a germanium crystal seed 4 are shown with their respective ends 2a and 4a in abutment and supported in a quartz vessel or "boat" 6. A graphite ring or cylinder 8 encompasses the boat and charge in the neighborhood of the junction of the seed and solid block. The boat with its charge and the ring are enclosed within an elongated envelope 10 of transparent and refractory glass such as that made by Corning Glass Works under the trade name Vycor, and a coil 12 adapted to carry the radio frequency currents for induction heating of the ring 8, surrounds the tube 10 in the region of the ring. Within the envelope 10 is a neutral gas such as a mixture of nitrogen and hydrogen and between the ends 2a and 4a of the block 2 and seed 4 there is a measured small quantity of the donor or acceptor material to be introduced into the crystal as it is grown; the particular material to be added depending upon whether n-type or p-type crystals are desired. With the boat and charge positioned about as shown in Fig. 1, high frequency currents are passed through the windings of the coil 12 to heat the ring 8 by induction and thereby provide a heated zone within the ring which melts the seed and block in the neighborhood of their junction. The boat with its charge is then drawn slowly in the direction of the arrow 14, as by a cable 16 secured to the boat, to cause the block 2 to progressively melt and solidify and, in solidifying, to grow from the seed 4 into a single crystal.

In accordance with the present invention, the ring 8 is provided with a longitudinal slot 18 which, in the particular embodiment illustrated, is closed at each end and which extends substantially throughout the length of the heating zone. When such slot is provided, the charge is not completely shielded from the high frequency fields, as it is in conventional practice, and stirring action occurs in the molten material. In the parts of the ring between the ends thereof and the slot, the induced high frequency currents are confined to the outer surface of the ring, as diagrammatically indicated in Fig. 2, while in the part of the ring in which the slot is disposed, the induced high frequency currents travel on both the inner and outer surfaces of the ring, as diagrammatically indicated in Fig. 2. The current distribution of Fig. 2 creates complex fluctuating magnetic fields within and about the molten charge which in turn cause circulation of the particles of the charge. Typical resultant movement of the germanium and impurity particles as a result of the interacting fields, is diagrammatically indicated in Fig. 4 by the dashed paths 20 and 22.

From the foregoing description, it will be apparent that by the simple expedient of providing a closed or open ended slot in the heating ring, automatic stirring of the molten charge within the ring is effected and a more uniform homogeneous mixture of germanium and additives is obtained. The single crystal grown from such mixture is thus of substantially uniform consistency, and the electrical characteristics of solid state devices made therefrom will likewise be substantially uniform.

The following is claimed:

1. In apparatus for growing from a seed, single crystals of semi-conductive material containing controlled amounts of additive material wherein a graphite ring in a neutral atmosphere is subjected to radio frequency in-

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duction heating to provide a heating zone in which abutting ends of a solid block of a semi-conductor and of a seed with added material therebetween are adapted to be melted, the improvement which comprises a longitudinal slot provided in the ring to permit induced high frequency currents to traverse the inner surface of the ring for part of its length and thereby create interacting high frequency fields in the heating zone effective to create convection currents that stir the semi-conductor when in molten condition within the heating zone.

2. The improvement according to claim 1 wherein

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said slot is closed at least at one end and extends for a length commensurate with the heating zone.

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