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(54) Benævnelse: **FREMGANGSMÅDE OG ANLÆG TIL TRÆKNING AF EN ENKRYSTAL IFØLGE FZ-FREMGANGSMÅDEN**

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Description

The present invention relates to a method for pulling a single crystal by the FZ method, in which a polycrystal is melted by means of an electromagnetic melting apparatus and then recrystallized, and also to a corresponding plant.

Prior art

In the pulling of single crystals, particularly those of semiconductor material, by the FZ method, the so-called floating zone method or zone melting method, it is possible to generate single crystals of high purity. In this method, a polycrystal, in other words more particularly a crystal made of polycrystalline semiconductor material, is melted and then recrystallized.

In such a method, there are different phases that can be distinguished, as they are described in WO 2014/033212 A1, for example. The polycrystal in this case is first of all melted and then recrystallized on a monocrystalline seed.

The diameter of the monocrystal to be fabricated is reduced from to start with approximately the diameter of the seed, in what is called a thin neck section, and is subsequently widened to a desired diameter in a conical section. The diameter can then be kept constant in order to give, for example, a monocrystal in rod form.

JP 2010076979 A discloses a method for pulling a single crystal according to the FZ method, in which at the start of the phase for formation of the conical portion, the diameter of the crystallization interface is calculated by means of triangulation and using two cameras in order to enable automated process control.

JP H11189486 A discloses a method for pulling a single crystal by the FZ method, in which, for automated process control, both

crystallization interfaces and the shape of the melting zone are captured by means of a camera and analysed.

Known from JP 4 016 363 B2, for example, is an FZ method wherein four different cameras are used to record different regions of the polycrystal, of the seed attached thereto, and of the liquid or molten material located between them. From these recordings, determinations are then made not only of diameters of the polycrystal and of the monocrystal, but also of a height of the region or the zone of the liquid or molten material, referred to as the zone height.

In a method of this kind, it is possible to determine a distance between a lower edge at the outer margin of the polycrystal, and a lower phase boundary between liquid material and solid material on the part of the seed. Based on these determinations, there are various regulating operations that can be performed.

In a phase in which the conical section of the polycrystal is to be melted, the need is generally for an (occasionally drastic) reduction in the rate at which the polycrystal is moved relative to the melting apparatus. In this way it is possible to melt the necessary amount of material. Using a distance, as mentioned above, it is not possible, however, or is difficult, to determine a position of the polycrystal at which the reduction in rate is to take place.

Against this background, therefore, the object is that of providing an easier and/or more precise means of adjusting a position of the polycrystal at which its rate is to be reduced, in order thus in particular to allow the operation to be automated.

Disclosure of the invention

Proposed in accordance with the invention are a method and a plant for pulling a single crystal, with the features of the independent claims. Advantageous embodiments are subjects of the

dependent claims and also of the description hereinafter.

The starting point for the invention is a method for pulling a single crystal by the FZ method, in which a polycrystal is melted by means of an electromagnetic melting apparatus and then recrystallized. Material eligible for the polycrystal and hence also for the monocrystal to be fabricated here is, in particular, a semiconductor material, preferably silicon. It will be understood that the material may also include certain impurities or dopants.

In a first phase, the polycrystal, which as a general rule is in the form of a rod having a diameter of 160 mm, for example, is first melted by means of a melting apparatus, beginning at a lower (in relation to gravity in the case of vertical disposition of the rod-shaped polycrystal) end. The melting apparatus contemplated here is, in particular, an inductor or an induction coil. In this case, by means of radiofrequency excitation, electromagnetic energy can be coupled into the polycrystal, which is brought into the vicinity of the inductor.

In the aforementioned first phase, the polycrystal, which as a general rule is conical at its lower end, optionally with a shallow lower section, can be lowered and brought up to a central hole in the inductor. In order to maximize the amount of electromagnetic energy coupled into the polycrystal, it is useful to bring the lower end of the polycrystal to the edge of the hole. The polycrystal then begins to melt at the lower end, with the formation initially of a drop of liquid material hanging from the polycrystal.

Then, in a second phase, a monocrystalline seed, which in particular is likewise rod-shaped and has a diameter of around 4 to 7 mm, for example, is attached to the lower end of the polycrystal and hence to the drop of liquid material, and is then melted, beginning from an upper end of the seed. The melting of the seed generally begins only after the temperature of the seed has adjusted itself to that of the material that is already

liquid. The seed may usefully be melted over a certain region of its length, a length which may be, for example, between 5 and 20 mm. It will be understood, however, that a certain region at its lower end is not melted, since this region is required for fixing in a pulling apparatus. For the melting of the seed, the seed and the polycrystal are moved upward. This means, for example, that the seed is moved in the direction of the hole in the inductor. In this procedure, a preliminary seed is formed at the lower end of the polycrystal. A preliminary seed in this context is a region, more particularly in the form of a plug, at the lower end of the polycrystal, on which the seed is then attached.

In a third phase, then, between a lower section of the seed (at which the seed may be held, for example, in the aforementioned pulling apparatus) and the polycrystal (that is, the portion of the polycrystal which is still solid and has not yet melted), a thin neck section is formed whose diameter is smaller than that of the seed. This thin neck section is formed in order to remove any dislocations which form, for example, as a result of the attaching of the seed to the liquid material on the polycrystal. The diameter of the thin neck section here may amount, for example, to between 2 and 4 mm. In order to form this thin neck section, the seed and the polycrystal, after the seed has been melted as desired, can be moved downward again. By now increasing the rate of lowering of the seed, there is a decrease in the diameter of the zone of liquid material, or of the material which then crystallizes, owing to the conservation of mass.

After the thin neck section, the diameter of the monocrystal can then be increased to a desired diameter of, for example, around 200 mm and then retained.

For this purpose, in a fourth phase in the FZ method, a conical section may now be formed between the thin neck section and the polycrystal. A conical section of this kind serves to widen the diameter from that of the thin neck section to a desired diameter. For this purpose it is necessary as a general rule to

alter a rate of lowering of the seed (together with the material already crystallized thereon) and of the polycrystal, in order to increase the diameter. In particular, a reduction in the rate of lowering means that more material is able to crystallize, thereby increasing the diameter. In particular, in this fourth phase, the polycrystal may be moved or lowered initially at a moderate rate, then at an increased rate, and subsequently at a very low rate. Such different rates are necessary in order to overcome as quickly as possible any phase in which the phase boundary is not present uniformly. In particular, the reduction in the rate (to the aforementioned very low rate) serves to allow sufficient material of the polycrystal to be melted continuously, since this is also necessary for the increasing diameter of the conical section. A reduction may take place, for example, from a rate of 0.5 mm/min or more, more particularly between 0.5 and 1 mm/min, to a rate of less than 0.5 mm/min, more particularly between 0.1 and 0.5 mm/min. Before and after the reduction in the rate, however, the polycrystal may in particular be moved in accordance with a target curve for the rate.

In accordance with the invention, before the fourth phase is reached, a switchover position of the polycrystal is determined, being the position at which a rate at which the polycrystal is moved relative to the melting apparatus is to be reduced in amount. Then, in the fourth phase, the rate at which the polycrystal is moved relative to the melting apparatus is reduced correspondingly in amount when the switchover position is reached.

Customarily, a so-called plug is formed at the lower end of the polycrystal. In the case of a new polycrystal, this plug generally has a planar face. However, if the polycrystal used has already been melted, in an FZ method, for example, which - for whatever reasons - had to be terminated, then the plug (which in that case, in particular in the terminated method, was formed as a preliminary seed) no longer has a defined shape. In particular, this shape may also be dependent on the melting

apparatus used in the case of the terminated FZ method. Accordingly, the shape of the plug and/or its position of the base on the conical section may vary from polycrystal to polycrystal. Correspondingly, the switchover position as well may vary from polycrystal to polycrystal.

Since, therefore, the corresponding switchover position is determined at an early phase of the FZ method, more particularly as early as in the first phase, it is very easily possible to reduce the rate in the fourth phase, in other words, in particular, when the switchover is needed. This therefore makes it possible to control the rate at which the polycrystal is moved. Regulation is unnecessary. In particular, therefore, automation of the method is made significantly easier.

It is preferred here if, for the purpose of determining the switchover position, a measurement is made of a distance of a location which is characteristic of the polycrystal, this location being situated on the lower end of a conical section of the polycrystal, relative to a fixed reference point, as for example a defined location on the melting apparatus, with the switchover position then being determined from the distance. This characteristic location may in particular be a location at which an angle of inclination of the conical section of the polycrystal changes by more than a predetermined value. This therefore includes, in particular, the so-called plug on the lower end of the polycrystal. Such a location may be recognized, for example, on the basis of a characteristic or predetermined diameter of the polycrystal. The distance here is therefore not known beforehand and is measured first by suitable means, as part of an image processing procedure, for example.

In relation to this distance it is possible, particularly synchronously, to determine an intermediate position of the polycrystal, more particularly relative to that of the melting apparatus, on the basis, for example, of a current position of a lowering or pulling apparatus. The intermediate position may therefore be a readily measurable or outputable position of the

polycrystal (particularly in the vertical direction). Using a desired distance of the characteristic location from the melting apparatus, at which the rate is to be reduced, hence in particular a near-ideal distance at which precisely the correct amount of material is melted if the rate there is reduced accordingly, it is therefore possible - by addition or subtraction (depending on situation) of a suitable value, for example - to determine the switchover position from the previously determined intermediate position of the polycrystal, then likewise, for example, as a defined position of the lowering or pulling apparatus. It is therefore possible by this means to determine a previously unknown position of the characteristic location in relation to the entire polycrystal, and the reduction in rate can be accomplished very simply during the fourth phase.

Alternatively, it is preferred, for the purpose of determining the switchover position, to determine an intermediate position of the polycrystal at which the location which is characteristic of the polycrystal, and which is situated at the lower end of a conical section of the polycrystal, reaches or exceeds a predetermined distance from a fixed reference point during movement of the polycrystal, with the switchover position being determined from the intermediate position. Here again, the characteristic location may be recognized in particular from a characteristic or predetermined diameter of the polycrystal. If then, for example, during raising or lowering of the polycrystal, the diameter at the predetermined distance is captured accordingly, continuously or repeatedly, the intermediate position of the polycrystal, especially relative to the melting apparatus, may then likewise be determined as a defined location of the lowering or pulling apparatus, for example when the characteristic location reaches or exceeds the predetermined distance. This may be recognized, for example, by the diameter at the height of the predetermined distance undershooting or exceeding a defined value. By adding the corresponding distance, in other words, here, the aforementioned predetermined distance from the fixed reference point, corrected

to include the desired distance of the location from the fixed reference point, at the time at which the rate is to be reduced, it is therefore possible very easily to determine the switchover position.

With both variants, therefore, the intermediate position can be determined, and can be used to determine the switchover position. Whereas in the case of the first variant, the distance of the characteristic location from the reference point (for example, at a suitable point in time) can easily be measured, in the case of the second variant the distance from the reference point is predetermined, so to speak, and this distance is then monitored until the characteristic location reaches or passes this distance during movement of the polycrystal. Depending on circumstances, one variant or the other may be more simple and/or more advantageous.

The location which is characteristic of the polycrystal is preferably captured using a camera, which in particular is disposed above the melting apparatus. This allows the distance to be determined or captured particularly easily. For example, by means of a camera, it is possible to recognize light/dark differences or light/dark transitions very readily, hence also allowing a change in the angle of inclination - as a result of which there is a change in reflection at the crystal - to be captured effectively.

Advantageously, the switchover position is determined in the first phase and/or in the second phase, in other words, for example, also during a transition from the first to the second phase. The switchover position can be determined particularly well here, since a good view of the aforementioned location for determining the diameter is possible by means of a camera, for example.

A further subject of the invention is a plant which is equipped for implementing the method of the invention. For this purpose the plant may comprise in particular a melting apparatus, of the

kind already mentioned multiply, for example, and also a suitable arithmetic unit. The arithmetic unit may then be equipped accordingly to implement the individual method steps and also, for example, to drive the cameras accordingly and to evaluate their images.

In order to avoid repetition, reference may otherwise be made to the above elucidations concerning the method of the invention, with regard to further embodiments and also to the advantages of the plant.

Further advantages and embodiments of the invention will be apparent from the description and the appended drawing.

It will be appreciated that the features identified above and those still to be elucidated hereinafter can be used not only in the particular combination indicated but also in other combinations, or on their own, without departing from the scope of the present invention.

The invention is illustrated schematically in the drawing by an exemplary embodiment, and is described below with reference to the drawing.

Description of figures

Figure 1a shows, schematically, a polycrystal and a melting apparatus with which a method of the invention can be implemented.

Figure 1b shows the melting apparatus from figure 1 in a different view.

Figure 2 shows various shapes of the lower end of a polycrystal.

Figures 3a to 3g show, schematically, various phases of a method of the invention in one preferred embodiment.

Figure 4 shows a temporal sequence of a method of the invention in one preferred embodiment.

Embodiment of the invention

Illustrated schematically in a side view in figure 1a are a polycrystal 100 and a melting apparatus 300 with which a method of the invention can be implemented. The melting apparatus 300 here has an inductor or induction coil 310, which can be driven or operated correspondingly with radiofrequency, for example, by means of a drive unit 320 which is connected via corresponding lines.

This melting apparatus 300 may be part of a plant which is equipped for the pulling of a single crystal. A plant of this kind may then also have corresponding holding devices for the inductor 300, the single crystal 100, and the cameras 351, 352 and 353. Moreover, a plant of this kind may have an arithmetic unit (not shown) for controlling the other constituents.

The polycrystal 100, which in particular may comprise or consist of silicon, is predominantly rod-shaped or cylindrical. In the rod-shaped or cylindrical region, of which only part is shown here, the polycrystal 100 has a diameter d_P which may be, for example, 160 mm. At its lower end, however, the polycrystal 100 is conical in shape, thus having a conical section 110. It can be seen, furthermore, that the conical section 110 may in turn have what is called a plug 111, in this case with a flat end, at its lower end.

Also visible is a seed 140 having diameter d_I which may be, for example, 4 to 7 mm. The seed comprises a monocrystal, which may likewise be rod-shaped or cylindrical in form.

In figure 1b, the melting apparatus 300 from figure 1a is shown in a different view, in the present case a plan view, albeit without the polycrystal 100. Clearly visible here, then, is a recess or a hole in the middle of the inductor 310, through

which the polycrystal is guided - during the melting operation and then in the liquefied state.

Visible in particular here, then, is a primary slot 311 and also three ancillary slots 312, advantageous for the function of the melting apparatus, more particularly for generation of the electromagnetic energy. As can be seen, the inductor is not closed, because of the primary slot 311.

Shown again in figure 2 (top) is the lower end of the polycrystal 100 from figure 1a with the conical section 110 and the plug 111. Shown additionally (bottom) for comparison is a lower end or conical section of a polycrystal which has not been machined but which instead originates, for example, from an - uncompleted - melting operation. In this instance, as can be seen, the conical section and the plug 111' are somewhat different in shape.

This different shape comes about as a result of the melting and solidifying again. In this case, in particular, the base P_S of the plug may have undergone shifting to a location characteristic of the polycrystal. However, a defined distance of precisely this location or base P_S from the melting apparatus 300 ought to be maintained if the rate of the polycrystal is reduced, in order to maximize the quality of the transition to the conical section that is to be shaped.

Figures 3a to 3g then show, schematically, different phases of a method of the invention in one preferred embodiment. The process of the method will be elucidated in more detail below with reference to figures 3a to 3g and also to figure 4, which shows the rates v_P of the polycrystal and v_I of the seed in the individual phases over the time t.

In a first phase P_1, the polycrystal 100 is first brought up to the inductor 310 or the recess in its center. For this purpose, for example, the polycrystal is lowered at a constant rate. The seed 140 here need not as yet be moved. Contrary to the

orientation shown here, the polycrystal 100 may also be brought closer to an inner margin of the inductor 310, in order to allow more effective coupling of the electromagnetic energy into the polycrystal 100.

The polycrystal 100 thus begins to melt at its lower end, hence including the lower end of the conical section. In this case, a drop 120 of liquid material which hangs from the polycrystal is formed, as can be seen in figure 3a. Here and in the following figures, liquid material is shown with hatching, whereas solid material is shown in white or without hatching.

In this first phase P_1, it is then possible to determine a switchover position of the polycrystal 100, being the position at which a rate at which the polycrystal 100 is moved relative to the melting apparatus 300 is to be reduced. With regard to the switchover position, reference may be made at this point to figure 3e as well.

In this regard, in the example shown, a distance d is measured of a location P_S, which is characteristic of the polycrystal, at the lower end of the conical section of the polycrystal 100, in the present instance the base of the (partially melted) plug, and hence of the drop 120, relative to a fixed reference point P_B, which corresponds here, by way of example, to a defined location on the inductor 310. This can be done using one of the cameras that are shown in figure 1a, more particularly the camera 351 or 353. The location P_S can be recognized in particular from its characteristic diameter.

Furthermore, an intermediate position of the polycrystal 100 relative to that of the melting apparatus 300 is determined. In the example shown, this intermediate position corresponds to the distance h of a defined location of a lowering or drawing apparatus 350, by means of which the polycrystal 100 can be moved, from the fixed reference point P_B. It will be appreciated that a distance h of this kind may also be determined relative to any desired alternative reference point. It may be noted in

particular that as a general rule, a current position of the polycrystal (relative to the fixedly installed lowering or drawing apparatus) can be output by the lowering or drawing apparatus 350 itself.

From this intermediate position or this distance h, the switchover position h' can then be determined, being the position at which the location P_S, for example, then has a defined distance d' from the fixed reference point P_B. As can be seen from the figure 3a, a switchover position of this kind can be determined very easily from the position or the distance h.

Instead of measuring the distance d, it is also possible – as already mentioned earlier – to stipulate the distance d beforehand and then to monitor this stipulated distance until the location P_S reaches or passes this distance. It will be appreciated that it is only for the sake of ease of comprehension that in the figure the two distances, i.e., the distance determined relative to the location, and the distance predetermined and monitored, are identical.

In a second phase P_2, the seed 140 is then attached to the lower end of the polycrystal 100 and hence to the drop 120 of liquid material, as can be seen in figure 3b, and is melted beginning from an upper end of the seed 140. For this purpose, the seed is first of all moved toward the polycrystal 100, in other words upward, at a defined rate, for example, while the polycrystal 100 may be at rest. The melting of the seed 140 in this case generally begins only after the temperature of the seed 140 has equalized with that of the already liquid material.

When the seed 140 is attached to the drop of liquid material at the lower end of the polycrystal 100 and has melted together with it, the polycrystal 100 and the seed 140 are jointly moved upward, as can be seen in figure 3c. In this case the preliminary seed 141 is also formed at the lower end of the polycrystal 100. The seed may then be melted over a certain region of its length, between 5 and 20 mm, for example, by the seed being moved in the

direction of the hole in the inductor 310.

It will be understood, however, that a certain region at the lower end of the seed 140 will not be melted, since this section is needed for fastening in a pulling apparatus (as part of the aforementioned plant).

In a third phase P_3, then, between a lower section of the seed 140 and the polycrystal 100 (that is, the portion of the polycrystal that is still solid and has not yet melted), a thin neck section is formed whose diameter d_D, at 2 to 4 mm, for example, is smaller than that of the seed 140. For this purpose, the polycrystal 100 and the seed 140 are first of all moved downward simultaneously, i.e., at the same rate.

The lowering rate of the seed 140 is then increased at a certain time point relative to that of the polycrystal 100. Therefore, the diameter of the zone of liquid material or of the material which then crystallizes is reduced, owing to the conservation of mass. In figure 3d, for example, a thin neck section having a certain length is already formed.

In a fourth phase P_4, it is then possible, between the thin neck section and the polycrystal 100, for a conical section 135 to be formed, as can be seen in figures 3e and 3f. A conical section 135 of this kind serves to widen the diameter from that of the thin neck section to a desired diameter d_E of, for example, 200 mm of the monocrystal 150 to be fabricated, as can be seen in figure 3g. The conical section here has an angle φ of inclination.

Formation of the conical section 135, i.e. at the start of the increase in diameter, requires a reduction in amount of the rate at which the polycrystal 100 is moved, or lowered, relative to the melting apparatus 300, in order to be able to melt the corresponding amount of material. This is apparent in figure 4 from the last rate change shown in phase P_4.

Whereas the phase boundary between liquid and solid material is located here in a region with a large diameter and extends extensively over the diameter, the phase boundary beforehand is located only in a relatively thin region of the preliminary seed. Consequently, a relatively high rate is desired initially, in order to advance the transition rapidly, whereas later on a relatively low rate is desirable so as not to melt an excessive quantity of material, something which, in view of the extensive phase boundary, would be accompanied by difficulties with regard to the near-ideal shaping of the cone.

This reduction in rate takes place at a point in time at which the polycrystal 100 is located at the previously determined switchover position h'. In figure 3e, this switchover position is represented with a distance h' relative to the fixed reference point P_B, similarly to the case with the position or distance h in figure 3a. When this distance h' is reached, therefore, the characteristic location P_S has a desired distance d' from the reference point P_B. This distance d' defines a near-ideal distance at which, with the maximum possible accuracy, the desired amount of material of the polycrystal 100 is melted, on the predetermined reduction in the rate, so as to form the desired conical section 135. A reduction in rate of this kind can be very easily automated, since there is no need for regulation.

Patentkrav

1. Fremgangsmåde til trækning af en enkrystal (150) ifølge FZ-fremgangsmåden, hvor en polykrystal (100) smeltes ved hjælp af en elektromagnetisk smelteanordning (300) og efterfølgende igen udkrystalliseres,
idet en nedre ende på polykrystallen (100) i en første fase (P_1) smeltes ved hjælp af smelteanordningen (300),
i det en enkrystallinsk podekrystal (140) i en anden fase (P_2) anbringes på den nedre ende af polykrystallen (100) og smeltes begyndende fra en øvre ende på podekrystallen (140),
idet der i en tredje fase (P_3) mellem et nedre afsnit på podekrystallen (140) og polykrystallen (100) dannes et tyndhalsafsnit (130), hvis diameter (d_D) er mindre end diameteren (d_I) på podekrystallen (140), og
idet der i en fjerde fase (P_4) mellem tyndhalsafsnittet (130) og polykrystallen (100) dannes et konisk afsnit (135) på enkrystallen,
kendetegnet ved, at der, inden den fjerde fase (P_4) nås, fastlægges en omskifter-position (h') af polykrystallen (100), hvor en hastighed, med hvilken polykrystallen (100) bevæges i forhold til smelteanordningen (300), skal reduceres størrelsesmæssigt, idet der til fastlæggelse af omskifterpositionen (h')
a) måles en afstand (d) på et for polykrystallen karakteristisk sted (P_S), som befinder sig på den nedre ende af et konisk afsnit (110) på polykrystallen (100), i forhold til et fast referencepunkt (P_B), og idet omskifterpositionen (h') fastlægges ud fra afstanden (d), eller
b) der fastlægges en mellemposition (h) for polykrystallen, hvor et for polykrystallen karakteristisk sted (P_S), som befinder sig i den nedre ende af et konisk afsnit (110) på polykrystallen (100), under en bevægelse af polykrystallen (100) når eller overskrider en forud givet afstand (d) til et fast referencepunkt (P_B), og idet omskifterpositionen (h') fastlægges ud fra af mellempositionen (h), og
idet hastigheden, hvormed polykrystallen (100) bevæges i forhold til smelteanordningen (300), i en fjerde fase (P_4) reduceres

størrelsesmæssigt, når omskifterpositionen (h') nås.

2. Fremgangsmåde ifølge krav 1, idet omskifterpositionen (h') fastlægges ud fra afstanden (d), idet der ud over afstanden (d) fastlægges en mellemposition (h) for polykrystallen (100), ud fra hvilken omskifterpositionen (h') fastlægges ved at anvende afstanden (d).

3. Fremgangsmåde ifølge krav 1 eller krav 2, idet det for polykrystallen (100) karakteristiske sted (Ps) registreres ved hjælp af en karakteristisk eller forud bestemt diameter på polykrystallen (100).

4. Fremgangsmåde ifølge et af kravene 1 til 3, idet det for polykrystallen (100) karakteristiske sted (Ps) på den nedre ende af det koniske afsnit (110) på polykrystallen (100) omfatter et sted, hvor en hældningsvinkel i det koniske afsnit på polykrystallen (100) ændres med mere end en forud bestemt værdi.

5. Fremgangsmåde ifølge et af kravene 1 til 4, idet det for polykrystallen (100) karakteristiske sted (Ps) registres under anvendelse af et kamera (351), som navnlig er placeret oven over smelteanordningen (300).

6. Fremgangsmåde ifølge et af de foregående krav, idet omskifterpositionen (h') fastlægges i den første fase (P_1) og/eller i den anden fase (P_2).

7. Fremgangsmåde ifølge et af de foregående krav, idet den hastighed, hvormed polykrystallen (100) bevæges i forhold til smelteanordningen (300), før reduktionen udgør 0,5 mm/min eller mere, navnlig mellem 0,5 og 2 mm/min, og efter reduktionen mindre end 0,5 mm/min, navnlig mellem 0,1 und 0,5 mm/min.

8. Fremgangsmåde ifølge et af de foregående krav, idet den hastighed, hvormed polykrystallen (100) bevæges i forhold til smelteanordningen (300), før og efter reduktionen af hastigheden bevæges svarende til en ønsket kurve for hastigheden.

Fig. 1a

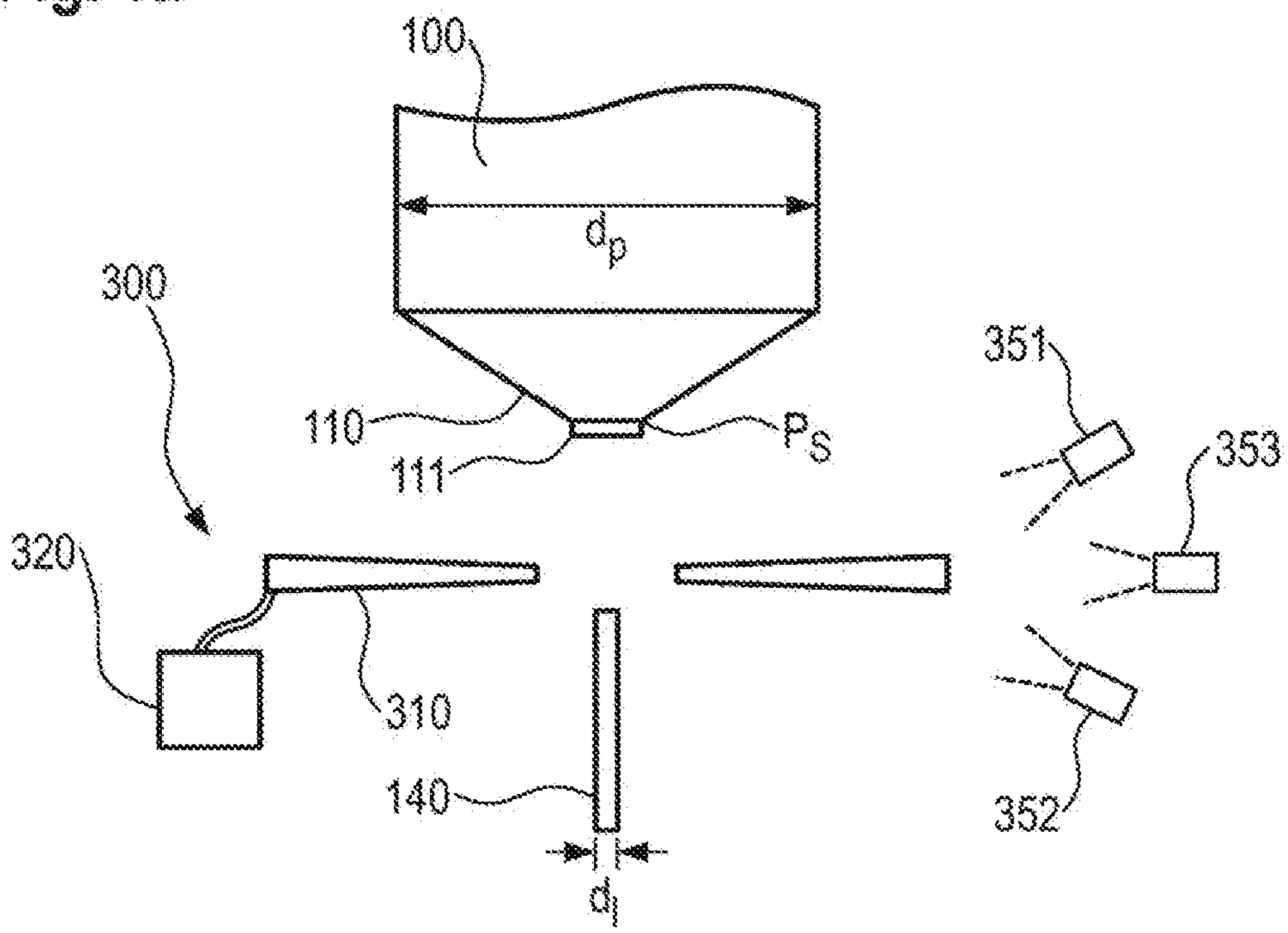

100
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110
111
P_S
351
353
320
310
140
352
d_f

Fig. 1b

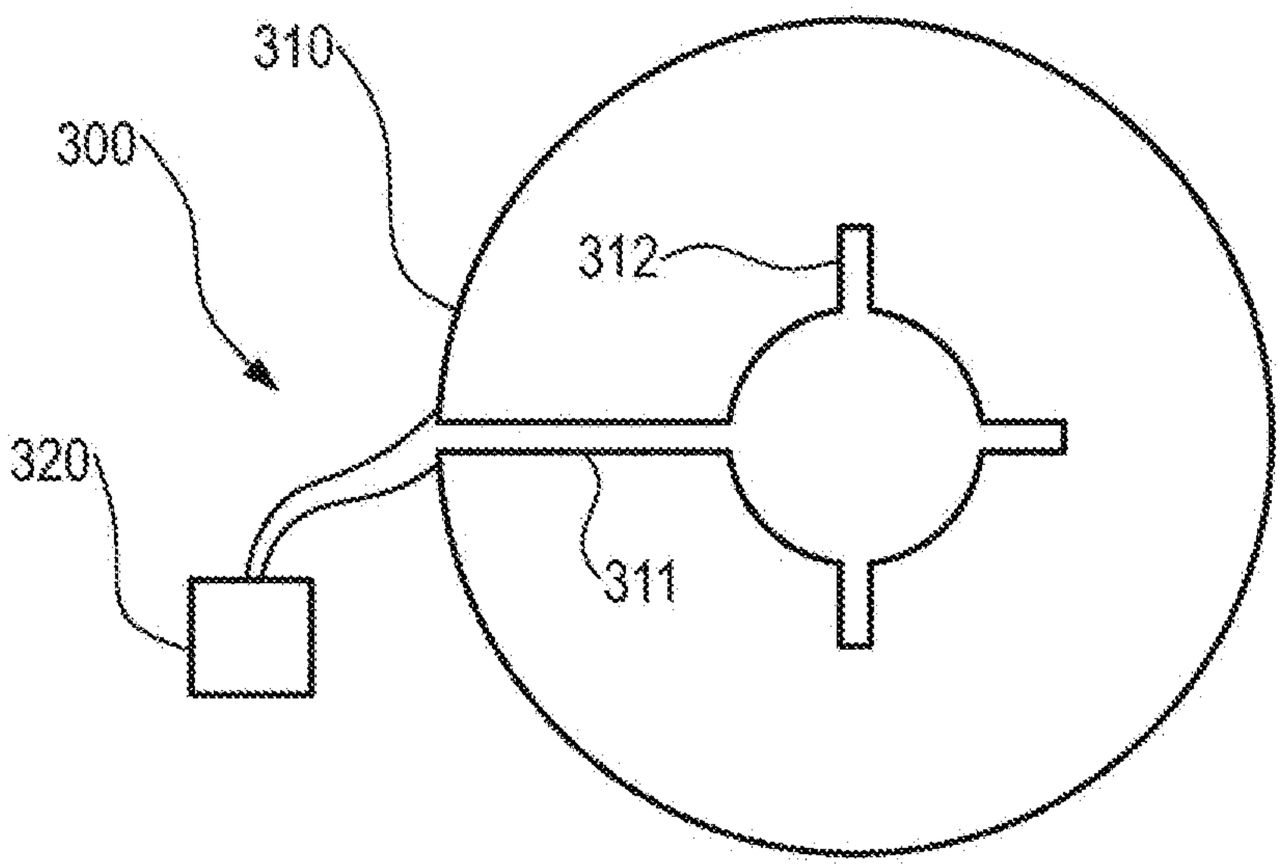
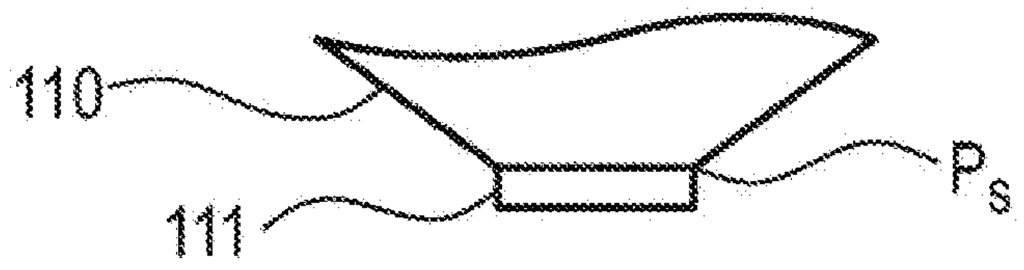

310
300
312
320
311

Fig. 2



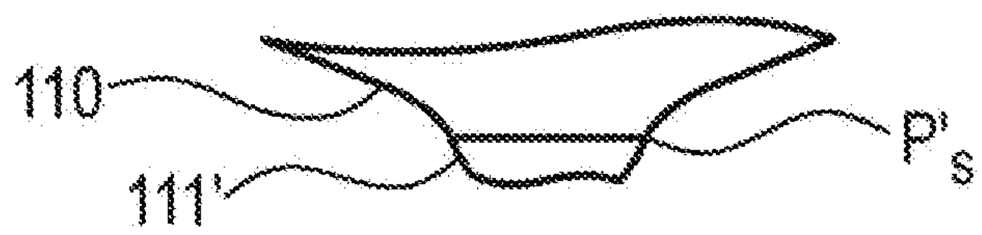


Fig. 3a

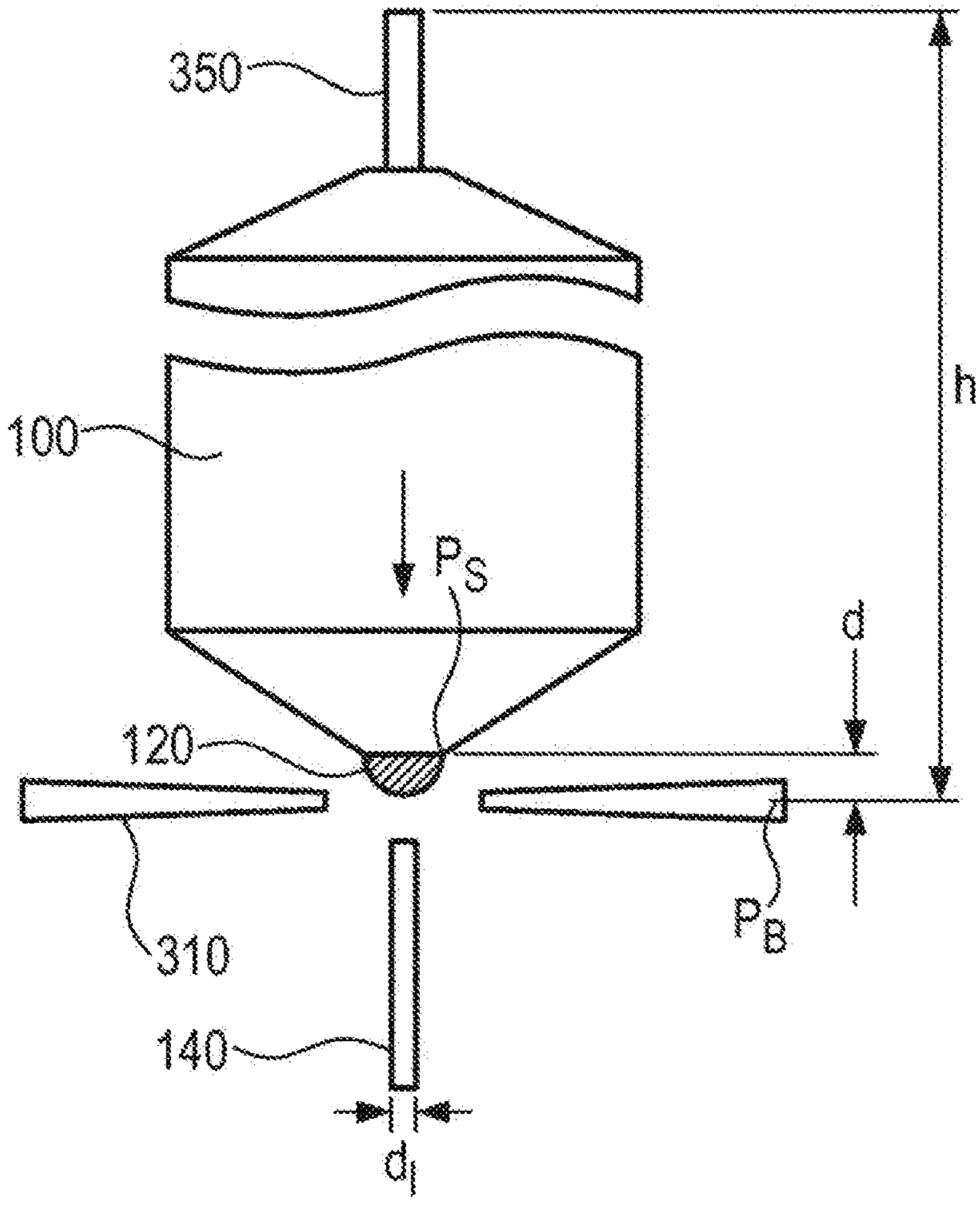


Fig. 3b

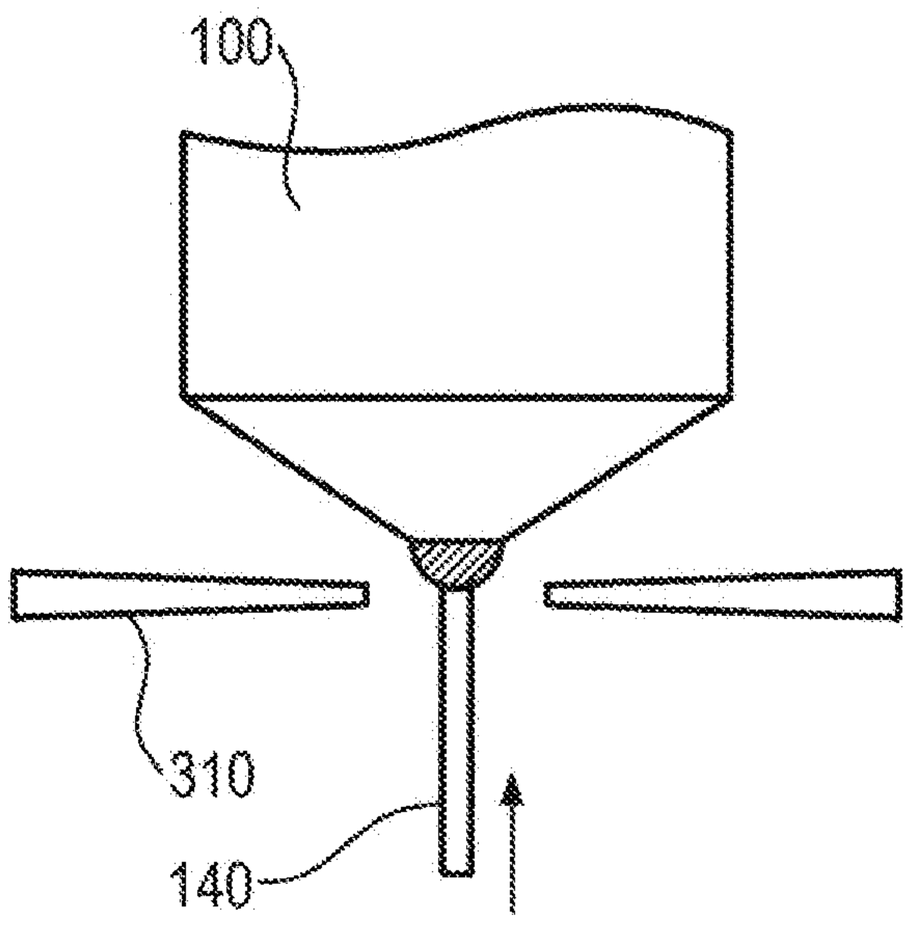


Fig. 3c

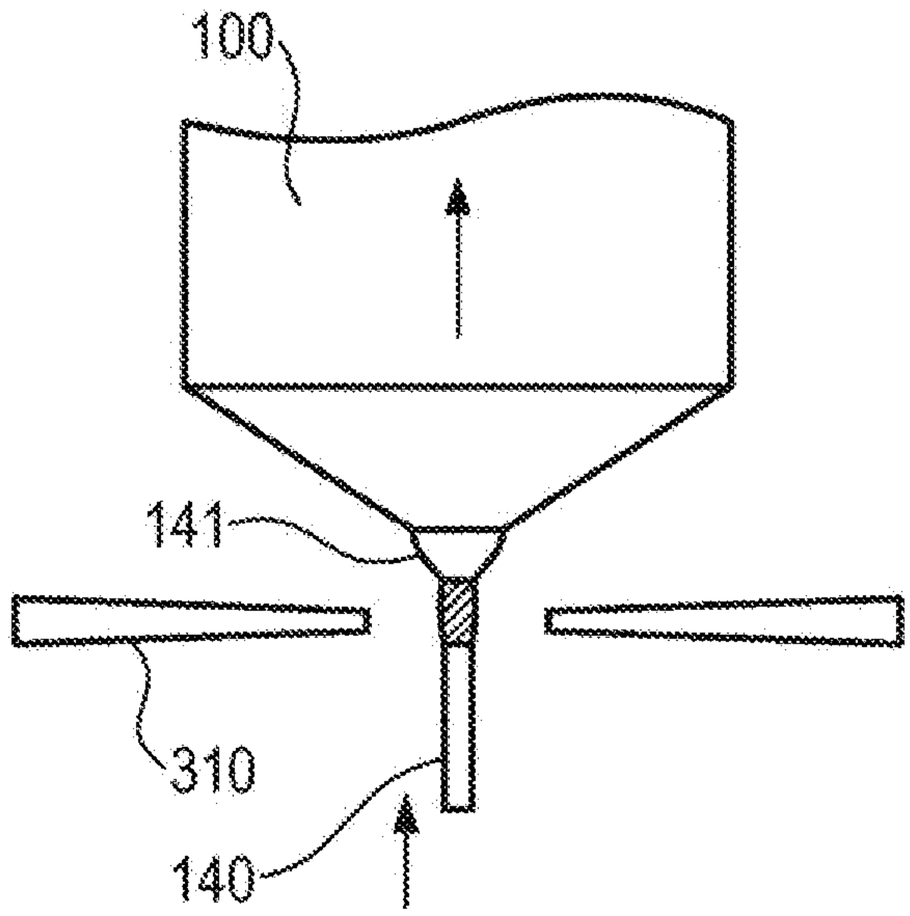


Fig. 3d

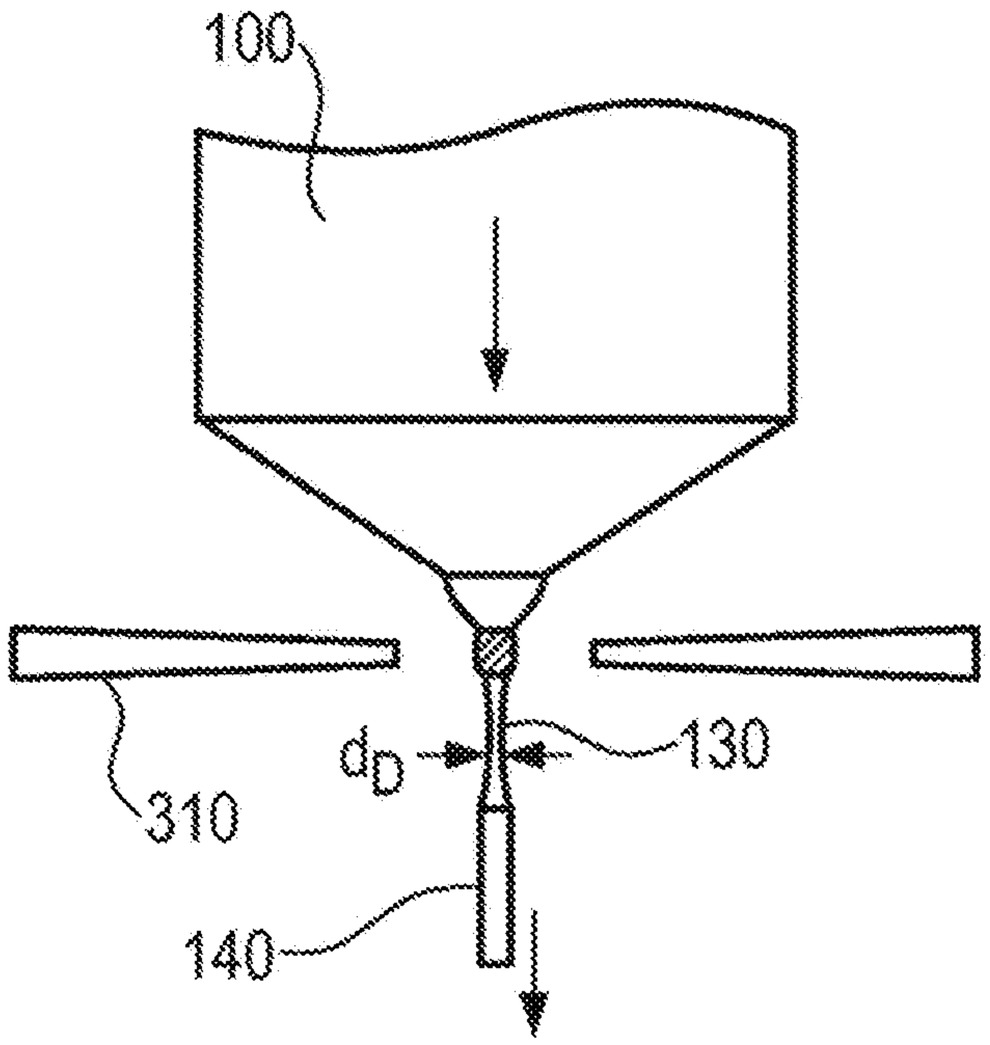


Fig. 3e

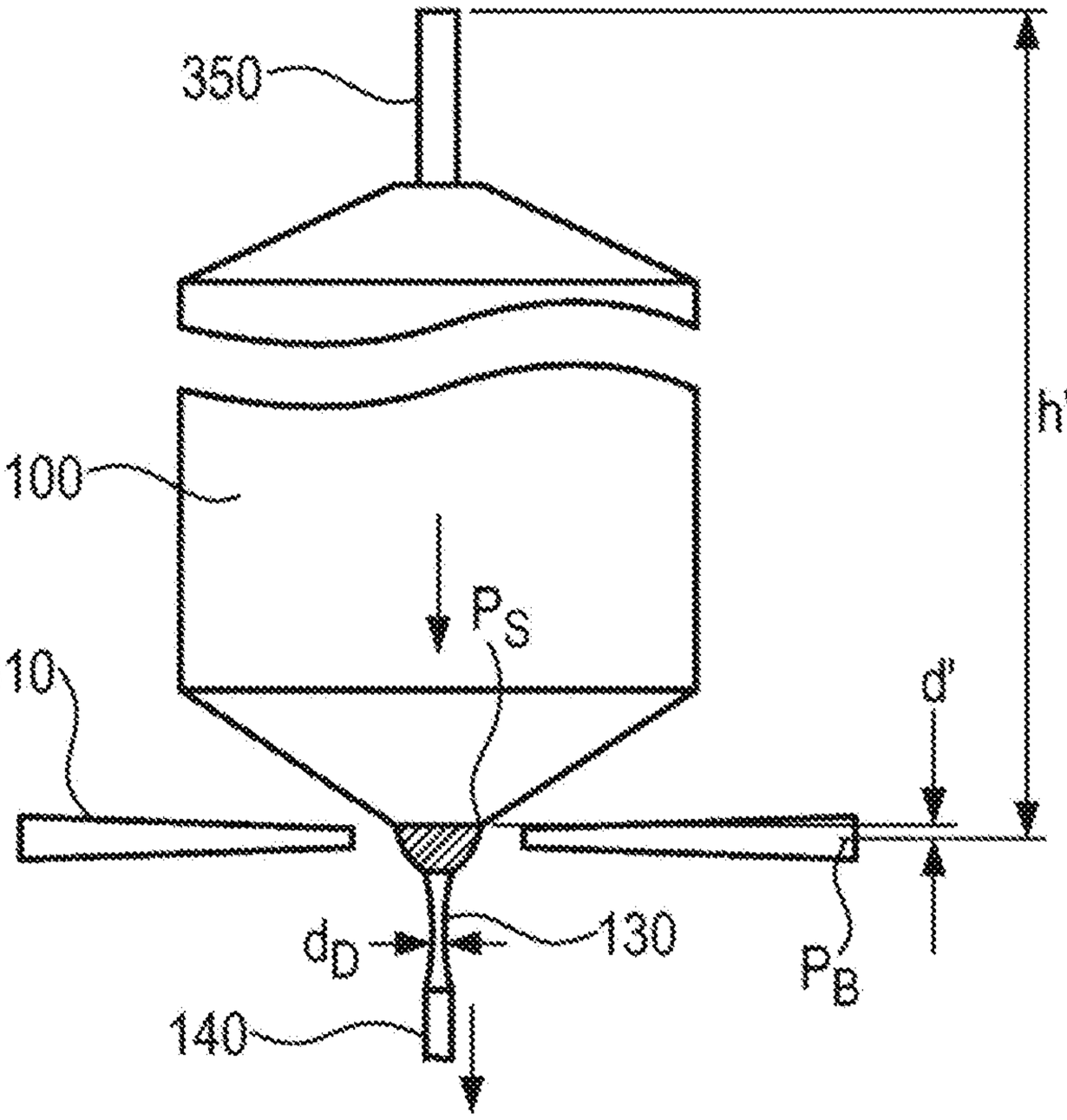


Fig. 3f

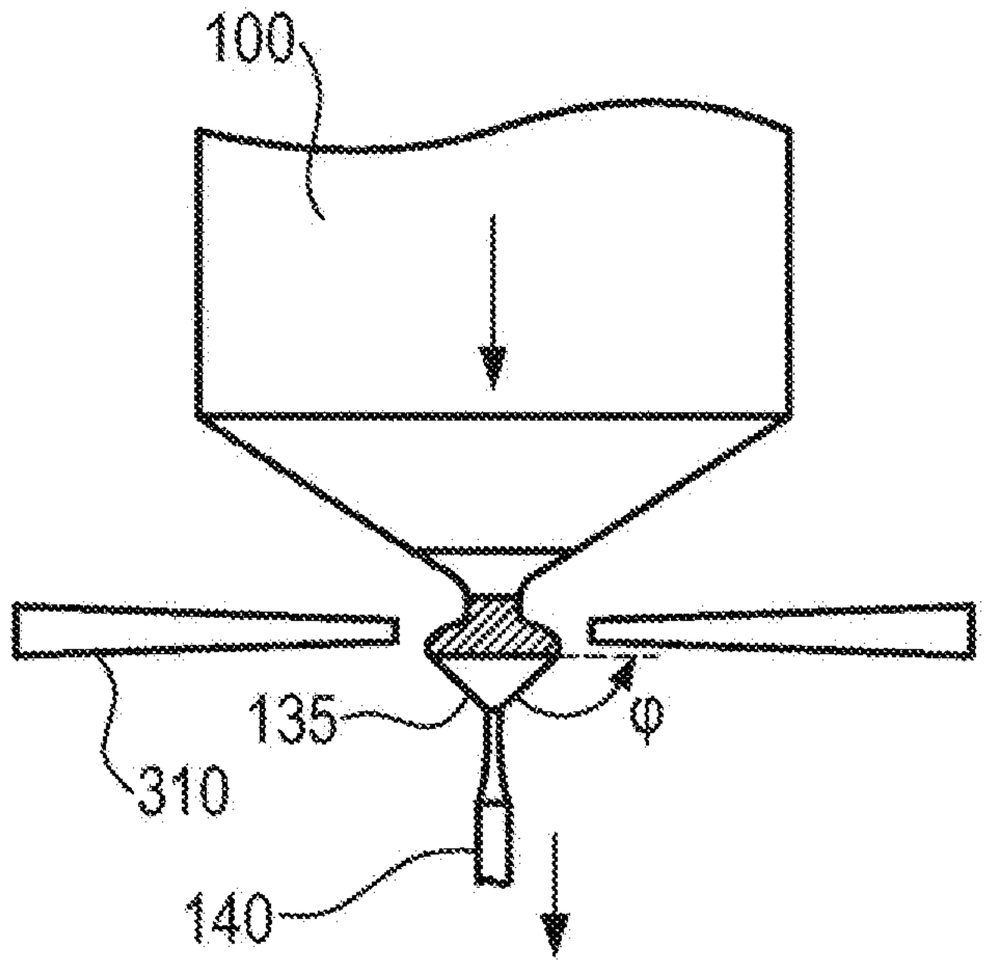


Fig. 3g

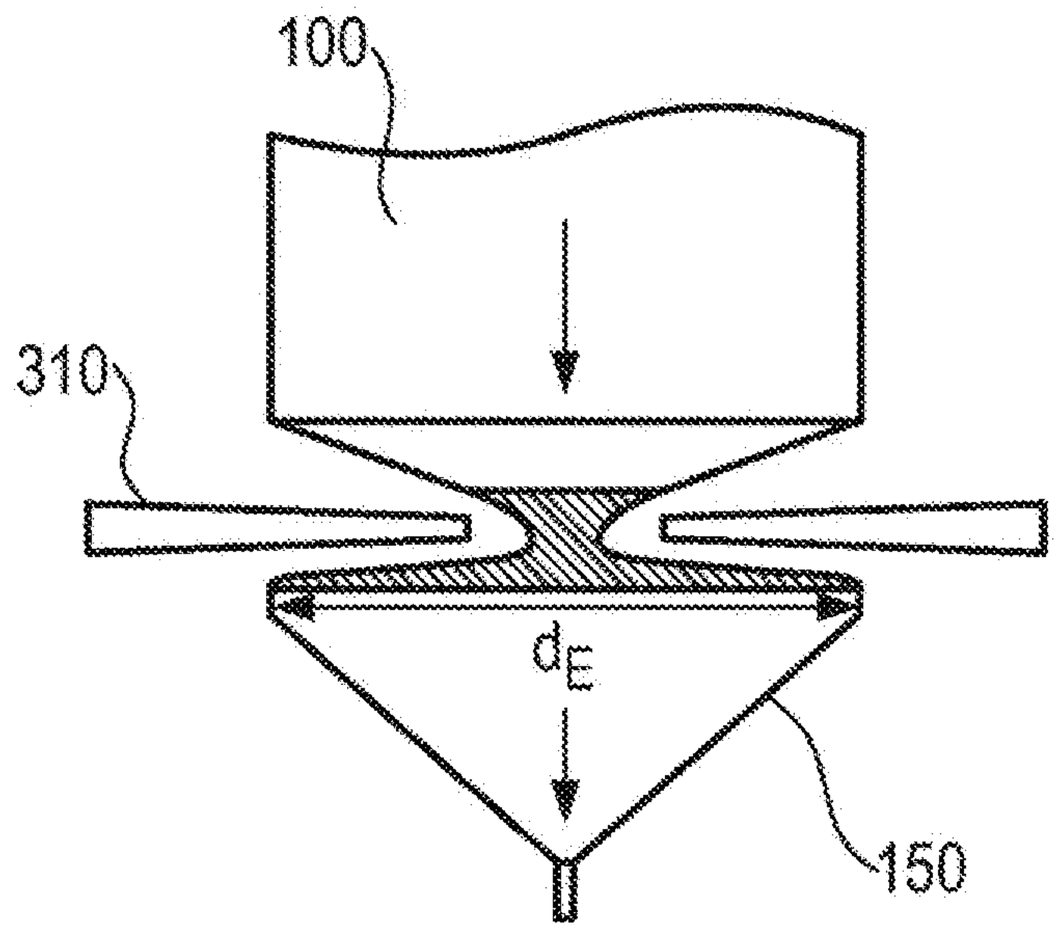


Fig. 4

