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(54) Title: ADDITIVE MANUFACTURING SYSTEM WITH THERMAL CONTROL OF MATERIAL

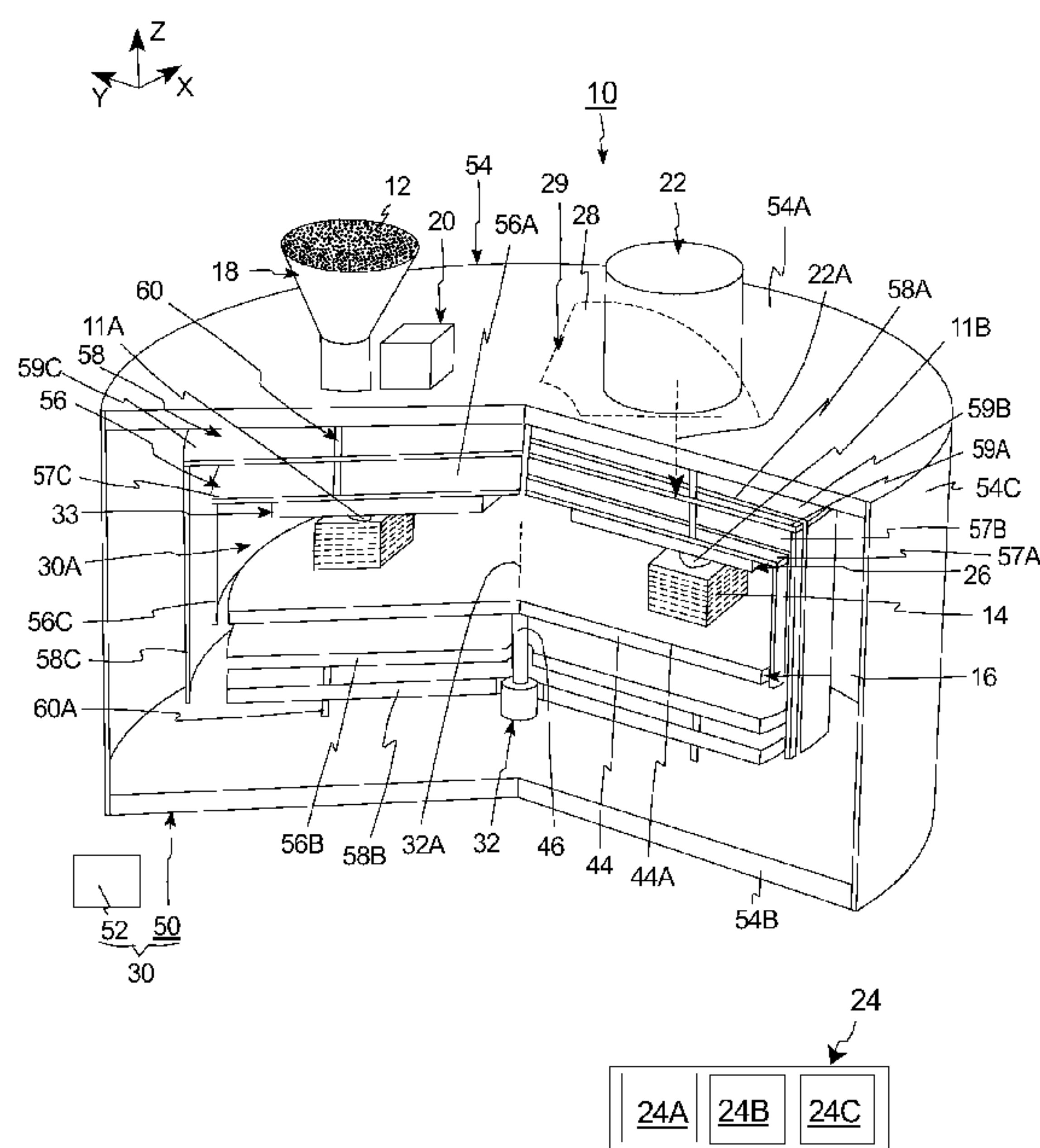


Fig. 1B

(57) Abstract: A processing machine (10) for building an object (11 A) includes: (i) a build platform (44) that supports a material (12); (ii) a build chamber assembly; (iii) a material supply device (18) that deposits material onto the build platform (44) in a deposition area (34); (iv) an energy system (22) that selectively melts the material (12) in a melting area (36); (v) a heating assembly (26) that heats the material (12) in a heating area (38); (vi) a cooling assembly (28) that cools the material (12) in a cooling area (40); (vii) a mover assembly (32) that moves the build platform (44); and (viii) a control system (24) that controls the energy system (22), the heating assembly (26) and the cooling assembly (28) to actively control the temperature on the build platform (44).

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for

**ADDITIVE MANUFACTURING SYSTEM WITH
THERMAL CONTROL OF MATERIAL**

RELATED APPLICATIONS

[0001] This application claims priority on U.S. Provisional Application No: 62/943,011 filed on December 3, 2019, and entitled "Heating, sintering, and temperature control of metal material in additive manufacturing systems". As far as permitted the contents of U.S. Provisional Application No: 62/943,011 are incorporated in their entirety herein by reference.

[0002] Additionally, as far as permitted the contents of PCT Application No: PCT/US18/67407 entitled "ADDITIVE MANUFACTURING SYSTEM WITH ROTARY MATERIAL BED" filed on December 22, 2018, and the contents of PCT Application No: PCT/US18/67406 entitled "ROTATING ENERGY BEAM FOR THREE-DIMENSIONAL PRINTER" filed on December 22, 2018 are incorporated in their entirety herein by reference.

BACKGROUND

[0003] Three-dimensional printing systems are used to print three-dimensional objects. Existing three-dimensional printing systems are relatively slow, have a low

throughput, are expensive to operate, and/or generate excessive waste. Accordingly, there is a need for a faster, less expensive, more accurate, and higher output three-dimensional printer.

SUMMARY

[0004] The present implementation is directed to a processing machine for building a three-dimensional object from a material. In one implementation, the processing machine includes (i) a build platform that supports the material; (ii) a build chamber assembly that provides a build space for the object that is being built; the build chamber assembly including a deposition area, a melting area, a temperature control area; (iii) a material supply device that deposits material onto the build platform in the deposition area; (iv) an energy system that directs an energy beam at the material on the build platform to selectively melt the material in the melting area; (v) a temperature control assembly that controls the temperature of the material on the build platform in the temperature control area; (vi) a mover assembly that causes relative movement between the build platform and areas of the build chamber assembly; and (vii) a control system that controls the energy system, the temperature control assembly to actively control the temperature of at least a portion of the material on the build platform during relative movement between the build platform and the areas of the build chamber assembly.

[0005] The temperature control areas can include a heating area and/or a cooling area. Further the temperature control assembly can include (i) a heating assembly that heats the material on the build platform in the heating area; and/or (ii) a cooling assembly that cools the material on the build platform in the cooling area.

[0006] With this design, the processing machine provides precise area-by-area temperature control of the material during the build process of the object during relative movement between the build platform and the areas. Because the temperature of the material is actively controlled during the manufacturing of the object, the object can be made with increased accuracy and speed, and the machine has a high throughput.

[0007] As provided herein, the processing machine can include one or more of the following features: (i) the mover assembly rotates the build platform and the material

on the build platform relative to the areas; (ii) the heating assembly sinters at least a portion of a top material layer of the material in the heating area; and (iii) the cooling assembly cools at least a portion of a top material layer of the material in the cooling area.

[0008] Additionally, or alternatively, the build chamber assembly can include a temperature adjustment area between the cooling area and the heating area; and the processing machine can include a temperature adjuster that adds or removes heat from the material on the build platform in the temperature adjustment area.

[0009] In one implementation, the cooling area at least partly encircles the melting area.

[0010] In another implementation, the heating area is adjacent to the melting area.

[0011] Additionally, the build chamber assembly can include a chamber structure that encircles the build platform, and a first shield assembly that reduces the transfer of heat between the build space and the chamber structure. In this design, the first shield assembly can be positioned between the build platform and the chamber structure; and/or the first shield assembly can be spaced apart from the build platform and the chamber structure.

[0012] In certain implementations, the first shield assembly includes a first shield segment and a second shield segment that is spaced apart from the first shield segment. With this design, the heating assembly can maintain the first shield segment at a heating temperature, and the cooling assembly can maintain the second shield segment at a cooling temperature that is different from the heating temperature. In one implementation, the heating temperature is at least one degrees Celsius higher than the cooling temperature.

[0013] Additionally, the processing machine can include a mount assembly that couples the first shield assembly to the chamber structure with the first shield assembly spaced apart from the chamber structure, wherein the mount assembly reduces (inhibits) the transfer of heat between the first shield assembly and the chamber structure.

[0014] Additionally, the build chamber assembly can include a second shield assembly that reduces the transfer of heat between the first shield assembly and the

chamber structure. In this implementation, the second shield assembly can be positioned between the first shield assembly and the chamber structure, and the first shield assembly can be positioned between the build platform and the second shield assembly.

[0015] Further, the first shield assembly can include a first shield segment and a second shield segment that is spaced apart from the first shield segment; and the second shield assembly can include a first shield area and a second shield area that is spaced apart from the first shield area. Moreover, the heating assembly can maintain the first shield segment at a heating temperature, and the cooling assembly can maintain the second shield segment at a cooling temperature that is different from the heating temperature.

[0016] Additionally, a mount assembly can couple the first shield assembly to the second shield assembly with the first shield assembly spaced apart from the second shield assembly; and/or the mount assembly can couple the second shield assembly to the chamber structure with the second shield assembly spaced apart from the chamber structure. In this design, the mount assembly reduces the transfer of heat between the first shield assembly and the second shield assembly; and/or the mount assembly reduces the transfer of heat between the second shield assembly and the chamber structure.

[0017] The first shield assembly can include a reflective surface that faces the build platform.

[0018] The heating assembly can include an infrared lamp, a tungsten halogen lamp, a conduction heater, and/or a microwave generator.

[0019] In one implementation, the energy system is controlled to add excess heat to the material on the build platform so that a subsequent material layer deposited thereon at least partly sinters.

[0020] In one implementation, the material supply device includes a supply heater that heats the material that is being deposited onto the build platform in the deposition area.

[0021] In another implementation, the processing machine includes: (i) a build platform that supports the material while the object is being built; and (ii) a build

chamber that defines a build space for the object that is being built. In this implementation, the build chamber includes a chamber structure that at least partly encircles the build platform, and a first shield assembly positioned between the build platform and the chamber structure. The first shield assembly reduces the amount of thermal transfer between build space and the chamber structure. In this design, the build chamber is uniquely designed to reduce the amount of heat transferred from the build space to the components that are outside of the build space. This will simplify the design of the components outside of the build space because they will not have to operate in the extreme environment in the build space.

[0022] In another implementation a method for building a three-dimensional object includes: (i) supporting the material with a build platform; (ii) providing a build space for the object that is being built with a build chamber assembly that includes a deposition area, a melting area, a heating area, and a cooling area; (iii) depositing material onto the build platform in the deposition area with a material supply device; (iv) directing an energy beam at the material on the build platform to selectively melt the material in the melting area; (v) heating the material on the build platform in the heating area with a heating assembly; (vi) cooling the material on the build platform in the cooling area with a cooling assembly; (vii) moving the build platform relative to the areas of the build chamber assembly; and (viii) controlling the energy system, the heating assembly and the cooling assembly to actively control the temperature of at least a portion of the material on the build platform during movement between the build platform and the areas of the build chamber assembly.

[0023] In still another implementation, a method for building a three-dimensional object from a material includes: (i) supporting the material on a build platform while the object is being built; and (ii) providing a build space for the object that is being built with a build chamber. The build chamber can include a chamber structure that at least partly encircles the build platform, and a first shield assembly positioned between the build platform and the wall assembly. The first shield assembly reduces the amount of thermal transfer between build space and the structure.

[0024] In yet another implementation, the processing machine for building a three-dimensional object from a material includes (i) a build platform that supports the

material; (ii) a material supply device that deposits material onto the build platform; (iii) an energy system that directs an energy beam at the material on the build platform to selectively melt the material; and (iv) a temperature control assembly that is configured to heat the material on the build platform to sinter the material before the energy system selectively melts the sintered material.

[0025] The temperature control assembly can include a lamp configured to irradiate light at the material on the build platform to sinter the material. The lamp can irradiate light and sinter a surface of the material on the build platform approximately all at once. The lamp can include at least one of an infrared lamp, a visible light lamp, or a tungsten halogen lamp.

[0026] The temperature control assembly can be configured to lower the temperature of the material on the build platform after the energy system selectively melts the sintered material. The temperature control assembly can irradiate the melted material with light which has lower energy than the energy beam directed from the energy system. The temperature control assembly can also include a chiller (chilling unit) that actively removes heat from the melted material.

[0027] In still another implementation, a processing machine for building a three-dimensional object from a material includes: (i) a build platform that supports the material; (ii) a material supply device that deposits material onto the build platform; (iii) an energy system that directs an energy beam at the material on the build platform to selectively melt the material; and (iv) a temperature control assembly configured to cool at least part of the material on the build platform, the temperature control assembly having a cooling area through which the melted material passes to control the cooling of the melted material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The novel features of this embodiment, as well as the embodiment itself, both as to its structure and its operation, will be best understood from the accompanying drawings, taken in conjunction with the accompanying description, in which similar reference characters refer to similar parts, and in which:

[0029] Figure 1A is a simplified perspective view of a processing machine that is

usable for building an object from material;

[0030] Figure 1B is a simplified, cut-away perspective view of the processing machine and object of Figure 1A;

[0031] Figure 1C is a simplified top view of the material bed assembly;

[0032] Figure 1D is a graph that illustrates one, non-exclusive plot of how an average (or characteristic) temperature of a material layer can vary relative to time;

[0033] Figure 1E is a graph that illustrates two, non-exclusive plots of how an average (or characteristic) temperature of a material layer can vary relative to time;

[0034] Figures 2A and 2B are alternative, cut-away, perspective views of another implementation of a processing machine;

[0035] Figure 2C is an enlarged cut-away view of a portion of the processing machine of Figures 2A and 2B;

[0036] Figure 2D is a simplified illustration of a portion of the processing machine and an object with a cooling assembly controlled to cool at a first cooling rate;

[0037] Figure 2E is a simplified illustration of a portion of the processing machine and an object with the cooling assembly controlled to cool at a second cooling rate;

[0038] Figure 2F is a simplified illustration of a portion of the processing machine and an object with the cooling assembly controlled to cool at a third cooling rate;

[0039] Figure 2G is a simplified illustration of the cooling assembly cooling at the first cooling rate and corresponding energy generated by the cooling assembly;

[0040] Figure 3 is a simplified perspective view of portion of a material bed assembly, and a portion of a heating unit;

[0041] Figure 4A is a simplified perspective view of a portion of another implementation of a heating unit;

[0042] Figure 4B is a simplified side view of an array of the heating units;

[0043] Figure 5 is a perspective of a conduction heating unit;

[0044] Figure 6A is a simplified illustration of the energy system, the build platform assembly, and another implementation of the heating unit;

[0045] Figure 6B is another simplified illustration of the energy system, the build platform assembly, and another implementation of the heating unit;

[0046] Figure 7 is a simplified illustration of the energy system, the build platform

assembly, and a shield segment;

[0047] Figure 8 is a simplified illustration of the energy system, the build platform assembly, and another implementation of the shield segment;

[0048] Figure 9 is a flow chart that illustrates a method to reduce smoking of the material;

[0049] Figure 10A is another flow chart that illustrates another method to reduce smoking of the material

[0050] Figure 10B is a simplified illustration of the object with the material at a first time;

[0051] Figure 10C is a simplified illustration of the object with the material at a second time;

[0052] Figure 11A is another flow chart that illustrates another method to reduce smoking of the material;

[0053] Figure 11B is a simplified illustration of the object with the material and a material supply device; and

[0054] Figure 12 is a simplified illustration of another material supply device.

DESCRIPTION

[0055] Figure 1A is a simplified perspective view of a processing machine 10 that may be used to manufacture one or more three-dimensional objects 11A, 11B (illustrated in phantom). As provided herein, the processing machine 10 can be an additive manufacturing system, e.g. a three-dimensional printer, in which a material 12 (illustrated as small circles) is joined, melted, solidified, and/or fused together in a series of material layers 14 (illustrated as dashed horizontal lines) to manufacture one or more three-dimensional object(s) 11A, 11B. The non-exclusive implementation of Figure 1A illustrates two objects, namely a first object 11A, and a second object 11B that are being made concurrently. However, the processing machine 10 can be designed to make a single object 11A, 11B or more than two objects 11A, 11B substantially concurrently.

[0056] The type of three-dimensional object(s) 11A, 11B manufactured with the

processing machine 10 may be almost any shape or geometry. In Figure 1A, each built object 11A, 11B is illustrated as being irregular shaped, and is formed in the series of generally rectangular shaped material layers 14. In this non-exclusive example, only a portion of the material 12 in each rectangular shaped material layer 14 is actually melted together. With this design, when the un-melted material 12 is removed, the built objects 11A, 11B will have a shape other than rectangular. The three-dimensional objects 11A, 11B may also be referred to as a “built part”.

[0057] The type of material 12 joined and/or fused together may be varied to suit the desired properties of the object(s) 11A, 11B. As a non-exclusive example, the material 12 may include metal material particles (e.g., including one or more of titanium, aluminum, vanadium, chromium, copper, stainless steel, or other suitable metals) or alloys for metal three-dimensional printing. Alternatively, the material 12 may be non-metal material, a plastic, polymer, glass, ceramic material, organic material, an inorganic material, or any other material known to people skilled in the art. The material 12 may also be referred to as “powder”.

[0058] A number of Figures include an orientation system that illustrates an X axis, a Y axis that is orthogonal to the X axis, and a Z axis that is orthogonal to the X and Y axes. It should be noted that any of these axes can also be referred to as the first, second, and/or third axes. Further, as used herein, movement with six degrees of freedom shall mean along and about the X, Y, and Z axes.

[0059] A number of different designs of the processing machine 10 are provided herein. Figure 1B is a simplified, cut-away perspective view of the processing machine 10 and the objects 11A, 11B of Figure 1A. With reference to Figures 1A and 1B, in this implementation, the processing machine 10 includes (i) a material bed assembly 16; (ii) a material supply device 18; (iii) a measurement device 20 (illustrated as a box); (iv) an energy system 22; (v) a control system 24 (illustrated as a box); (vi) a heating assembly 26; (vii) a cooling assembly 28 (also called as a chiller) illustrated in phantom in Figure 1B); (viii) a build chamber assembly 30 that provides a build space 30A for building the object(s) 11A, 11B; and (ix) a mover assembly 32 that causes relative movement between the material bed assembly 16 and the build chamber assembly 30. The design of each of these components may be varied pursuant to the teachings

provided herein. Further, the positions of the components of the processing machine 10 may be different than that illustrated in Figures 1A and 1B. Moreover, the processing machine 10 can include more components or fewer components than illustrated in Figures 1A and 1B. For example, the processing machine 10 can be designed to include a temperature adjuster 33 that selectively adjusts the temperature of the material 12 as necessary. Further, the heating assembly 26, the cooling assembly 28, and the temperature adjuster 33 can be collectively or individually referred to as a temperature control assembly 29.

[0060] Figure 1C is a simplified top view of the material bed assembly 16.

[0061] As an overview, with reference to Figures 1A-1C, in certain implementations, the build chamber assembly 30 is uniquely designed to include a deposition area 34, a melting area 36, a heating area 38, a cooling area 40, and a temperature adjustment area 42. Further, the heating area 38, the cooling area 40, the temperature adjustment area can be collectively or individually referred to as a temperature control area 43. More specifically, in this design, (i) the material supply device 18 deposits material 12 onto the material bed assembly 16 in the deposition area 34; (ii) the energy system 22 selectively melts the material 12 in the melting area 36; (iii) the heating assembly 26 heats the material 12 in the heating area 38; (iv) the cooling assembly 28 cools the material 12 in the cooling area 40; and (v) the temperature adjuster 33 adjusts the temperature of the material 12 in the temperature adjustment area 42. With this design, the control system 24 controls the material supply device 18, the energy system 22, the temperature control assembly 19 (the heating assembly 26, the cooling assembly 28, and the temperature adjuster 33) to actively control the temperature of the material 12 on the material bed assembly 16 during relative movement between the material bed assembly 16 and the areas 34, 36, 38, 40, 42 of the build chamber assembly 30.

[0062] As provided herein, the machine 10 is uniquely design to provide precise area-by-area temperature control of the material 12 during the build process of the object(s) 11A, 11B during relative movement between the material bed assembly 16 and the areas 34, 36, 38, 40, 42. Because the temperature of the material 12 is actively controlled during the manufacturing of the object(s) 11A, 11B, the object(s) 11A, 11B

can be made with increased accuracy and speed, and the machine 10 has a high throughput.

[0063] Moreover, in certain implementations, the build chamber assembly 30 is uniquely designed to (i) enhance the transfer of heat from the heating assembly 26 to the material 12 in the heating area 38; (ii) enhance the transfer of heat from the material 12 to the cooling assembly 28 in the cooling area 40; and (iii) enhance the transfer of heat between the temperature adjuster 33 and the material 12 in the temperature adjustment area 42. Further, the build chamber assembly 30 is uniquely designed to reduce the amount of heat transferred from the build space 30A to the components that are outside of the build space 30A. This will simplify the design of the components outside of the build space 30A because they will not have to operate in the extreme environment in the build space 30A.

[0064] In a specific example, as provided herein, for a processing machine 10 that uses a metal material 12, it may be desirable to maintain a sufficiently high temperature of the object(s) 11A, 11B throughout the build process to minimize thermal stress and deformation while also creating optimal metallurgy in the object(s) 11A, 11B. Additionally, sometimes it may be important to remove heat from the melting process as quickly as possible so the metal will solidify in the desired shape and melting throughput can be increased. Moreover, it is also important to keep at least a portion of the build chamber assembly 30 and various components (e.g., O-ring seals, measurement devices 10, magnets, and electronics) at sufficiently low temperatures to avoid damage. Further, for example, when the material 12 is metal, the machine 10 can control a composition of metal material as desired based on a metallurgy knowledge by actively controlling the temperature of the object(s) 11A, 11B during the build process.

[0065] The design, shape, size, and location of the areas 34, 36, 38, 40, 42 can be varied pursuant to the teachings provided herein. Further one or more of the areas 34, 36, 38, 40, 42 can be partly or fully overlapping. In the non-exclusive implementation of Figure 1C, the material bed assembly 16 may be referenced as a clock face for ease of discussion. In this embodiment, (i) the temperature adjustment area 42 extends from about 7:30 to about 1:00 shown by an arc shape in Figure 1C; (ii) the deposition

area 34 overlaps a portion of the temperature adjustment area 42, and extends from about 8:00 to about 11:00 shown by an arc shaped in Figure 1C; (iii) the heating area 38 extends from about 4:30 to about 7:00 shown by an arc shape in Figure 1C; (iv) the cooling area 40 is generally arc shaped and extends from about 1:00 to about 4:00 shown by an arc shape in Figure 1C; and (v) the melting area 36 overlaps a portion of the cooling area 40 and is shown by a circular shape position at about 3:30. Further, in this example, (i) the temperature adjustment area 42 is positioned between the cooling area 40 and the heating area 38 when moving counter-clockwise; (ii) the temperature adjustment area 42 encircles the deposition area 34; and (iii) the cooling area 40 encircles the melting area 36. It is appreciated that the layout of the areas 34, 36, 38, 40, 42 relative to the material bed assembly 16 illustrated in Figure 1C is just one representative example, and the size, shape, and/or location of areas 34, 36, 38, 40, 42 can be different than illustrated in Figure 1C.

[0066] The desired thermal profile for each area 34, 36, 38, 40, 42 can be varied and controlled according to the material being utilized. As a non-exclusive example, (i) the heating assembly 26 can maintain a section of the heating area 38 at a heating temperature that is between approximately 800 and 1400 degrees Celsius; (ii) the cooling assembly 28 can maintain a section of the cooling area 40 at a cooling temperature that is between approximately 500 and 900 degrees Celsius; and/or (iii) the temperature adjuster 33 can maintain the temperature adjustment of a section of area 42 at an adjustment temperature that is between approximately 500 and 1400 degrees Celsius. However, other values higher or lower are possible. In certain implementations, the temperatures are decided depending on the material 12 being processed and to a lesser extent the design of the object 11 (e.g. some object designs will retain heat more easily than others).

[0067] The desired thermal profile of a section of material 12 (e.g. the top material layer 14) might be determined by the desire to control the cooling rate of a section for any number of metallurgical reasons such as but not limited to solidification, vaporization, grain boundary generation, or heat-treating. The thermal profile of a section will typically be governed by the radiation environment that this section can “see”, the thermal conduction coefficient of this material 12 to other parts of the

machine 10, and any thermal “breaks” that have been built into the physical conduction path(s). The primary source of thermal control is achieved by adjusting the heating of “radiation shields” located inside of the build chamber assembly 30. These shields may be useful to even-out the heating effects from heating elements that have discrete “hot spots”. This shield heating might be accomplished through the use of resistive conductive heating elements such as NiChrome Wire, or it might be accomplished through the use of thermal radiation elements, such as infrared lamps. Temperature control can be improved through thermal isolation of the shield from the lower temperature build chamber assembly 30. Excess heat can be removed from the shield by providing liquid cooling of another shield element that absorbs by radiation heat from the shield under thermal control. For particular applications any combination of these methods may be used. For the bulk volume of material, its predominant thermal radiation path may be to the thermal shields of the build chamber assembly 30, and for the topmost section of the build material 12, the top shields may likely be the primary thermal radiation path. By controlling the side and top shield temperatures independently, different thermal profiles may be obtained for different sections of material 12. Also, it may be possible to build the thermal shields in separate sections so that different areas 34, 36, 38, 40, 42 may have significantly different thermal shield temperatures. Furthermore, it may be possible to heat different build sections in different areas 34, 36, 38, 40, 42 of the build chamber assembly 30 through the usage of direct radiation heating elements without using an intermediate shield between the section and the heating element. It may be that the thermal conduction path and coefficient of sintered, melted, and un-melted material 12 differs due to surface effects of the section materials 12, and that this may be further exploited to control temperature profiles of different areas 34, 36, 38, 40, 42. Finally, the heat conduction path of the build materials 12 into the rest of the build chamber assembly 30 may be a dominant form of heat transfer – and the deliberate installation of thermal controls (e.g., thermal breaks, heaters, or radiative coolers) in this thermal conduction path may be an effective method of thermal gradient control.

[0068] It should also be noted that with the unique design provided herein, that multiple objects 11A, 11B may be made concurrently, and multiple operations may be

performed at the same time (simultaneously) to improve the throughput of the processing machine 10. Further, some or all of the above operations can be happening simultaneously on different parts of the material bed assembly 16.

[0069] The material bed assembly 16 supports the material 12 and the object(s) 11A, 11B while being built. In the simplified implementation illustrated in Figure 1B, the material bed assembly 16 includes (i) a build platform 44 having a support surface 44A that supports the material 12; and (ii) a platform shaft 46 that extends downward from the build platform 44. In this implementation, the build platform 44 is flat, disk shaped. However, other shapes of the build platform 44 are possible. As non-exclusive examples, the build platform 44 can be flat rectangular shaped, or polygonal-shaped.

[0070] It should be noted that other designs of the material bed assembly 16 are possible. For example, the material bed assembly 16 can include a tube shaped side wall and/or one or more receptacles for capturing material 12 that is directed off of the build platform 44.

[0071] As provided above, the mover assembly 32 causes relative movement between the material bed assembly 16 and the build chamber assembly 30. In the non-exclusive implementation of Figure 1B, the mover assembly 32 is coupled to the platform shaft 46, and rotates the build platform 44 about a movement axis 32A relative to the build chamber assembly 30 and the other components. Further, the mover assembly 32 can be controlled to move the build platform 44 downward along the movement axis 32A relative to the build chamber assembly 30 and the other components to allow each subsequent powder layer 14 to be added. Still alternatively, the mover assembly 32 can cause the relative motion in a different fashion. For example, the mover assembly 32 can be additionally or alternatively be designed to move the build platform 44 linearly (e.g. along the X and/or Y axis) relative to the other components.

[0072] The material supply device 18 deposits the material 12 onto the build platform 44 in the deposition area 34 to sequentially form each material layer 14. In one non-exclusive implementation, the material supply device 18 is a single overhead material supply that supplies the material 12 onto the top of the moving build platform

44. In this design, the material supply device 18 can include a rake (not shown) or other device that distributes/levels each sequential material layer 14. Alternatively, the material supply device 18 can be designed to include multiple material supplies (at different locations) and/or other ways to distribute/level each sequential material layer 14.

[0073] Still alternatively, the material supply device 18 can be a table-integrated material supply which delivers the material 12 from the side or through the material bed assembly 16, or another type of material supply device.

[0074] It should be noted that the material supply device 18 can maintain the material 12 at a spread temperature that allows the material 12 to be easily and accurately spread into the respective material layer 14. Typically, the spread temperature is well below a melt temperature of material 12 and below a sinter temperature of the material 12. In some embodiments, the spread temperature is the ambient “room temperature.” In alternative embodiments, the spread temperature may be warmer than the ambient “room temperature”, but lower than the sinter temperature and the melt temperature.

[0075] In the non-exclusive of Figures 1A and 1B, for each object 11A, 11B, the material supply device 18 deposits a rectangular shaped material layer 14 onto the build platform 44 during each rotation of the build platform 44. For simplicity, only eight separate, stacked material layers 14 are illustrated. However, it should be noted that depending upon the design of the object(s) 11A, 11B, the building process will require many more material layers 14 than eight.

[0076] The measurement device 20 (illustrated as a box) inspects and monitors the melted (fused) layers of the object(s) 11A, 11B as they are being built, and/or the deposition of the material layers 14. The number of the measurement devices 20 may be one or plural. The measurement device 20 may inspect the material layer(s) 14 or the object(s) 11A, 11B optically, electrically, or physically. As non-exclusive examples, the measurement device 20 may include one or more optical elements such as a uniform illumination device, a fringe illumination device (structured illumination device), cameras that function at one or more wavelengths, a lens, an interferometer, or a photodetector, or a non-optical measurement device such as an ultrasonic, eddy

current, or capacitive sensor.

[0077] The measurement by the measurement device 20 can occur in a measurement area 48 of the build chamber assembly 30. In the non-exclusive implementation of Figure 1C, the measurement area 48 is in and near the deposition area 34. Alternatively, the measurement device 20 can be at a different location.

[0078] Additionally, the measurement device 20 can include one or more sensors that can be used for closed loop control of the energy system 22, the heating assembly 26, the cooling assembly 28, and/or the temperature adjuster 33. For example, the measurement device 20 can include one or more temperature sensors.

[0079] The energy system 22 generates and directs an energy beam 22A (illustrated with a dashed arrow) at the material 12 in the top material layer 14 on the build platform 44 to selectively melt the material 12 in the melting area 36. In Figure 1B, the energy system 22 is illustrated as a single system that generates the energy beam 22A that is steered to melt (by heating) the desired portion of each material layer 14. Alternatively, the energy system 22 can include multiple energy systems.

[0080] In one embodiment, the energy system 22 is an electron beam generator and the energy beam 22A is a charged particle electron beam. In this design, for each material layer 14, the electron beam generator 22 is controlled (based on a data regarding the object(s) 11A, 11B being built) to steer the electron beam 22A to the desired portions of the respective material layer 14. The data may be corresponding to a computer-aided design (CAD) model data. In the electron beam generator 22, the electrons can be quickly and accurately manipulated by electric and magnetic fields to precisely steer the electron beam 22A. The electrons collide with the material 12 to heat and melt the material 12.

[0081] Alternatively, the energy system 22 can include (i) an irradiation system that generates an irradiation beam; (ii) an infrared laser that generates an infrared beam; (iii) a mercury lamp; (iv) a thermal radiation system; (v) a visual wavelength system; (vi) a microwave wavelength system; or (vii) an ion beam system.

[0082] The temperature required to fully melt and fully fuse the material 12 will vary according to a number of factors, including the type of material 12 and the pressure in the build space 30A. As non-exclusive examples, the melt temperature may be at least

1000, 1400, 1700, 2000, or more degrees Celsius. In one specific example, the material 12 is stainless steel. In this example, the melt temperature is at about 1450 degrees Celsius.

[0083] The control system 24 controls the components of the processing machine 10 to build the three-dimensional object(s) 11A, 11B from the computer-aided design (CAD) model. For example, as provided herein, the control system 24 can control operation of the heating assembly 26, the cooling assembly 28, and the temperature adjuster 33 to actively control the temperature of the material 12 at the different areas 34, 36, 38, 40, 42, and the energy system 22 to melt the desired material 12 of each material layer 14.

[0084] The control system 24 may include, for example, a CPU (Central Processing Unit) 24A, a GPU (Graphics Processing Unit) 24B, and an electronic memory 24C. The control system 24 functions as a device that controls the operation of the processing machine 10 by the CPU executing the computer program. This computer program is a computer program for causing the control system 24 (for example, a CPU) to perform an operation to be described later to be performed by the control system 24 (that is, to execute it). That is, this computer program is a computer program for making the control system 24 function so that the processing machine 10 will perform the operation to be described later. A computer program executed by the CPU may be recorded in a memory (that is, a recording medium) included in the control system 24, or an arbitrary storage medium built in the control system 24 or externally attachable to the control system 24, for example, a hard disk or a semiconductor memory. Alternatively, the CPU may download a computer program to be executed from a device external to the control system 24 via the network interface. Further, the control system 24 may not be disposed inside the processing machine 10, and may be arranged as a server or the like outside the processing machine 10, for example. In this case, the control system 24 and the processing machine 10 may be connected via a communication line such as a wired communications line (cable communications), a wireless communications line, or a network. In the case of physically connecting with a wired communications line, it is possible to use serial connection or parallel connection of IEEE1394, RS-232x, RS-422, RS-423, RS-485, USB, etc. or 10BASE-T, 100BASE-

TX, 1000BASE-T or the like via a network. Further, when connecting using radio, radio waves such as IEEE 802.1x, OFDM, or the like, radio waves such as Bluetooth (registered trademark), infrared rays, optical communication, and the like may be used. In this case, the control system 24 and the processing machine 10 may be configured to be able to transmit and receive various types of information via a communication line or a network. Further, the control system 24 may be capable of transmitting information such as commands and control parameters to the processing machine 10 via the communication line and the network. The processing machine 10 may include a receiving device (receiver) that receives information such as commands and control parameters from the control system 24 via the communication line or the network. As a recording medium for recording the computer program executed by the CPU, a CD-ROM, a CD-R, a CD-RW, a flexible disk, an MO, a DVD-ROM, a DVD-RAM, a DVD-R, a DVD + R, a DVD-RW, a magnetic medium such as a magnetic disk and a magnetic tape such as DVD + RW and Blu-ray (registered trademark), a semiconductor memory such as an optical disk, a magneto-optical disk, a USB memory, or the like, and a medium capable of storing other programs. In addition to the program stored in the recording medium and distributed, the program includes a form distributed by downloading through a network line such as the Internet. Further, the recording medium includes a device capable of recording a program, for example, a general-purpose or dedicated device mounted in a state in which the program can be executed in the form of software, firmware or the like. Furthermore, each processing and function included in the program may be executed by program software that can be executed by a computer, or processing of each part may be executed by hardware such as a predetermined gate array (FPGA, ASIC) or program software, and a partial hardware module that realizes a part of hardware elements may be implemented in a mixed form.

[0085] The heating assembly 26 heats the material 12 in the top material layer 14 on the build platform 44 in the heating area 38 to sinter ("preheat and/or partly melt and lightly bond") the material 12 just prior to the material 12 being melted by the energy system 22. As is known, during melting of certain material 12 with an electron energy beam 22A, the material particles 12 can develop a charge and repulse each

other. When the charge is large enough, the material particles 12 develop enough repulsive force to overcome gravity and fly apart. This phenomenon is known as “smoking” or “spreading”.

[0086] The present design can utilize the heating assembly 26 to at least partly sinter the material 12 in the uppermost material layer 14 to inhibit smoking of the material 12 during the subsequent melting process. For each material layer 14, once the top is sintered together, the electron beam 22A can be controlled to melt the desired regions of the material layer 14 to form a portion of the objects 11A, 11B. Further, the sintering bonds the material 12 together and also creates a higher conductivity path through which the accumulated charge from the energy beam 22A can be dissipated.

[0087] The design of the heating assembly 26 can be varied. As non-exclusive examples, the heating assembly 26 can include one or more heating units that generate visible or infrared light. The heating assembly 26 can include one or more lasers or high intensity lamps that heat the material 12 without electrically charging the material 12. Alternatively, for example, the heating assembly 26 can generate other wavelengths, such as microwave or ultraviolet light. Still alternatively, the heating assembly 26 can include an electron beam generator that is slightly defocused when heating so that the charge buildup in the material 12 is given time to dissipate while the material 12 slowly heats relatively slowly.

[0088] The temperature and heating time required to sinter the material 12 will depend on many things, including the type of material 12, particle size, and chamber pressure, etc. It is understood that different materials 12 have different sintering points. The sinter temperature (and sinter time) is selected to partly melt the material 12 enough to lightly stick together, while not melting it enough to be structurally strong. It is this slight melting that keeps the material 12 from flying apart when the energy beam 22A from the energy system 22 hits the material 12.

[0089] In alternative, non-exclusive examples, the sinter temperature is at least fifty, sixty, sixty-five, seventy, seventy-five, eighty, ninety percent of the melt temperature to achieve the slight melting. As non-exclusive examples, the desired sinter temperature may be at least 300, 500, 700, 900, or 1000 degrees Celsius. Stated in a different

fashion, in alternative, non-exclusive examples, the sinter temperature is at least 50, 100, 200, 300, 500, 700, or 1000 degrees Celsius less than the melt temperature.

[0090] As illustrated in Figure 1C, in one implementation, the build platform 44 is rotated in a movement direction 32B about the movement axis 32A (illustrated with a “+”) relative to the areas 34, 36, 38, 40, 42. In this example, the movement direction 32B is counterclockwise. Further, in Figure 1C, the melting area 36 is adjacent to the heating area 38. With this design, the material 12 will be moved from the heating area 38, directly to the melting area 36. Thus, in this example, there is no (or very little) cooling time between sintering and melting as it is generally desired to have the sintered material layer 14 at the elevated temperature at the start of melting.

[0091] The cooling assembly 28 cools the material 12 in the top material layer 14 on the build platform 46 in the cooling area 40 after the material 12 has been melted. With this design, the cooling assembly 28 can be controlled to cool (e.g. rapidly, slowly, or somewhere therebetween) the melted portion of the material layer 14 at the desired rate so that the material 12 will solidify in the desired shape, and remove heat to prepare the stack of material layers 14 for the next material layer 14. Stated in another fashion, after the top material layer 14 is melted, if heat is not removed from the molten surface, it can stay liquid and slowly spread losing the design integrity of the object(s) 11A, 11B. The cooling assembly 28 can rapidly, slowly, or somewhere therebetween remove the heat to inhibit spreading of the melted material 12, and achieve the desired properties of the object(s) 11A, 11B.

[0092] For example, the cooling assembly 28 can use one or more cooling units that use radiation, conduction, and/or convection to cool the material 12.

[0093] In certain implementations, the cooling assembly 28 can be used not only for rapid cooling but also for controlled cooling over time. For example, from a metallurgy perspective, sometimes it would be better for the material 12 to be cooled slowly. The processing machine 10 can meet such requirement by controlling the cooling assembly 28. For that purpose, for example, the cooling assembly 28 can include one or more adjustable heaters (heating units) to selectively control the cooling rate of the upper material layer 14.

[0094] The cooling assembly 28 and/or the cooling area 40 can encircle the melting

area 36 to absorb radiative heat from the melted material 12. Further, the cooling assembly 28 can ground scattered/emitted electrons. Moreover, the cooling assembly 28 and the temperature adjustment area 42 can be partly or fully joined together.

[0095] The build chamber assembly 30 provides the controlled environment, build space 30A for building the object(s) 11A, 11B. The design, size and shape of the build chamber assembly 30 can be varied pursuant to the teachings provided herein. In the non-exclusive implementation of Figures 1A and 1B, the build chamber assembly 30 includes a build chamber 50 that defines the build space 30A, and an environment controller 52 that controls the environment in the build space 30A.

[0096] In one, non-exclusive implementation, the build chamber 50 defines the build space 30A that is generally cylindrical shaped. However, the build chamber 50 can be designed so that the build space 30A has a shape other than cylindrical shaped, e.g. rectangular shaped.

[0097] Further, in the non-exclusive implementation of Figure 1B, the build chamber 50 includes a chamber structure 54 that at least partly encircles the build platform 44, and one or more shield assemblies 56, 58 positioned between the build platform 44 and the chamber structure 54. In this design, the shield assemblies 56, 58 reduce the thermal transfer between the build space 30A and the chamber structure 54. As a result thereof, the temperature in the build space 30A is more accurate, and at least a portion of the chamber structure 54 and other components are not subjected to the harsh temperatures in the build space 30A. Stated in another fashion, the unique design of the build chamber 50 allows for many of the components (e.g. the material supply device 18, the measurement device 20, the energy system 22, and/or the mover assembly 32) to not be subjected to the heat within the build space 30A. This simplifies the design of these components.

[0098] The chamber structure 54 provides a rigid, outer enclosure around the shield assemblies 56, 58 and the build platform 44. Further, the chamber structure 54 can completely encircle the shield assemblies 56, 58 and the build platform 44. Additionally, the chamber structure 54 can define the vacuum chamber. The design of the chamber structure 54 can be varied. In the non-exclusive implementation of Figure 1B, the chamber structure 54 is generally cylindrical box shaped and includes a

generally disk shaped top structure wall 54A, a generally disk shaped bottom structure wall 54B, and a generally tubular shaped structure sidewall 54C. In this design, the structure sidewall 54C extends between the top structure wall 54A and the bottom structure wall 54B; and the structure sidewall 54C seals the top structure wall 54A to the bottom structure wall 54B. Further, as illustrated, the structure walls 54A, 54B are oriented horizontally, and the structure sidewall 54C is oriented vertically. As non-exclusive examples, the chamber structure 54 can be made of steel, stainless steel, titanium, tungsten, aluminum, molybdenum, or titanium.

[0099] In the non-exclusive implementation Figure 1B, (i) the material supply device 18; (ii) the measurement device 20; (iii) an energy system 22; (iv) the heating assembly 26; (v) the cooling assembly 28; and (vi) the temperature adjuster 33 are directly or indirectly secured and/or coupled to the top wall 54A. Further, in this implementation, the mover assembly 36 couples the material bed assembly 16 to the bottom wall 54B. However, the positions of the components of the processing machine 10 may be different than that illustrated in Figure 1B. Further, one or more of these components can be individually and selectively movable relative to chamber structure 54.

[00100] Further, the temperature of the chamber structure 54 can be maintained at a fixed, chamber temperature. Additionally, the chamber structure 54 can include a thermal insulation system. In one implementation, the chamber structure 54 can be maintained at a chamber temperature that is approximately room temperature (approximately twenty degrees Celsius). In another implementation, an outer surface of the chamber structure 54 can be a low enough temperature to prevent burns to humans if touched, while portions (or all) of the inside are maintained at extremely high temperature. For example, even if the metal object 11A, 11B is being cooled, it is still a high temperature for humans.

[00101] The number and design of shield assemblies 56, 58 can be varied to achieve the desired level of reduction in energy transfer from the hot build space 30A and the rest of the system. Note that the addition of more shield assemblies 56, 58 typically reduces the total heat losses of the system and therefore also reduces the power required from the heating assembly 26. Conversely, fewer shield assemblies 56, 58 will result in more heat transfer into and through the chamber structure 254.

[00102] In the non-exclusive implementation of Figure 1B, the build chamber 50 includes two shield assemblies 56, 58, namely a first shield assembly 56 and a second shield assembly 58 that are spaced apart from each other and the chamber structure 54. In this implementation, the build chamber 50 includes a multilayer thermal shield 56,58 that reduces energy transfer from the hot build space 30A to the rest of the system. Stated in a different fashion, the build space 30A is surrounded by concentric layers of radiation shields 56, 58. It should be noted that the build chamber 50 can be designed to include more than two or fewer than two shield assemblies 56, 58 positioned between the build platform 44 and the chamber structure 54. Generally speaking, as the number of shield assemblies 56, 58 is increased, the thermal isolation of the chamber structure 54 is increased.

[00103] The first shield assembly 56 is the innermost shield assembly (closest to the build platform 44) and can be referred to as an inner thermal shield. The design of the first shield assembly 56 can be varied. In the non-exclusive implementation of Figure 1B, the first shield assembly 56 can be generally cylindrical box shaped and can encircle the build platform 44 and the object(s) 11A, 11B being built. In this design, the first shield assembly 56 includes a generally disk shaped, top shield wall 56A, a generally disk shaped, bottom shield wall 56B, and a generally tubular shaped shield sidewall 56C. In this design, the shield sidewall 56C extends between the top shield wall 56A and the bottom shield wall 56B. Further, the top shield wall 56A is above the build platform 44 and the bottom shield wall 56B is positioned below the build platform 44. Moreover, as illustrated, the shield walls 56A, 56B are oriented horizontally, and the shield sidewall 56C is oriented vertically. It should be noted that the temperature of each of the walls 56A, 56B, 56C can be individually controlled to control the thermal profile of the object 11 being built.

[00104] In a non-exclusive implementation, one or more the top shield wall 56A, the bottom shield wall 56B, and the shield sidewall 56C are made of a sheet metal or another material. In some cases, it is desirable to have low emissivity (i.e., high reflectivity polished surfaces or high reflectivity coatings) in some locations or all of the surfaces of the top shield wall 56A and/or the shield sidewall 56C that face the build platform 44 to reduce radiative heat transfer. Alternatively, or additionally, it can be

desirable to have high emissivity (i.e., a flat black low reflectivity surface) in some locations or all of the surfaces of the top shield wall 56A and/or the shield sidewall 56C that face the build platform 44 to increase radiative heat transfer.

[00105] In certain implementations, the first shield assembly 56 (e.g. the top shield wall 56A, the bottom shield wall 56B, and/or the shield sidewall 56C) can be divided into two or more, spaced apart shield segments 57A, 57B, 57C. For example, the top shield wall 56A can be divided into a plurality (two or more) of spaced apart, shield segments 57A, 57B, 57C. With this design, the shield segments 57A, 57B, 57C can be maintained at different temperatures. Thus, in this design, the shield segments 57A, 57B, 57C can be at least partly, thermally isolated from each other.

[00106] In the non-exclusive, simplistic example of Figure 1B, the top shield wall 56A has been divided into a first shield segment 57A, a second shield segment 57B that is spaced apart from the first shield segment 57A, and a third shield segment 57C that is spaced apart from the first shield segment 57A and the second shield segment 57B. For example, the heating assembly 26 can be thermally coupled to the first shield segment 57A, the cooling assembly 28 can be thermally coupled to the second shield segment 57B, and the temperature adjuster 33 can be thermally coupled to the third shield segment 57C.

[00107] Additionally, and optionally the temperature of one or more of the shield segments 57A, 57B, 57C can be actively and individually maintained. In one implementation, (i) the heating assembly 26 can actively maintain the temperature of the first shield segment 57A, and the first shield segment 57A can define at least a portion of the heating area 38; (ii) the cooling assembly 28 can be actively maintain the temperature of the second shield segment 57B, and the second shield segment 57B can define at least a portion of the cooling area 40; and (iii) the temperature adjuster 33 can actively maintain the temperature of the third shield segment 57C, and the third shield segment 57C can define at least a portion of the temperature adjustment area 42. With this design, each of the shield segments 57A, 57B, 57C can be at a different temperature. Further, adjusting the temperature of the innermost first shield assembly 56 allows the system to accommodate a wider variety of process recipes, melting energy, and throughput.

[00108] As a non-exclusive example, (i) the heating assembly 26 can actively maintain the temperature of the first shield segment 57A to be approximately equal to the heating temperature (e.g. between approximately 300 and 1000 degrees Celsius); (ii) the cooling assembly 28 can maintain the second shield segment 57B to be approximately equal to the cooling temperature (e.g. between approximately 20 and 500 degrees Celsius); and (iii) the temperature adjuster 33 can actively maintain the temperature of the third shield segment 57C to be approximately equal to the adjustment temperature (e.g. adjustable between approximately twenty and five hundred degrees Celsius). In alternative, non-exclusive implementations, the heating temperature is at least 100, 200, 500, 1000 degrees Celsius greater than the cooling temperature. Adjusting the temperature of the innermost shield assembly 56 allows the system 10 to accommodate a wider variety of process recipes, melting energy, and throughput.

[00109] Similarly, the shield sidewall 56C can be divided into one or more shield segments, and/or the shield sidewall 56C can be spaced apart from the top shield wall 56A. It should be noted that the first shield assembly 56 can be divided in a fashion different than illustrated in Figure 1B.

[00110] The thickness of the first shield assembly 56 can be of any thickness, with the critical criteria being a low “Radiative Emissivity” to provide insulation and the materials ability to withstand the desired temperature. Typically, high-temperature refractive metals such as Molybdenum may be used, but Stainless Steel (with a low softening temperature) may also be effective. Typically, the thickness can be between one and five millimeters. However, other materials and thicknesses can be utilized for the first shield assembly 56. One or more of the walls 56A, 56B, 56C of the first shield assembly 56 can include a reflective surface that faces the build platform 44.

[00111] The second shield assembly 58 is positioned between the first shield assembly 56 and the chamber structure 54. The second shield assembly 58 can be referred to as an intermediate thermal shield and can be made of sheet metal. The design of the second shield assembly 58 can be varied. In the non-exclusive implementation of Figure 1B, the second shield assembly 58 can be generally cylindrical box shaped and encircle the first shield assembly 56. In this design, the

second shield assembly 58 includes a generally disk shaped, top intermediate wall 58A, a generally disk shaped, bottom intermediate wall 58B, and a generally tubular shaped intermediate sidewall 58C. In this design, the intermediate sidewall 58C extends downward from the top intermediate wall 58A. Moreover, as illustrated, the shield walls 58A, 58B are oriented horizontally, and the shield sidewall 58C is oriented vertically.

[00112] Further, (i) the top intermediate wall 58A of the second shield assembly 58 is positioned between the top shield wall 56A of the first shield assembly 56 and the top structure wall 54A of the chamber structure 54; (ii) the bottom intermediate wall 58B of the second shield assembly 58 is positioned between the bottom shield wall 56B of the first shield assembly 56 and the bottom structure wall 54B of the chamber structure 54; and (iii) the intermediate sidewall 58C of the second shield assembly 58 is positioned between the shield sidewall 56C of the first shield assembly 56 and the structure sidewall 54C of the chamber structure 54;

[00113] In certain implementations, the second shield assembly 58 (e.g. the top intermediate wall 58A, the bottom intermediate wall 58B, and/or the intermediate sidewall 58C) can be divided into two or more, spaced apart shield areas 59A, 59B, 59C. For example, the top intermediate wall 58A can be divided into a plurality (two or more) of spaced apart, shield area 59A, 59B, 59C. With this design, the shield areas 59A, 59B, 59C can be maintained at different temperatures. Thus, in this design, the shield areas 59A, 59B, 59C can be at least partly, thermally isolated from each other.

[00114] In the non-exclusive, simplistic example of Figure 1B, the top intermediate wall 58A has been divided into a first shield area 59A, a second shield area 59B that is spaced apart from the first shield area 59A, and a third shield area 59C that is spaced apart from the first shield area 59A and the second shield area 59B. For example, the heating assembly 26 can be thermally coupled to the first shield area 59A, the cooling assembly 28 can be thermally coupled to the second shield area 59B, and the temperature adjuster 33 can be thermally coupled to the third shield area 59C.

[00115] Additionally, and optionally the temperature of one or more of the shield areas 59A, 59B, 59C can be actively maintained.

[00116] Similarly, the intermediate sidewall 58C can be divided into one or more

shield areas, and/or the intermediate sidewall 58C can be spaced apart from the top intermediate wall 58A. It should be noted that the second shield assembly 58 can be divided in a fashion different than illustrated in Figure 1B.

[00117] The thickness of the second shield assembly 58 can be of any thickness, with the critical criteria being a low “Radiative Emissivity” to provide insulation and the materials ability to withstand the desired temperature. Typically, high-temperature refractive metals such as Molybdenum may be used, but Stainless Steel (with a low softening temperature) may also be effective. Typically, the thickness can be between one and five millimeters. However, other materials and thicknesses can be utilized for the second shield assembly 58. One or more of the walls 58A, 58B, 58C of the second shield assembly 58 can be reflective.

[00118] Additionally, the chamber structure 54 can includes a mount assembly 60 that couples the second shield assembly 58 to the chamber structure 54, and the first shield assembly 56 to the second shield assembly 58. In certain implementations, the mount assembly 60 (i) fixedly secures the second shield assembly 58 to the chamber structure 54 while reducing (minimizing) the thermal transfer between the second shield assembly 58 and the chamber structure 54; and (ii) fixedly secures the first shield assembly 56 to the second shield assembly 58 while reducing (minimizing) the thermal transfer between the first shield assembly 56 and the second shield assembly 58. For example, the mount assembly 60 can include one or more spaced apart mounts 60A that each have a relatively low thermal conductivity.

[00119] As disclosed herein, the build chamber assembly 30 is uniquely designed to control the temperature of a build platform 44 and the object(s) 11A, 11B. The disclosed technique includes providing a multilayer thermal shield 56, 58 that reduces energy transfer from the hot build platform 44 to the rest of the system and optionally provides active control of at least one shield segment 57A, 57B, 57C to allow indirect control of the temperature of the build platform 44.

[00120] The mover assembly 32 causes relative movement between the build platform 44 and areas 34, 36, 38, 40, 42 of the build chamber assembly 30. In the non-exclusive implementation of Figure 1B, the mover assembly 32 rotates the build platform 44 about the movement axis 32A in the movement direction 32B relative to

the build chamber assembly 30 and moves the build platform 44 downward along the movement axis 32A relative to the build chamber assembly 30 and the other components to allow each subsequent powder layer 14 to be added. Additionally, or alternatively, the mover assembly 32 can move the build platform linearly (e.g. along the X and/or Y axis). For example, the mover assembly 32 can include one or more rotary or linear actuators.

[00121] In Figure 1B, the platform shaft 46 extends through an aperture in the bottom shield wall 56B, and an aperture in the bottom intermediate wall 58B. Further, the mover assembly 32 is secured to the bottom structure wall 54B and is coupled to the platform shaft 46.

[00122] In one implementation, the mover assembly 32 can rotate the build platform 44 at a substantially constant or variable angular velocity. As alternative, non-exclusive examples, the mover assembly 32 rotate the build platform at a substantially constant angular velocity of at least approximately 2, 5, 10, 20, 30, 60, or more revolutions per minute (RPM).

[00123] Still alternatively, the mover assembly 32 can cause the relative motion in a different fashion. For example, the mover assembly 32 can be designed to move the build chamber 50 relative to the build platform 44, and/or the mover assembly 32 can be designed to move the build platform 44 linearly in the horizontal axis.

[00124] The temperature adjuster 33 adjusts the temperature of the material 12 in the temperature adjustment area 42. For example, the temperature adjuster 33 can be controlled by the control system 24 to heat or cool the material 12 as necessary so that the material 12 is at the desired temperature in the temperature adjustment area 42. More specifically, if the material 12 entering the temperature adjustment area 42 is too hot, the temperature adjuster 33 can remove heat to lower the temperature of the material 12. Alternatively, if the material 12 entering the temperature adjustment area 42 is too cold, the temperature adjuster 33 can add heat to raise the temperature of the material 12. For example, the temperature adjuster 33 can include one or more adjustable heaters or chillers.

[00125] The environmental controller 52 controls the pressure inside the build space 30A. For example, the environmental controller 52 can include one or more pumps

that create a vacuum in the build space 30A. Still alternatively, the environmental controller 52 may be controlled to create a non-vacuum environment such as an inert gas (e.g., nitrogen gas or argon gas) environment in the build space 30A.

[00126] With reference to Figures 1B and 1C, the operation of the processing machine 10 for building the first object 11A includes depositing a first material layer 14 onto the moving build platform 44 which is being rotated counter-clockwise 32B. Next, the first material layer 14 is moved into the heating area 38 where it can be sintered with the heating assembly 26. At this time, the heating assembly 26 heats the first material layer 14 to a sinter temperature (the first target temperature), and the first material layer 14 is sintered. Subsequently, the first material layer 14 is moved to the melting area 36 where the energy beam 22A can be steered to melt the desired portions of the first material layer 14. Next, the first material layer 14 is moved to the cooling area 40 where the cooling assembly 28 removes heat and chills the melted first material layer 14. Subsequently, the first material layer 14 is moved to the temperature adjustment area 42 where the temperature adjuster 33 can either add heat or remove heat as necessary so that the first material layer 14 is at the appropriate temperature (the second target temperature). Next, the first material layer 14 is moved to the deposition area 34 where the second material layer 14 is added by the material supply device 18 on top of the first material layer 14. The process is then repeated for each subsequent material layer 14 until the first object 11A is built. Stated in another fashion, the first three-dimensional object 11A is formed through consecutive fusions of consecutively formed cross-sections of material layers 14.

[00127] It should be noted that with the present design, the second object 11B can be formed substantially concurrently with the first object 11A.

[00128] Figure 1D is a graph that illustrates one, non-exclusive plot (thermal time profile) of how an average (or characteristic) temperature of the upper material layer 14 (illustrated in Figure 1B) can vary versus time in the processing machine 10 (illustrated in Figure 1B). At the start of the process (left side of the graph), the upper material layer 14 is at the sinter temperature 62 (the first temperature, represented with a dashed line) which represents the temperature of the top of the upper material layer 14 when it exits the heating area 38.

[00129] In this example, during a first time segment “S1”, the upper material layer 14 is in the melting area 36, the energy system 22 is melting at least a portion of the upper material layer 14, and the temperature of the upper material layer 14 is increasing. Next, during a second time segment “S2”, the upper material layer 14 is now moved to the cooling area 40, the cooling assembly 28 is removing heat from the upper material layer 14, and the temperature of the upper material layer 14 is decreasing. Subsequently, during a third time segment “S3”, the partly build object including the upper material layer 14 is now moved to the temperature adjustment area 42, the temperature adjuster 33 is either adding heat or removing heat from the upper material layer 14 as necessary to adjust the temperature of the upper material layer 14 to the appropriate temperature (the second target temperature). In the illustrated implementation, the temperature adjuster 33 is adding a little heat to the upper material layer 14, and the temperature of the upper material layer 14 is increasing slightly.

[00130] Next, during a fourth time segment “S4”, in the deposition area 34, the next material layer 14 is now added on top of the previous material layer 14 by the material supply device 18. The new, uppermost material layer 14 is relatively cold, and the temperature decreases. Subsequently, during a fifth time segment “S5”, the new upper material layer 14 is now moved to the heating area 38, the heating assembly 26 is adding heat to the upper material layer 14 to sinter the upper material layer 14, and the temperature of the upper material layer 14 is increasing to the sinter temperature 62. Now, the new upper material layer 14 is ready for melting and the process repeated.

[00131] It should be noted that the actual temperature of the upper material layer 14 will vary according to what percentage of the upper material layer 14 is melted to form each layer the respective object 11A, 11B and will vary depending on the material 12 being used.

[00132] Figure 1E is a graph that illustrates (i) an upper plot 64 (maximum thermal time profile) of how the average (or characteristic) temperature of the upper material layer 14 (illustrated in Figure 1B) can vary versus time in the processing machine 10 (illustrated in Figure 1B) when almost the entire material layer 14 is being melted; and (ii) a lower plot 66 (minimum thermal time profile) of how the average (or characteristic)

temperature of the upper material layer 14 can vary versus time in the processing machine 10 when very little of the material layer 14 is being melted.

[00133] For the upper plot 64, at the start of the process (left side of the graph), the upper material layer 14 is at the sinter temperature 62 (represented with a dashed line) which represents the temperature of the upper material layer 14 when it exits the heating area 38. In this example, during the first time segment “S1”, almost the entire upper material layer 14 is being melted by the energy system 22 in the melting area 36, and the temperature of the upper material layer 14 is increasing. Next, during the second time segment “S2”, the upper material layer 14 is now moved to the cooling area 40, the cooling assembly 28 is removing heat from the upper material layer 14, and the temperature of the upper material layer 14 is decreasing. Subsequently, during the third time segment “S3”, the upper material layer 14 is now moved to the temperature adjustment area 42, the temperature adjuster 33 is also removing heat from the upper material layer 14 to lower the temperature of the upper material layer 14.

[00134] Next, during the fourth time segment “S4”, in the deposition area 34, the next material layer 14 is now added on top of the previous material layer 14 by the material supply device 18. The new, uppermost material layer 14 is relatively cold, and the temperature decreases. Subsequently, during the fifth time segment “S5”, the new upper material layer 14 is now moved to the heating area 38, the heating assembly 26 is adding heat to the upper material layer 14 to sinter the upper material layer 14, and the temperature of the upper material layer 14 is increasing to the sinter temperature 62. Now, the new upper material layer 14 is ready for melting and the process repeated.

[00135] Somewhat similarly, for the lower plot 66, at the start of the process (left side of the graph), the upper material layer 14 is at the sinter temperature 62. In this example, during the first time segment “S1”, just a small portion of the upper material layer 14 is being melted by the energy system 22 in the melting area 36, and the average temperature of the upper material layer 14 is actually decreasing slightly (not enough beam energy to keep the top level hot). Next, during the second time segment “S2”, the upper material layer 14 is now moved to the cooling area 40, the cooling

assembly 28 is removing heat from the upper material layer 14, and the temperature of the upper material layer 14 is decreasing. Subsequently, during the third time segment "S3", the upper material layer 14 is now moved to the temperature adjustment area 42, the temperature adjuster 33 is also removing heat from the upper material layer 14 to lower the temperature of the upper material layer 14.

[00136] Next, during the fourth time segment "S4", in the deposition area 34, the next material layer 14 is now added on top of the previous material layer 14 by the material supply device 18. The new, uppermost material layer 14 is relatively cold, and the temperature decreases. Subsequently, during the fifth time segment "S5", the new upper material layer 14 is now moved to the heating area 38, the heating assembly 26 is adding heat to the upper material layer 14 to sinter the upper material layer 14, and the temperature of the upper material layer 14 is increasing to the sinter temperature 62. Now, the new upper material layer 14 is ready for melting and the process repeated.

[00137] As mentioned above, the temperature of each material layer 14 will varied depending on melting geometry of each material layer (e.g. how much of the layer is being melted). In case of the upper plot 64, the temperature at the beginning of material deposition (start of time segment S4) is above the sinter temperature 62, and the temperature of the material lowers to just below the sinter temperature 62 at the end of the material deposition (end of time segment S4). In certain implementations, this can cause partial sintering of the material during the fourth time segment (S4) and/or over-sintering of the material during the fifth time segment (S5). In certain implementations, the temperature during the second time segment (S2) and third time segment (S3) can be controlled so that at the beginning of the fourth time segment "S4" (at the time of new powder deposition), the temperature is lower than the sinter temperature 62. On the other hand, in case of the lower plot 66, the temperature just after material deposition is much lower than the sinter temperature 62. Since the powder layer can have very low conduction, it is difficult to heat the new material layer 14 up to the sinter temperature from the much lower temperature. As a consequence, in certain implementations, the temperature during the second time segment (S2) and third time segment (S3) can be controlled so that the temperature just before the

powder deposition (start of S4) is at the appropriate target temperature (the second target temperature) for making appropriate new material layer. Accordingly, the cooling assembly 28 (illustrated in Figure 1B) and the temperature adjuster 33 (illustrated in Figure 1B) can be jointly or individually be used for making the temperature of the material layer 14 at the beginning of powder deposition constant (at the desired temperature) regardless of melting geometries.

[00138] Figures 2A and 2B are alternative, cut-away, perspective views of a portion of another implementation of a processing machine 210. In this implementation, (i) the material bed assembly 216; (ii) the material supply device 218; (iii) the energy system 222; (iv) the heating assembly 226; (v) the build chamber assembly 230 that provides the build space 230A for building the object 211 (represented as a box); (vi) the mover assembly 232 that causes relative movement between the material bed assembly 216 and the build chamber assembly 230; (vii) the cooling assembly 228; and (viii) the temperature adjuster 233 that selectively adjusts the temperature of the material 12 (illustrated in Figure 1A) as necessary. It should be noted that these components are somewhat similar to the corresponding components described above, however, Figures 2A and 2B illustrate an actual implementation of the design. Further, it should be noted that components like the measurement device, and the control system are not illustrated in Figures 2A and 2B, but can be implemented into this version of the processing machine 210

[00139] The material bed assembly 216 supports the material 12 (illustrated in Figure 1A) and the object 211 while being built. In this implementation, the material bed assembly 216 includes (i) a build platform assembly 244 that supports the material 12; (ii) a turntable 245 that retains the build platform assembly 244; and (iii) a turntable shaft 246 that extends downward from the turntable 245. In this implementation, the mover assembly 232 can rotate the turntable 245 (and the build platform assembly 244 concurrently) via the turntable shaft 246.

[00140] Further, in this design, the build platform assembly 244 includes a build platform 244A, and a platform mover assembly 244B that selectively moves the build platform 244A relative to the turntable 245. For example, the platform mover assembly 244B can rotate the build platform 244A and/or move the build platform 244A linearly

(e.g. downward for each added material layer) relative to the rotating turntable 245 during the forming of the object 211. For example, the platform mover assembly 244B can rotate the build platform 244A in the same or opposite rotational direction as the turntable 245 is be rotated. With this design, the build platform 244A is rotated relative to the build chamber assembly 230, and is rotated relative to the turntable 245 as the build platform 244A is being moved relative to the areas 34, 36, 38, 40, 42 (illustrated in Figure 1C). Alternatively, for example, the build platform 244A and the turntable can be moved downward concurrently during the building the object(s) 211.

[00141] Additionally, the build platform assembly 244 can include one or more receptacles 244C for capturing excess material 12 that is being ejected from the moving build platform 244A via centrifugal forces, or capture material 212 kicked out by the energy beam 222A.

[00142] The material supply device 218 deposits the material 12 onto the build platform 244 to sequentially form each material layer 14 (illustrated in Figure 1A). In one non-exclusive implementation, the material supply device 218 is again a single overhead material supply that supplies the material 12 onto the top of the moving build platform assembly 244. The relatively cold material 12 falls on the relatively warm, partly formed object 211 to insulate it. The material supply device 218 can include one or more rakes to level the material 12.

[00143] The energy system 222 generates and directs the energy beam 222A at the material 12 on the build platform 244A to selectively melt the material 12. For example, the energy system 222 can be an electron beam generator.

[00144] The heating assembly 226 heats the top of the material 212 on the build platform 244 to sinter the material 12. The heating assembly 226 can include one or more heating units 226A that heat the material 12. In Figures 2A and 2B, the heating assembly 226 includes a plurality of heating units 226A that are attached to and/or positioned adjacent to the top shield wall 256A and the shield sidewall 256C of the first shield assembly 256. As non-exclusive examples, each heating unit 226A can generate visible or infrared light. As a specific example, each heating unit 226A can be an adjustable, two kilowatt heater to sinter the material 12.

[00145] The cooling assembly 228 cools the material 12 on the build platform 244.

The cooling assembly 228 can include one or more chilling units (not shown) and one or more heating units 228A that can control cooling rate of the material 12 by balancing the chilling units and the heating units. Stated in another fashion, the chilling units and/or the heating units 228A can be controlled to precisely control the temperature of the upper material layer when the partly built object 211 is in the cooling area.

[00146] The temperature adjuster 233 heats or cools the material 12 (as necessary) on the build platform 244A. The temperature adjuster 233 can include one or more chilling units (not shown) and one or more adjuster heating units 233A that selectively heat the material 12. In Figures 2A and 2B, the temperature adjuster 233 includes a plurality of heating units 233A that are attached to and/or positioned adjacent to the top shield wall 256A and the shield sidewall 256C of the first shield assembly 256. As non-exclusive examples, each adjuster heating unit 233A can generate visible or infrared light. As a specific example, each adjuster heating unit 233A can be an adjustable, twelve kilowatt heater.

[00147] The build chamber assembly 230 again includes the build chamber 250 having a chamber structure 254, the first shield assembly 256, the second shield assembly 258, and the mount assembly 260 (illustrated in Figure 2C) that are somewhat similar to the corresponding components described above. In this design, the shield assemblies 256, 258 reduce the thermal transfer between the build space 230A and the chamber structure 254. As a result thereof, the temperature in the build space 230A is more accurate, and at least a portion of the chamber structure 254 and other components are not subjected to the harsh temperatures in the build space 230A.

[00148] In Figures 2A and 2B, (i) the chamber structure 254 includes the top structure wall 254A, the bottom structure wall 254B, and the structure sidewall 254C that are somewhat similar to the corresponding components described above; (ii) the first shield assembly 256 includes the top shield wall 256A, the bottom shield wall 256B, and the shield sidewall 256C that are somewhat similar to the corresponding components described above; and (iii) the second shield assembly 258 includes the top intermediate wall 258A, the bottom intermediate wall 258B, and the intermediate sidewall 258C that are somewhat similar to the corresponding components described above. In this design, the chamber structure 254, and the shield assemblies 256, 258

are statically fixed in position while the hot object 211 is rotating inside of it.

[00149] In this example, the first shield assembly 256 faces the object 211 and the build chamber space 230A, and the chamber structure 254 can maintain a vacuum in the build chamber space 230A. In this design, the first shield assembly 256 is maintain at the controlled, elevated temperatures.

[00150] It should be noted that the first shield assembly 256 and/or the second shield assembly can include one or more apertures 268 for cables, the energy beam 22A, electrical components, optical components, and/or equipment for the measurement device 20 (illustrated in Figure 1A). These apertures 268 represent thermal radiation leaks for the shield assemblies 256, 258. However, in the present design, because the object 211 is moving relative to these apertures 268, the localized effects of the apertures 268 will be averaged out over the rotation cycle.

[00151] Figure 2C is an enlarged cut-away view of a portion of the processing machine 210 of Figures 2A and 2B. More specifically, Figure 2C illustrates a portion of (i) the chamber structure 254 with the top structure wall 254A, and the structure sidewall 254C; (ii) the first shield assembly 256 with the top shield wall 256A, and the shield sidewall 256C; and (iii) the second shield assembly 258 with the top intermediate wall 258A, and the intermediate sidewall 258C.

[00152] As illustrated in Figure 2C, the chamber structure 254 can include multiple structure segments 254D, with seals 254E therebetween so that the chamber structure 254 can maintain the controlled environment.

[00153] Further, as illustrated in Figure 2C, the first shield assembly 256 is again divided into two or more (only two are shown), spaced apart shield segments 257A, 257B. With this design, the shield segments 257A, 257B can be maintained at different temperatures, and/or the shield segments 257A, 257B can be at least partly, thermally isolated from each other. Further, for example, the top shield wall 256A can be maintained at a different temperature from the shield sidewall 256C. This design allows for the creation of a thermal gradient in the object being built.

[00154] Further, in this example, a heating unit 226A is thermally connected to and controls the temperature of the first shield segment 257A. For example, the heating unit 226A can be an infrared heating element, a resistance heater, or another type of

heater.

[00155] Additionally, and optionally, the second shield assembly 258 can be divided into two or more (only two are shown), spaced apart shield areas 259A, 259B. With this design, the shield areas 259A, 259B can be maintained at different temperatures, and/or the shield areas 259A, 259B. Further, for example, the top intermediate wall 258A can be maintained at a different temperature from the intermediate sidewall 258C. This design allows for the creation of a thermal gradient in the object being built.

[00156] The mount assembly 260 couples the second shield assembly 258 to the chamber structure 254, and the first shield assembly 256 to the second shield assembly 258. In certain implementations, the mount assembly 260 (i) fixedly secures (or couples) the second shield assembly 258 to the chamber structure 254 while reducing (minimizing) the thermal transfer between the second shield assembly 258 and the chamber structure 254; and (ii) fixedly secures (or couples) the first shield assembly 256 to the second shield assembly 258 while reducing (minimizing) the thermal transfer between the first shield assembly 256 and the second shield assembly 258 (and the chamber structure 254). For example, the mount assembly 260 can include (i) one or more spaced apart first mounts 260A that fixedly secures the second shield assembly 258 to the chamber structure 254; and (ii) one or more spaced apart second mounts 260B that fixedly secures the first shield assembly 256 to the second shield assembly 258. For example, each mount 260A, 260B can have a relatively low thermal conductivity. In the non-exclusive illustration in Figure 2C, each mount 260A, 260B can include (i) a fastener 260C that is threaded into the chamber structure 254; and (ii) a thermal isolator 260D that maintains the desired spacing between the shield assembly 256, 258, and maintains the desired spacing between the chamber structure 254 and the second shield assembly 258.

[00157] The desired amount of spacing between the shield assembly 256, 258, and the desired amount of spacing between the chamber structure 254 and the second shield assembly 258 can be varied. As a non-exclusive example, (i) the first shield assembly 256 is maintained a first gap 270A spaced apart from the second shield assembly 258 of between approximately one and fifty millimeters; and (ii) the second shield assembly 258 is maintained a second gap 270B spaced apart from the chamber

structure 254 of between approximately one and fifty millimeters. As a result thereof, by adjusting the temperature of the first shield assembly 256, and maintaining a physical gap 270A between shield assemblies 256, 258, different temperatures may be maintained. This physical gap 256, 258 also accommodates different possible thermal expansions of materials at different temperatures.

[00158] With the present design, the build chamber 250, and the shield assemblies 256, 258 can maintain different temperatures on the rotating object 211 (illustrated in Figure 2A). As thermal radiation is predominant between facing planar surfaces due to significantly increased “radiation view factors,” the top structure wall 254A faces the object 211, while the structure sidewall 254C faces the side of the object 211.

[00159] It should be noted that the thermal expansion/contraction of the shield segments 257A, 257B of the first shield assembly 256 can be significant. Similarly, the thermal expansion/contraction of the shield areas 259A, 259B of the second shield assembly 258 can be significant. In certain implementations, the mounts 260A, 260B are designed to allow for this expansion and contraction. For example, the first shield assembly 256 can include enlarged first slots 254F and the second shield assembly 258 can include enlarged second slots 256D. With this design, if the fasteners 260C are a little loose, the shield segments 257A, 257B, and the shield areas 259A, 259B can expand or contract while being maintained in position. Alternatively, the thermal movement can be accommodated in another fashion.

[00160] In some embodiments, the measurement of the temperatures of the shield assemblies 256, 258 can be achieved with standard measurement devices such as thermocouples attached to the shield assemblies 256, 258. Additionally, or alternatively, the measurement of the temperature can be achieved with Pyrometry Sensors and IR measurement thermometers.

[00161] Figure 2D is a simplified schematic illustration of a portion of the processing machine 210 and the object 211 while the cooling assembly 228 is controlled to remove heat from the object 211 at a first cooling rate in the cooling area 240 of the first shield assembly 256. The first cooling rate at this time can also be referred to a general cooling rate.

[00162] Figure 2D also illustrates (i) the energy system 222 that generates the

energy beam 222A in the melting area 236; (ii) the new melted upper material layer 214; (iii) the build platform 244A that supports the object 211; (iv) the build platform 244A and the object 211 in phantom while in the melting area 236; and (v) an arrow 255 to illustrate that the build platform 244A and the object 211 was moved from the melting area 236 to the cooling area 240. It should be noted that the cooling area 240 illustrated in Figure 2D can also be considered to be a portion of the temperature adjustment area 42 (illustrated in Figure 1C) or can be generically referred to as the temperature control area 43 (illustrated in Figure 1C).

[00163] The design of the cooling assembly 228 can be varied and/or controlled to accurately control the rate in which heat is removed from the recently formed layer 214. For example, the cooling assembly 228 can be designed and/or controlled to remove heat rapidly, slowly, or somewhere therebetween to achieve the desired properties of the object 211.

[00164] In Figure 2D, the cooling assembly 228 includes five heating units 228A and a chilling unit 228B (“chillers”) that are controlled to precisely control the heat removal rate (e.g. the cooling rate) of the upper material layer 214. For convenience, the five heating units 228A can be referred to as a first heating unit A, a second heating unit B, a third heating unit C, a fourth heating unit D, and a fifth heating unit E while moving away from the melting area 236. In this example, the plurality of the heating units 228A are used in the cooling assembly 228, because these heating units 228A allow for the cooling of the material layer 214 at a slower rate than if only chilling units 228B were utilized. Stated in another fashion, when the cooling assembly 228 only includes one or more chilling units 228B, it can be difficult to make the cooling rate (heat removal rate) slower. Since the temperature of the upper material layer 214 just after melting is very high, sometimes it is necessary to use the heating units 228B instead of using the chilling units 228B for controlling the cooling rate. Thus, even though these heating units 228B are generating heat, they are able to remove heat from a relatively hotter upper material layer 214.

[00165] As provided herein, depending on the material to be processed and the desired metal composition, the cooling rate after melting of the upper material layer 214 needs to be changed as required from a metallurgy perspective. Figure 2D

illustrates one, non-exclusive example of how the cooling assembly 228 can be controlled to precisely control the temperature of the upper material layer 214 and the heat removal from the upper material layer.

[00166] As shown in Figure 2D, after melting the upper material layer 214 in the melting area 236 (during the first time segment S1, shown in Figure 1D), the build platform 244A is moving in the cooling area 240 (during the second time segment S2, shown in Figure 1D).

[00167] As illustrated in Figure 2D, each of the heating units 228A can be individually controlled to precisely control the temperature of (and heat removal from) the upper material layer 214 as it is being moved under the respective heating units 228A in the cooling area 240. In this example, to achieve the first cooling rate, (i) the first heating unit A is controlled to generate the most energy (heat); (ii) the second heating unit B is controlled to generate the second most energy (heat); (iii) the third heating unit C is controlled to generate the third most heat; (iv) the fourth heating unit D is controlled to generate the fourth most heat; and (v) the fifth heating unit E is controlled to generate the fifth most heat (or least heat in this example for the heating units 228A). This is represented with different arrows 228C, namely with the most heat being represented by thick arrows, and the least heat being represented by thin, short-dashed arrows. With this design, to achieve the first cooling rate, each of the subsequent heating units A-E is controlled to generate less heat than the previous heating unit A-E. Stated in yet a different fashion, the power of the heating units 228A is controlled to vary from higher to lower moving away from the melting area 236. Further, in this example, the chilling unit 228B may or may not be utilized, depending upon the desired cooling characteristics of the material layer 214.

[00168] Figure 2E is a simplified schematic illustration of the portion of the processing machine 210 and the object 211 from Figure 2D, while the cooling assembly 228 is controlled to remove heat from the object 211 at a second cooling rate (that is different from the first cooling rate) in the cooling area 240 of the first shield assembly 256. The second cooling rate in this example can also be referred to a gradual cooling rate.

[00169] Figure 2E also illustrates (i) the energy system 222 that generates the

energy beam 222A in the melting area 236; (ii) the new melted upper material layer 214; (iii) the build platform 244A that supports the object 211; (iv) the build platform 244A and the object 211 in phantom while in the melting area 236; and (v) the arrow 255 to illustrate that the build platform 244A and the object 211 was moved from the melting area 236 to the cooling area 240.

[00170] In Figure 2E, the cooling assembly 228 again includes the five heating units 228A and the chilling unit 228B (“chillers”) that are controlled to precisely control the heat removal rate (e.g. the cooling rate) of the upper material layer 214. Figure 2E illustrates another, non-exclusive example of how the cooling assembly 228 can be controlled to precisely control the temperature of the upper material layer 214 and the heat removal from the upper material layer.

[00171] As shown in Figure 2E, to achieve the second cooling rate (gradual cooling of the upper layer 214), all five heating units A-E are controlled to generate the same, relatively high heat. This is represented with thick arrows 228C having the same thickness. Further, in this example, the chilling unit 228B may or may not be utilized, depending upon the desired cooling characteristics of the material layer 214 at that time.

[00172] Figure 2F is another simplified schematic illustration of a portion of the processing machine 210 of Figure 2D, and the object 211 while the cooling assembly 228 is controlled to remove heat from the object 211 at a third cooling rate (that is different from the first and second cooling rates) in the cooling area 240 of the first shield assembly 256. The third cooling rate in this example can also be referred to a rapid cooling rate.

[00173] Figure 2F also illustrates (i) the energy system 222 that generates the energy beam 222A in the melting area 236; (ii) the new melted upper material layer 214; (iii) the build platform 244A that supports the object 211; (iv) the build platform 244A and the object 211 in phantom while in the melting area 236; and (v) the arrow 255 to illustrate that the build platform 244A and the object 211 was moved from the melting area 236 to the cooling area 240.

[00174] In Figure 2F, the cooling assembly 228 again includes the five heating units 228A and the chilling unit 228B that are controlled to precisely control the heat removal

rate (e.g. the cooling rate) of the upper material layer 214. Figure 2F illustrates another, non-exclusive example of how the cooling assembly 228 can be controlled to precisely control the temperature of the upper material layer 214 and the heat removal from the upper material layer.

[00175] As shown in Figure 2F, to achieve the third cooling rate (rapid cooling of the upper layer 214), all five heating units A-E are controlled to generate the same, relatively low heat. This is represented with thin, dashed arrows 228C having the same thickness. Further, in this example, the chilling unit 228B may or may not be utilized, depending upon the desired cooling characteristics of the material layer 214.

[00176] With reference to Figures 2D-2F, by controlling each of the heating units 228A separately, the cooling rate (heat removal rate) during the second time segment S2 (and possibly the third time segment S3) can be controlled as desired. For example, when more gradual cooling is required, as shown in Figure 2E, each of the heating units 228A are maintained at near maximum power to keep a relatively higher target temperature of the upper material layer 214 but lower than the melting temperature. When rapid cooling is desired, as shown in Figure 2F, each of the heating units 228A is maintained at relatively low power to cool the upper material layer 14 (and the object 211) more rapidly to target temperature. If even more rapid cooling is required, one or more (e.g. all) of the heating units 228A can be turned off, and/or the chilling units 228B can be used. The target temperature to cool, the cooling time duration (S2), and a profile of temperature changing during cooling can be determined based upon a kind of material to be processed, desired metal composition, cooling rate after melting, and other conditions from a metallurgical point of view.

[00177] As illustrated in Figure 2D-2F, the plurality of heating units 228A are arranged so that each of heating areas partially overlap each other. The degree of overlap of the heating area is determined based upon energy distribution in the heating area of the each of heating units 228A.

[00178] Figure 2G is a simplified illustration with the heating units 228A of the cooling assembly 228 cooling at the first cooling rate (similar to Figure 2D) and the corresponding energy generated by the cooling assembly 228. Stated in a different fashion, Figure 2G illustrates the energy distribution of heating units 228A when

controlled at the first cooling rate. At this time, each heating units 228A has energy distribution 228D (solid line) and integrally, the heating units 228A have a total energy distribution is like dashed line 228E. Since the heating area of each heating units 228A is partially overlapped, the total energy distribution profile can be varied. Then, by controlling the plurality of heating units 228A based upon the known characteristics (e.g. energy distribution) of each heating units 228A, the desired energy input/output profile 228E can be realized. This means that the cooling assembly 228 can control the temperature of the upper material layer 214 (and the object 211) and the cooling rate as desired.

[00179] Figure 3 is a simplified perspective view of portion of a material bed assembly 316 and a portion of a heating unit 333A that can be used in any of the processing machines 10, 210 disclosed herein.

[00180] In this implementation, the material bed assembly 316 includes a rotatable turntable 345 and three spaced apart, rotatable build platform assemblies 344 that are somewhat similar to the corresponding components described above.

[00181] Further, in this design, the heating unit 333A can be used in the heating assembly 226 (illustrated in Figure 2A) and/or the temperature adjuster 233 (illustrated in Figure 2A). In Figure 3, the heating unit 333A includes one or more (two are shown) microwave generators (magnetrons) 333B which are relatively inexpensive, powerful, and have relatively long operational lifetimes. High energy microwave generators 333B have been proven to efficiently heat metal material to a near-melting temperature. Additionally, researchers indicate that microwave heating in material is volumetric as opposed to being limited to surface heating. Volumetric heating can be more efficient at keeping the build platform assembly 344 warm which is one of the purposes of preheating.

[00182] As a non-exclusive example, the microwave generators 333B can have 2.45 GHz and 580 Watts as the output power.

[00183] Additionally, and optionally, the heating unit 333A can include a rake 333C that is used to level the material 12 (illustrated in Figure 1A) on the build platform assembly 344. In this design, the heating unit 333A preheats the material 12 and the rake 333C levels the material on the build platform assembly 344. This heating unit

333A design can, (1) reduce preheating time as compared with existing systems that use an electron beam for preheating; (2) prolongs the lifetime of electron beam generator used for melting by shifting the preheating function to the heating unit 333A; (3) improves spread quality by potentially increasing the rake time; and (4) increases efficiency and throughput of the system due to volumetric heating, which more efficiently maintains heat in the material bed.

[00184] It should be noted that the microwave generators 333B may require cooling (e.g. water cooling). Additionally, the microwave generators 333B can each include a waveguide 333D to guide and/or focus the generated microwave energy onto the build platform assembly 344. In Figure 3, one of the waveguides 333D is illustrated in phantom, while the other one is not. For example, the waveguides 333D can be rectangular shaped tubes that are made of aluminum. It should be noted that the waveguides 333D also reduce the influence of the microwave energy on the electron beam 22A (illustrated in Figure 1A).

[00185] In some embodiments, microwave generators 333B are only on during the raking process and off during the melting process, so that microwaves do not interfere with the electron beam 22A.

[00186] It should be noted that many other designs of the heating unit 333A are possible. For example, one or more heating units can include one or more high power lasers providing visible, infrared, or ultraviolet light. In other embodiments, the heating unit is one or more high power lamps, such as tungsten filament lamps optimized for use in vacuum. These heating units heat the material 12 without generating an electric charge in the material 12.

[00187] When lamps are used as the heating unit 333A, it may be desirable to surround the heating unit 333A with a reflector (or reflective surface) that directs a majority of the energy from the heating unit 333A to the build platform assembly 344. The reflector may be integral to the individual heating units 333A, they may be integral in the first shield assembly 56 (illustrated in Figure 1A) and/or may comprise additional high reflectivity components configured to direct the energy in the desired directions.

[00188] In additional embodiments, the heating unit may be a resistive heater or other type of heated body that radiates light as blackbody radiation. In effect, this is

actually the same principle as a lamp that contains a hot filament which emits light by blackbody radiation.

[00189] Figure 4A is a simplified perspective view of a portion of another implementation of a heating unit 433A that can be used in any of the processing machines 10, 210 disclosed herein. Further, Figure 4B is a simplified side view of an array of the heating units 433A of Figure 4A. For example, these heating unit 433A can be used in the heating assembly 226 (illustrated in Figure 2A) and/or the temperature adjuster 233 (illustrated in Figure 2A). In Figures 4A and 4B, the heating unit 433A is an infrared heat lamp. These lamps can be designed for vacuum usage and can have a Tungsten core. The core can reach extremely high temperatures and therefore radiates significant visible as well as infrared light.

[00190] In this design, while some light will be reflected from the surface of the material 12 (illustrated in Figure 1A), a significant portion of the illumination energy will reflect between the particles of the material 12 in a “pachinko style” downwards below the top-most layer of the material 12. Much of the light that reflects into the empty spaces between material particles and will eventually be absorbed by the material 12. In this way, the interstitial spaces between the material particles can act as a light trap, improving the efficiency of energy transfer into the material.

[00191] Figure 5 is a perspective of a conduction heating unit 533A that can be used in any of the processing machines 10, 210 disclosed herein. For example, this heating unit 533A can be used in the heating assembly 226 (illustrated in Figure 2A) and/or the temperature adjuster 233 (illustrated in Figure 2A). The conduction-based heating unit 533A can reach a temperature of 950 degrees Celsius, so its radiant light will have more infrared.

[00192] Figure 6A is a simplified illustration of the energy system 622 that generates the energy beam 622A, the build platform assembly 644, and another embodiment of a heating unit 633A that can be used in any of the processing machines 10, 210 disclosed herein. For example, this heating unit 633A can be used in the heating assembly 226 (illustrated in Figure 2A) and/or the temperature adjuster 233 (illustrated in Figure 2A).

[00193] In Figure 6A, the heating unit 633A includes a plurality of tungsten halogen

lamps. This type of heating unit 633A rapidly heats the material 12 (illustrated in Figure 1A) in an efficient non-contact method that does not electrically charge the material 12. The tungsten halogen lamp 633A can have a wavelength range of 320 to 1100 nanometers.

[00194] Figure 6B is a simplified illustration of the energy system 622 that generates the energy beam 622A, the build platform assembly 644, and another embodiment that includes a pair of heating units 633A that can be used in any of the processing machines 10, 210 disclosed herein. For example, these heating units 633A can be used in the heating assembly 226 (illustrated in Figure 2A) and/or the temperature adjuster 233 (illustrated in Figure 2A).

[00195] Figure 7 is a simplified illustration of the energy system 722 that generates the energy beam 722A, the build platform assembly 744 with an object 711 (illustrated as a box), and a simplified cut-away view of a shield segment 757A of a first shield assembly 756. In this implement, the shield segment 757A is maintained at a cold temperature by the cooling assembly 728 (illustrated as a box) and can define at least a portion of the cooling area 740. In this implementation, the build platform assembly 744 and the object 711 are moved relative to the shield segment 757A and the energy system 722.

[00196] As provided herein, the problem of heat buildup in the object 711 after melting with the energy beam 722A is solved by placing a temperature controlled shield segment 757A over at least a portion of the build platform assembly 744 and the object 711.

[00197] As provided above, an electron beam 722A is operated in a vacuum environment. In a vacuum, heat transfer by convection is nearly nonexistent and heat transfer by the object 711 via conduction is extremely poor. After the top material layer is melted, if heat is not removed from the molten surface, then the object 711 may stay liquid and slowly spread losing the design integrity of the part. The temperature controlled shield segment 757A provided herein can quickly remove the heat from the partly formed object 711 to maintain its shape.

[00198] In Figure 7, the shield segment 757A has an arch shape. In this design, the potentially hot sides and top of the object 711 are facing the cold shield segment 757A

so that heat 770 (represented as arrows) radiated from the object 711 is transferred to the shield segment 757A. However, the shape of the temperature controlled shield segment 757A can be different than that illustrated in Figure 7, and still remove a significant amount of heat. For example, in the embodiment of Figure 1B described above, the second shield segment 57B has an “L” shaped cross-section.

[00199] In certain implementations, the shield segment 757A can use a coatings and/or anodization to increase the emissivity.

[00200] Additionally, when performing a melt with the energy beam 722A, there is always a chance for the material to boil and splatter. With the present design, the shield segment 757A can serve the secondary purpose of absorbing this splattered material.

[00201] The design of the cooling assembly 728 can be varied. For example, the cooling assembly 728 can circulate a relatively cool fluid (not shown) near or through the shield segment 757A to maintain the temperature of the shield segment 757A.

[00202] Still another alternative embodiment of Figure 7, the cooling assembly 728 can include one or more heating devices. Depending on a material to be processed and desired metal composition, gradual cooling after melting is required from a metallurgy perspective. In such case, the cooling assembly 728 controls the temperature of the shield segment 757A to a target temperature that is below the melting temperature, but still above the ambient temperature. Therefore, the cooling assembly 728 can include one or more heating devices that are controlled to achieve the desired target temperature in this region. The target temperature can be changed gradually when the object 711 is within the first shield assembly 756. The target temperature can be determined based upon a material to be processed, desired metal composition, cooling rate after melting, and other conditions from a metallurgical point of view. As the heater in the cooling assembly 728, several kinds of devices can be used, such as an infrared lamp, a tungsten halogen lamp, a conduction heater, and/or a microwave generator to control the temperature of the shield segment 757A. The first shield segment 57A in Figure 1B can be the shield segment 757A, or the shield segment 757A can be added additionally and separately with the first shield segment 57A.

[00203] Figure 8 is a simplified illustration of a system 822 that generates a light beam 822A, the build platform assembly 844 with the object 811 (illustrated as a box), and a simplified cut-away view of another shield segment 857A of a first shield assembly 856 of the build chamber assembly 830. In one implementation, the system 822 can be an energy system that melts the material, the shield segment 857A can define at least a portion of the melting area 836, and the shield segment 857A can include an inner reflective (e.g. mirror) coating 872 or other reflective surface. In this implementation, the build platform assembly 844 and the object 811 can be moved relative to the shield segment 857A and the system 822. Further, the light beam 822A is directed at an incident location 875 on the object 811 to melt the object 811. With the present design, the build chamber assembly 830 is designed to reimage scattered/reflected light 874 from the incident location 875 back at the incident location 875. This will increase the efficiency of the system.

[00204] In another implementation, the system 822 can be a heating system that sinters the material, the shield segment 857A can define at least a portion of the heating area. In this implementation, the light beam 822A is directed at an incident location 875 on the object 811 to sinter the object 811. With the present design, the build chamber assembly 830 is designed to reimage scattered/reflected light 874 from the incident location 875 back at the incident location 875. This will increase the efficiency of the system.

[00205] As provided herein, the problem of high reflectance and scattering of energy beam 822A from the material used to form the object 811 is solved by reimagining the scattered/reflected light 874 back to the incidence location of the object 811 with the mirror coating 872.

[00206] In Figure 8, the shield segment 857A has an arch shaped. However, the shape of the shield segment 857A can be different than that illustrated in Figure 8, and still redirect a significant amount of light 874 back at the object 811. For example, in the embodiment of Figure 1B described above, the shield segments 57A, 57B, 57C have an “L” shaped cross-section. Still alternatively, the shield segment 857A can define a spherical mirror, centered on the beam incidence location, that will re-image the scattered light 874 to the same position.

[00207] It should be noted that the reflective coating 872 can be used in other areas. For example, with reference to Figures 1B and 1C, (i) the first shield segment 57A can also include the reflective coating 872 (illustrated in Figure 8) to enhance heating in the heating area 38; and/or (ii) the temperature adjusted shield segment 57C can also include the reflective coating 872 to enhance heating in the temperature adjustment area 42. With this design, the scattered light 874 is recycled and redirected back to the region from which it scattered.

[00208] Figure 9 is a flow chart that illustrates a method to reduce smoking of the material during melting with a high-energy electron beam. With reference to Figures 9 and 1B, as provided herein, at step 900, the material supply device 18 can deposit a uniform layer of material 12 on the build platform 44. Next, at step 902, for example, the material 12 can be heated with the temperature adjuster 33 to semi-sinter the material 12 to partly anchor the particles. This is called “jump safe”. Subsequently, at step 904, the heating assembly 26 can be used on the material 12 to fully sinter and further anchor the particles in order to make the material 12 “melt safe”. Next, at step 906, the energy system 22 can use high energy to rapidly melt the material 12.

[00209] Figure 10A is a flow chart that illustrates another method to reduce smoking of the material during melting with a high-energy electron beam. With reference to Figures 10A and 1B, as provided herein, at step 1000, the material supply device 18 can deposit a uniform layer of material 12 on the build platform 44, and the surplus heat from the prior layer can be used to sinter (both jump and melt safe) the material 12. Next, at step 1002, the energy system 22 can use high energy to rapidly melt the material 12. Subsequently, at step 1004, the energy system 22 (or another heating source) can be used to add surplus heat to the material 12 to subsequently anchor the next material layer.

[00210] Figure 10B is a simplified illustration of the object 1011 with the material 1012 at a first time. At this time, the energy beam 1022A is used to melt the material to form the object 1011. Further, at this time, the energy system 22 (illustrated in Figure 1B) can add surplus heat (overheat) the object 1011. The dark ovals in Figure 10B represent sintered material.

[00211] Figure 10C is a simplified illustration of the object 1011 with the material

1012 at a second (subsequent) time after another layer has been deposited thereon. At this time, because the object 1011 was overheated, the subsequently material layer will become sintered (anchored) because of the excess heat. Now it is ready again for the melting process to be repeated. The dark ovals In Figure 10C represent sintered material.

[00212] Figure 11A is another flow chart that illustrates another method to reduce smoking of the material during melting with a high-energy electron beam. With reference to Figures 11A and 1B, as provided herein, at step 1100, the material supply device 18 can deposit a uniform layer of material 12 on the build platform 44 while heat is being added to the material to sinter the material 12. Next, at step 1102, the energy system 22 can use high energy to rapidly melt the material 12.

[00213] Figure 11B is a simplified illustration of a partly formed object 1111 with the material supply device 1118 depositing the material 1112 onto the moving, partly formed object 1111 on a build platform 1144. In this example, the material supply device 1118 can include a container 1180 that releases the material 1112, and one or more supply heaters 1181 (two are shown) that added heat 1181A to the material 1112 to sinter (anchor) the material 1112. The dark ovals In Figure 11B represent sintered material. With this design, the problem of pre-heat process steps limiting throughput in an electron beam additive manufacturing process is solved by applying powder-anchoring heat 1181A during the distribution process.

[00214] Additionally, the material supply device 1118 can include a rake 1182 to level the material 1112. With this design, the build platform 1144 moves in one direction, while rake 1182, the material supply device 1118, and the supply heaters 1180 are stationary.

[00215] Stated in another fashion, the material anchoring heat 1181A is added to the dispensed material 1112 by (in one embodiment) non-contact, radiant supply heaters 1180. The selective material 1112 anchoring to the object 1111 can be achieved by adjusting the one or more supply heaters 1181 to heat the material 1112 to a temperature (for example 800K) where it will only anchor to the object 1111 (which is typically warmer than the surrounding material 1112). Material anchoring to both the object 1111 and build platform 1144 requires increased heat 1180A to heat the material

1112 to a higher temperature (for example 1000K). Non-contact radiant supply heaters 1180 include tungsten lamps, infrared lamps, or elevated temperature ($\geq 2000\text{K}$) bodies. By selectively anchoring material 1112 only to object 1111, excess material 1112 falling in other regions may be easily raked away to provide a leveled build platform 1144.

[00216] Figure 12 is a simplified illustration of another implementation of the material supply device 1218 for depositing the material 1212 onto the moving build platform 1244. In this example, the material supply device 1218 can include a container 1280 that releases the material 1212, and a supply heater 1281 that adds heat 1281A to the material 1212 to heat and sinter (anchor) the material 1212. In this implementation, the supply heater 1281 is (i) spherical shaped, (ii) generates heat 1181A that is directed inward, and (iii) includes an open top 1281B and an open bottom 1281C. With this design, material 1212 falls through the supply heater 1281 and is uniformly heated.

[00217] For example, the supply heater 1281 can be maintained at two thousand degrees Kelvin. The shape of the supply heater 1281 can be different than that illustrated in Figure 12. For example, in the embodiment of Figure 1B described above, the third shield segment 57C and the temperature adjuster 33 can work function as the supply heater for heating the material.

[00218] The invention can be implemented in numerous ways, including as a process; an apparatus; a system; a composition of matter; a computer program product embodied on a computer readable storage medium; and/or a processor, such as a processor configured to execute instructions stored on and/or provided by a memory coupled to the processor. In this specification, these implementations, or any other form that the invention may take, may be referred to as techniques. In general, the order of the steps of disclosed processes may be altered within the scope of the invention. Unless stated otherwise, a component such as a processor or a memory described as being configured to perform a task may be implemented as a general component that is temporarily configured to perform the task at a given time or a specific component that is manufactured to perform the task. As used herein, the term 'processor' refers to one or more devices, circuits, and/or processing cores configured to process data, such as computer program instructions.

[00219] It is understood that although a number of different embodiments of the processing machine have been illustrated and described herein, one or more features of any one embodiment can be combined with one or more features of one or more of the other embodiments, provided that such combination satisfies the intent of the present disclosure.

[00220] While a number of exemplary aspects and embodiments of the processing machine have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit and scope.

What is claimed is:

1. A processing machine for building a three-dimensional object from a material, the processing machine comprising:
 - a build platform that supports the material;
 - a material supply device that deposits material onto the build platform;
 - an energy system that directs an energy beam at the material on the build platform to selectively melt the material; and
 - a temperature control assembly that is configured to heat the material on the build platform to sinter the material before the energy system selectively melts the sintered material.
2. The processing machine of claim 1, wherein the temperature control assembly includes a lamp configured to irradiate light on the material on the build platform to sinter the material.
3. The processing machine of claim 2, wherein the lamp irradiates light and sinters a surface of the material on the build platform at once.
4. The processing machine any one of claims 2 and 3, wherein the lamp is at least one of an infrared lamp, a visible light lamp, or a tungsten halogen lamp.
5. The processing machine any one of claims 1-4, wherein the temperature control assembly is configured to lower the temperature of the material on the build platform after the energy system selectively melts the sintered material.
6. The processing machine of claim 5, wherein the temperature control assembly irradiates the melted material with light which has lower energy than the energy beam directed from the energy system.

7. The processing machine of one of claims 5 or 6, wherein the temperature control assembly further includes a chiller that actively removes heat from the melted material.

8. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

- a build platform that supports the material;
- a material supply device that deposits material onto the build platform;
- an energy system that directs an energy beam at the material on the build platform to selectively melt the material; and
- a temperature control assembly configured to cool at least part of the material on the build platform, the temperature control assembly having a cooling area through which the melted material passes to control the cooling of the melted material.

9. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

- a build platform that supports the material;
- a build chamber assembly that provides a build space for the object that is being built; the build chamber assembly including a deposition area, and a melting area;
- a material supply device that deposits material onto the build platform in the deposition area;
- an energy system that directs an energy beam at the material on the build platform to selectively melt the material in the melting area;
- a temperature control assembly that controls the temperature of the material on the build platform in the build chamber assembly;
- a mover assembly that causes relative movement between the build platform and areas of the build chamber assembly; and
- a control system that controls the material supply device, the energy system, the temperature control assembly and the mover assembly,

wherein the temperature control assembly actively controls the temperature of at least a portion of the material on the build platform during relative movement between the build platform and the areas of the build chamber assembly.

10. The processing machine of claim 9, wherein the temperature control assembly controls the temperature of a portion of the material on the build platform to a first target temperature before the build platform is moved into the melting area.

11. The processing machine of claim 10, wherein the temperature control assembly controls the temperature of the portion of the material on the build platform to a second target temperature that is different from the first target temperature before the build platform is moved into the deposition area.

12. The processing machine of claim 9, wherein the temperature control assembly controls a cooling rate after the melting of the portion of the material on the build platform during movement of the build platform from the melting area to the deposition area.

13. The processing machine of claim 9, wherein the temperature control assembly includes a heating assembly that heats the material on the build platform in a heating area in the build chamber assembly.

14. The processing machine of claim 13, wherein the heating assembly controls the temperature of the portion of the material on the build platform to a first target temperature at the heating area in the build chamber.

15. The processing machine of claim 9, wherein the temperature control assembly includes a cooling assembly that cools the material on the build platform in a cooling area in the build chamber.

16. The processing machine of claim 15, wherein the cooling assembly controls the temperature of the portion of the material on the build platform to a second target temperature at the cooling area in the build chamber.

17. The processing machine of claim 16, wherein the cooling assembly controls a cooling rate of the portion of the material on the build platform after melting in the melting area.

18. The processing machine of claim 9, wherein the temperature control assembly includes a heating assembly that heats the material on the build platform in a heating area, and a cooling assembly that cools the material on the build platform in a cooling area.

19. The processing machine of claim 18, wherein the heating assembly controls the temperature of the portion of the material on the build platform to a first target temperature at the heating area and the cooling assembly controls the temperature of the portion of the material on the build platform to a second target temperature at the cooling area in the build chamber.

20. The processing machine of any one of claims 18 and 19, wherein the cooling area at least partly encircles the melting area.

21. The processing machine of claim 18, wherein the heating area is adjacent to the melting area.

22. The processing machine of any one of claims 18-21, wherein the heating assembly sinters at least a portion of a top material layer of the material in the heating area.

23. The processing machine of any one of claims 18-21, wherein the cooling assembly cools at least a portion of a top material layer of the material in the cooling area.

24. The processing machine of any one of claims 18-21, wherein the build chamber assembly includes a temperature adjustment area between the cooling area and the heating area; and the processing machine further comprises a temperature adjuster that adds or removes heat from the material on the build platform in the temperature adjustment area.

25. The processing machine of claim 9, wherein the mover assembly rotates the build platform and the material on the build platform relative to the areas.

26. The processing machine of claim 9, wherein the mover assembly moves the build platform and the material on the build platform linearly relative to the areas.

27. The processing machine of any one of claims 9-26, wherein the build chamber assembly includes a chamber structure that encircles the build platform, and a first shield assembly that reduces the transfer of heat between the build space and the chamber structure.

28. The processing machine of claim 27, wherein the first shield assembly is positioned between the build platform and the chamber structure.

29. The processing machine of any one of claims 27 and 28, wherein the first shield assembly is spaced apart from the build platform and the chamber structure.

30. The processing machine of claim 27, wherein the first shield assembly includes a first shield segment and a second shield segment that is spaced apart from the first shield segment.

31. The processing machine of claim 30, wherein the temperature control assembly maintains the first shield segment at a heating temperature, and the temperature control assembly maintains the second shield segment at a cooling temperature that is different from the heating temperature.

32. The processing machine of claim 31, wherein the heating temperature is at least one hundred degrees Celsius higher than the cooling temperature.

33. The processing machine of claim 29, further comprising a mount assembly that couples the first shield assembly to the chamber structure with the first shield assembly spaced apart from the chamber structure, wherein the mount assembly inhibits the transfer of heat between the first shield assembly and the chamber structure.

34. The processing machine of claim 33 wherein the build chamber assembly includes a second shield assembly that reduces the transfer of heat between the first shield assembly and the chamber structure.

35. The processing machine of claim 34, wherein the second shield assembly is positioned between the first shield assembly and the chamber structure, and the first shield assembly is positioned between the build platform and the second shield assembly.

36. The processing machine of claim 34, wherein the first shield assembly includes a first shield segment and a second shield segment that is spaced apart from the first shield segment; and the second shield assembly includes a first shield area and a second shield area that is spaced apart from the first shield area.

37. The processing machine of claim 36, wherein the temperature control assembly maintains the first shield segment at a heating temperature, and the temperature control assembly maintains the second shield segment at a cooling temperature that is different from the heating temperature.

38. The processing machine of claim 37, wherein the heating temperature is at least one hundred degrees Celsius higher than the cooling temperature.

39. The processing machine of claim 34, further comprising a mount assembly that couples the first shield assembly to the second shield assembly with the first shield assembly spaced apart from the second shield assembly, wherein the mount assembly inhibits the transfer of heat between the first shield assembly and the second shield assembly.

40. The processing machine of claim 39 wherein the mount assembly couples the second shield assembly to the chamber structure with the second shield assembly spaced apart from the chamber structure, wherein the mount assembly inhibits the transfer of heat between the second shield assembly and the chamber structure.

41. The processing machine of claim 34, wherein at least one of the shield assemblies includes a reflective surface.

42. The processing machine of claim 27, wherein the first shield assembly includes a reflective surface.

43. The processing machine of claim 27, wherein the first shield assembly includes a reflective surface that faces the build platform.

44. The processing machine of any one of claims 9-43, wherein the temperature control assembly includes an infrared lamp.

45. The processing machine of any one of claims 9-43, wherein the temperature control assembly includes a visible light lamp.

46. The processing machine of any one of claims 9-43, wherein the temperature control assembly includes a tungsten halogen lamp.

47. The processing machine of any one of claims 9-43, wherein the temperature control assembly includes a conduction heater.

48. The processing machine of any one of claims 9-43, wherein the temperature control assembly includes a microwave generator.

49. The processing machine of claim 9, wherein the energy system is controlled to add excess heat to the material on the build platform so that a subsequent material layer deposited thereon at least partly sinters.

50. The processing machine of claim 9, wherein the material supply device includes a supply heater that heats the material that is being deposited onto the build platform in the deposition area.

51. The processing machine of claim 9 wherein the temperature control assembly directs light at an incident location, and wherein the build chamber assembly reimages scattered/reflected light from the incident location back at the incident location.

52. The processing machine of claim 9 wherein the energy system directs light at an incident location, and wherein the build chamber assembly reimages scattered/reflected light from the incident location back at the incident location.

53. A processing machine for building a three-dimensional object from a material, the processing machine comprising:

a build platform that supports the material while the object is being built;
and

a build chamber that defines a build space for the object that is being built; the build chamber including a chamber structure that at least partly encircles the build platform, and a first shield assembly positioned between the build platform and the chamber structure, the first shield assembly reducing the amount of thermal transfer between build space and the chamber structure.

54. The processing machine of claim 53, wherein the first shield assembly is positioned between the build platform and the chamber structure.

55. The processing machine of claim 53, wherein the first shield assembly is spaced apart from the build platform and the chamber structure.

56. The processing machine of claim 53, wherein the first shield assembly includes a first shield segment and a second shield segment that is spaced apart from the first shield segment.

57. The processing machine of claim 56, further comprising a heating assembly that maintains the first shield segment at a heating temperature, and a cooling assembly that maintains the second shield segment at a cooling temperature that is different from the heating temperature.

58. The processing machine of claim 57, wherein the heating temperature is at least one hundred degrees Celsius higher than the cooling temperature.

59. The processing machine of claim 53, further comprising a mount assembly that couples the first shield assembly to the chamber structure with the first shield assembly spaced apart from the chamber structure, wherein the mount assembly inhibits the transfer of heat between the first shield assembly and the chamber structure.

60. The processing machine of claim 53 wherein the build chamber assembly includes a second shield assembly that reduces the transfer of heat between the first shield assembly and the chamber structure.

61. The processing machine of claim 60, wherein the second shield assembly is positioned between the first shield assembly and the chamber structure, and the first shield assembly is positioned between the build platform and the second shield assembly.

62. The processing machine of claim 60, wherein the first shield assembly includes a first shield segment and a second shield segment that is spaced apart from the first shield segment; and the second shield assembly includes a first shield area and a second shield area that is spaced apart from the first shield area.

63. The processing machine of claim 62, further comprising a heating assembly that maintains the first shield segment at a heating temperature, and a cooling assembly that maintains the second shield segment at a cooling temperature that is different from the heating temperature.

64. The processing machine of claim 63, wherein the heating temperature is at least one hundred degrees Celsius higher than the cooling temperature.

65. The processing machine of claim 60, further comprising a mount assembly that couples the first shield assembly to the second shield assembly with the first shield assembly spaced apart from the second shield assembly, wherein the mount assembly inhibits the transfer of heat between the first shield assembly and the second shield assembly.

66. The processing machine of claim 65 wherein the mount assembly couples the second shield assembly to the chamber structure with the second shield assembly spaced apart from the chamber structure, wherein the mount assembly inhibits the transfer of heat between the second shield assembly and the chamber structure.

67. The processing machine of claim 60, wherein at least one of the shield assemblies includes a reflective surface.

68. The processing machine of claim 53, wherein the first shield assembly includes a reflective surface.

69. The processing machine of claim 53, wherein the first shield assembly includes a reflective surface that faces the build platform.

70. The processing machine of claim 53 further comprising (i) a material supply device that deposits material onto the build platform in the deposition area; (ii) an energy system that directs an energy beam at the material on the build platform to selectively melt the material in a melting area; (iii) a temperature control assembly that controls the temperature of the material on the build platform in the build chamber; (iv) a mover assembly that causes relative movement between the build platform and areas; and (v) a control system that controls the energy system, the temperature control assembly to actively control the temperature of at least a portion of the material on the build platform during relative movement between the build platform and the areas of the build chamber assembly.

71. The processing machine of claim 70, wherein the temperature control assembly includes a heating assembly that heats the material on the build platform in a heating area.

72. The processing machine of any one of claims 70 and 71, wherein the temperature control assembly includes a cooling assembly that cools the material on the build platform in a cooling area.

73. The processing machine of claim 71, wherein the heating assembly includes an infrared lamp.

74. The processing machine of claim 71, wherein the heating assembly includes a visible light lamp.

75. The processing machine of claim 71, wherein the heating assembly includes a tungsten halogen lamp.

76. The processing machine of claim 71, wherein the heating assembly includes a conduction heater.

77. The processing machine of claim 71, wherein the heating assembly includes a microwave generator.

78. The processing machine of claim 53, further comprising an energy system that is controlled to melt the material, and add excess heat to the material on the build platform so that a subsequent material layer deposited thereon at least partly sinters.

79. The processing machine of claim 53, further comprising a material supply device that deposits material onto the build platform, wherein the material supply device includes a supply heater that heats the material that is being deposited onto the build platform.

80. A method for building a three-dimensional object from a material comprising:

supporting the material with a build platform;

providing a build space for the object that is being built with a build chamber assembly that includes a deposition area, a melting area, and a temperature control area;

depositing material onto the build platform in the deposition area with a material supply device;

directing an energy beam at the material on the build platform to selectively melt the material in the melting area;

controlling the temperature of the material on the build platform in the temperature control area with a temperature control assembly;

moving the build platform relative to the areas of the build chamber assembly; and

controlling the energy system, the heating assembly and the cooling assembly to actively control the temperature of at least a portion of the material on the build platform during movement between the build platform and the areas of the build chamber assembly.

81. The method of claim 80, wherein controlling the temperature includes heating the material with a heating assembly.

82. The method of claim 80, wherein controlling the temperature includes cooling the material with a cooling assembly.

83. A method for building a three-dimensional object from a material comprising:

supporting the material on a build platform while the object is being built;

and

providing a build space for the object that is being built with a build chamber; the build chamber including a chamber structure that at least partly encircles the build platform, and a first shield assembly positioned between the build platform and the wall assembly, the first shield assembly reducing the amount of thermal transfer between build space and the structure.

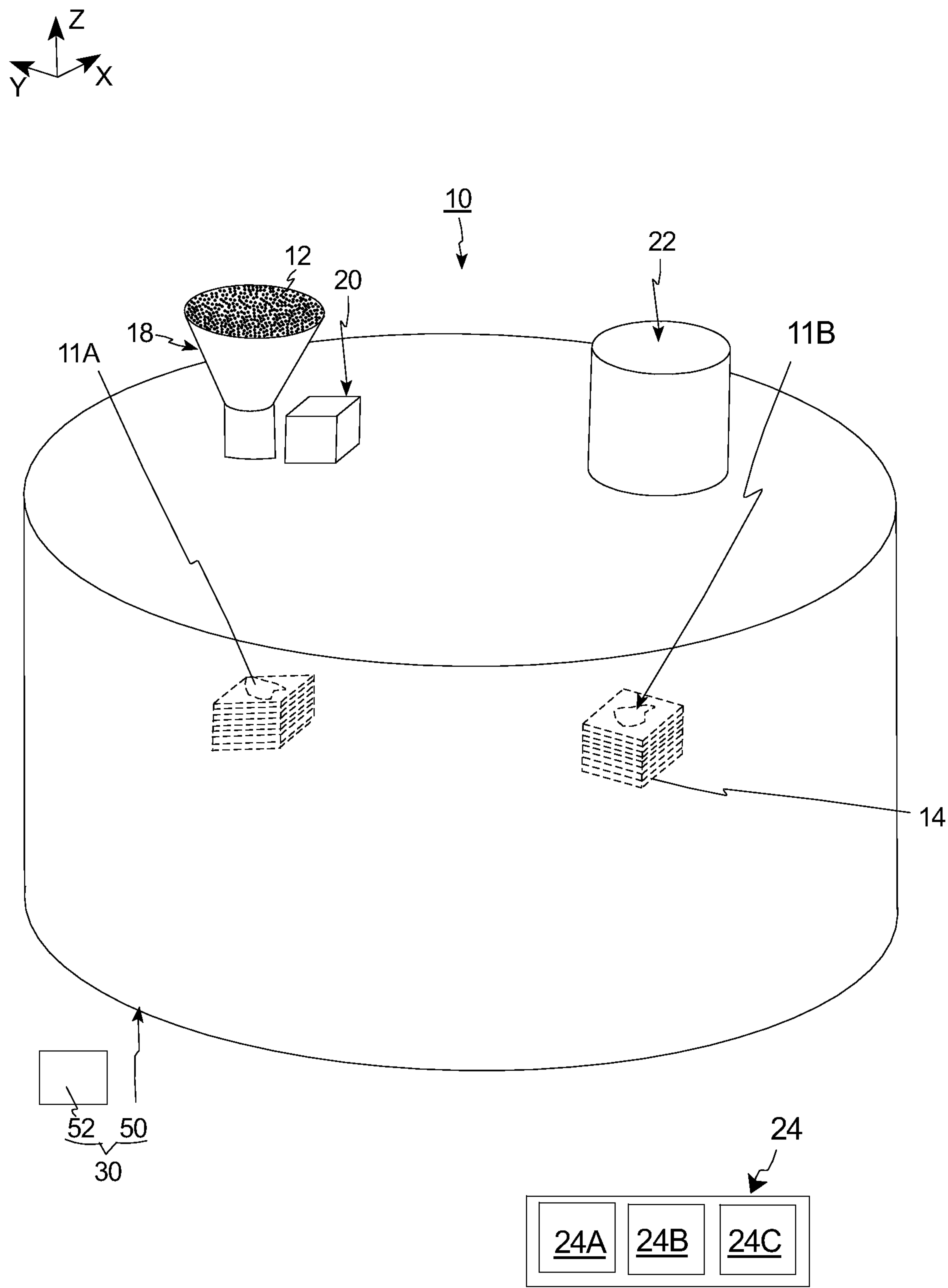


Fig. 1A

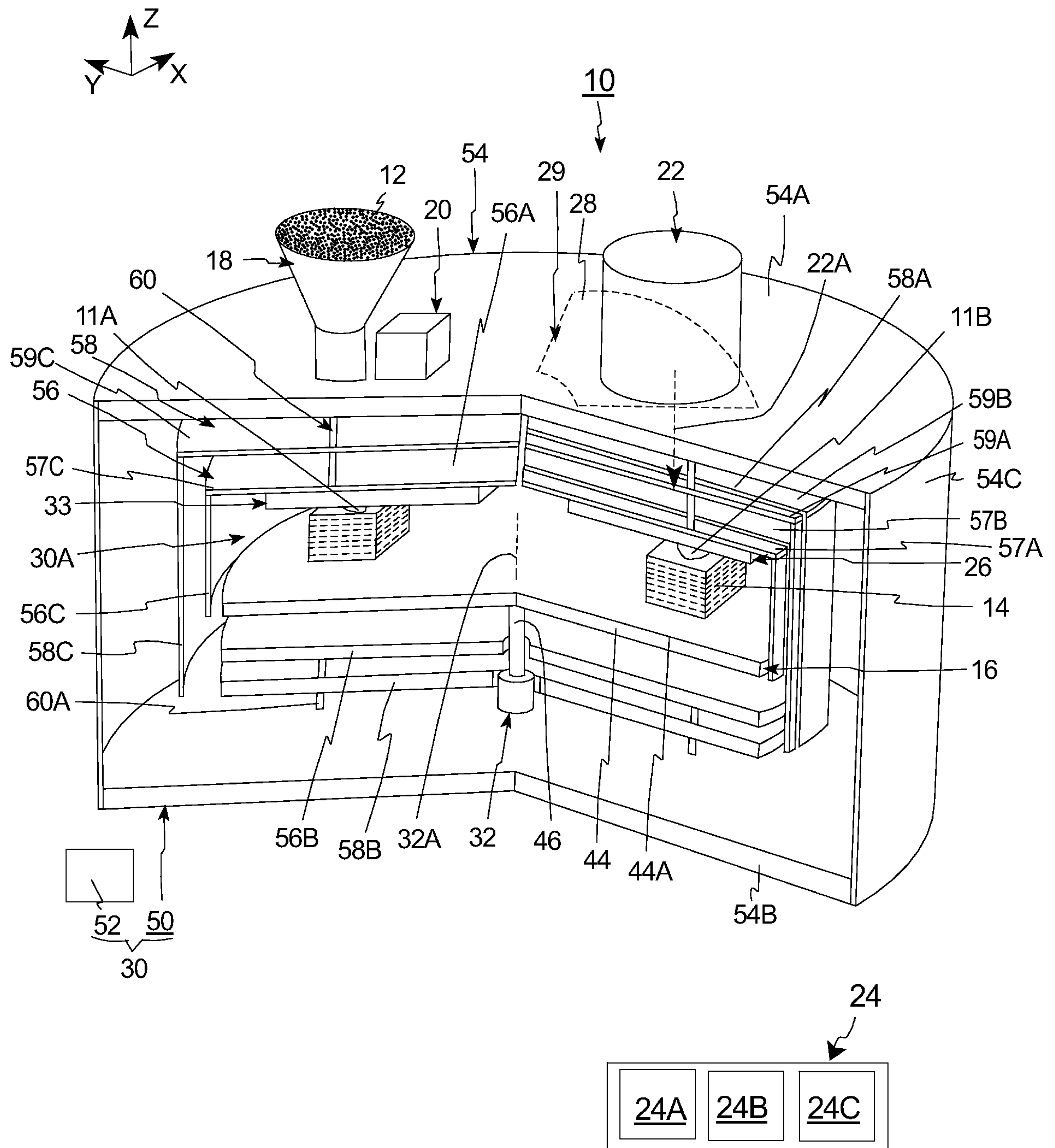


Fig. 1B

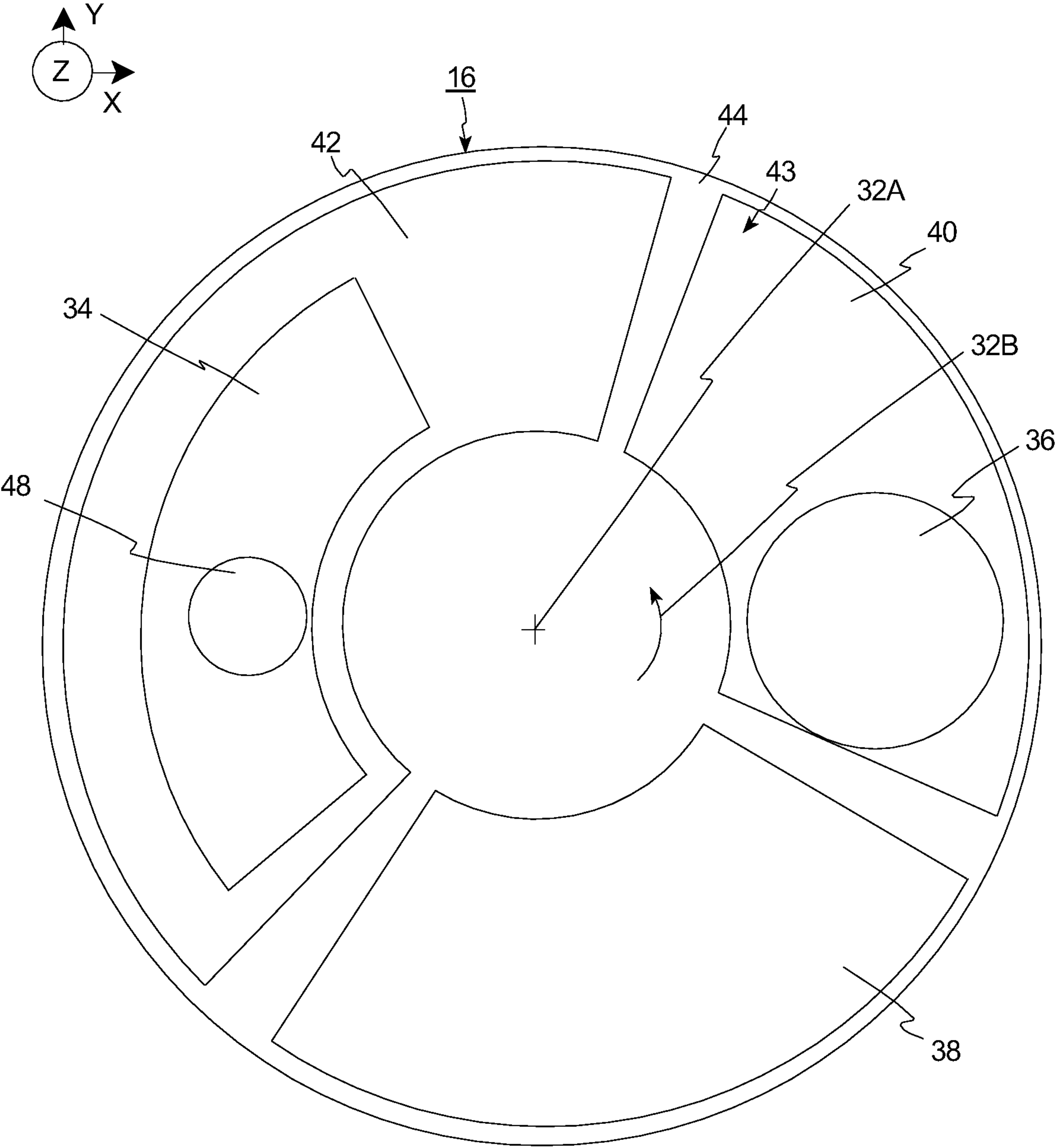


Fig. 1C

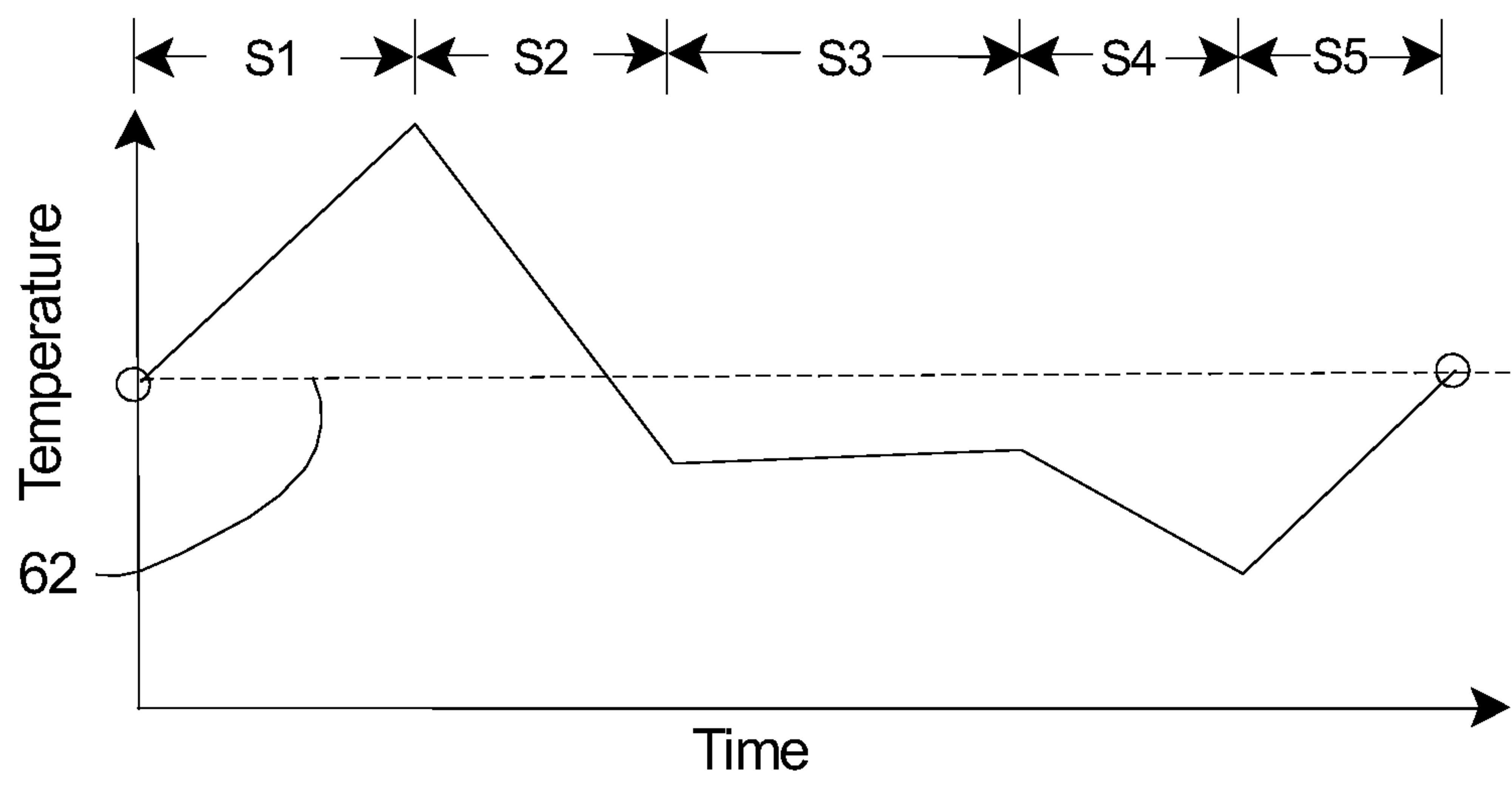


Fig. 1D

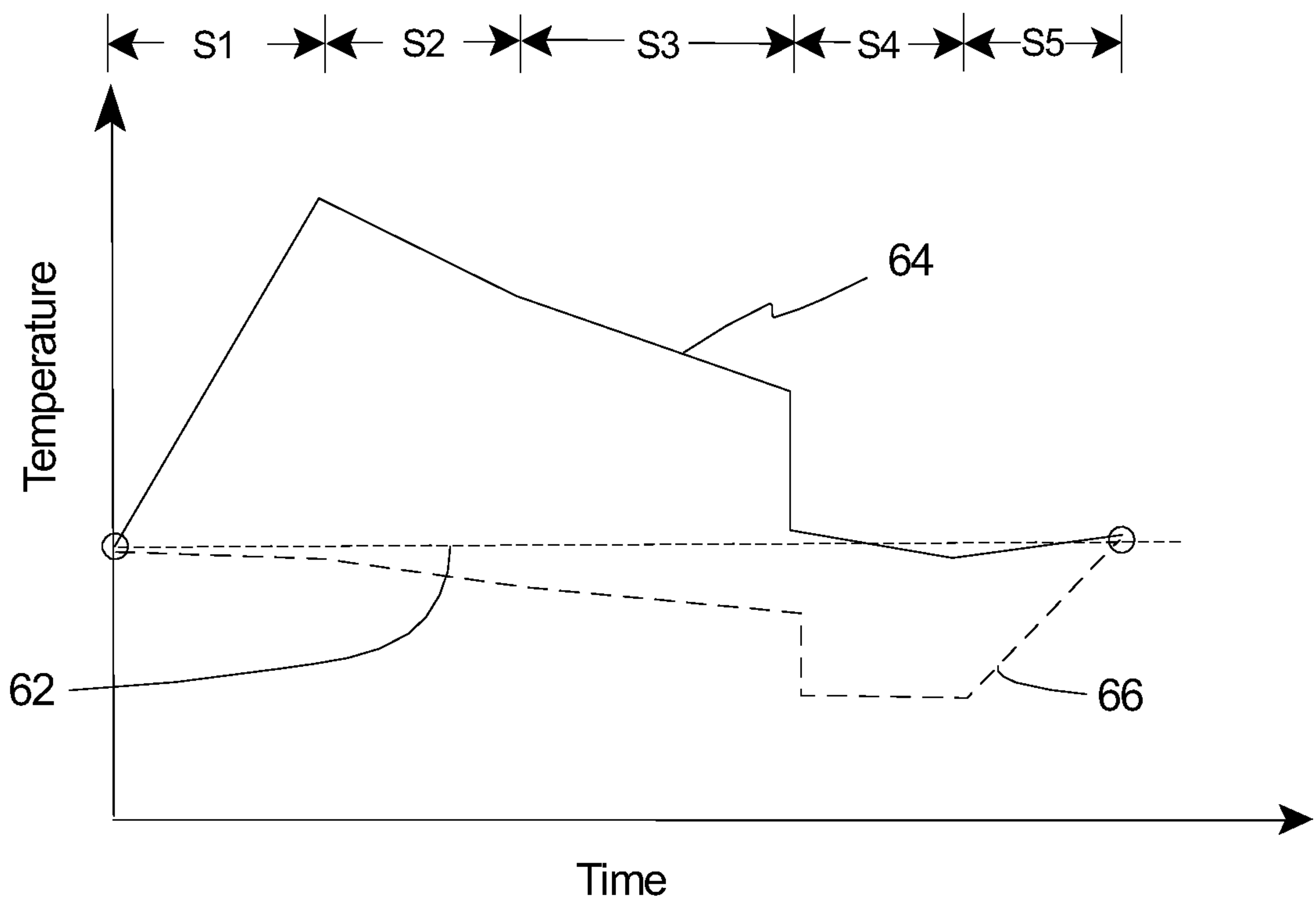


Fig. 1E

5/15

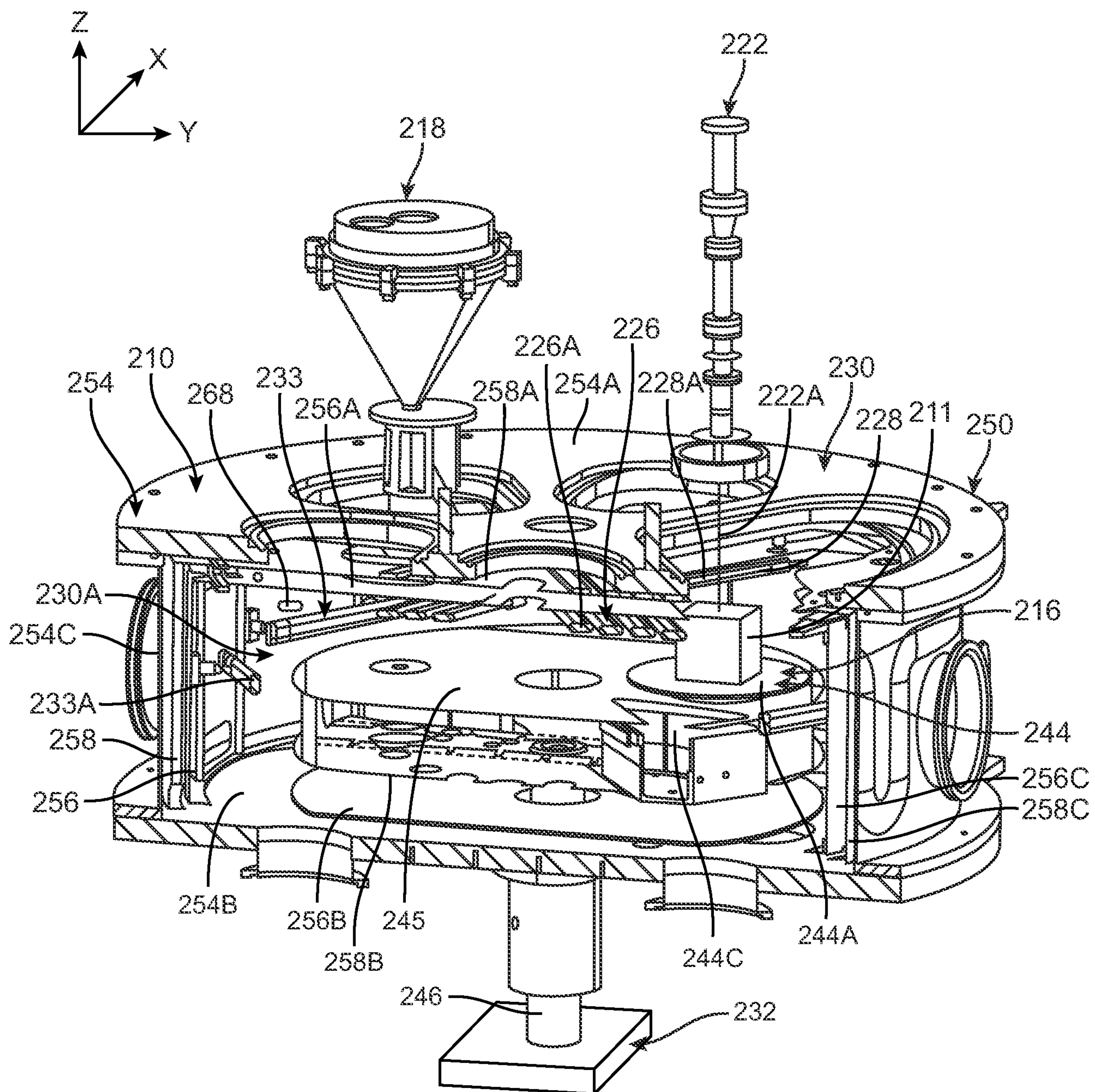


FIG. 2A

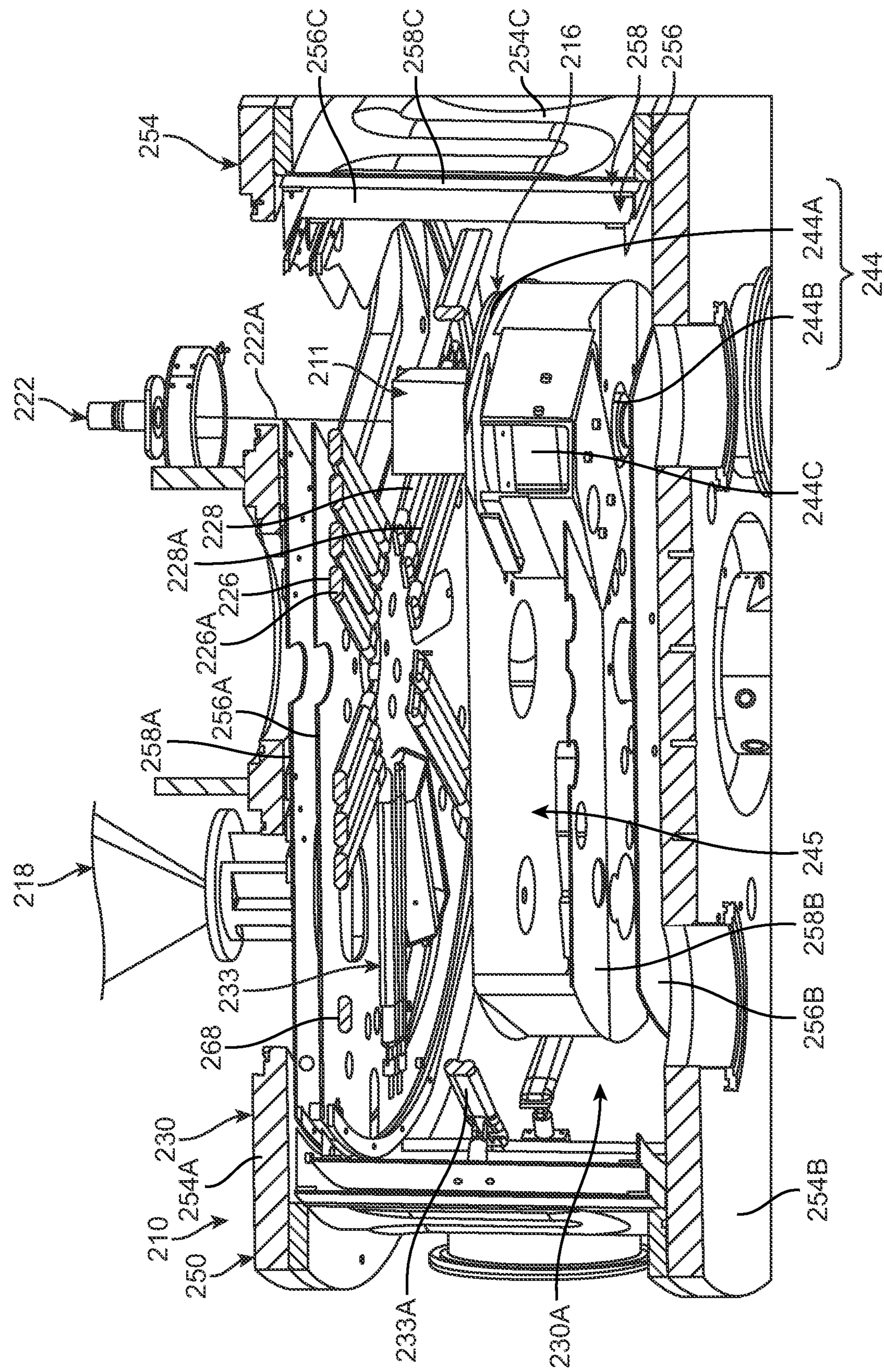


FIG. 2B

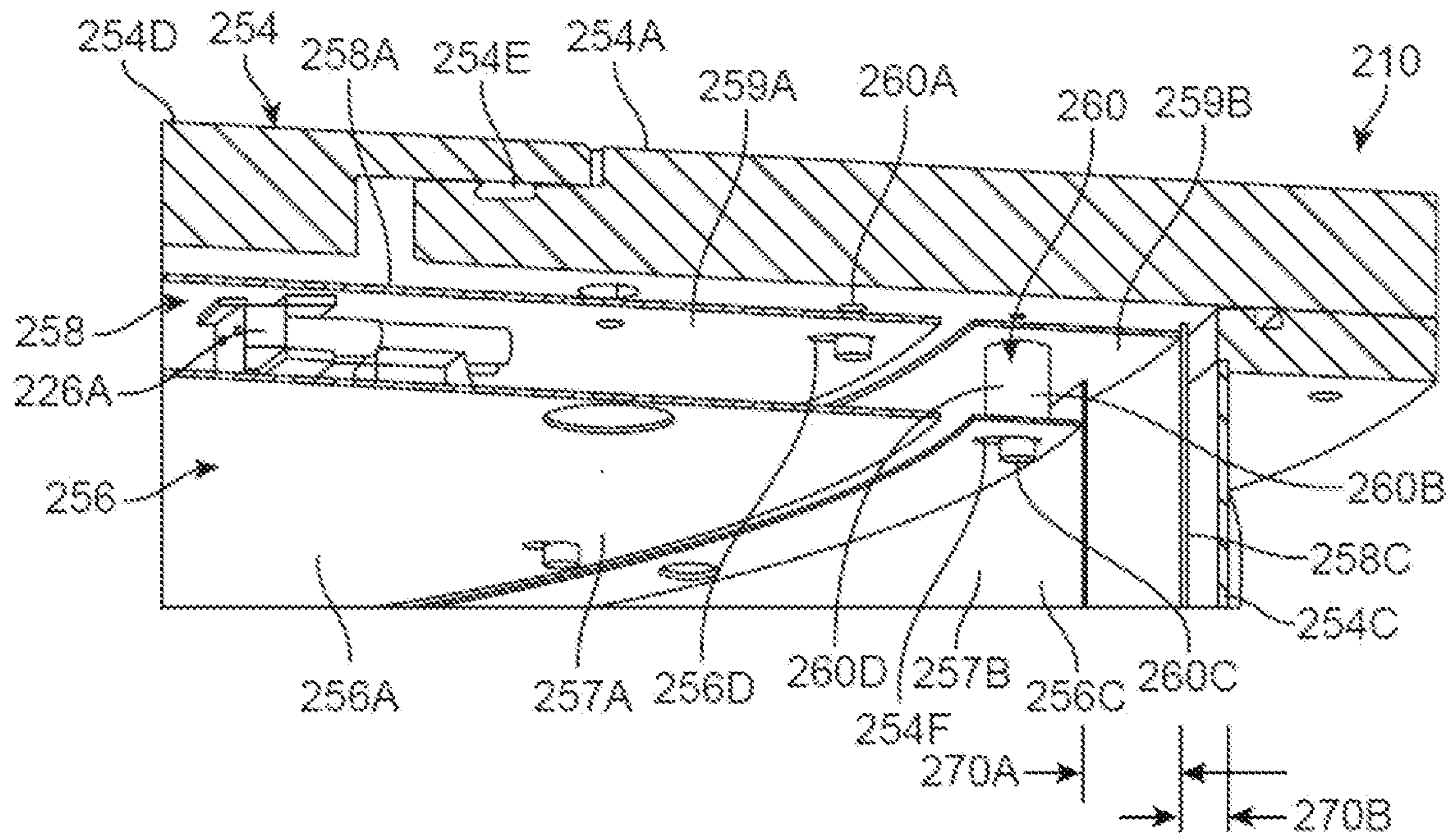


FIG. 2C

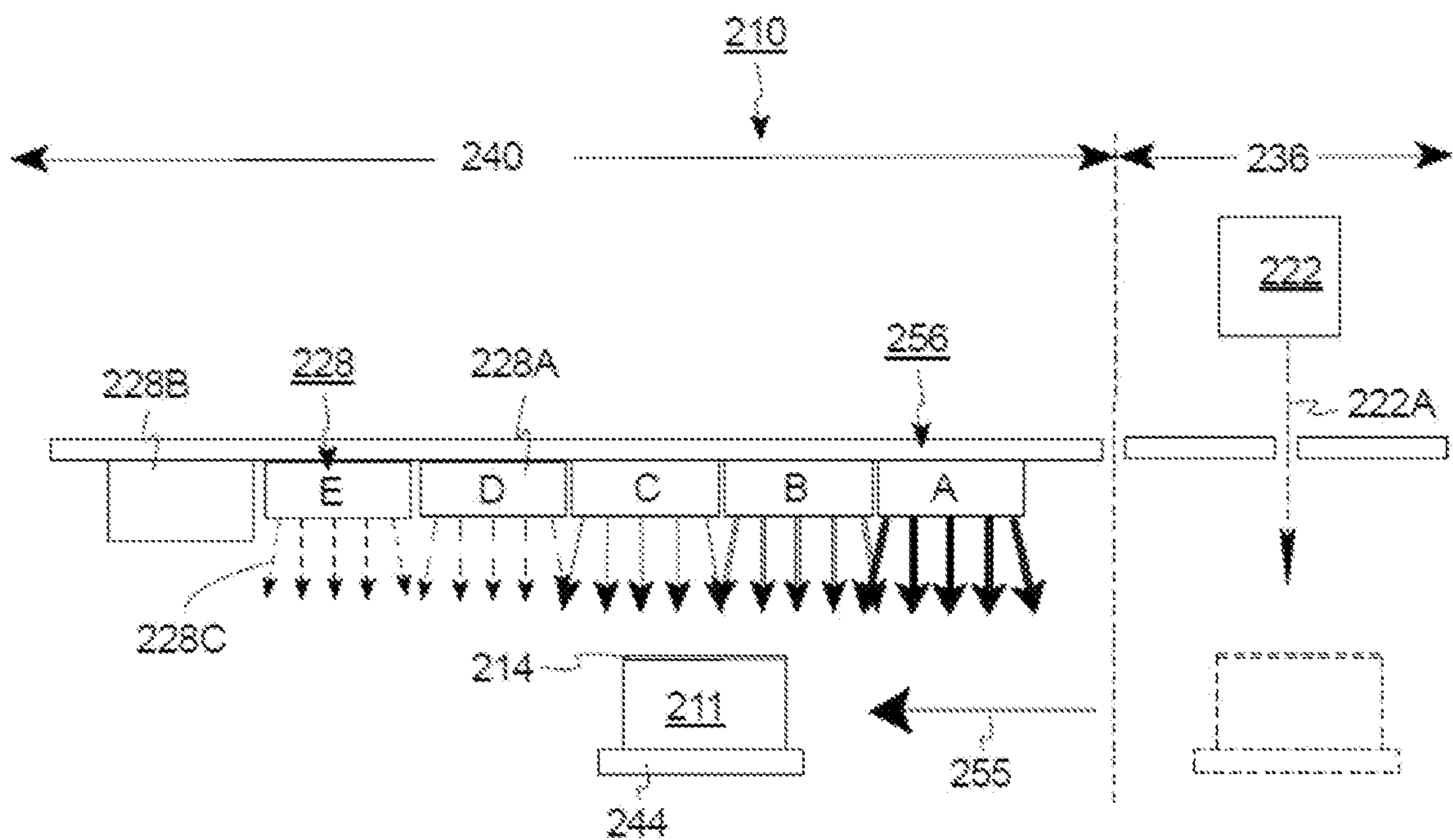


Fig. 2D

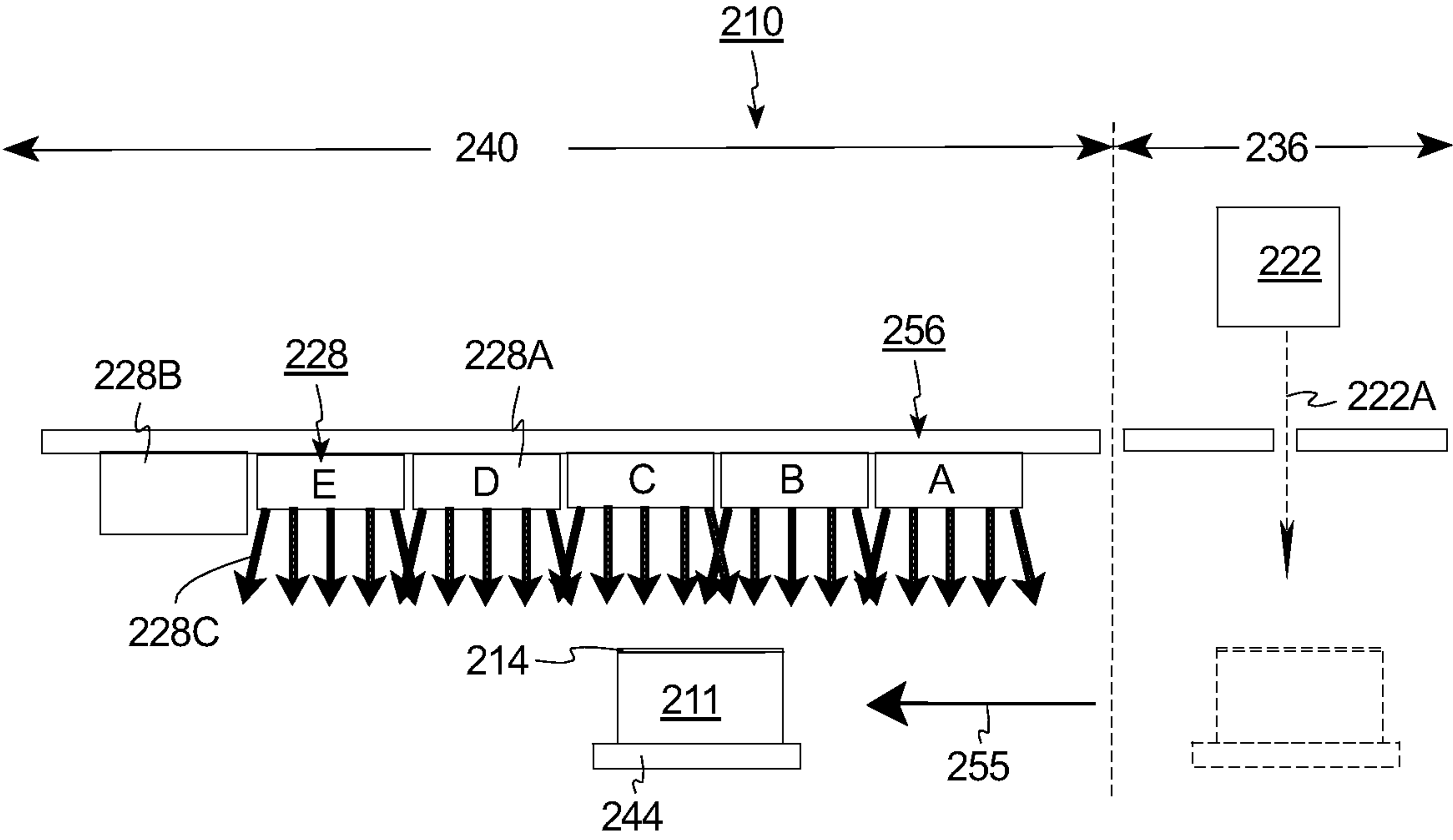


Fig. 2E

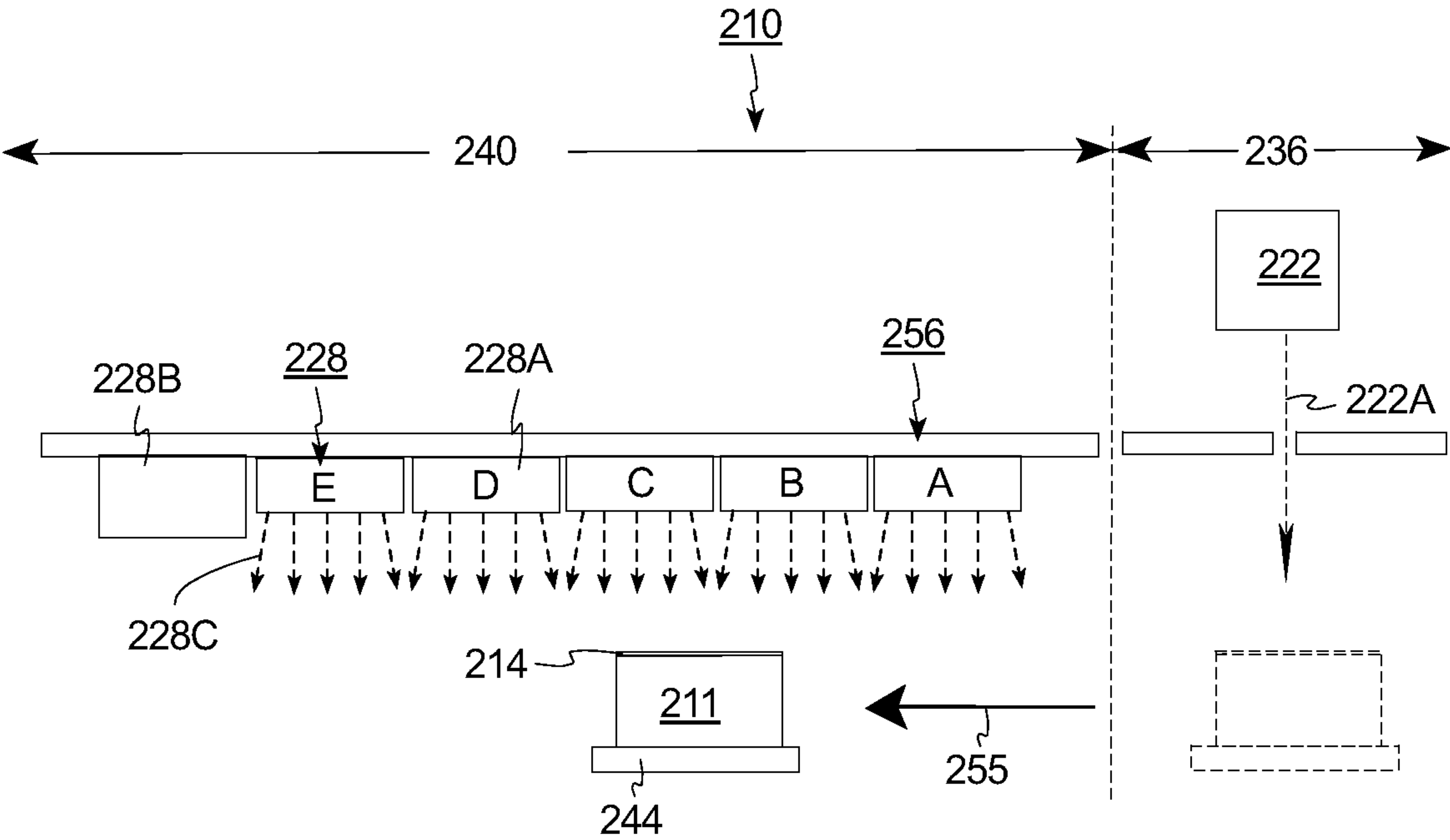


Fig. 2F

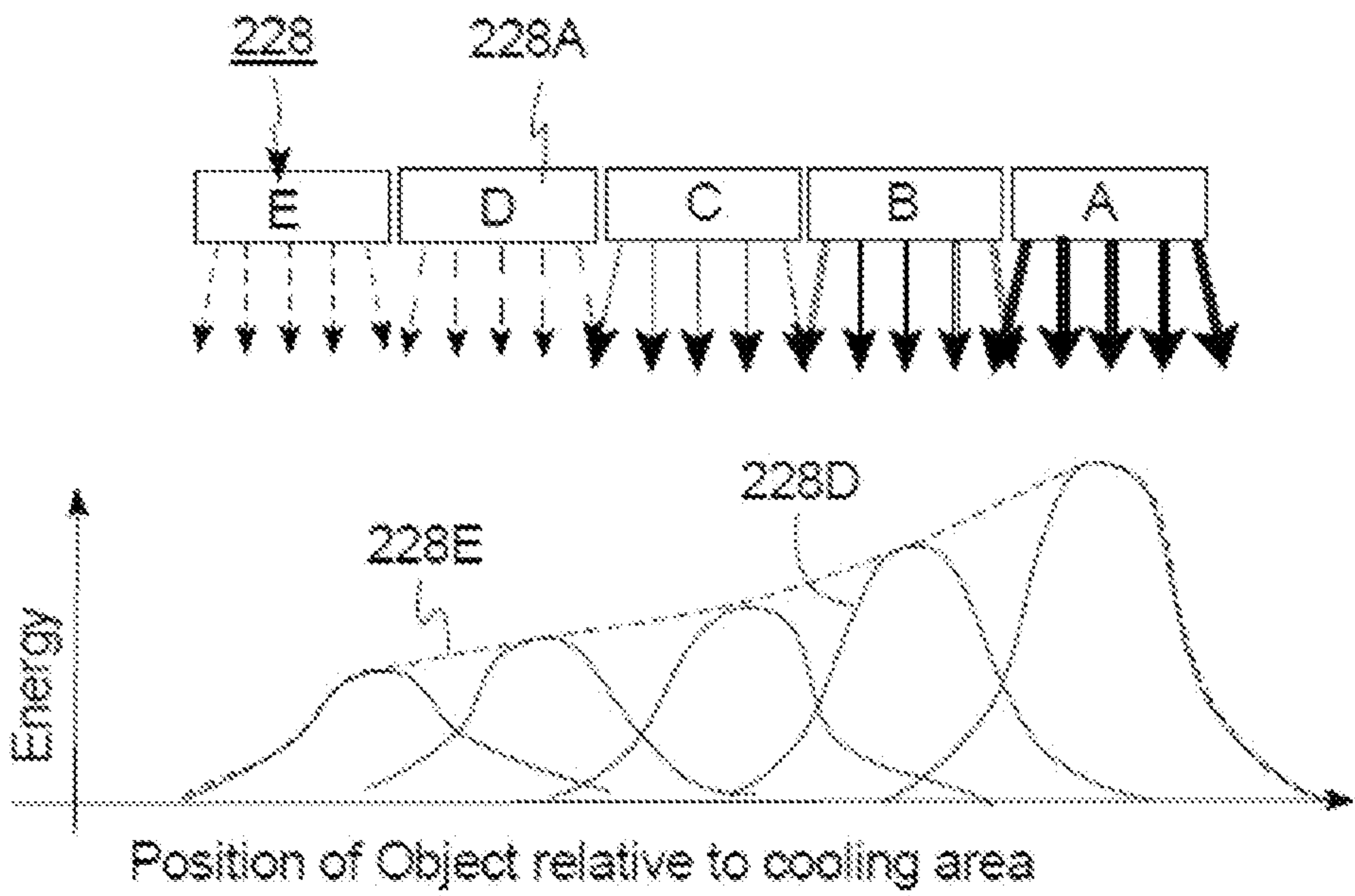


Fig. 2G

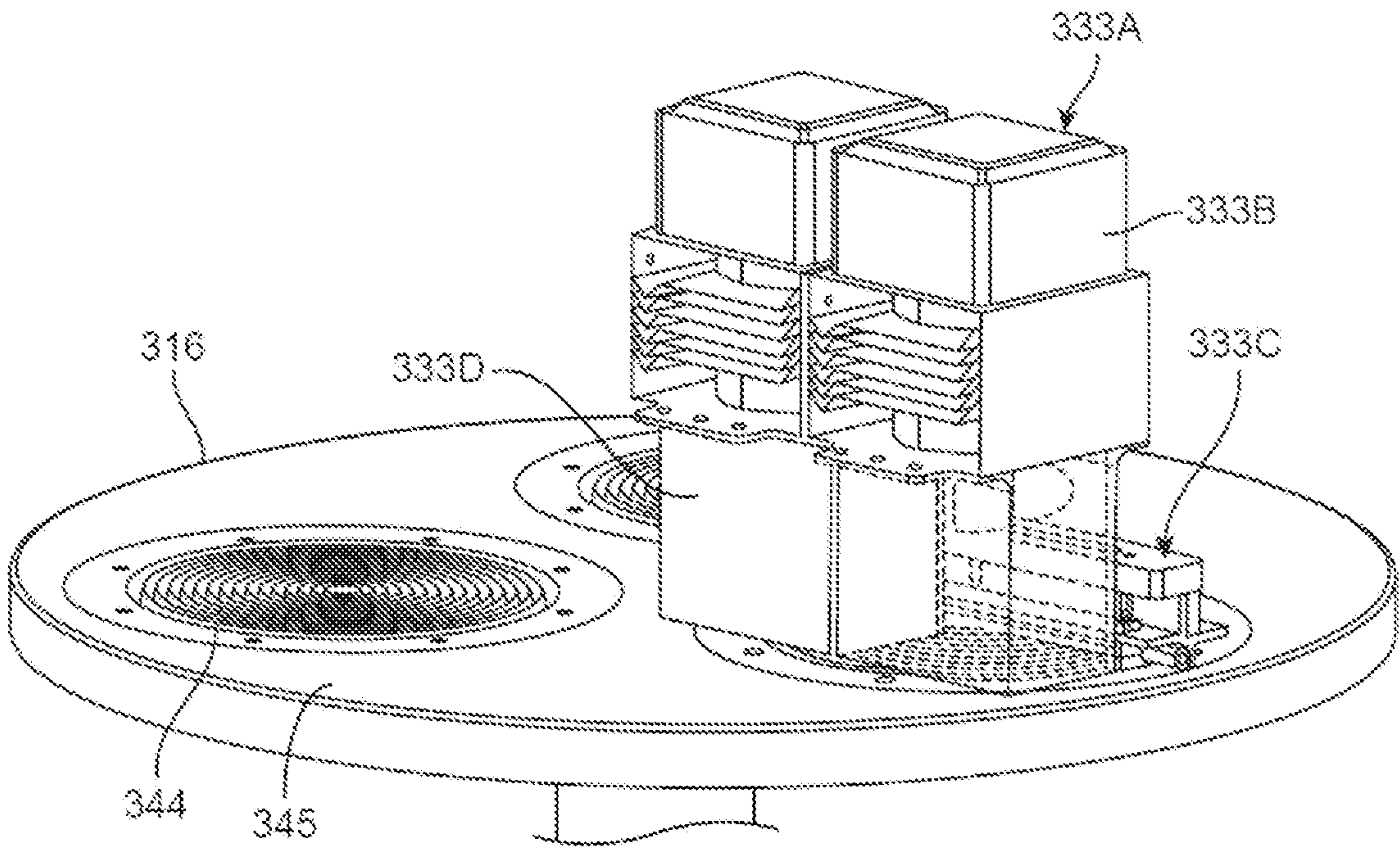


FIG. 3

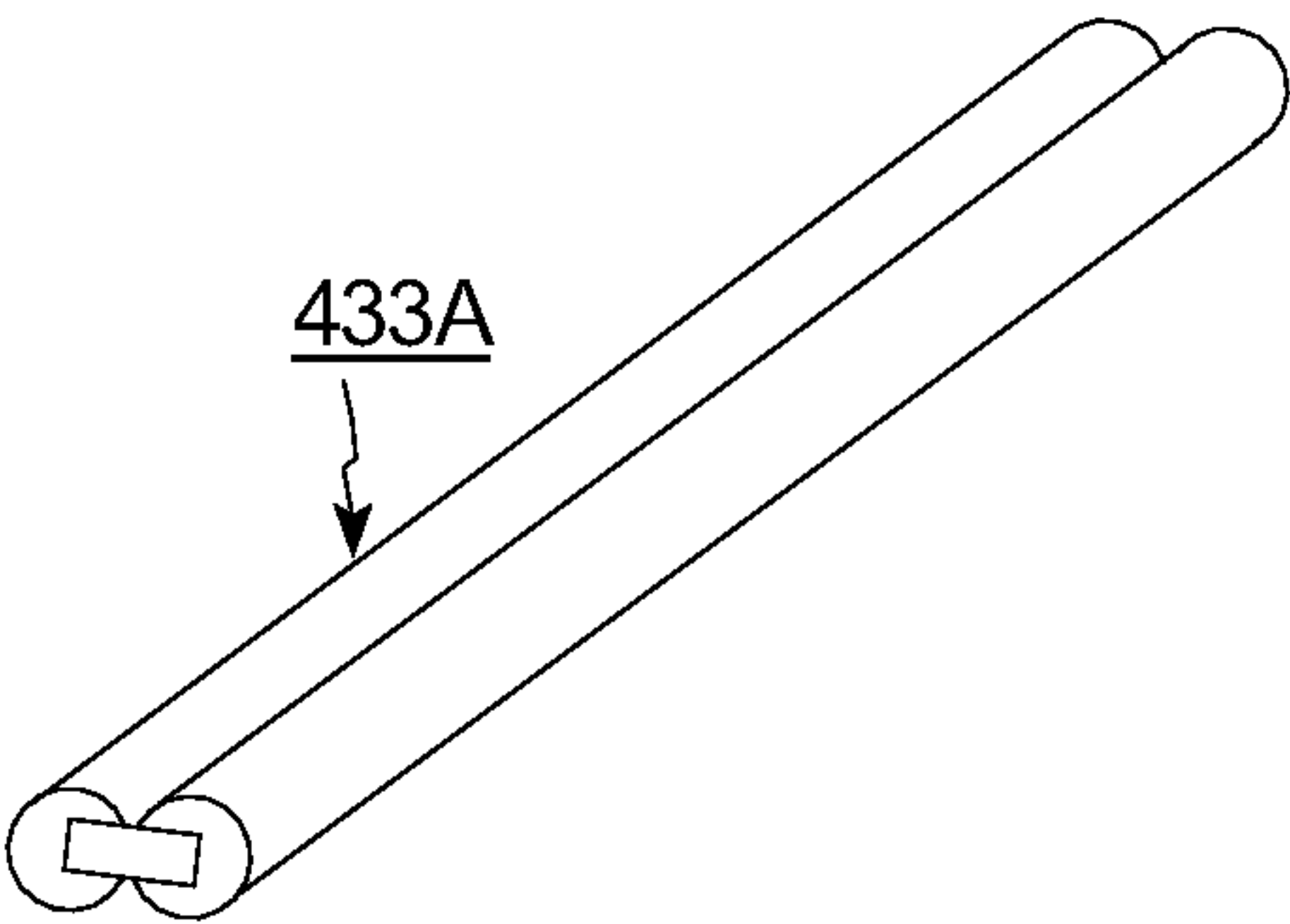


Fig. 4A

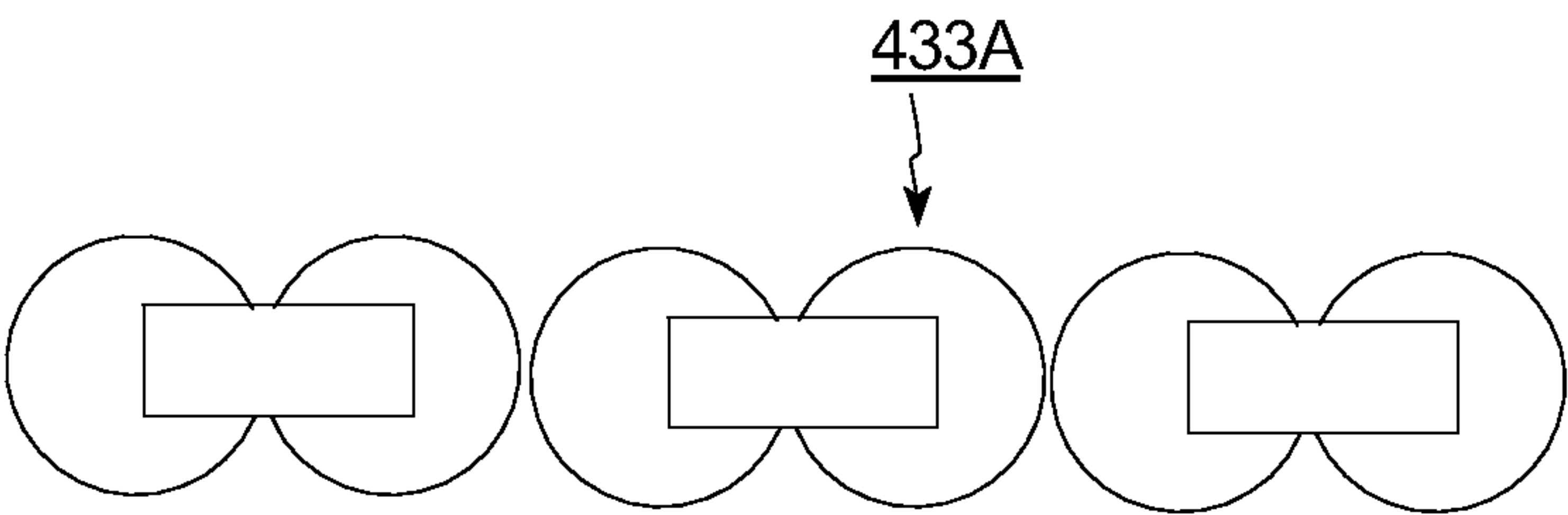


Fig. 4B

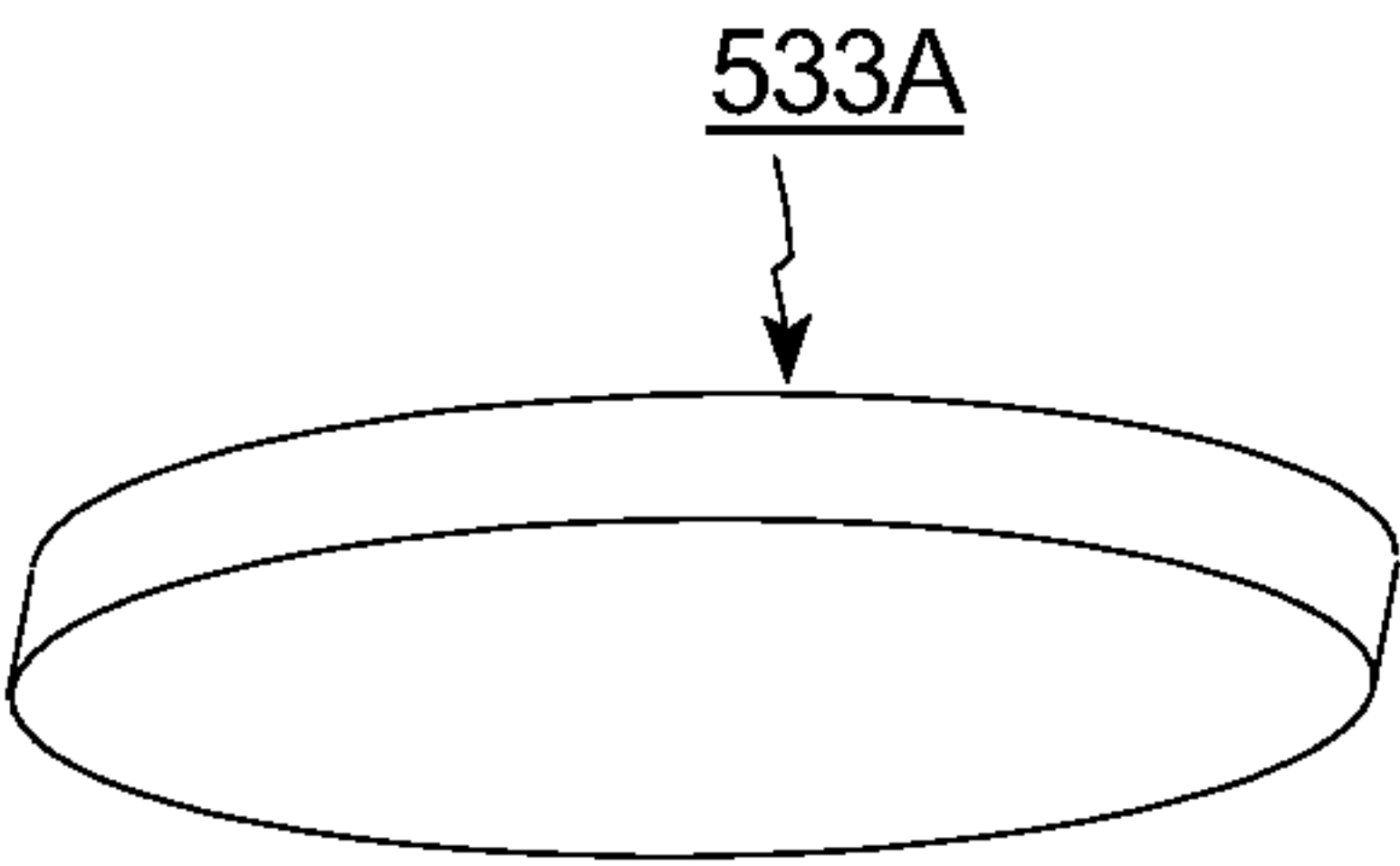


Fig. 5

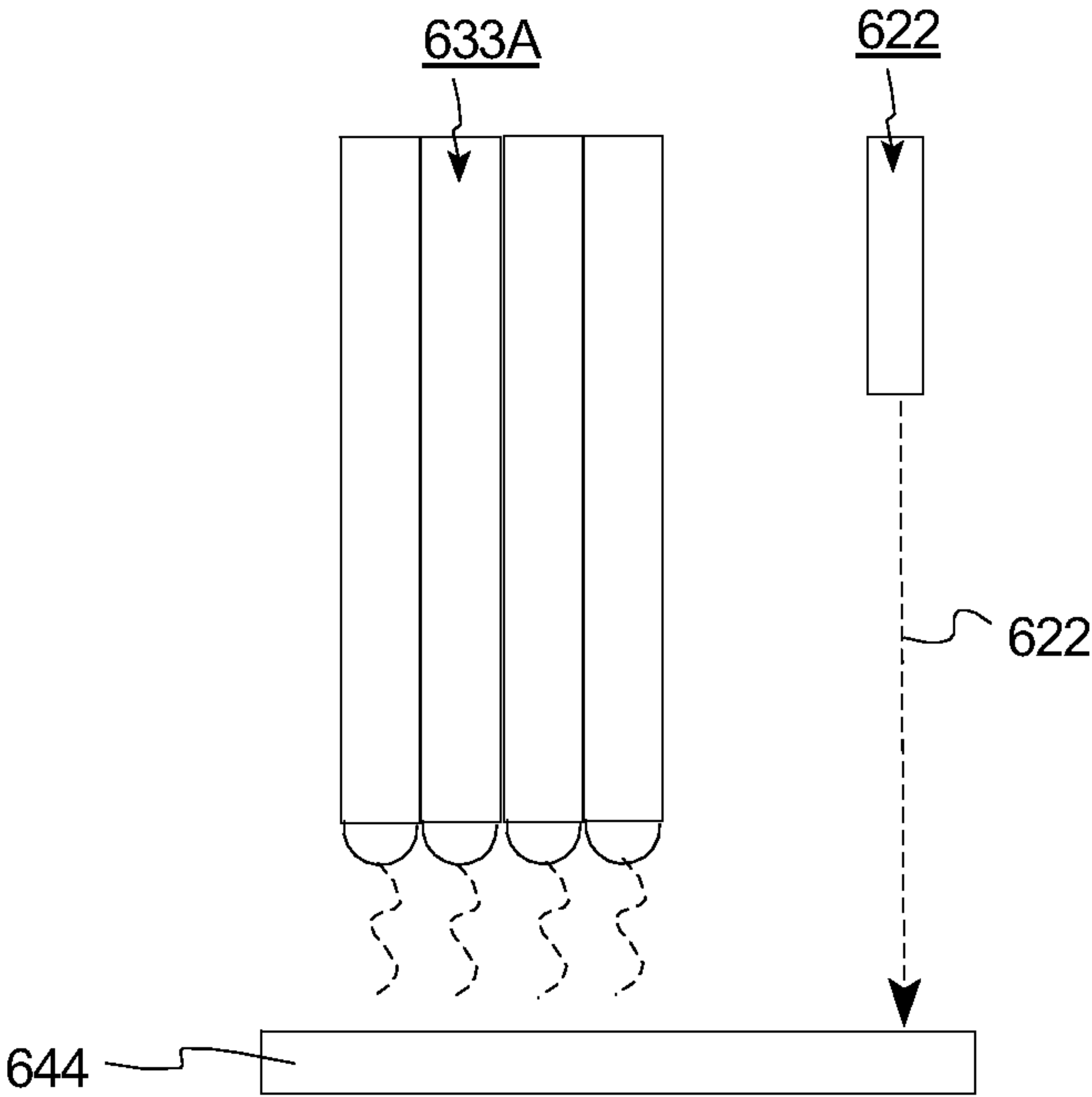


Fig. 6A

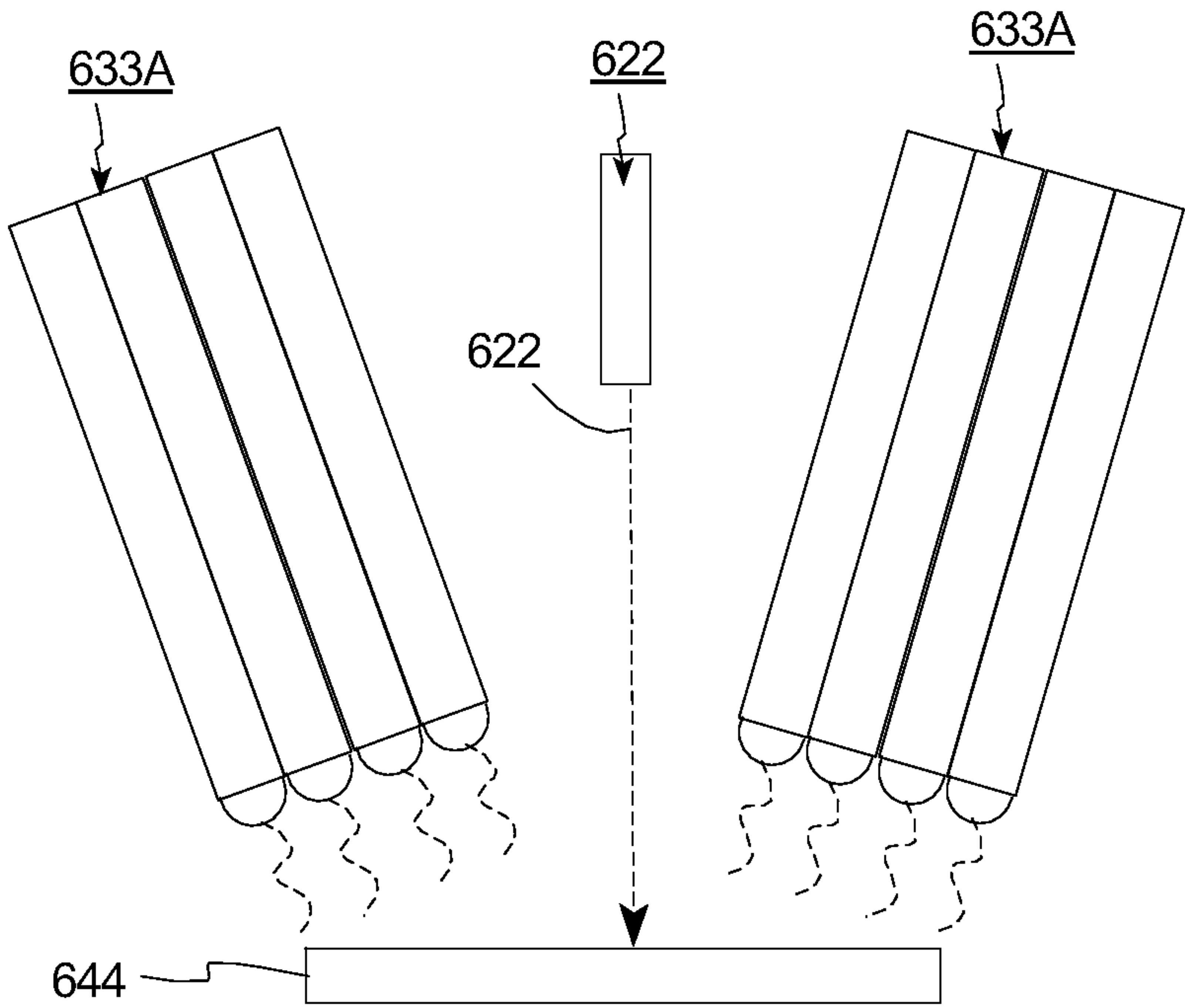


Fig. 6B

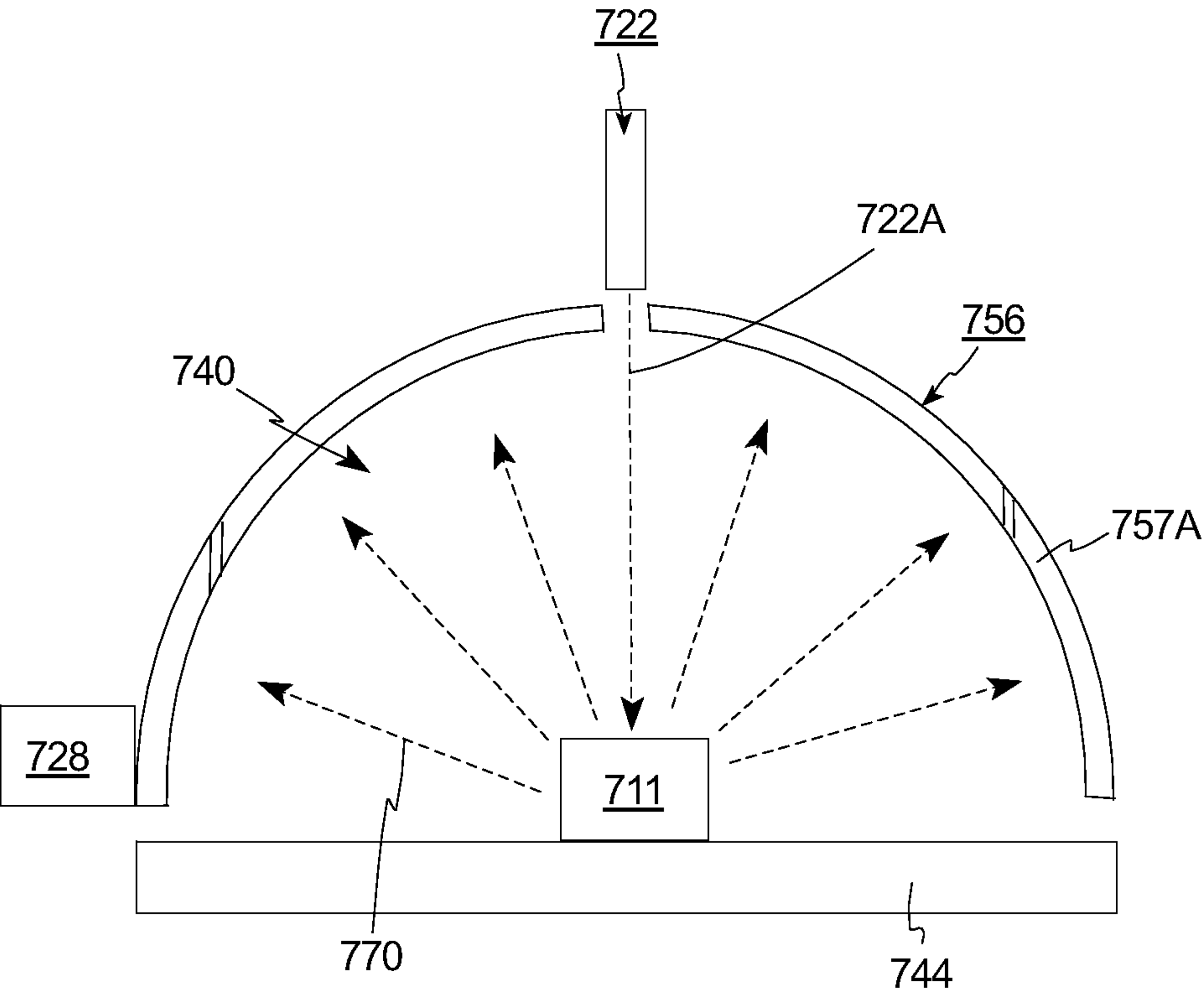


Fig. 7

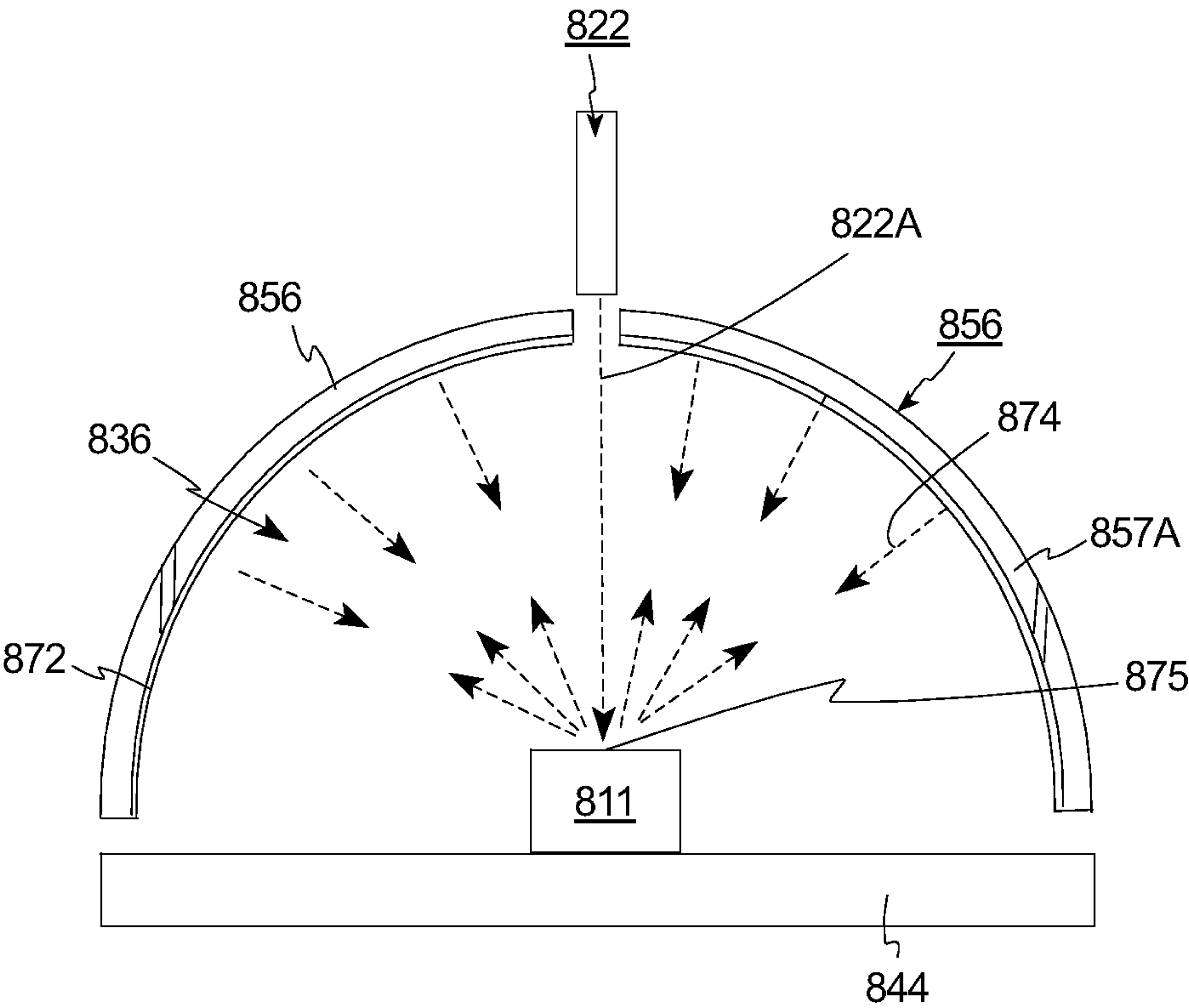


Fig. 8

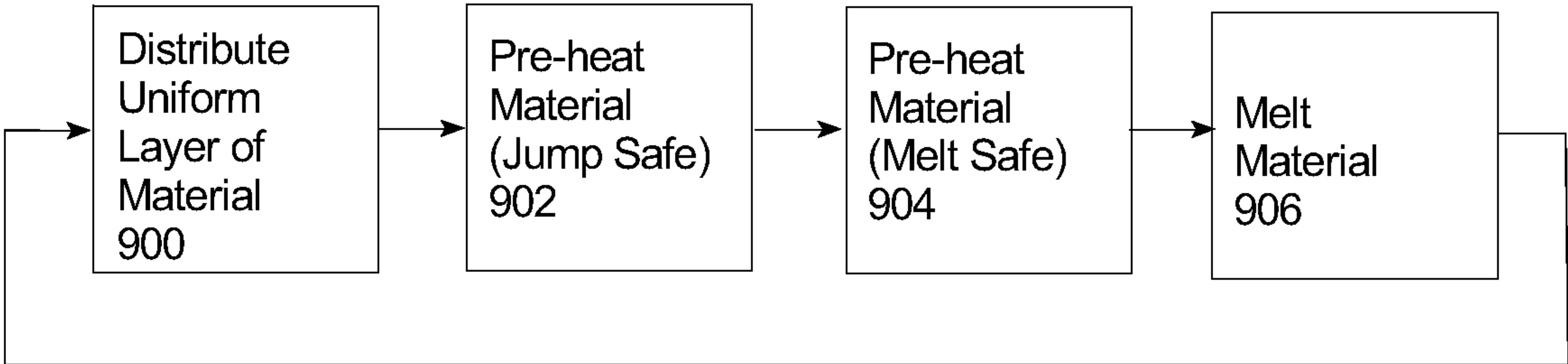


Fig. 9

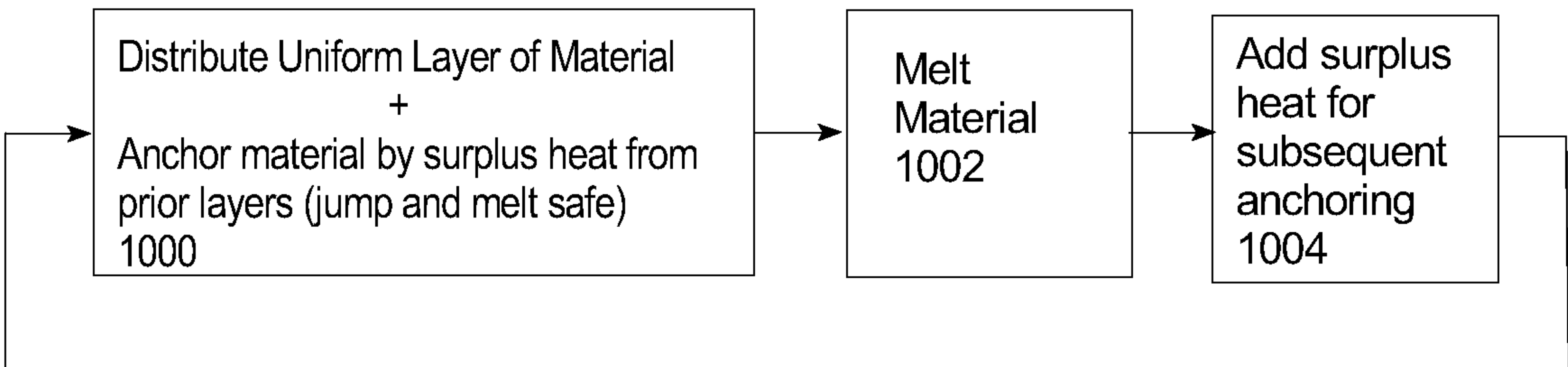


Fig. 10A

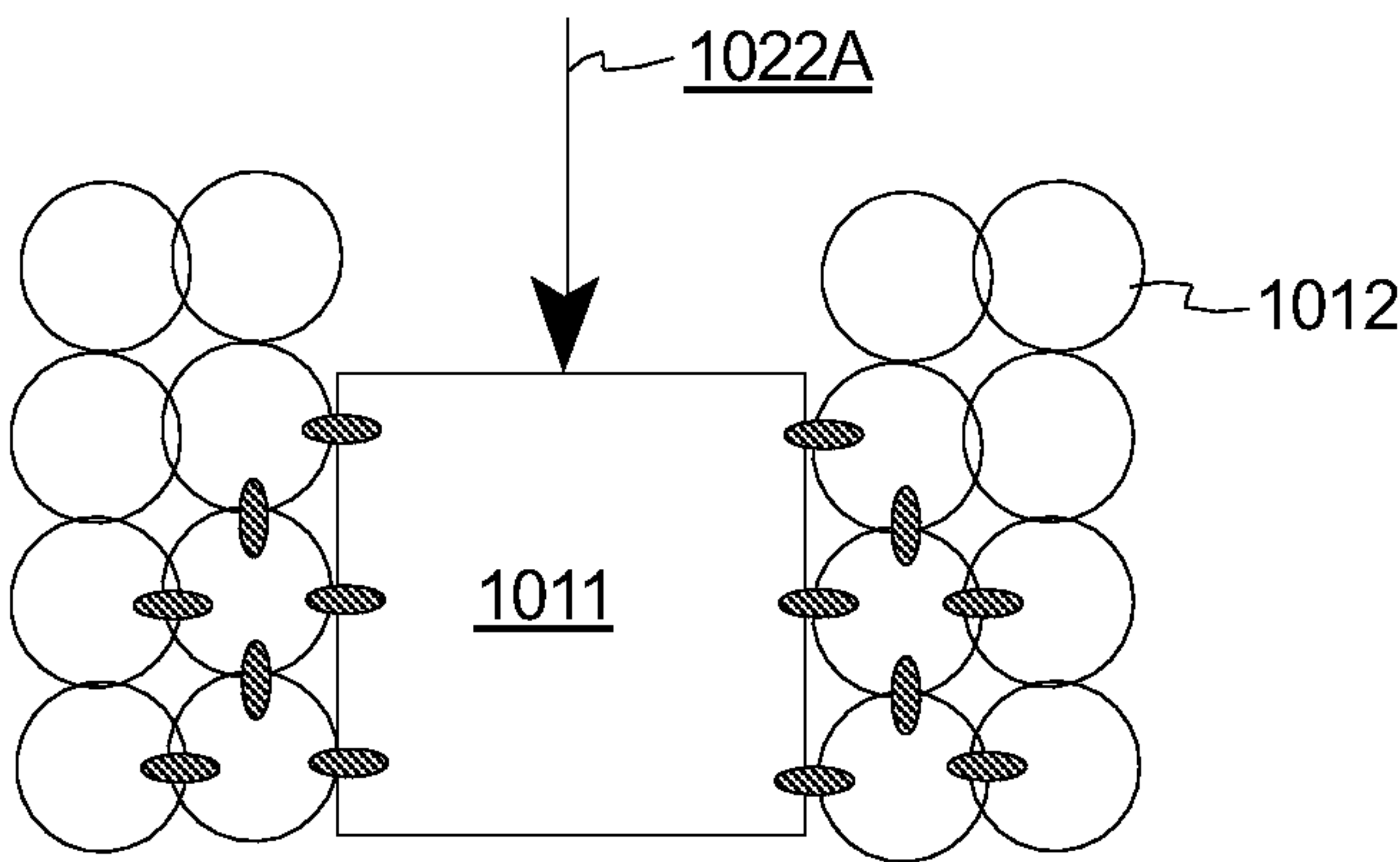


Fig. 10B

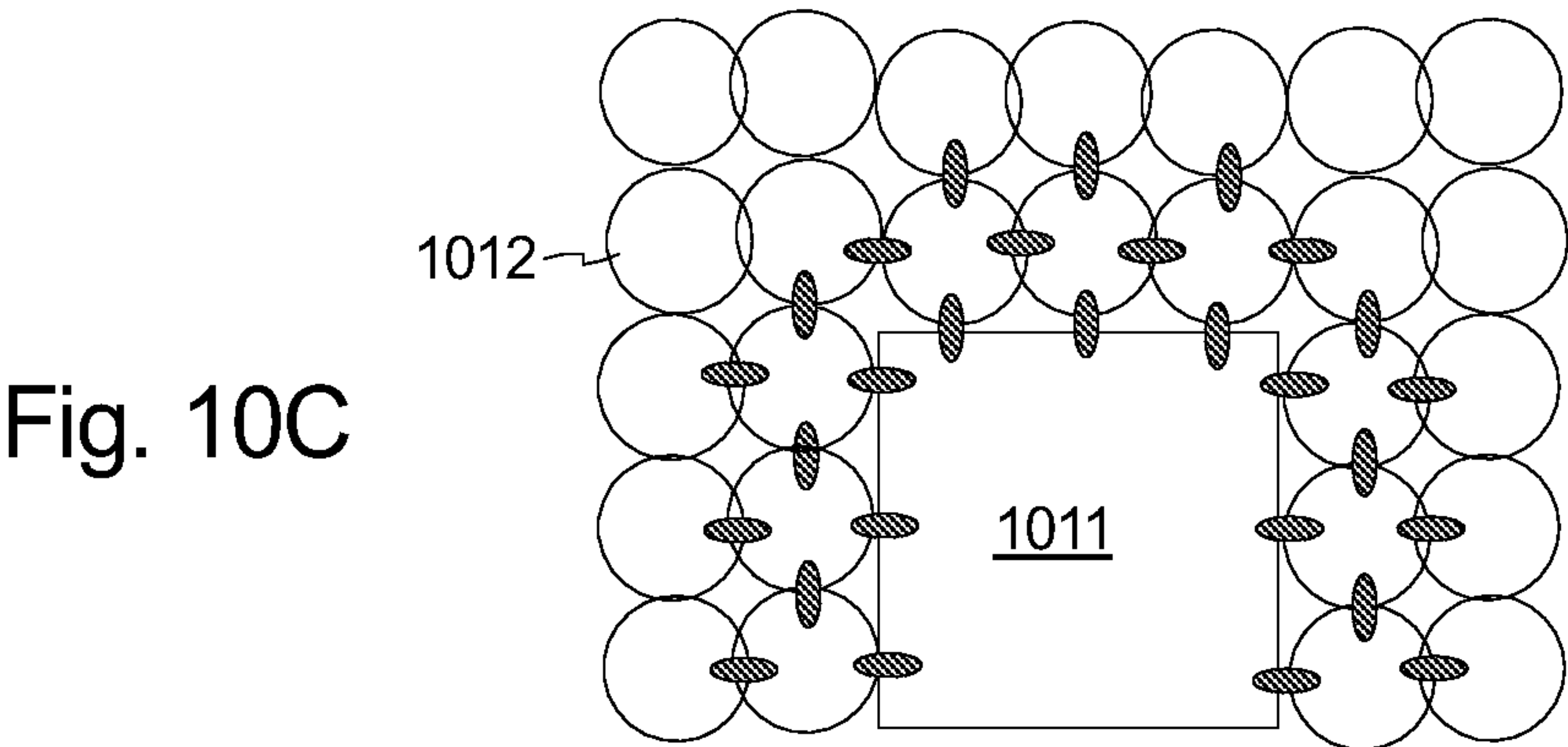


Fig. 10C

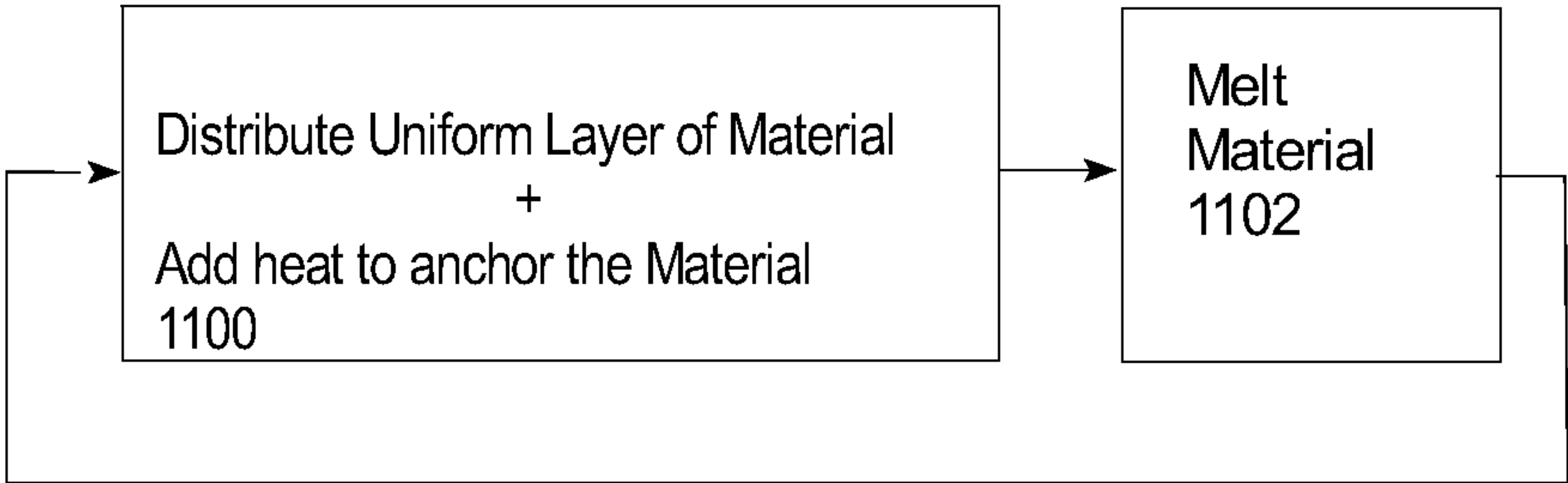


Fig. 11A

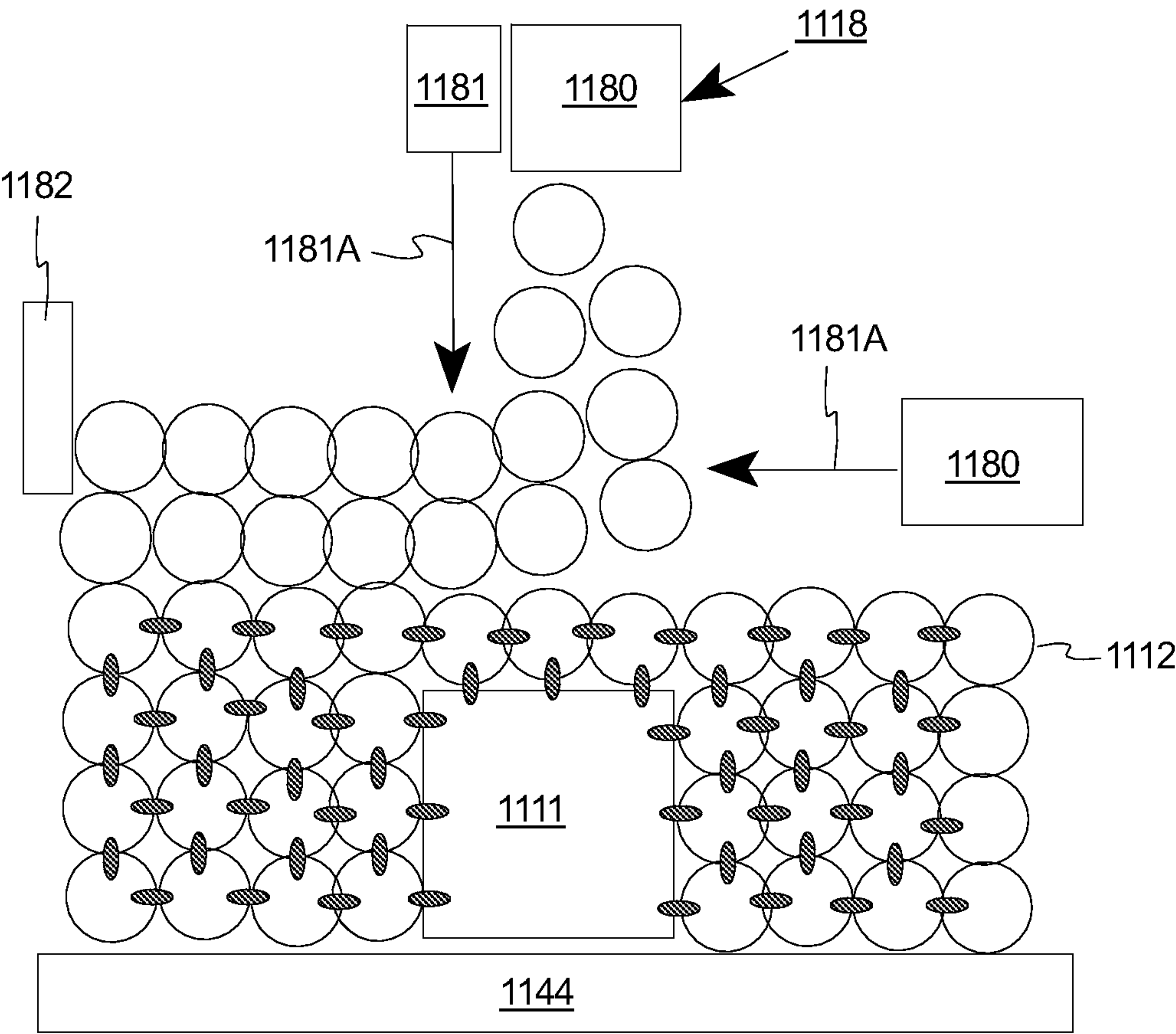


Fig. 11B

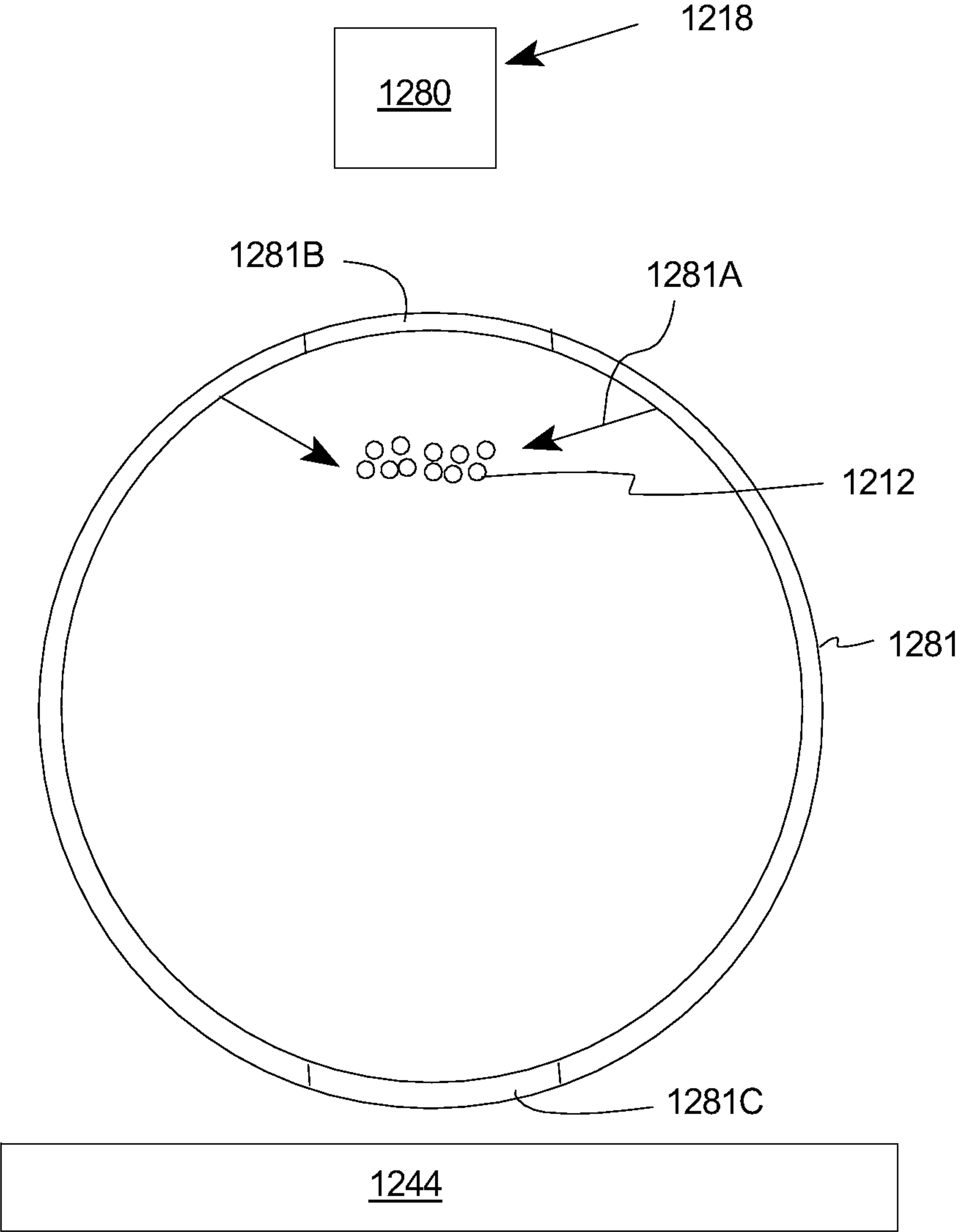


Fig. 12