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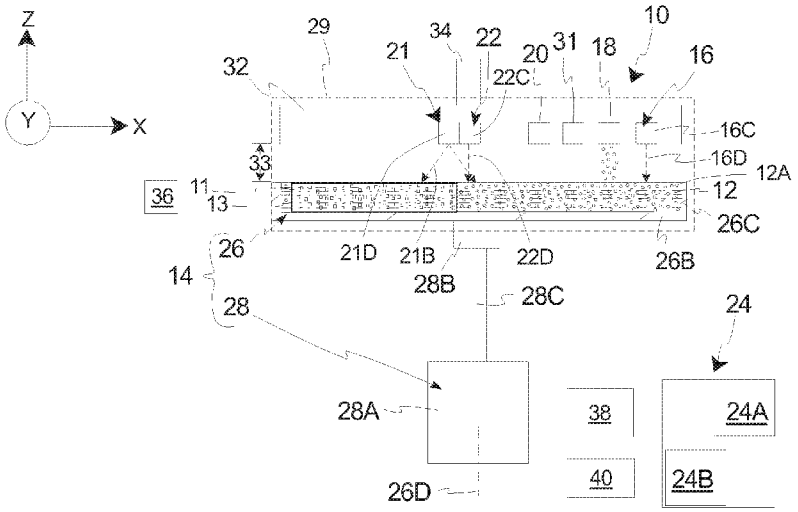


Fig. 1A

(57) Abstract: A processing machine (10) for building an object (11) from powder particles (12) includes a build platform (26), an excitation system (21) and an electron beam irradiation device (22). The build platform (26) includes a support surface (26B) that supports the powder particles (12). The excitation system (21) directs an excitation light (21B) at a plurality of the powder particles (12). The electron beam irradiation device (22) irradiates the plurality of the powder particles (12) with an electron beam (22D).

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PCT PATENT APPLICATION

of

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for

ENHANCED POWDER BED DISCHARGING

RELATED APPLICATIONS

[0001] This application claims priority on U.S. Provisional Application No: 62/869,760 filed on July 2, 2019, and entitled "ENHANCED POWDER BED DISCHARGING". As far as permitted, the contents of U.S. Provisional Application No. 62/869,760 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 POWDER BED" filed on December 22, 2018, and the contents of PCT Application No: PCT/US18/67406 entitled "ROTATING ENEGY BEAM FOR THREE-DIMENSIONAL PRINTER" filed on December 22, 2018 are incorporated herein by reference.

BACKGROUND

[0003] Current three-dimensional printing systems are relatively slow, have a low throughput, are expensive to operate, and/or may only make relatively small parts.

[0004] One such system is referred to as an electron beam additive manufacturing (EBAM) system. In EBAM, a powder on a build platform is heated to either sinter or melt the powder via electron bombardment. While an inner core of the powder is electrically conductive, e.g., metal, an outer layer of the powder is more electrically insulative (oxide). The resistivity of oxide layers inhibits rapid discharge, thus allowing charge to build to the point where the charged powder particles intensely repel one

another in an adverse phenomenon known in the industry as “smoking”. Ultimately, the relatively slow discharge rate limits system throughput as the powder can only be heated by the electron beam at a rate that will inhibit smoking.

SUMMARY

[0005] The present implementation is directed to a processing machine for building an object from powder particles. In various embodiments, the processing machine includes a build platform, an excitation system and an electron beam irradiation device. The build platform supports the powder particles on a support surface. The excitation system directs an excitation light at a plurality (at least a portion of) the powder particles. The electron beam irradiation device irradiates at least a portion of the powder particles with an electron beam.

[0006] In one embodiment, at least a portion of the powder particles is irradiated with the electron beam to form at least a portion of the object from the powder particles.

[0007] Additionally, in certain embodiments, the excitation light increases electrical conductivity of the powder particles via photoconductivity. Further, in some such embodiments, each of the powder particles has an outer layer, and the excitation light increases the electrical conductivity of the outer layer of the powder particles (that receive the excitation light) via photoconductivity. Still further, the excitation light can increase an electrical conductivity of the powder particles at least fifty percent compared to the powder particles before the excitation light is directed at the at least a portion of the powder particles.

[0008] In some embodiments, the excitation light has a wavelength that is below a predetermined wavelength determined based upon a type of material of the powder particles. In certain such alternative embodiments, the excitation light has a wavelength that is below an infrared range, below six hundred nanometers, below five hundred nanometers, below four hundred nanometers, below three hundred nanometers, or below two hundred nanometers.

[0009] Additionally, in certain embodiments, the processing machine further includes a material identification system that is configured to identify the type of material of the powder particles. For example, the material identification system can

determine the type of material of the powder particles based at least in part on one of a powder particles weight and a powder particles specific gravity of the powder particles. Further, or in the alternative, the processing machine can include an input interface that is configured to receive input including information about the type of material of the powder particles.

[0010] In some embodiments, the excitation system directs a plurality of spaced apart excitation lights at at least a portion of the powder particles on the support surface.

[0011] In various embodiments, the wavelength of the excitation light can be varied depending on the type of material of the powder particles. In such embodiments, the excitation light can have a wavelength that excites electrons in the powder particles. For example, in certain non-exclusive examples, (i) when the powder particles are made of Ti-6AL-4V, the excitation light can have a wavelength of less than 178 nanometers; (ii) when the powder particles are made of copper, the excitation light can have a wavelength of less than 572 nanometers; and (iii) when the powder particles are made of stainless steel, the excitation light can have a wavelength of less than 249 nanometers. Additionally, the excitation system can irradiate the powder particles with the excitation light having two or more different wavelengths. In some such embodiments, the excitation system irradiates the powder particles using only the excitation light having an optimum wavelength that is based upon on the type of material of the powder particles. Further, the excitation system can have a wavelength converter. Additionally, in certain embodiments, the excitation system has multiple excitation light sources. Each of the multiple excitation light sources can have a different wavelength. Further, or in the alternative, the excitation system can have one of a beam splitter and a spatial light modulator to divide excitation light from a single excitation light source into multiple excitation lights.

[0012] In certain alternative embodiments, the excitation light can change a temperature of the powder particles less than five hundred degrees Kelvin, less than two hundred fifty degrees Kelvin, or less than one hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles.

[0013] In some embodiments, the processing machine includes a build chamber.

In one such embodiment, the build chamber has a chamber window, the support surface is arranged inside the build chamber, the excitation light source is arranged outside the build chamber, and the excitation light from the excitation light source is irradiated to the powder particles through the chamber window. In another such embodiment, the build chamber has a cooling system, the support surface is arranged inside the build chamber, the excitation light source is arranged inside the build chamber, and the excitation light source is cooled by the cooling system.

[0014] In alternative embodiments, the excitation light can be utilized to irradiate the powder particles before, at approximately the same time, or after the irradiation of the powder particles with the electron beam. Further, in one embodiment, the excitation system irradiates the powder particles with the excitation light before the powder particles are supplied to the support surface. Alternatively, in another embodiment, the excitation system irradiates the powder particles with the excitation light after the powder particles are supplied to the support surface.

[0015] Additionally, in some embodiments, the excitation system can change an irradiation direction of the excitation light. Such change can increase an area of the powder particles that is irradiated by the excitation light. Further, or in the alternative, the excitation system can include a position control mechanism to change a position of an excitation light-emitting port.

[0016] Further, in certain embodiments, the processing machine can include one or more movers that move the support surface, e.g., parallel to the support surface and/or in either direction about a first axis intersecting the support surface. Additionally, the excitation system can change the irradiation direction of the excitation light according to the movement of the support surface on which the powder particles are supplied. Further, the excitation system can change the position of the excitation light-emitting port according to the movement of the support surface on which the powder particles are supplied.

[0017] In some embodiments, the support surface supports the powder particles in layers and the excitation system directs the excitation light over the outer layer of the powder particles.

[0018] Further, in certain embodiments, the excitation light includes a light beam.

[0019] Additionally, in one embodiment, the processing machine further includes a control system that identifies an area where irradiation is required on the support surface and instructs the excitation system to direct the excitation light to the area.

[0020] In another application, the present embodiment is directed toward a processing machine for building an object from powder particles, the powder particles having an outer layer, the processing machine including (i) a build platform that supports the powder particles; (ii) an excitation system that directs an excitation light at a plurality (at least a portion) of the powder particles on the build platform, the excitation light increasing electrical conductivity of the outer layer of the powder particles at least fifty percent via photoconductivity; and (iii) an electron beam system that directs an electron beam at the powder particles having the increased electrical conductivity to form at least a portion of the object from the powder particles, the excitation light changing a temperature of the powder particles less than five hundred degrees Kelvin prior to the electron beam system directing the electron beam at the powder particles.

[0021] In a first general implementation, the processing machine includes: (i) a build platform that includes a support surface that supports the powder particles; (ii) an excitation system that directs an excitation light at a plurality (at least a portion) of the powder particles; and (iii) an electron beam irradiation device that irradiates the plurality (at least a portion) of the powder particles with an electron beam.

[0022] Additionally, one or more of the following implementations can be utilized with the first general implementation: (i) wherein the at least a portion (a plurality) of the powder particles are irradiated with the electron beam to form at least a portion of the object from the powder particles; (ii) wherein the excitation light increases a photoconductivity of the plurality of powder particles; (iii) wherein each of the powder particles has an outer layer, and wherein the excitation light increases the photoconductivity of the outer layer of a plurality of the powder particles; (iv) wherein the excitation light increases an electrical conductivity of a plurality of the powder particles at least fifty percent compared to the powder particles before the excitation light is directed at the at least a portion of the powder particles; (v) wherein the excitation light has a wavelength that is below a predetermined wavelength determined

based upon a type of material of the powder particles; (vi) further including a material identification system that is configured to identify the type of material of the powder particles; (vii) wherein the material identification system determines the type of material of the powder particles based at least in part on one of a powder particles weight and a powder particles specific gravity of the powder particles; (viii) further including an input interface that is configured to receive input including information about the type of material of the powder particles; (ix) wherein the excitation light has a wavelength that is below an infrared range; (x) wherein the excitation light has a wavelength that is below six hundred nanometers; (xi) wherein the excitation light has a wavelength that is below five hundred nanometers; (xii) wherein the excitation light has a wavelength that is below four hundred nanometers; (xiii) wherein the excitation light has a wavelength that is below three hundred nanometers; (xiv) wherein the excitation light has a wavelength that is below two hundred nanometers; (xv) wherein the excitation system directs a plurality of spaced apart excitation lights at the plurality (at least a portion) of the powder particles on the build platform; (xvi) wherein the excitation light has a wavelength that excites electrons in the powder particles; (xvii) wherein the powder particles are made of Ti-6AL-4V, and the excitation light has a wavelength of less than 178 nanometers; (xviii) wherein the powder particles are made of copper, and the excitation light has a wavelength of less than 572 nanometers; (xix) wherein the powder particles aremade of stainless steel, and the excitation light has a wavelength of less than 249 nanometers; (xx) wherein the excitation system can irradiate the powder particles with the excitation light having two or more different wavelengths; (xxi) wherein the excitation system irradiates the powder particles using only the excitation light having an optimum wavelength that is based upon on the type of material of the powder particles; (xxii) wherein the excitation system has multiple excitation light sources, each of the multiple excitation light sources having a different wavelength; (xxiii) wherein the excitation system has a wavelength converter; (xxiv) wherein the excitation system has multiple excitation light sources; (xxv) wherein the excitation system has one of a beam splitter and a spatial light modulator to divide excitation light from a single excitation light source into multiple excitation lights; (xxvi) wherein the excitation light changes a temperature of the powder particles less than

five hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles; (xxvii) wherein the excitation light changes a temperature of the powder particles less than two hundred fifty degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles; (xxviii) wherein the excitation light changes a temperature of the powder particles less than one hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles; (xxix) further including a build chamber having a chamber window, wherein the support surface is arranged inside the build chamber, the excitation light source is arranged outside the build chamber, and the excitation light from the excitation light source is irradiated to the powder particles through the chamber window; (xxx) further including a build chamber having a cooling system, wherein the support surface is arranged inside the build chamber, the excitation light source is arranged inside the build chamber, and the excitation light source is cooled by the cooling system; (xxxi) wherein the excitation light is directed at the powder particles before the electron beam irradiates the powder particles; (xxxii) wherein the electron beam irradiates the plurality (at least a portion) of the powder particles having the increased photoconductivity; (xxxiii) wherein the electron beam irradiates the plurality (at least a portion) of the powder particles having the electrical conductivity of the powder particles that has been increased at least fifty percent; (xxxiv) wherein the excitation light irradiates the powder particles in parallel with the irradiation of the powder particles with the electron beam; (xxxv) wherein the excitation light irradiates the powder particles in a time period as the at least a portion of the object is formed from the powder particles by irradiations of the electron beam; (xxxvi) wherein the excitation light irradiates the powder particles after the electron beam irradiates the powder particles; (xxxvii) wherein the excitation system irradiates the powder particles with the excitation light before the powder particles are supplied to the support surface; (xxxviii) wherein the excitation system irradiates the powder particles with the excitation light after the powder particles are supplied to the support surface; (xxxix) wherein the excitation system can change an irradiation direction of the excitation light; (xl) wherein the excitation system includes a position control mechanism to change a position of an excitation light-emitting port; (xli) wherein the

excitation system increases an area of the powder particles that is irradiated by the excitation light by changing the irradiation direction; (xlii) further including a first mover that moves the support surface, wherein the excitation system irradiates the powder particles with the excitation light before the support surface is moved such that the electron beam can irradiate the powder particles; (xliii) wherein the excitation system changes the irradiation direction of the excitation light according to the movement of the support surface on which the powder particles are supplied; (xliv) wherein the excitation system changes the position of the excitation light-emitting port according to the movement of the support surface on which the powder particles are supplied; (xlv) wherein the excitation system increases the area of the powder particles that is irradiated by the excitation light by changing the irradiation direction; (xlvi) wherein the first mover moves the support surface parallel to the support surface; (xlvii) the first mover moves the support surface by rotating the support surface about a first axis intersecting the support surface; (xlviii) further comprising a second mover that moves the support surface; (xlix) wherein the second mover rotates the support surface by rotating the support surface about a second axis intersecting the support surface; (l) wherein the second mover rotates the support surface to the contrary direction to the direction that the support surface is rotated by the first mover; (li) wherein the second mover rotates the support surface to maintain the attitude of the support surface against the rotation of the support surface by the first mover; (lii) wherein the support surface supports the powder particles in layers and the excitation system directs the excitation light over the outer layer of the powder particles; (liii) wherein the excitation light includes a light beam; and (liv) further including a control system that identifies an area where irradiation is required on the support surface and instructs the excitation system to direct the excitation light to the area.

[0023] In a second general implementation, the processing machine includes (i) a build platform that supports the powder particles; (ii) an excitation system that directs an excitation light at a plurality (at least a portion) of the powder particles on the build platform, the excitation light increasing a photoconductivity of the outer layer of the powder particles at least fifty percent; and (iii) an electron beam irradiation device that irradiates the powder particles having the increased photoconductivity with an electron

beam to form at least a portion of the object from the powder particles, the excitation light changing a temperature of the powder particles less than five hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles.

[0024] Additionally, one or more of the following implementations can be utilized with the second general implementation: (i) wherein the excitation light has a wavelength that is below an infrared range; (ii) wherein the excitation light has a wavelength that is below six hundred nanometers; and (iii) wherein the excitation light includes a light beam.

[0025] Further, in another application, the present invention is directed toward a method for building an object from powder particles, the method including the steps of supporting the powder particles on a support surface of a build platform; directing an excitation light toward at a plurality (portion) of the powder particles with an excitation system; and irradiating at least a plurality (portion) of the powder particles with an electron beam of an electron beam irradiation device.

[0026] In another implementation, the processing machine includes (i) a mover that moves the build platform so a specific position on the build platform is moved along a moving direction; (ii) a powder supply device which supplies the powder to the moving build platform; (iii) an energy system (irradiation device) that irradiates at least a portion of the powder layer with an energy beam to form at least a portion of the object from the powder layer during a first period of time; and (iv) a measurement device which measures at least portion of the object during a second period of time; wherein at least part of the first period in which the energy system irradiates the powder with the energy beam and at least part of the second period in which the measurement device measures are overlapped.

[0027] In still another implementation, the processing machine includes: (i) a mover which moves the build platform so as to move a specific position on the build platform along a moving direction; (ii) a powder supply device which supplies a powder to the build platform which moves, and forms a powder layer; and (iii) an irradiation device that changes an irradiation position where the beam is irradiated to the powder layer along a direction crossing the moving direction.

[0028] In yet another implementation, the processing machine includes: (i) a mover which moves the build platform so as to move a specific position on the build platform along a moving direction; (ii) a powder supply device which supplies a powder to the support device which moves, and forms a powder layer; and (iii) an irradiation device including a plurality of irradiation systems which irradiate the layer with an energy beam to form a built part from the powder layer, wherein the irradiation systems arranged along a direction crossing the moving direction.

[0029] In still another implementation, the processing machine includes: (i) a build platform; (ii) a powder supply device that deposits the powder onto the build platform; and (iii) a mover that rotates at least one of the build platform and the powder supply device about a rotation axis while the powder supply device deposits the powder onto the build platform.

[0030] In another implementation, the processing machine includes: (i) a build platform including a support surface; (ii) a mover which moves the build platform so a specific position on the support surface is moved along a moving direction; (iii) a powder supply device which supplies a powder to the moving build platform to form a powder layer during a powder supply time; and (iv) an irradiation device which irradiates at least a portion of the powder layer with an energy beam to form at least a portion of the part from the powder layer during an irradiation time; and wherein at least part of the powder supply time and the irradiation time are overlapped.

[0031] In still another implementation, the processing machine includes: (i) a support device including a non-flat support surface; (ii) a powder supply device which supplies a powder to the support device and which forms a curved powder layer; and (iii) an irradiation device which irradiates the layer with an energy beam to form a built part from the powder layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] 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:

[0033] Figure 1A is a simplified schematic side view illustration of an embodiment of a processing machine having features of the present embodiments that is usable for building an object from powder particles;

[0034] Figure 1B is a simplified schematic top view illustration of a portion of the processing machine illustrated in Figure 1A, and the object;

[0035] Figure 2 is a simplified schematic side view illustration of another embodiment of the processing machine;

[0036] Figure 3 is a simplified schematic top view illustration of a portion of still another embodiment of the processing machine;

[0037] Figure 4 is a simplified schematic side view illustration of yet another embodiment of the processing machine;

[0038] Figure 5 is a simplified schematic side view illustration of an embodiment of an excitation system that is usable as part of the processing machine illustrated in Figure 1A;

[0039] Figure 6 is a simplified schematic side view illustration of another embodiment of the excitation system;

[0040] Figure 7 is a simplified schematic side view illustration of still another embodiment of the excitation system;

[0041] Figure 8 is a simplified schematic side view illustration of a portion of another embodiment of the processing machine;

[0042] Figure 9 is a simplified schematic side view illustration of yet another embodiment of the processing machine;

[0043] Figure 10 is a simplified top view of a portion of still another embodiment of the processing machine;

[0044] Figure 11 is a simplified top view of a portion of still another embodiment of the processing machine for building an object from powder;

[0045] Figure 12 is a simplified side illustration of a portion of yet another embodiment of the processing machine;

[0046] Figure 13A is a simplified side illustration of a portion of yet another embodiment of the processing machine;

[0047] Figure 13B is a top view of a build platform in which curved support regions

are shaped into linear rows;

[0048] Figure 13C is a top view of a build platform in which curved support regions are shaped into annular rows;

[0049] Figure 14 is a simplified side illustration of a portion of still another embodiment of the processing machine; and

[0050] Figure 15 is a simplified side perspective illustration of a portion of yet another embodiment of the processing machine for building an object from powder.

DESCRIPTION

[0051] Figure 1A is a simplified schematic side view illustration of an embodiment of a processing machine 10 that may be used to manufacture one or more three-dimensional objects 11 (illustrated as a box). As provided herein, the processing machine 10 may be an additive manufacturing system, e.g., an electron beam additive manufacturing system, provided in the form of a three-dimensional printer in which powder particles 12 (illustrated as small circles) is joined, melted, solidified, and/or fused together in a series of powder layers 13 (illustrated as dashed horizontal lines) to manufacture one or more three-dimensional object(s) 11. In Figure 1A, the object 11 includes a plurality of small squares that represent the joining of the powder layers 13 to form the object 11.

[0052] The type of three-dimensional object(s) 11 manufactured with the processing machine 10 may be almost any shape or geometry. As a non-exclusive example, the three-dimensional object 11 may be a metal part, or another type of part, for example, a resin (plastic) part or a ceramic part, etc. The three-dimensional object 11 may also be referred to as a "built part".

[0053] The type of powder particles 12, i.e. the type of material of the powder particles, joined and/or fused together may be varied to suit the desired properties of the object(s) 11. As a non-exclusive example, the powder particles 12 may include metal powder grains (e.g., including one or more of titanium, aluminum, vanadium, chromium, copper, stainless steel, or other suitable metals) for metal three-dimensional printing. Alternatively, the powder particles 12 may be non-metal powder particles, a plastic, polymer, glass, ceramic powder particles, or any other material

known to people skilled in the art. The powder particles 12 may also be referred to as "material" or "powder".

[0054] In certain embodiments, the processing machine 10 includes (i) a powder bed assembly 14; (ii) a pre-heat device 16 (illustrated as a box); (iii) a powder supply device 18 (illustrated as a box); (iv) a measurement device 20 (illustrated as a box); (v) an excitation system 21 (illustrated as a box); (vi) an electron beam irradiation device 22 (illustrated as a box, also referred to herein generally as an "irradiation device"); and (vii) a control system 24 that cooperate to make each three-dimensional object 11. The design of each of these components may be varied pursuant to the teachings provided herein. It should be noted that the positions of the components of the processing machine 10 may be different than that illustrated in Figure 1A. Further, it should be noted that the processing machine 10 may include more components or fewer components than illustrated in Figure 1A.

[0055] Figure 1B is a simplified schematic top view illustration of a portion of the powder bed assembly 14 of Figure 1A and the three-dimensional object 11. Figure 1B also illustrates (i) the pre-heat device 16 (illustrated as box) and a pre-heat zone 16A (illustrated with dashed lines) which represents the area in which the powder particles 12 are being pre-heated with the pre-heat device 16; (ii) the powder supply device 18 (illustrated as a box) and a deposit zone 18A (illustrated in phantom) which represents the area in which the powder particles 12 are being added to the powder bed assembly 14 by the powder supply device 18; (iii) the measurement device 20 (illustrated as a box) and a measurement zone 20A (illustrated in phantom) which represents the area in which the powder particles 12 and/or the object 11 is being measured by the measurement device 20; (iv) the excitation system 21 (illustrated as a box) and an excitation zone 21A (illustrated in phantom) which represents the area in which the powder particles 12 are excited by the excitation system 21; and (v) the electron beam irradiation device 22 (illustrated as a box) and an irradiation zone 22A (illustrated in phantom) which represents the area in which the powder particles 12 are irradiated and fused together by the irradiation device 22. It should be noted that these zones may be spaced apart differently from the non-exclusive example illustrated in Figure 1B. Additionally, or in the alternative, one or more of the zones may overlap one

another. For example, in the implementation illustrated in Figures 1A and 1B, the excitation zone 21A and the irradiation zone 22A are at least partially overlapping. Still alternatively, it is appreciated that the excitation zone 21A and the irradiation zone 22A can be adjacent each other without overlapping or spaced apart from each other.

[0056] With reference to Figures 1A and 1B, in certain embodiments, the processing machine 10 can be designed so that there is substantially constant relative motion along a moving direction 25 (illustrated by an arrow in Figure 1B) between the object 11 being formed and each of the pre-heat device 16, the powder supply device 18, the measurement device 20, the excitation system 21, and the irradiation device 22. The moving direction 25 may include a rotation direction about a support rotation axis 26D. With this design, the powder particles 12 may be deposited and fused relatively quickly. This allows for the faster forming of the objects 11, increased throughput of the processing machine 10, and reduced cost for the objects 11. Additionally, or in the alternative, the moving direction 25 may include a lateral direction that is parallel to a support surface 26B of a build platform 26 (also sometimes referred to as a "powder bed" or a "support device") of the powder bed assembly 14.

[0057] As an overview, the excitation system 21 is uniquely designed to enhance discharge of electrons from the powder particles 12 by increasing electrical conductivity of the powder particles 12 via photoconductivity, e.g., by increasing electrical conductivity of an outer layer 12A of the powder particles 12. Additionally, a wavelength of an excitation light 21B, e.g., a light beam, of the excitation system 21 can be controlled to excite electrons in the powder particles 12 and thus enhance electrical conductivity in the powder particles 12, which can reduce band gap and increase discharge rate in the powder particles 12. With such design, the excitation system 21 more effectively inhibits and/or reduces the onset of smoking without compromise, so that the powder particles 12 can be heated and melted more quickly. This allows for faster forming of the objects 11, increased system throughput of the processing machine 10, and reduced cost for the objects 11.

[0058] A number of different designs of the processing machine 10 are provided herein. In the embodiment illustrated in Figure 1A and 1B, the powder bed assembly 14 includes (i) the build platform 26 that supports the powder particles 12 and the object

11 while being formed, and (ii) at least one device mover 28 (e.g., one or more actuators) that selectively moves the build platform 26 along a support movement direction 26A relative to the pre-heat device 16 (and the pre-heat zone 16A), the powder supply device 18 (and the deposit zone 18A), the measurement device 20 (and the measurement zone 20A), the excitation system 21 (and the excitation zone 21A), and the irradiation device 22 (and the irradiation zone 22A). For example, in some embodiments, the at least one device mover 28 can include a first mover 28A that moves the build platform 26 in a first direction (e.g. rotation about a support rotation axis 26D), and a second mover 28B that moves the build platform 26 in a second direction (e.g. along the support rotation axis 26D) that is different than the first direction. With this design, the device mover 28 moves the build platform 26 so a specific position on the build platform 26 is moved along the support movement direction 26A.

[0059] Alternatively, or additionally, the device mover 28 may be designed to move at least one of the pre-heat device 16 (and the pre-heat zone 16A), the powder supply device 18 (and the deposit zone 18A), the measurement device 20 (and the measurement zone 20A), the excitation system 21 (and the excitation zone 21A), and the irradiation device 22 (and the irradiation zone 22A) relative to the build platform 26.

[0060] It is appreciated that although the powder bed assembly 14 is noted as including at least one device mover 28, each of the “first mover”, the “second mover”, and any other movers may be referred to herein individually or collectively as the “device mover”.

[0061] It should be noted that any of the processing machines 10 described herein may be operated in a controlled environment, e.g. such as a vacuum, using a build chamber 29 (illustrated in Figures 1A as a dashed box). For example, in some such embodiments, each of the pre-heat device 16, the powder supply device 18, the measurement system 20, the excitation system 21, the irradiation device 22, and the powder bed assembly 14 may be positioned substantially within the build chamber 29. Alternatively, in other such embodiments, at least a portion of one or more of the pre-heat device 16, the powder supply device 18, the measurement system 20, the excitation system 21, the irradiation device 22, and the powder bed assembly 14 may

be positioned outside the build chamber 29. For example, in one non-exclusive such alternative embodiment, the excitation system 21 can be positioned outside the build chamber 29 and the excitation light 21B can be irradiated to the powder particles through a window of the build chamber 29. Still alternatively, the processing machine 10 may be operated in non-vacuum environment such as inert gas (e.g., nitrogen gas or argon gas) environment.

[0062] In one embodiment, the build platform 26 is moved (e.g., rotated) at a constant radial velocity relative to the pre-heat device 16, the powder supply device 18, the measurement device 20, the excitation system 21, and the irradiation device 22. This allows nearly all of the rest of the components of the processing machine 10 to be fixed while the build platform 26 is moved. Because, the build platform 26 is constantly moving, the object 11 may be made faster. Alternatively, the device mover 28 may move the build platform 26 at other than a constant radial velocity. Still alternatively, in other embodiments, it is appreciated that the general concepts of the present invention is also applicable for use in a processing machine 10 wherein the build platform 26 is moved linearly, i.e. with a linear motion stage. Yet alternatively, in still other embodiments, the general concepts of the present invention can also be applicable in a processing machine 10 utilizing a stationary build platform 26, i.e. a stationary stage.

[0063] In the simplified schematic illustrated in Figure 1A and 1B, the build platform 26 includes a support surface 26B and a support side wall 26C. In this embodiment, the support surface 26B is flat disk-shaped, and the support side wall 26C is tubular-shaped and extends upward from a perimeter of the support surface 26B. Alternatively, other shapes of the support surface 26B and the support side wall 26C may be utilized. It should be noted that the build platform 26 is illustrated as a cut-away in Figure 1A so that the powder particles 12, the powder layers 13 and the object 11 are clearly visible on the build platform 26. In some embodiments, the support surface 26B can be move somewhat similar to a piston relative to the support side wall 26C which act like the piston's cylinder wall. Alternatively, the shape of the support surface 26B may be other than flat disk-shaped or circle-shaped, e.g., it may be a rectangle-shaped or polygonal-shaped. Further, the shape of the support side wall

26C may be other than tubular-shaped, e.g., it may be a rectangle pillar-shaped or polygonal pillar-shaped.

[0064] Still alternatively, the build platform 26 can include one or more removable support members (not shown in Figures 1A and 1B) (e.g., a container or receptacle) that defines the support surface 26B. With this design, the one or more support members can be removed from the rest of the build platform 26 after completion of the build operation of forming the object 11, and another support member can be positioned on the build platform 26 before starting the next build operation for forming the next object 11.

[0065] The device mover 28 may move the build platform 26 at a substantially constant or variable angular velocity along the support movement direction 26A. As alternative, non-exclusive examples, the device mover 28 may move the build platform 26 at a substantially constant angular velocity of at least approximately 2, 5, 10, 20, 30, 60, or more revolutions per minute (RPM) along the support movement direction 26A. As used herein, the term "substantially constant angular velocity" shall mean a velocity that varies less than 5% over time. In one embodiment, the term "substantially constant angular velocity" shall mean a velocity that varies less 0.1% from the target velocity. The device mover 28 may also be referred to as a "drive device".

[0066] In one embodiment, the device mover 28 rotates the build platform 26 in a rotational direction (e.g., the support movement direction 26A) that has a support rotation axis 26D (e.g., about the Z axis in Figure 1A) that passes through and/or intersects the support surface 26B. Additionally, the device mover 28 may move the build platform 26 at a variable velocity or in a stepped or other fashion. Further, the device mover 28 can rotate the build platform 26 and/or the support surface 26B in either direction about the support rotation axis 26D. For example, the first mover 28A of the device mover 28 may move the build platform 26 and/or the support surface 26B in a first direction (e.g. about the support rotation axis 26D); and/or the second mover 28B of the device mover 28 may move the build platform 26 and/or the support surface 26B in a second direction (e.g. along the support rotation axis 26D) that is different to the first direction. Additionally, in such embodiment, the second mover 28B can move the build platform 26 and/or the support surface 26B to maintain the desired height of

the support surface 26B relative to the other components. The support rotation axis 26D may be aligned along with gravity direction, and may be along with an inclination direction about the gravity direction. Still alternatively, the device mover 28 may move the build platform 26 in a direction that is parallel to the support surface 26B of the build platform 26. Yet alternatively, the device mover 28 may move the build platform 26 and/or the support surface 26B about an axis that intersects the support surface 26B other than the support rotation axis 26D.

[0067] In Figure 1A, the device mover 28 includes the first mover 28A (i.e. a rotary motor), the second mover 28B (e.g. a linear motor) that is connected to the build platform 26 (i.e. the support device or powder bed), and a device connector 28C (i.e. a rigid shaft) that fixedly connects the first mover 28A to the second mover 28B. In other embodiments, the device connector 28C may include a transmission device such as at least one gear, belt, chain, or friction drive.

[0068] In one embodiment, the support surface 26B faces in a first direction (e.g., along the Z axis), and the device mover 28 drives the build platform 26 so as to move the specific position on the support surface 26B along a second direction (e.g., the support movement direction 26A) crossing the first direction.

[0069] The powder particles 12 used to make the object 11 is deposited onto the build platform 26 in a series of powder layers 13. Depending upon the design of the processing machine 10, the build platform 26 with the powder particles 12 may be very heavy. With the present design, this large mass may be rotated at a constant or substantially constant speed to avoid accelerations and decelerations, and the required motion is a continuous rotation of a large mass, with no non-centripetal acceleration other than at the beginning and end of the entire exposure process. With the present design, rotary motion of the build platform 26 eliminates the need for linear motors to move the build platform 26. The exposure process may be performed during the period when the motion is constant velocity motion.

[0070] In one embodiment, the build platform 26 either has an axis in the center, or at least a “no-print” zone 30 (illustrated as a circle), such that parts 11 may either be very large (the diameter of the build platform) with the restriction that they have a hollow center, or they must be smaller than the radius of the build platform 26. Alternatively,

the build platform 26 may be moved to eliminate the no-print zone 30. For example, the axis 26D of the build platform 26 may be arranged away from the center.

[0071] The pre-heat device 16 selectively preheats the powder particles 12 in the pre-heat zone 16A that has been deposited on the build platform 26 during a pre-heat time. Stated in another fashion, the pre-heat device 16 may be used to bring the powder particles 12 in the build platform 26 up to a desired preheated temperature. In certain embodiments, the pre-heat device 16 heats the powder particles 12 in the pre-heat zone 16A when the object 11 being built is moved through the pre-heat zone 16A.

[0072] In one embodiment, the pre-heat device 16 extends along a pre-heat axis (direction) 16B and is arranged between the powder supply device 18 and the irradiation device 22 along the movement direction 26A. Further, the pre-heat axis 16B crosses the movement direction 26A and is transverse to the rotation axis 26D. With this design, the pre-heat zone 16A is positioned between the deposit zone 18A and the irradiation zone 22A, and the pre-heat device 16 may pre-heat the powder particles 12 in the pre-heat zone 16A away from the irradiation zone 22A along the moving direction 25. In Figure 1B, the pre-heat zone 16A is illustrated far from the irradiation zone 22A. However, the relative positioning of these zones 16A, 22A may be different than that illustrated in Figure 1B. Additionally, the relative sizes of the zones 16A, 22A may be different than what is illustrated in Figure 1B. For example, the pre-heat zone 16A may be much larger than the irradiation zone 22A. For example, these zones 16A, 22A may be adjacent to each other. The number of the pre-heat device 16 may be one or plural.

[0073] Similarly, in one embodiment, the pre-heat device 16 extends along the pre-heat axis (direction) 16B and is arranged between the powder supply device 18 and the excitation system 21 along the movement direction 26A. With this design, the pre-heat zone 16A is positioned between the deposit zone 18A and the excitation zone 21A, and the pre-heat device 16 may pre-heat the powder particles 12 in the pre-heat zone 16A away from the excitation zone 21A along the moving direction 25. In Figure 1B, the pre-heat zone 16A is illustrated far from the excitation zone 21A. However, the relative positioning of these zones 16A, 21A may be different than that illustrated in Figure 1B. Additionally, the relative sizes of the zones 16A, 21A may be different than

what is illustrated in Figure 1B. For example, the pre-heat zone 16A may be much larger than the excitation zone 21A. For example, these zones 16A, 21A may be adjacent to each other. The number of the pre-heat device 16 may be one or plural.

[0074] The pre-heat device 16 preheats the powder particles 12 to inhibit smoking of the powder particles 12 when they are subsequently melted by the irradiation device 22. The preheating of the powder particles 12 also increases the electrical conductivity of the powder particles 12. The design of the pre-heat device 16 and the desired preheated temperature may be varied. In one embodiment, the pre-heat device 16 may include one or more pre-heat energy source(s) 16C that direct one or more pre-heat beam(s) 16C at the powder particles 12. If one pre-heat source 16C is utilized, the pre-heat beam 16D may be steered radially along the pre-heat axis 16B to heat the powder particles 12 in the pre-heat zone 16A. Alternatively, multiple pre-heat sources 16C may be positioned to heat the pre-heat zone 16A. As alternative, non-exclusives examples, each pre-heat energy source 16C may be an electron beam system, a mercury lamp, an infrared laser, a supply of heated air, thermal radiation system, a visual wavelength optical system or a microwave optical system. The desired pre-heat temperature is a temperature that is less than the melting temperature of the powder particles 12, but sufficient to inhibit smoking when used in conjunction with the excitation system 21. As, alternatively, non-exclusive examples, the desired preheated temperature may be 50%, 75%, 90% or 95% of the melting temperature of the powder particles 12. It is understood that different powder particles 12 have different melting points and therefore different desired pre-heating points. As non-exclusive examples, the desired preheated temperature may be at least 300, 500, 700, 900, or 1000 degrees Celsius. Further, it should be noted that the preheated temperature will vary according to the amount time the powder particles 12 are subjected to the heating and the design of the excitation system 21. Generally, the preheated temperature can be less if the time the powder particles 12 are subjected to the heat is increased. The pre-heat axis 16B may not be one straight line.

[0075] The powder supply device 18 deposits the powder particles 12 onto the build platform 26 during a deposit time (also referred to as “powder deposition time”). In certain embodiments, the powder supply device 18 supplies the powder particles 12 to

the build platform 26 positioned in the deposit zone 18A while the build platform 26 is being rotated to form a powder layer 13 on the build platform 26. In one embodiment, the powder supply device 18 extends along a powder supply axis (direction) 18B and is arranged between the measurement device 20 and the pre-heat device 16 along the movement direction 26A. Further, the powder supply axis 18B crosses the movement direction 26A and is transverse to the rotation axis 26D. In one embodiment, the powder supply device 18 includes one or more reservoirs (not shown) which retain the powder particles 12 and a powder mover (not shown) that moves the powder particles 12 from the reservoir(s) to the deposit zone 18A above the build platform 26. The powder supply axis 18B may not be one straight line. The number of the powder supply device 18 may be one or plural.

[0076] With the present design, the powder supply device 18 forms an individual layer 13 of a powder particles 12 along the support surface 26B of the build platform 26 during each rotation, and the support surface 26B crosses the support moving direction 26A and the support rotation axis 26D.

[0077] In the embodiment illustrated in Figures 1A and 1B, the powder supply device 18 is illustrated as an overhead powder supply that supplies the powder particles 12 onto the top of the build platform 26. Alternatively, in each of the processing machines 10 disclosed herein, the powder supply device 18 can be a table integrated powder supply (not shown) which delivers the powder particles 12 from the side or through the build platform 26.

[0078] Once a layer of powder particles 12 has been melted with the irradiation device 22, it is necessary to deposit another (subsequent) layer 13 of powder particles 12, as evenly and uniformly as possible with the powder supply device 18. In the case of a rotating build platform 26, the deposition may take place at multiple different locations with multiple spaced apart powder depositors 18 being utilized.

[0079] The measurement device 20 inspects and monitors the melted (fused) layer and the deposition of the powder particles 12 in the measurement zone 18A during a measurement time. Stated in another fashion, the measurement device 20 measures at least a portion of the powder particles 12 and a portion of the part 11 while the build platform 26 and the powder particles 12 are being moved. In one embodiment, the

measurement device 20 is arranged at a position away from the rotation axis 26D along a measurement device axis (direction) 20B that crosses the rotation direction 26D. The measurement device 20 may inspect at least portion of the powder layer only, may inspect at least portion of the part 11 only, or both. The number of the measurement devices 20 may be one or plural. The measurement device axis 20B may not be one straight line. In this design, the measurement device 20 is arranged between the excitation system 21 and the powder supply device 18 (upstream of the powder supply device 18), however, the measurement device 20 may be arranged downstream of the powder supply device 18 along the moving direction 26A, may be arranged between the powder supply device 18 and the pre-heat device 16, or may be arranged downstream of the pre-heat device 16. The measurement device 20 may inspect at least one of the powder layer 13 or the built part 11 by way of optically, electrically, or physically.

[0080] As non-exclusive examples, the measurement device 20 may include one or more optical elements such as a uniform illumination device, fringe illumination device, cameras that function at one or more wavelengths, lens, interferometer, or photodetector, or a non-optical measurement device such as an ultrasonic, eddy current, or capacitive sensor.

[0081] As described in detail herein, the excitation system 21 selectively excites electrons within the powder particles 12 by directing the excitation light 21B, e.g., a light beam such as a generally cone-shaped light beam, at a plurality (at least a portion) of the powder particles 12 in order to increase the electrical conductivity of the powder particles 12 via photoconductivity. More particularly, in various embodiments, the excitation system 21 directs the excitation light 21B the plurality (at least a portion) of the powder particles 12 to increase the electrical conductivity in the outer layer 12A of the powder particles 12 via photoconductivity.

[0082] Additionally, it is appreciated that, in alternative embodiments, (i) the excitation light 21B can be directed at the powder particles 12 before the powder particles 12 has been deposited on the support surface 26B of the build platform 26, i.e. while the powder particles 12 are still retained within the powder supply device 18, or (ii) the excitation light 21B can be directed at the powder particles 12 after the

powder particles 12 have been deposited onto the support surface 26B by the powder supply device 18.

[0083] In one non-exclusive embodiment, the excitation system 21 extends along an excitation axis (direction) 21C and is arranged to overlap with the irradiation device 22 between the pre-heat device 16 and the measurement device 20 along the movement direction 26A. Further, the excitation axis 21C crosses the movement direction 26A and is transverse to the rotation axis 26D. Alternatively, in other embodiments, the excitation system 21 and the irradiation device 22 need not overlap one another, i.e. the excitation system 21 and the irradiation device 22 need not coincide in space and/or position. For example, in one non-exclusive alternative embodiment, the excitation system 21 can be placed right before the irradiation device 22, i.e. an arrangement/configuration such that irradiation by an excitation light is immediately followed by printing by an electron beam.

[0084] The design of the excitation system 21 may be varied. In certain embodiments, the excitation system 21 may include one or more excitation light source(s) 21D that direct one or more excitation light(s) 21B at the powder particles 12. If one excitation light source 21D is utilized, the excitation light 21B may be steered radially to irradiate the excitation zone 21A. With this design, the excitation system 21 may be controlled to sweep the excitation light 21B along a sweep direction (e.g. along the excitation axis 21C) which crosses to the moving direction 25 of the support surface 26B. In alternative embodiments, the excitation system 21 may include multiple excitation light sources 21D which can each direct excitation light 21B at the powder particles 12, or the excitation system 21 may include a single excitation light source 21D that can be divided into multiple excitation lights 21B, e.g., with a beam splitter, a diffuser such as a diffractive optical element (DOE), and/or a spatial light modulator (e.g. liquid crystal display (LCD) or digital light processing (DLP)). Additionally or alternatively, in any embodiments of the processing machine 10 illustrated and described herein, the excitation system 21 may be positioned near the pre-heat device 16. More particularly, in such embodiments, the excitation zone 21A may be positioned over the pre-heat zone 16A, the excitation zone 21A may overlap with at least a portion of the pre-heat zone 16A, and/or the pre-heat zone 16A may be included within the

excitation zone 21A. Moreover, in some such embodiments, the excitation system 21 can be used to increase electrical conductivity of the powder particles 12 in the pre-heat zone 16A by irradiating the excitation light 21B to the powder particles 12 within the pre-heat zone 16A.

[0085] Additionally, as provided herein, the excitation system 21 can be configured such that the excitation light 21B has a wavelength that most effectively excites the electrons in the powder particles 12 (also sometimes referred to herein as an "optimum wavelength"). It is appreciated that the optimum wavelength of the excitation light 21B can be selected based on the type of material of the powder particles 12. Stated in another manner, in such embodiments, the excitation light 21B can have a wavelength that is below a predetermined wavelength that is determined according to the type of material of the powder particles 12. In certain embodiments, the excitation light 21B can have a wavelength that is below an infrared range. More specifically, in some such embodiments, the excitation light 21B can have a wavelength that is below approximately six hundred nanometers, below approximately five hundred nanometers, below approximately four hundred nanometers, below approximately three hundred nanometers, or below approximately two hundred nanometers.

[0086] In certain specific non-exclusive examples, (i) where the powder particles 12 are made of Ti-6Al-4V, the excitation light 21B can have a wavelength of less than 178 nanometers; (ii) where the powder particles 12 are made of copper, the excitation light 21B can have a wavelength of less than 572 nanometers; (iii) where the powder particles 12 are made of stainless steel, the excitation light 21B can have a wavelength of less than 249 nanometers.

[0087] It is appreciated that in embodiments where the excitation system 21 includes multiple excitation light sources 21D and/or where a single excitation light source 21D is divided into multiple excitation lights 21B, the excitation system 21 can irradiate the powder particles 12 with excitation light 21B having two or more different wavelengths. For example, in such embodiments, the multiple excitation lights 21B can each have different wavelengths. In embodiments that include multiple excitation light sources 21D, each of the excitation light sources 21D can generate excitation light 21B having a different wavelength from each of the other excitation light sources 21D.

Additionally, in embodiments that include multiple excitation lights 21B from a single excitation light source 21D and/or a single excitation light 21B from a single excitation light source 21D, the excitation system 21 can further include a wavelength converter that is usable to convert the wavelength of one or more of the excitation lights 21B to provide excitation light 21B having a wavelength that is better able to excite the electrons in the powder particles 12 depending on the type of material of the powder particles 12. However, it is also appreciated that any of the multiple excitation light sources 21D and/or any of the multiple excitation lights 21B can have the same wavelength.

[0088] Additionally, it is further appreciated that use of the excitation system 21 can change a temperature of the powder particles 12. In some implementations, as described in greater detail herein below, it is desired to control the change in temperature of the powder particles 12 due to the excitation light 21B to be below a certain predetermined temperature level. As non-exclusive examples, the desired predetermined temperature level may be less than 5, 10, 20, 30, 40, 50, 75, 90, or 95 percent of the melting temperature of the powder particles 12. It is understood that different powder particles 12 have different melting points and therefore different predetermined temperature levels. It should be noted in implementations that use the pre-heat device 16, the excitation system 21 can be controlled so that the excitation system 21 does not raise the temperature sufficient to melt the powder particles 12. In some implementations, the processing machine 10 can further include a temperature sensor 36 (illustrated as a box positioned away from the build platform 26 for simplicity of illustration) that senses and/or monitors a temperature of the powder particles 12 to provide feedback to control the pre-heat device 16 and/or the excitation system 21 so that the powder particles 12 are heated to the desired levels.

[0089] Further, it is also appreciated that in certain applications, it may be desired to control a direction in which the excitation light 21B is directed at the powder particles 12 to more effectively excite the electrons in the powder particles 12 in an area of the build platform 26 in which the excitation light 21B is required. In some such applications, such direction control of the excitation light 21B can be accomplished through use of an excitation direction controller (not shown in Figures 1A and 1B), a

position control mechanism (not shown in Figures 1A and 1B) for controlling a position of an excitation light-emitting port of the excitation light source 21D, or by another suitable method.

[0090] The irradiation device 22 selectively heats and melts the powder particles 12 in the irradiation zone 22A that has been deposited on the build platform 26 to form the object 11 during an irradiation time. More specifically, the irradiation device 22 sequentially exposes the powder particles 12 to sequentially form each of the layers 13 of the object 11 while the build platform 26 and the object 11 are being moved. The irradiation device 22 selectively irradiates the powder particles 12 at least based on a data regarding to an object 11 to be built. The data may be corresponding to a computer-aided design (CAD) model data. The number of the irradiation devices 22 may be one or plural.

[0091] As noted above, in one non-exclusive embodiment, the irradiation device 22 extends along an irradiation axis (direction) 22B and is arranged to overlap with the excitation system 21 between the pre-heat device 16 and the measurement device 20 along the movement direction 26A. Further, the irradiation axis 22B crosses the movement direction 26A and is transverse to the rotation axis 26D. Alternatively, as also noted above, the excitation system 21 and the irradiation device 22 need not overlap one another.

[0092] The design of the irradiation device 22 and the desired irradiation temperature may be varied. In one embodiment, the irradiation device 22 may include one or more irradiation energy source(s) 22C ("irradiation systems") that direct one or more electron beams 22D (also sometimes referred to as "irradiation beams" or "energy beams") at the powder particles 12. If one irradiation energy source 22C is utilized, the irradiation beam 22D may be steered radially to irradiate the powder particles irradiation zone 22A. With this design, the irradiation device 22 may be controlled to sweep the energy beam 22D along a sweep direction (e.g., along the irradiation axis 22B) which crosses to the moving direction 25 of the support surface 26B. Alternatively, multiple energy sources 22C may be positioned to irradiate the irradiation zone 22A along the irradiation axis 22B with each having a separate energy beam 22D. In this embodiment, the plurality of irradiation systems 22C are arranged

along a direction (e.g., the irradiation axis 22B) that crosses to the moving direction 26A. The plural irradiation devices (the multiple energy sources 22C) may be arranged along the moving direction 26A or across the moving direction 26A.

[0093] As an example, in each of the embodiments of the processing machine 10 provided herein, one or more of the irradiation energy sources 22C may be an electron beam system that generates a charged particle electron beam. In this version, the irradiation device 22 can be referred to as an electron beam system. As alternative, non-exclusive examples, one or more of the irradiation energy sources 22C can be a laser beam system that generates a laser beam, an ion beam system that generates a charged particle beam, or an electric discharge arc, and the desired irradiation temperature may be at least 1000, 1400, 1700, 2000, or more degrees Celsius. In another embodiment, each of the irradiation energy sources 22C may be designed to generate a charged particle beam, an infrared light beam, a visual beam or a microwave beam, and the desired irradiation temperature may be at least 50%, 75%, 90% or 95% of the melting temperature of the powder material used in the printing. It is understood that different powder particles have different melting points and therefore different desired pre-heating points.

[0094] As provided herein, the irradiation device 22 may be arranged at a position away from the rotation axis 26D along an irradiation device direction (e.g., the irradiation axis 22B) that crosses the rotation direction 26A. Further, the irradiation device 22 is spaced apart from the measurement device 22 along the rotation direction 26A.

[0095] Additionally, as noted herein, in various embodiments, the excitation system 21 can be used to direct excitation light 21B at the powder particles 12 prior to the electron beam irradiation device 22 being used to irradiate the powder particles with an electron beam 22D. In such applications, it can be desired to limit the change of temperature due to the excitation light 21B being directed at the powder particles. For example, in certain non-exclusive embodiments, the excitation system 21 can be controlled such that (i) the excitation light 21B changes a temperature of the powder particles 12 less than five hundred degrees Kelvin prior to the electron beam irradiation device 22 directing the electron beam 22D at the powder particles 12; (ii) the excitation

light 21B changes a temperature of the powder particles 12 less than two hundred fifty degrees Kelvin prior to the electron beam irradiation device 22 directing the electron beam 22D at the powder particles 12; or (iii) the excitation light 21B changes a temperature of the powder particles 12 less than one hundred degrees Kelvin prior to the electron beam irradiation device 22 directing the electron beam 22D at the powder particles 12. Alternatively, the excitation system 21 can be controlled such that the excitation light 21B changes a temperature of the powder particles 12 a different amount prior to the electron beam irradiation device 22 directing the electron beam 22D at the powder particles 12.

[0096] Still alternatively, the excitation system 21 can be used to direct excitation light 21B at the powder particles 12 after the electron beam irradiation device 22 is used to irradiate the powder particles with an electron beam 22D, or the excitation system 21 can be used to direct excitation light 21B at the powder particles 12 at approximately the same time as (i.e. in parallel with) the electron beam irradiation device 22 is used to irradiate the powder particles with an electron beam 22D.

[0097] In some applications, the irradiation device 22 irradiates the portion of the powder particles 12 having the increased electrical conductivity with the electron beam 22D. For example, the electron beam 22D can irradiate the portion of the powder particles 12 where the electrical conductivity of the powder particles 12 has been increased at least fifty percent.

[0098] Additionally, or in the alternative, in certain embodiments, the portion of the powder particles 12 irradiated with electron beam 22D of the irradiation device 22 need not precisely coincide with the portion of the powder particles 12 at which the excitation light 21B of the excitation system 21 is directed. For example, in one non-exclusive such embodiment, the excitation light 21B is directed at a first portion of the powder particles 12, and the electron beam 22D irradiates a second portion of the powder particles 12 that is different than, e.g., a subset of, the first portion of the powder particles 12. Stated in another manner, in such embodiment, the electron beam 22D may only irradiate a portion of the first portion of the powder particles 12 at which the excitation light 21B has been directed.

[0099] The control system 24 controls the components of the processing machine

10 to build the three-dimensional object 11 from the computer-aided design (CAD) model by successively adding powder particles 12 layer by layer. For example, as provided herein, the control system 24 can control operation of the excitation system 21 so that the electrical conductivity of the powder particles 12 is increased via photoconductivity as desired. In certain applications, the control system 24 can be used to control one or more of (i) selective operation of one or more excitation light sources 21D; (ii) a wavelength of the excitation light 21B used that may be based, at least in part, on the type of material of the powder particles 12 (e.g., to use excitation light 21B having the optimum wavelength); (iii) a direction of the excitation light 21B as it is directed at at least a portion of the powder particles 12; and (iv) identification of an area on the build platform 26 where excitation irradiation or excitation light 21B is required. The control system 24 may include one or more processors 24A and one or more electronic storage devices 24B.

[00100] The control system 24 may include, for example, a CPU (Central Processing Unit), a GPU (Graphics Processing Unit), and a memory. 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 case of physically connecting with wired, 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.

[00101] Additionally, optionally, the processing machine 10 may include a cooling system 31 (illustrated as a box) that cools the powder particles 12 on the build platform 26 in a cooling zone 31A (illustrated in phantom) after fusing with the irradiation device

22. In one embodiment, the cooling system 31 extends along a cooling axis 31B and is arranged between the measurement device 20 and the powder supply device 18 along the movement direction 26A. With this design, the cooling system 31 cools the powder particles 12 in the cooling zone 31A away from the irradiation zone 22A along the moving direction 26A. Further, the cooling zone 31A may be arranged between the irradiation zone 22A of irradiation device 22 and the supply zone 18A of the powder supply device 15 along the moving direction 26A. Still further, the cooling zone 31A may be arranged between the excitation zone 21A of excitation system 21 and the supply zone 18A of the powder supply device 15 along the moving direction 26A. The cooling axis 31B may not be one straight line.

[00102] Additionally, the cooling system 31 may further be utilized to cool the excitation light source(s) 21D of the excitation system 21 and/or the irradiation energy source(s) 22D of the irradiation device 22. In some embodiments, the processing machine 10 may include separate cooling systems to cool each of the powder particles 12 on the build platform 26, the excitation light source(s) 21D of the excitation system 21 and the irradiation energy source(s) of the irradiation device 22.

[00103] As non-exclusive examples, the cooling system 31 may utilize radiation, conduction, and/or convection to cool the newly melted material (e.g., metal) to a desired temperature.

[00104] In the non-exclusive example in Figure 1A, the pre-heat device 16, the powder depositor 18, the measurement device 20, the excitation system 21, the irradiation device 22, and the cooler device 31 may be fixed together and retained by a common component housing 32. Collectively these components may be referred to as the top assembly.

[00105] Alternatively, one or more of these components may be retained by one or more separate housings. In this design, the common component housing 32 may be rotated along the moving direction 26A or an opposite direction of the moving direction 26A. At this situation, the build platform 26 may be fixed or may be moved (rotated) along the moving direction.

[00106] Still alternatively, at least one of the pre-heat device 16, the powder depositor 18, the measurement device 20, the excitation system 21, the irradiation

device 22, and the cooling system 31 may be movable in a direction crossing to the moving direction 26A.

[00107] It is appreciated, however, that the processing machine 10 need not include each of the components noted herein. For example, in some embodiments, the processing machine 10 need not include each of the pre-heat device 16, the measurement device 20 and the cooling system 31. In one such non-exclusive embodiment, the processing machine 10 may include only one of the pre-heat device 16 and the cooling system 31, and the temperature of the powder particles 12 can be effectively controlled as desired with only the one of the pre-heat device 16 and the cooling system 31. For example, the processing machine 10 can be designed without the pre-heat device 16.

[00108] With reference to Figures 1A and 1B, the build platform 26 may be referenced as a clock face for ease of discussion. It is appreciated that the layout of the use of the components relative to the build platform 26 as shown in Figures 1A and 1B is just one representative example, and the components can be positioned and/or applied in a different manner than is specifically shown. In this embodiment, at 12:00 on the clock face, the excitation of the electrons in the powder particles 12 takes place using the excitation system 21. Additionally, also at 12:00, the exposure takes place using the irradiation device 22. Thus, in certain embodiments, the excitation of electrons in the powder particles 12 with the excitation system 21 and the exposure of the powder particles 12 with the irradiation device can overlap in time, i.e. can occur substantially simultaneously. Note the local rate of travel of the build platform 26 will be faster at the edge than at the center, so adjustments in the positioning of the multiple irradiation energy sources 22B may be needed. It is appreciated that during alternative applications and uses of the processing machine 10, the use of the excitation system 21 may occur (i) just prior to the use of the irradiation device 22 to irradiate at least a portion of the powder particles 12 with the electron beam 22D, (ii) just after the use of the irradiation device 22 to irradiate at least a portion of the powder particles 12 with the electron beam 22D, or (iii) in parallel with the use of the irradiation device 22 to irradiate at least a portion of the powder particles 12 with the electron beam 22D (i.e. at approximately the same time such that the excitation zone 21A and the irradiation

zone 22A overlap one another). Thus, it is appreciated that, in certain embodiments, the excitation light 21B is always applied to the powder particles 12 regardless of the timing of the electron beam 22D being used to irradiate the powder particles 12.

[00109] A suitable rotation angle away, say at 1:30 on the clock face, the measurement with the measurement device 20 (illustrated in Figure 1A) may take place. The measurement device 20 only needs to span the radius of the build platform 26, rather than the full area of the build platform 12 in other methods.

[00110] At about 2:30, the cooling system 31 may cool one or more of the powder particles 12 on the build platform 26, the excitation light source(s) 21D of the excitation system 21, and the irradiation energy source(s) 22D of the irradiation device 22. At about 3:15, the powder supply device 18 may be positioned to deposit the powder particles 12 onto the build platform 26. Excess powder particles 12 may be driven off the edge of the rotary build platform 26 via centrifugal forces or by the design of the powder supply device 18. In certain embodiments, the deposition rate of the powder supply device 18 is radially dependent. If desired, metrology of deposition may be added, followed by a supplemental powder deposition system that could use feedback from the powder metrology system to selectively add or remove powder particles where needed.

[00111] Next, at about 5 o'clock, the pre-heating with the pre-heat device 16 may occur.

[00112] As provided above, (i) the pre-heat device 16 preheats the powder particles 12 in the pre-heat zone 16A during the pre-heat time; (ii) the powder supply device 18 deposits the powder particles 12 onto the build platform 26 in the deposit zone 18A during the deposit time; (iii) the measurement device 20 measures the powder particles 12 in the measurement zone 20A during the measurement time; (iv) the excitation system 21 excites electrons in the powder particles 12 in the excitation zone 21A during the excitation time, (v) the irradiation device 22 irradiates the powder particles 12 in the irradiation zone 22A during the irradiation time; and (vi) the cooling system 31 cools the powder particles 12 (and potentially the excitation light source(s) 21D and the irradiation energy source(s) 22D) in the cooling zone 31A during the cooling time. It should be noted that any of the pre-heat time, the deposit time, the measurement time,

the excitation time, the irradiation time, and/or the cooling time may be referred to as a first period of time, a second period of time, a third period of time, a fourth period of time, a fifth period of time and/or a sixth period of time. The number of the pre-heat devices 16, the powder supply devices 18, the measurement devices 20, the excitation systems 21, the irradiation devices 22, and the cooling systems 31 may be plural. In this situation, another excitation system and another irradiation device may be positioned at 6:00, another measurement device may be positioned at 7:30, another cooling system may be positioned at 8:30, another powder supply device may be positioned at 9:15, and another pre-heating device may be positioned at 11 o'clock, for example.

[00113] It should also be noted that with the unique design provided herein, multiple operations may be performed at the same time (simultaneously) to improve the throughput of the processing machine 10. Stated in another fashion, one or more of the pre-heat time, the deposit time, the measurement time, the excitation time, the irradiation time, and the cooling time may be partly or fully overlapping in time for any given processing of a layer 13 of powder particles 12 to improve the throughput of the processing machine 10. For example, two, three, four, or all five of these times may be partly or fully overlapping.

[00114] More specifically, (i) the pre-heat time may be at least partly overlapping with the deposit time, the measurement time, the excitation time, the irradiation time, and/or the cooling time; (ii) the deposit time may be at least partly overlapping with the pre-heat time, the measurement time, the excitation time, the irradiation time, and/or the cooling time; (iii) the measurement time may be at least partly overlapping with the deposit time, the pre-heat time, the excitation time, the irradiation time, and/or the cooling time; (iv) the excitation time may be at least partially overlapping with the deposit time, the pre-heat time, the measurement time, the irradiation time, and/or the cooling time, (v) the irradiation time may be at least partly overlapping with the deposit time, the measurement time, the pre-heat time, the excitation time and/or the cooling time; and/or (vi) the cooling time may be at least partly overlapping with the pre-heat time, the deposit time, the measurement time, the excitation time, and/or the irradiation time.

[00115] As a first example, (i) during a first period of time, the excitation system 21 excites the electrons in at least part of the powder particles 12, (ii) during a second period of time, the irradiation device 22 irradiates the powder layer with the irradiation beam 22C, and (iii) the first period of time and the second period of time are at least partly overlapping. Additionally, during a third period of time, the measurement device 20 measures at least part of the object 11/powder particles 12, and the third period of time may be partly overlapping with one or both of the first period of time and the second period of time. Further, during a fourth period of time, the pre-heat device 16 pre-heats the powder particles 12, and the fourth period of time is at least partly overlapping with one or more of the first period of time, the second period of time, and the third period of time. Alternatively, during the fourth period of time, the powder supply device 18 deposits the powder particles 12, and the fourth period of time is at least partly overlapping with one or more of the first period of time, the second period of time, and the third period of time. Still alternatively, at least part of the fourth period and at least part of a fifth period in which the pre-heat device 16 pre-heats the powder particles 12 may be overlapped.

[00116] In certain embodiments for maximum throughput, the part 11 (or multiple parts 11) cover a maximum area of the support surface 26B, and all of the deposit time, pre-heat time, measurement time, irradiation time, excitation time, and cooling time are substantially continuous and simultaneous; i.e., all of the processes of deposition, pre-heat, measurement, irradiation, excitation, and cooling are performed concurrently during a maximum amount of the part fabrication time.

[00117] In one embodiment, (i) the excitation system 21 directs the excitation light 21B towards at least a portion of the powder particles 12 to increase the electrical conductivity of the powder particles 12 via photoconductivity; (ii) the irradiation device 22 irradiates at least a portion of the powder particles 12 to form at least a portion of the part 11 from the layer 13 of powder particles 12; (iii) the device mover 28 drives the build platform 26 so as to move a specific position on the support surface 26B along the moving direction 26A; (iv) the powder supply device 18 supplies the powder particles 12 to the build platform 26 which moves, and forms the powder layer 13; and (v) the irradiation device 22 irradiates the layer 13 with the energy beam 22D to form

the built part 11 from the powder layer 13. In this embodiment, the irradiation device 22 changes an irradiation position where the energy beam 22D is irradiated to the powder layer 13 along a direction (irradiation axis 22B) that crosses to the moving direction 26A. Additionally, the device mover 28 may drive the build platform 26 so as to rotate about the rotation axis 26D, and the irradiation device 22 may change the irradiation position along the direction (irradiation axis 22B) orthogonal the rotation axis 26D.

[00118] In another embodiment, the processing machine 10 includes: (i) the build platform 26 having the support surface 26B; (ii) the device mover 28 which drives the build platform 26 so as to move a specific position on the support surface 26B along the moving direction 26A; (iii) the powder supply device 18 which supplies the powder particles 12 to the build platform 26 which moves, and forms the powder layer 13; (iv) the excitation system 21 including a plurality of excitation light sources 21D that direct excitation light 21B at the powder particles 12; and (v) the irradiation device 22 including a plurality of irradiation systems 22C which irradiate the layer 13 with the energy beam 22D to form the built part 11 from the powder layer 13. In this embodiment, the irradiation systems 22C are arranged along a direction (e.g., the irradiation axis 22B) crossing to the moving direction 26A.

[00119] It should be noted that Figure 1B illustrates that all of the necessary steps may take place in half of the rotation cycle of the build platform 26. This means a complete second system (not shown) that includes another pre-heat device, powder depositor, measurement device, excitation system and irradiation device could be added on the other half, to allow twice as high a rate of three-dimensional printing for the same rotary velocity of the build platform 26. Further, the arrangement of components could be compressed to add a complete third system (not shown) or more if desired. Alternatively, for a “single system” embodiment the size of the areas 16A, 18A, 20A, 21A, 22A, 31A may be increased to cover a greater portion, or substantially all, of the support surface 26B.

[00120] It should also be noted that some or all of the above steps are happening simultaneously on different parts of the build platform 26, so that the duty cycle of three-dimensional printing is 100%, and there is one or more of pre-heating, powder

depositing, measuring, exciting, and/or irradiating happening at all times. Adding the second (or third) printing region pushes the effective duty cycle to 200% (or 300%).

[00121] The least efficient way to use this processing machine 10 is to make only one object 11 at a time, that does not utilize the full donut shaped exposure region of the build platform 26. In this case, the object 11 sequentially goes from exposure to excitation, to metrology, to deposition, to pre-heating, and then repeats. However, even in this least efficient mode of operation, the part fabrication speed is comparable to a more traditional system.

[00122] If large parts or multiple parts are made simultaneously, the system may run at almost 100% duty cycle, with some or all stages happening in parallel, resulting in large throughput and tool utilization improvements.

[00123] In certain embodiments, the build platform 26 may be moved down with the device mover 28 along the support rotation axis 26D in a continuous rate via a fine pitch screw or some equivalent method. With this design, a height 33 between the most recent (top) layer of powder particles 12 and the powder supply device 18 (and other top assembly) may be maintained substantially constant for the entire process. Alternatively, the build platform 26 may be moved down in a step down fashion at each rotation, which could lead to the possibility of a discontinuity at one radial position in the build platform 26. As used herein, “substantially constant” shall mean the height 33 varies by less than a factor of three, since the typical thickness of each powder layer is less than one millimeter. In another embodiment, “substantially constant” shall mean the height 33 varies less than ten percent of the height 33 during the manufacturing process.

[00124] Still alternatively, the top assembly may include a housing mover 34 that moves the top assembly (or a portion thereof) upward a continuous (or stepped) rate while the powder particles 12 are being deposited to maintain the desired height. The housing mover 34 may include one or more actuators. The housing mover 34 and/or the device mover 28 may be referred to as a first mover or a second mover.

[00125] As provided herein, during use of the processing machine 10, it may often be desired to know the type of material being used for the powder particles 12 so that the processing machine 10 may operate most effectively. For example, as noted

above, the type of material of the powder particles 12 may impact the desired or optimum wavelength of the excitation light 21B to be used for most effectively exciting the electrons in the powder particles 12 to best increase the electrical conductivity of the powder particles 12, e.g., in the outer layer 12A of the powder particles 12.

[00126] As shown in Figure 1A, in certain embodiments, the processing machine 10 can further include one or more of a material identification system 38 (illustrated as a box for simplicity of illustration) and an input interface 40 (illustrated as a box for simplicity of illustration). These components can be electrically connected to the control system. In such embodiments, the material identification system 38 and/or the input interface 40 can be used for purposes of identifying the particular type of material of the powder particles 12 during any particular use of the processing machine 10. Subsequently, the control system 24 can use this information to properly control the components of the processing machine 10. Additionally, or alternatively, the desired properties of the excitation light 21B (e.g. wavelength, power, and/or irradiation time) or other information may be directly input into the input interface 40 so that the control system 24 can properly control the components of the processing machine 10.

[00127] The material identification system 38 is configured to identify and/or discriminate the type of material of the powder particles 38 during use of the processing machine 10. The material identification system 38 can have any suitable design for accomplishing such purposes. For example, in certain non-exclusive alternative embodiments, the material identification system 38 can identify and/or discriminate the type of material of the powder particles 12 based on one or more of a weight of the powder particles and a powder particles specific gravity of the powder particles 12. Alternatively, the material identification system 38 can identify and/or discriminate the type of material of the powder particles 12 in another suitable manner.

[00128] The input interface 40 can be accessed by a user of the processing machine 10 in order to input information about the type of material of the powder particles 12 during any particular use of the processing machine 10. Additionally, or in the alternative, the processing machine 10 may obtain information on the type of material of the powder particles 12 from a record on a container in which the powder particles 12 supplied by the powder supply device 18 was stored. The record on the container

may be, for example, text information, bar code, etc., printed on a label of the container. Alternatively, information on the type of material of the powder particles 12 may be recorded on a semiconductor memory chip attached to the container. Also, even if the information itself about the type of material of the powder particles 12 is not recorded on the container, for example, the information on the type of material of the powder particles 12 may be stored in a server on the network. The processing machine 10 may obtain the information on the type of material of the powder particles 12 from the server, by referring the link between the record on the container which the processing machine 10 read and the information on the type of material of the powder particles 12 in the server.

[00129] Although the diameter of the cylindrical build platform 26 will be much larger than the size of the parts 11 that may be made (except for parts that may have a hole in the center), the size of the rotary build platform 26 is not that much larger than the size needed for a rectangular build platform 26 capable of printing the same maximum size. That's because the rotary method has a fixed footprint, while the linear translation of the build platform requires space on all sides of the exposure region for scanning along a single axis.

[00130] As provided herein, in certain embodiments, a non-exclusive example of an advantage of the present embodiment is that the rotary build platform 26 system provided herein requires primarily only one moving part, the build platform 26, while everything else (pre-heat device 16, powder supply device 18, measurement device 20, excitation system 21, irradiation device 22) are all fixed, making the overall system simpler. Also, the throughput of a rotary based build platform 26 system is much higher since all steps are performed in parallel rather than serially.

[00131] It should be noted that the processing machine 10 illustrated in Figures 1A and 1B may be designed so that (i) the build platform 26 is rotated about the Z axis and moved along the Z axis to maintain the desired height 33; (ii) the build platform 26 is rotated about the Z axis, and the component housing 32 and the top assembly are moved along the Z axis only to maintain the desired height 33; and/or (iii) one or more of the pre-heat device 16, the powder supply device 18, the measurement device 20, the excitation system 21, and the irradiation device 22 are independently moved (e.g.

rotated about one or more axes and/or linearly along one or more axes). In certain embodiments, it may make sense to assign Z movement to one component and rotation to the other.

[00132] Figure 2 is a simplified schematic side view illustration of another embodiment of a processing machine 210 for making the object 11 from powder particles 12. In this embodiment, the processing machine 210, e.g., a three-dimensional printer, includes (i) a build platform 226; (ii) a pre-heat device 216 (illustrated as a box); (iii) a powder supply device 218 (illustrated as a box); (iv) a measurement device 220 (illustrated as a box); (v) an excitation system 221 (illustrated as a box); (v) an irradiation device 222 (illustrated as a box); (vi) a cooling system 231 (illustrated as a box); (vii) a control system 224; (viii) a material identification system 238 (illustrated as a box for simplicity); and (ix) an input interface 240 (illustrated as a box for simplicity) that are somewhat similar to the corresponding components described above. It is appreciated, however, that the processing machine 210 need not include each of the components noted herein. For example, in some embodiments, the processing machine 210 need not include each of the pre-heat device 216, the measurement device 220 and the cooling system 231. In one such non-exclusive embodiment, the processing machine 210 may include only one of the pre-heat device 216 and the cooling system 231, and the temperature of the powder particles 12 can be effectively controlled as desired with only the one of the pre-heat device 216 and the cooling system 231.

[00133] However, in this embodiment, the build platform 226 of the powder bed assembly 214 can be stationary, and the processing machine 210 can include a housing mover 234 that moves the component housing 232 with the pre-heat device 216, the powder supply device 218, the measurement device 220, the excitation system 221, the irradiation device 222, and the cooling system 231 relative to the build platform 226.

[00134] As a non-exclusive example, the housing mover 234 may rotate the component housing 232 with the pre-heat device 216, the powder supply device 218, the measurement device 220, the excitation system 221, the irradiation device 222, and the cooling system 231 (collectively “top assembly”) at a constant or variable

velocity about a rotation axis 236 (e.g., about the Z axis). Additionally or alternatively, the housing mover 234 may move the component housing 232 with the pre-heat device 216, the powder supply device 218, the measurement device 220, the excitation system 221, the irradiation device 222, and the cooling system 231 in a stepped fashion along the rotation axis 236.

[00135] It should be noted that the processing machine 210 of Figure 2 may be designed so that (i) the top assembly is rotated about the Z axis and moved along the Z axis to maintain the desired height 233 with the housing mover 234; (ii) the top assembly is rotated about the Z axis, and the build platform 226 is moved along the Z axis only with a device mover 228 to maintain the desired height 233; and/or (iii) one or more of the pre-heat device 216, the powder supply device 218, the measurement device 220, the excitation system 221, and the irradiation device 222 are independently moved (e.g. rotated about one or more axes and/or linearly along one or more axes). In certain embodiments, it may make sense to assign Z movement to one component and rotation to the other. The housing mover 234 and/or the device mover 228 may be referred to as a first mover or a second mover.

[00136] Additionally, it is noted that in the embodiment illustrated in Figure 2, various components of the processing machine 210 are not positioned in a vacuum environment, i.e. the processing machine 210 does not include a build chamber.

[00137] Figure 3 is a simplified schematic top view illustration of another embodiment of a processing machine 310. In this embodiment, the processing machine 310, e.g., a three-dimensional printer, is designed to make multiple objects 311 substantially simultaneously. The number of objects 311 that may be made concurrently may vary according the type of object 311 and the design of the processing machine 310. In the non-exclusive embodiment illustrated in Figure 3, six objects 311 are made simultaneously. Alternatively, more than six or fewer than six objects 311 may be made simultaneously.

[00138] In the embodiment illustrated in Figure 3, each of the objects 311 is the same design. Alternatively, for example, the processing machine 310 may be controlled so that one or more different types of objects 311 are made simultaneously.

[00139] In the embodiment illustrated in Figure 3, the three-dimensional printer 310

includes (i) a build platform 326; (ii) a pre-heat device 316 (illustrated in phantom); (iii) a powder supply device 318 (illustrated in phantom); (iv) a measurement device 320 (illustrated in phantom); (v) an excitation system 31 (illustrated in phantom); (vi) an irradiation device 322 (illustrated in phantom); (vii) a control system 324; (vii) a cooling system 331 (illustrated in phantom); (viii) a material identification system 338 (illustrated as a box for simplicity); and (ix) an input interface 340 (illustrated as a box for simplicity) that are somewhat similar to the corresponding components described above. However, in this embodiment, the build platform 326 may include a support surface 326B and a plurality of separate, spaced apart, build chambers 326E that are positioned on and supported by the support surface 326B.

[00140] In this embodiment, each of the build chambers 326E defines a separate support region 326F with side walls 326G for each separate part 311 that is being made. Further, in this embodiment, the separate build chambers 326E are positioned on the large common support surface 326B. Further, the plurality of build chambers 326E may be arranged along the moving direction 325. The number of separate build chambers 326E can be varied. In Figure 3, the build platform 326 includes six separate build chambers 326E. Alternatively, the build platform 326 can include more than six or fewer than six separate build chambers 326E.

[00141] In Figure 3, a single part 311 is made in each build chamber 326E. Alternatively, more than one part 311 may be built in each build chamber 326E. Similarly, also in the design of Figure 1, more than one part 11 can be built in the support device 26 substantially simultaneously.

[00142] Still alternatively, the support surface 326B of the build platform 326 may be divided to include the plurality of support regions 326F, with each support region 326F supporting the separate object 311. With this design, the support regions 326F may be adjacent to each other and only physically spaced apart (and not spaced apart with walls) on the common build platform 326. In this design, the plurality of support regions 326F are also arranged along the moving direction 325.

[00143] In one embodiment, the processing machine 310 may be designed so that the build platform 326 is rotated (e.g., at a substantially constant rate) in the moving direction 325 about a platform rotation axis 325A (illustrated with a “+”, e.g., the Z axis)

relative to the pre-heat device 316, the powder supply device 318, the measurement device 320, the excitation system 321, and the irradiation device 322. With this design, each build chamber 326E is rotated about at least one axis 325A during the build process. Further, in this embodiment, the separate build chambers 326E are spaced apart on the large common build platform 326. The build chambers 326E can be positioned on or embedded into the build platform 326. As non-exclusive examples, the build platform 326 can be disk-shaped or rectangular-shaped.

[00144] In this embodiment, the problem of building a practical and low cost three-dimensional printer 310 for high volume three-dimensional printing of metal parts 311 is solved by providing a rotating build platform 326 that supports multiple support regions 326F.

[00145] Alternatively, the processing machine 310 may be designed so that pre-heat device 316, the powder supply device 318, the measurement device 320, the excitation system 321, and the irradiation device 322 are rotated (e.g., at a substantially constant rate) relative to the build platform 326 and the multiple support regions 326F. Still alternatively, the processing machine 310 may be designed so that one or more of the pre-heat device 316, the powder supply device 318, the measurement device 320, the excitation system 321, and the irradiation device 322 are independently moved (e.g. rotated about one or more axes and/or linearly along one or more axes).

[00146] It should be noted that in this embodiment, the irradiation device 322 includes multiple (e.g., three) separate irradiation energy sources 322C that are positioned along the irradiation axis 322B. In this embodiment, each of the irradiation energy source 322C generates a separate irradiation beam (not shown). In alternate embodiments, the irradiation energy sources 322C may be lasers or electron beams. In the embodiment shown, three irradiation energy sources 322C are arranged in a line so that together they may cover the full width of each support region 326F. Because the exposure area covers the entire radial dimension of the desired build volume, every point in the required build volume may be reached by at least one of the energy beams. In an alternative embodiment, where lower throughput is acceptable, a single irradiation energy source 322C may be used with the beam being steered in the radial (sweep) direction along the irradiation axis 322B that crosses the rotation

axis. In another alternative embodiment, a single irradiation energy source 322C with sufficient beam deflection width to cover the desired part radius may expose every point within the build volume.

[00147] In some embodiments, for each build chamber 326E, the side walls 326G surround an "elevator platform" (support region 326F) that may be moved vertically (along the Z axis) relative to the side walls 326G with a platform mover assembly 326H (illustrated in phantom with a box) during fabrication of the objects 311. Each platform mover assembly 326H can include one or more actuators. Fabrication begins with the elevators (support regions 326F) placed near the top of the side walls 326G. The powder supply device 318 deposits a preferably thin layer of metal powder particles into each build chamber 326E as it is moved (rotated) below the powder supply device 318. At an appropriate time, the elevator platform (support region 326F) in each build chamber 326E is stepped down by one layer thickness so the next layer of powder particles may be distributed properly.

[00148] Additionally, in some embodiments, one or more platform mover assemblies 326H can also or alternatively be used to move (e.g., rotate) one or more of the build chambers 326E relative to the build platform 326 and each other in a chamber direction 326R about a chamber rotation axis 326X (illustrated with a "+", e.g., the Z axis). With this design, each build chamber 326E can be rotated about two, separate, spaced apart and parallel axes 325A, 326X during the build process.

[00149] In one, non-exclusive example, the build platform 326 can be rotated (e.g., at a substantially constant rate) in the moving direction 325 (e.g., counterclockwise), and one or more of the build chambers 326E can be moved (e.g., rotated) relative to the build platform 326 in the opposite direction 326R (e.g., clockwise) during the printing process. In this example, the rotational speed of the build platform 326 about the platform rotation axis 325A can be approximately the same or different from the rotational speed of each build chamber 326E relative to the build platform 326 about the chamber rotation axis 326X.

[00150] Alternatively, the build platform 326 can be rotated (e.g., at a substantially constant rate) in the moving direction 325 (e.g., counterclockwise), and one or more of the build chambers 326E can be moved (e.g., rotated) relative to the build platform 326

in the same direction (e.g., counterclockwise) during the printing process.

[00151] In some embodiments, a substantially planar surface (not shown) is provided between the side walls 326G of the build chambers 326E to prevent unwanted powder particles from falling outside the side walls 326G. In alternative embodiments, the powder supply device 318 includes features that allow the powder distribution to start and stop at appropriate times so that substantially all of the powder particles are deposited inside the build chambers 326E. For example, the powder supply device 318 may feed the powder particles when the build chamber 326E is located in the powder deposit zone of the powder supply device 318, and may stop the powder feeding when the building chamber 326E moves out of the powder deposit zone.

[00152] When a build chamber 326E is full and the part 311 is fully built, the support surface 326B may be momentarily stopped and a robot may exchange the full chamber 326E for an empty one. The full chamber 326E may be moved to a different location for controlled annealing or gradual cooling of the new part(s) 311 while fabrication of new parts 311 is begun in the empty chamber 326E. Depending on the requirements for a particular application, all of the build chambers 326E may be "cycled" at the same time, or the cycling may be staggered to substantially equally spaced times.

[00153] In one embodiment, the discrete build chambers 326E may be moved by robot (not shown) (potentially through an airlock) between the rotary turntable and auxiliary chambers where the parts 311 may be slowly cooled in a controlled manner, they may be vented to atmosphere, and/or they may be exchanged with empty build chambers 326E for subsequent fabrication processing.

[00154] The shape of each build chamber 326E may be square, rectangular, cylindrical, trapezoidal, or a sector of an annulus.

[00155] With the design illustrated in Figure 3, the three-dimensional printer 310 requires no back and forth motion, so throughput may be maximized, and many parts 311 may be built in parallel in the separate build chambers 326E.

[00156] Additionally, or in the alternative, it is appreciated that in certain non-exclusive alternative embodiments, one or more of the following movement characteristics can be utilized during use of the three-dimensional printer 310: (i) the build platform 326 is stationary; (ii) the build platform 326 is moved relative to the

powder supply device 318; (iii) the build platform 326 is moved linearly (along one or more axes) relative to the powder supply device 318; (iv) the build platform 326 is rotated (about one or more axes) relative to the powder supply device 318; (v) the powder supply device 318 is stationary; (vi) the powder supply device 318 is moved relative to the build platform 326; (vii) the powder supply device 318 is moved linearly (along one or more axes) relative to the build platform 326; and/or (viii) the powder supply assembly device 318 is rotated (about one or more axes) relative to the build platform 326.

[00157] Figure 4 is a simplified schematic side view illustration of yet another embodiment of a processing machine 410 for making the object 11 from powder particles 12. In this embodiment, the processing machine 410, e.g., a three-dimensional printer, includes (i) a build platform 426; (ii) a pre-heat device 416 (illustrated as a box); (iii) a powder supply device 418 (illustrated as a box); (iv) a measurement device 420 (illustrated as a box); (v) an excitation system 421 (illustrated as a box); (vi) an irradiation device 422 (illustrated as a box); (vii) a cooling system 431 (illustrated as a box); (viii) a control system 424; (ix) a material identification system 438; and (x) an input interface 440 that are somewhat similar to the corresponding components described above.

[00158] Additionally, in this embodiment, various components of the processing machine 410 are again positioned within a build chamber 429. However, in this embodiment, the excitation system 421 is positioned outside of the build chamber 429, i.e. in this embodiment, the excitation system 421 is positioned within a system chamber 441, which can also provide a vacuum environment. More particularly, as shown, the excitation system 421 includes an excitation light source 421D that directs an excitation light 421B, e.g., a light beam, through a chamber window 441A of the system chamber 441 and into the build chamber 429 and at the powder particles 12 through a chamber window 429A. It is appreciated, however, that even as positioned outside the build chamber 429 in which a majority of the components of the processing machine 410 are positioned, the excitation system 421 can be contained in a dedicated vacuum or inert gas system chamber 441 separate from the build chamber 429.

[00159] The chamber window 429A, 441A for each chamber 429, 441 can have any

suitable design and/or can be formed from any suitable materials. As utilized in this embodiment, it is desired that each of the chamber windows 429A, 441A be formed from materials, e.g., synthetic silica, MgF_2, or other suitable materials, which can efficiently transmit the excitation light 421B.

[00160] Further, as above, it is appreciated that the excitation light 421B can additionally or alternatively be directed at the powder particles 12 before the powder particles 12 have been deposited on the support surface 426B of the build platform 426, i.e. while the powder particles 12 are still retained within the powder supply device 418, or the excitation light 421B can be directed at the powder particles 12 after the powder particles 12 have been deposited onto the support surface 426B by the powder supply device 418. Additionally, or in the alternative, to enable excitation light to be more effectively directed at the powder particles 12 still retained within the powder supply device 418, the excitation system 421 can further include a second excitation light source 439 to direct second excitation light 439A at the powder particles 12 within the powder supply device 418.

[00161] As provided herein, it is appreciated that various features and aspects can be included within any embodiments of the excitation system so that the excitation light is better able to excite the electrons in the powder particles 12 (illustrated in Figure 1A) in order to more effectively increase the electrical conductivity of the powder particles 12, e.g., of the outer layer 12A (illustrated in Figure 1A) of the powder particles 12. Many of such features and aspects are illustrated and described herein below in relation to Figures 5-7. It is further appreciated, however, that any of the noted features and aspects of the excitation system can be combined in any suitable manner regardless of whether or not any and all such features are specifically shown in any one embodiment.

[00162] Figure 5 is a simplified schematic side view illustration of an embodiment of the excitation system 521 that can be used in any of the processing machines provided herein. As above, the excitation system 521 is uniquely configured to direct excitation light 521B at a plurality (at least a portion) of the powder particles 12 (illustrated in Figure 1A) to increase the electrical conductivity of the powder particles 12 via photoconductivity.

[00163] The design of the excitation system 521 can be varied to suit the requirements of the processing machine 10 (illustrated in Figure 1A) with which the excitation system 521 is being used. In the embodiment illustrated in Figure 5, the excitation system 521 includes a plurality of excitation light sources 521D (four are shown in Figure 5) that are each configured to direct an excitation light 521B at at least a portion of the powder particles 12. More particularly, each of the excitation light sources 521D includes an excitation light-emitting port 542 (illustrated in phantom) through which the excitation light 521B exits the excitation light source 521D and is directed at a plurality (at least a portion) of the powder particles 12.

[00164] As noted above, the wavelength of the excitation light 521B can be selected and/or controlled such that the excitation light 521B is most effectively able to excite the electrons in the plurality (at least a portion) of the powder particles 12. More particularly, the excitation light 521 can have an optimum wavelength that is based at least in part on the type of material of the powder particles 12. For example, in certain applications, only the excitation light source 521D that directs excitation light 521B of the optimum wavelength is used depending upon the type of material of the powder particles 12.

[00165] Additionally, in some embodiments, each of the plurality of excitation light sources 521D can direct excitation light 521B at the powder particles 12 that has a wavelength that is different than each of the other excitation light sources 521D. As such, each of the plurality of excitation light sources 521D can be better used when the powder particles 12 are formed from different types of material. For example, (i) a first excitation light source 521D can direct excitation light 521B having a first wavelength at the powder particles 12 when the powder particles 12 are formed from a first type of material; (ii) a second excitation light source 521D can direct excitation light 521B having a second wavelength at the powder particles 12 when the powder particles 12 are formed from a second type of material; (iii) a third excitation light source 521D can direct excitation light 521B having a third wavelength at the powder particles 12 when the powder particles 12 are formed from a third type of material; and (iv) a fourth excitation light source 521D can direct excitation light 521B having a fourth wavelength at the powder particles 12 when the powder particles 12 are formed from

a fourth type of material. Alternatively, each of the excitation light sources 521D can direct excitation light 521B having the same wavelength as one or more of the other excitation light sources 521D.

[00166] Further, in certain embodiments, it is desired to control the irradiation direction of the excitation light 521B as it is directed from the excitation light source 521D so that the excitation light 521B more accurately is directed at specific area(s) on the build platform 26 (illustrated in Figure 1A) in which the excitation light 521B is most required. More particularly, in some such embodiments, the processing machine 10 can identify the area on the build platform 26 where irradiation with the excitation light 521B is most required (e.g., using object data, image recognition, etc.), and the excitation light source 521D can then be controlled so that the excitation light 521B is directed at such area. It is appreciated that in some applications, the area identified as requiring the excitation light 521B can be identified according to movement of the support surface 26B (illustrated in Figure 1A) on which the powder particles 12 are supplied.

[00167] The manner for controlling the irradiation direction of the excitation light 521B can be varied. In certain applications, the excitation light source 521D can include an excitation direction controller 544 that specifically controls the irradiation direction at which the excitation light 521B is directed away from the excitation light source 521D at the powder particles 12. For example, the excitation direction controller 544 can include one or more steerable mirrors or optical elements such as optical fibers, prisms and lenses, and drive devices such as piezoelectric elements and actuators that can move them. Additionally, or in the alternative, in other applications, the irradiation direction of the excitation light 521B can be changed by changing the position of the excitation light-emitting port 542, e.g., with a position control mechanism 546 (illustrated in phantom), in order to maximize the area of the powder particles 12 exposed to the excitation light 521B. In one such application, this can be accomplished simply by moving the position of the excitation light source 521D.

[00168] Figure 6 is a simplified schematic side view illustration of another embodiment of the excitation system 621 that can be used in any of the processing machines provided herein. In this embodiment, the excitation system 621 is again

configured to direct excitation light 621B at a plurality (at least a portion) of the powder particles 12 (illustrated in Figure 1A) to increase the electrical conductivity of the powder particles 12 via photoconductivity.

[00169] In this embodiment, the excitation system 621 includes only a single excitation light source 621D. However, as shown, the excitation system 621 further includes a light divider 648 that converts excitation light from the single excitation light source 621D into a plurality of excitation lights 621B (two are shown in Figure 6). It is appreciated that the wavelength of each of the excitation lights 621B can be controlled as desired to most effectively excite the electrons in the powder particles 12 to increase the electrical conductivity of the powder particles 12 via photoconductivity.

[00170] The design of the light divider 648 can be varied. For example, in one embodiment, the light divider 648 is provided in the form of a beam splitter. Alternatively, in another embodiment, the light divider 648 is provided in the form of a spatial light modulator (e.g. LCD or DLP) and/or a diffuser such as a DOE. Still alternatively, the light divider 648 can be provided in another suitable form for purposes of converting excitation light from the single excitation light source 621D into the plurality of excitation lights 621B.

[00171] Additionally, as shown in this embodiment, the excitation system 621 can further include an excitation light-emitting port 642 (illustrated in phantom), an excitation direction controller 644, and a position control mechanism 646 (illustrated in phantom) that are substantially similar in design and function to what has been described above.

[00172] Figure 7 is a simplified schematic side view illustration of still another embodiment of the excitation system 721 that can be used in any of the processing machines provided herein. In this embodiment, the excitation system 721 is again configured to direct excitation light 721B at at least a portion of the powder particles 12 (illustrated in Figure 1A) to increase the electrical conductivity of the powder particles 12 via photoconductivity.

[00173] In this embodiment, the excitation system 721 again only includes a single excitation light source 721D. However, as shown, the excitation system 721 further includes a wavelength converter 750 that is configured to selectively convert the

wavelength of the excitation light 721B as desired. More particularly, the wavelength converter 750 can be utilized to convert the excitation light 721B to a wavelength that more efficiently increases the electrical conductivity of the powder particles 12 to increase the discharge rate. Further, it is appreciated that the wavelength converter 750 can be utilized to convert the excitation light 721B to an optimum wavelength for most efficiently increasing the electrical conductivity of the powder particles 12 that is based at least in part on the type of material of the powder particles 12. The wavelength converter 750 can have any suitable design. For example, in certain non-exclusive embodiments, the wavelength converter 750 can include a phosphor or anisotropic crystal to convert the wavelength of the excitation light 721B. Still further, or in the alternative, the desired or optimum wavelength can be achieved through use of a tunable excitation light source, multiple excitation light sources, or a very broadband excitation light source.

[00174] Additionally, as shown in this embodiment, the excitation system 721 can further include an excitation light-emitting port 742 (illustrated in phantom), an excitation direction controller 744, and a position control mechanism 746 (illustrated in phantom) that are substantially similar in design and function to what has been described above.

[00175] Figure 8 is a simplified schematic side view illustration of a portion of another embodiment of the processing machine 810 for building the object 11 from powder particles 12. As illustrated in this embodiment, the processing machine 810, e.g., a three-dimensional printer, includes (i) a build platform 826; (ii) a pre-heat device 816 (illustrated as a box); (iii) a powder supply device 818 (illustrated as a box); (iv) a measurement device 820 (illustrated as a box); (v) an excitation system 821 (illustrated as a box); (v) an irradiation device 822 (illustrated as a box); (vi) a cooling system 831 (illustrated as a box); (vii) a control system 824; (viii) a material identification system 838; and (ix) an input interface 840 that are somewhat similar to the corresponding components described above.

[00176] Additionally, in this embodiment, the processing machine 810 can be designed so that there is relative motion between (i) the support surface 826B and (ii) the excitation system 821 and the irradiation device 822. For example, the support

surface 826B can be moved back and forth (e.g., with a first mover 828) along the movement direction 825A along the page (X axis) and back and forth into the page (Y axis) relative to the excitation system 821 and the irradiation system 822, and other components within the component housing 832. With this design, the build platform 826 is moved relative to the excitation system 821 and the irradiation device 822. Further, for example, the build platform 826 can have a rectangular or other configuration.

[00177] Alternatively, or additionally, the excitation system 821 and/or the irradiation device 822 (and other components within the component housing 832) can be moved back and forth (e.g., with a second mover 834) along the movement direction 825B along the page (X axis) and back and forth into the page (Y axis) relative to the support surface 826B. With this design, the excitation system 821 and/or the irradiation system 822 are moved relative to the build platform 826.

[00178] Alternatively, or additionally, the processing machine 810 can be designed so that one or more of the pre-heat device 816, the powder supply device 818, the measurement device 820, the excitation system 821, and the irradiation device 822 are independently moved (e.g. rotated about one or more axes and/or linearly along one or more axes).

[00179] Figure 9 is a simplified schematic side view illustration of yet another embodiment of the processing machine 910 for making the object 11 from powder particles 12. In this embodiment, the processing machine 910, e.g., a three-dimensional printer 910 includes (i) a build platform 926; (ii) an excitation system 921 (illustrated as a box); (iii) an irradiation device 922 (illustrated as a box); and (iv) a control system 924 that are somewhat similar to the corresponding components described above. Additionally, the processing machine 910 can include (i) a pre-heat device; (ii) a powder supply device; (iii) a measurement device; (iv) a cooling system; (v) a material identification system; and (vi) an input interface which are not illustrated in Figure 9 for clarity.

[00180] In the embodiment illustrated in Figure 9, the irradiation device 922 can include a beam steerer 922S (illustrated as a box) for steering the electron beam 922A to build the object 11, and the excitation system 921, and thus the excitation light 921B,

can be stationary or movable with one or more actuators (not shown) relative to the irradiation device 922 and/or the build platform 926. Further, in this embodiment, the build platform 926 can include a support surface 926B that is selectively moved up or down like an elevator (or piston) along a support movement direction 926A by the device mover 928 to maintain the desired height 933.

[00181] Still alternatively, the excitation system 921, the irradiation device 922, and/or the support surface 926B can be designed to be moved individually, transversely and/or rotationally, as necessary to build the object 11.

[00182] Figure 10 is a simplified top view of a portion of still another embodiment of a processing machine 1010. In this embodiment, the processing machine 1010 includes (i) the build platform 1026; (ii) the powder depositor 1018 ("powder supply device"); and (iii) the irradiation device 1022 that are somewhat similar to the corresponding components described above. It should be noted that the processing machine 1010 may include the pre-heat device, the measurement device, the cooler device, and the control system, that have been omitted from Figure 10 for clarity. The powder depositor 1018, the irradiation device 1022, the pre-heat device, the cooler device, and the measurement device may collectively be referred to as the top assembly.

[00183] In this embodiment, the problem of building a practical and low cost three dimensional printer 1010 for three dimensional printing of one or more metal parts 1011 (illustrated as a box) is solved by providing a rotating build platform 1026, and the powder depositor 1018 is moved linearly across the build platform 1026 as the build platform 1026 is rotated in a moving direction 1025 about a rotation axis 1026D that is parallel to the Z axis. The part 1011 is built in the cylindrical shaped build platform 1026.

[00184] In one embodiment, the build platform 1026 includes the support surface 1026B having an elevator platform that may be moved vertically along the rotation axis 1026D (e.g. parallel to the Z axis), and the cylindrical side wall 1026C that surrounds an "elevator platform". With this design, fabrication begins with the support surface 1026B (elevator) placed near the top of the side wall 1026C. The powder depositor 1018 translates across the build platform 1026 spreading a thin powder layer across

the support surface 1026B.

[00185] In Figure 10, the irradiation device 1022 directs the irradiation beams 1022D to fuse the powder to form the parts 1011. In this embodiment, the irradiation device 1022 includes multiple (e.g. three), separate irradiation energy sources 1022C (each illustrated as a solid circle) that are positioned along the irradiation axis 1022B. In this embodiment, each of the energy sources 1022C generates a separate irradiation beam 1022D (illustrated with dashed circle). In the embodiment shown, three energy sources 1022C are arranged in a line along the irradiation axis 1022B (transverse to the rotation axis 1026D) so that together they may cover at least the radius of the support surface 1026B. Further, the three energy sources 1022C are substantially tangent to each other in this embodiment, and the irradiation beams 1022D are overlapping. Because the irradiation beams 1022D cover the entire radius of the build platform 1026, every point in the build platform 1026 may be reached by at least one of the irradiation beams 1022D. This prevents an exposure "blind spot" at the center of rotation of the build platform 1026.

[00186] In an alternative embodiment, where lower throughput is acceptable, a single energy source may be used with the beam being steered in the radial direction to smay in the radial direction. In this embodiment, the beam is scanned parallel to the irradiation axis 1022B that is transverse to the rotation axis 1026D and that crosses the movement direction. In another alternative embodiment, a single energy source with sufficient beam deflection width to cover the desired part radius may expose every point within the build volume.

[00187] The powder depositor 1018 distributes the powder across the top of the build platform 1026. In this embodiment, the powder depositor 1018 includes a powder spreader 1019A and a powder mover assembly 1019B that moves the powder spreader 1019A linearly, transversely to the build platform 1026.

[00188] In this embodiment, the powder spreader 1019A deposits the powder on the build platform 1026. In some embodiments, the powder spreader 1019A comprises features that control the width of the powder distribution area to minimize or prevent powder from falling outside the cylindrical build platform 1026. In other embodiments, the side walls 1026C may include flanges that extend into the corners of the powder

spreading area, wherein the flanges prevent excess powder from being spread outside the cylindrical build platform 1026.

[00189] The powder mover assembly 1019B moves the powder spreader 1019A linearly with respect to the build platform 1026, while the build platform 1026 and powder depositor 1018 are rotating together about the rotation axis 1026D. In one embodiment, the powder mover assembly 1019B includes a pair of spaced apart actuators 1019C (e.g. linear actuators) and a pair of spaced apart linear guides 1019D (illustrated in phantom) that move the powder spreader 1019A along the Y axis, transversely (perpendicular) to the rotation axis 1026D and the build platform 1026. The powder spreader 1019A may be moved across the build platform 1026 to the empty "parking space" 1019C shown in dotted lines at the top of the Figure 10.

[00190] After the powder spreader 1019A is parked at the opposite side of the rotating system, the irradiation device 1022 may be energized to selectively melt or fuse the appropriate powder into a solid part 1011.

[00191] In yet another embodiment, the build platform 1026 may be rectangular and hold a larger volume of powder, but the maximum part volume is confined to a cylindrical volume within the rectangular build platform 1026.

[00192] With this design, because the build platform 1026 rotates relative to the irradiation device 1022, it is possible to reach every point in the part volume without requiring any acceleration or deceleration time. This feature provides a substantial throughput improvement over prior art systems. Because the only scanning part is the powder spreader 1019A with relatively low mass, high acceleration may be used to maintain high throughput.

[00193] Moreover, because the powder spreader 1019A is moved in a linear fashion relative to the build platform 1026, the powder may be easily distributed in a flat and thin layer. This avoids an excess or lack of powder at the rotation center.

[00194] In another embodiment, the processing machine 1010 (i) may include more than one irradiation devices 1022 and more than one exposure areas (irradiation zones); and/or (ii) multiple parts 1011 may be made on the build platform 1026 at one time to increase throughput. For example, the processing machine 1010 may include two irradiation devices 1022 that define two exposure areas, or three irradiation

devices 1022 that define three exposure areas.

[00195] In certain embodiments, (i) the build platform 1026 and the entire powder depositor 1018 are rotating at a substantially constant velocity about the rotation axis 1026D relative to irradiation device 1022, the pre-heat device, the cooler device, and/or the measurement device, and (ii) the powder depositor 1018 is moved linearly, with respect to the build platform 1026 during the powder spreading operation. Alternatively, (i) the build platform 1026 is rotated at a substantially constant velocity relative to the powder depositor 1018, irradiation device 1022, the pre-heat device, the cooler device, and/or the measurement device about the rotation axis 1026D, and (ii) the powder depositor 1018 is moved linearly relative to the irradiation device 1022, the pre-heat device, the cooler device, and/or the measurement device during the powder spreading operation.

[00196] Further, in yet another embodiment, (i) the build platform 1026 is stationary, (ii) the irradiation device 1022, the pre-heat device, the cooler device, and/or the measurement device are rotated relative the build platform 1026 about the rotation axis 1026D, and (iii) the powder depositor 1018 is moved linearly, transversely to the rotation axis 1026D, with respect to the stationary build platform 1026 during the powder spreading operation.

[00197] In certain embodiments, the build platform 1026 or the top assembly is continuously moved along the Z axis while printing to maintain a substantially constant height. Alternatively, the build platform 1026 or the top assembly may be moved in a stepped like fashion along the Z axis. As another alternative, the build platform 1026 or the top assembly may be ramped down gradually to the next print level.

[00198] The embodiments in which the build platform 1026 is stationary and the top assembly is rotated may have the following benefits: (i) eliminate centrifugal forces on the melted metal and the dry powder at the surface, and, below the printing surface, on the build platform's varied mixture of unused powder and parts in progress; (ii) eliminating the Z-stepping of the build platform leaves the powder/melted metal/parts agglomeration truly undisturbed; (iii) Z-movement control may be easier with the much lighter and constant-mass top assembly than with the massive and growing build platform; (iv) the top assembly could finish one complete rotation, then do nothing for

20 degrees of rotation, then start a new layer: this would distribute and perhaps average out any discontinuities or metallurgical differences at the stepping point, and each layer would start 20 degrees farther on, for example; (v) easier cooling system connections to the build platform, if any are required; (vi) reduce controls complexity for the rotating part and Z-movement: a rotating build platform is constantly gaining mass, but it needs a steady rotational speed and a steady Z-movement (or a uniform Z-step distance), so the control system has to adjust for that; (vii) a rotating top assembly is far lighter and of roughly constant mass (depending on whether powder replenishment is continuous or periodic); (viii) possibly simplify measurement system because everything is measured against the fixed floor of the build platform 1026. In one embodiment, wireless communications and batteries may be used in the rotating top assembly. Further, printing could pause periodically to replenish power (via capacitors) and powder. Alternatively, if a pause would introduce build discontinuities, then continuous printing could be performed, and electricity might be supplied by continuous inductive charging or another non-contact method, and the powder hopper could be continuously replenished.

[00199] As provided above, in one embodiment, the build platform 1026 is moved along the rotation axis 1026D, and the top assembly is rotated about the rotation axis 1026D at a constant angular velocity. If the build platform 1026 is moved along the rotation axis 1026D at a constant speed, the relative motion between the build platform 1026 and the top assembly will be spiral shaped (i.e., helical). In one embodiment, the flat surfaces in the parts 1011 may be inclined to match the trajectory of the build platform 1026, or the axis of rotation 1026D may be tilted slightly with respect to the Z axis so that the exposure surface of the part 1011 is still planar.

[00200] In one embodiment, the powder depositor 1018 is designed to continuously feed powder to the build platform 1026. In this embodiment, the powder depositor 1018 could include a powder hopper (not shown) with a funnel on the rotating top assembly that covers the rotation axis 1026D (center zone), and a non-rotating feeder (not shown) (e.g. a screw drive, conveyor belt, etc.) that terminates directly over the funnel. If the center zone is not available due to the needs of other components, then a donut shaped funnel would have one at least one point in its annular opening under

a stationary off-axis feeder point at all times. In both of these embodiments it is advantageous to make the large and heavy powder supply mechanism stationary and feed the powder into the rotating top assembly.

[00201] If the "melting zone" of each column of the irradiation beam 1022D is approximately linear, it may be aligned to the slightly sloped radial surface of a helical surface. It doesn't matter if the helical surface is not planar, as long as it has a sufficiently straight radial line segment. It is also possible that some embodiments may treat a helical powder surface as "approximately flat" since the powder layer thickness is small compared to the part size, the build platform size, and the energy beam depth of focus.

[00202] Figure 11 is a simplified top view of a portion of still another embodiment of a processing machine 1110 for forming the three dimensional part 1111. In this embodiment, the processing machine 1110 includes (i) the build platform 1126; (ii) the powder depositor 1118; and (iii) the irradiation device 1122 that are somewhat similar to the corresponding components described above. It should be noted that the processing machine 1110 may include the pre-heat device, the cooler device, the measurement device, and the control system, that have been omitted from Figure 11 for clarity. The powder depositor 1118, the irradiation device 1122, the pre-heat device, the cooler device, and the measurement device may collectively be referred to as the top assembly.

[00203] In the embodiment illustrated in Figure 11, the build platform 1126 includes a large support platform 1127A and one or more build chambers 1127B (only one is illustrated) that are positioned on the support platform 1127A. In one embodiment, the support platform 1127A is holds and supports each build chamber 1127B while each part 1111 is being built. For example, the support platform 1127A may be disk shaped, or rectangular shaped.

[00204] In Figure 11, the build chamber 1127B contains the metal powder that is selectively fused or melted according to the desired part geometry. The size, shape and design of the build chamber 1127B may be varied. In Figure 11, the build chamber 1127B is generally annular shaped and includes (i) a tubular shaped, inner chamber wall 1127C, (ii) a tubular shape, outer chamber wall 1127D, and (iii) an annular disk

shaped support surface 1127E that extends between the chamber walls 1127C, 1127D.

[00205] In this embodiment, the support surface 1127E may function as an annular "elevator platform" that may be moved vertically relative to the chamber walls 1127C, 1127D. In certain embodiments, fabrication begins with the elevator 1127E placed near the top of the chamber walls 1127C, 1127D. The powder depositor 1118 deposits a preferably thin layer of metal powder into the build chamber 1127B during relative movement between the build chamber 1127B and the powder depositor 1118. During fabrication of the part 1111, the elevator support surface 1127E may be slowly lowered down by one layer thickness per revolution so the next layer of powder may be distributed properly in a continuous fashion. In this way, instead of building parts as a stack of thin parallel planar layers, the part(s) are built in a continuous helical layer that spirals on itself many times.

[00206] In the embodiment illustrated in Figure 11, the support platform 1127A and the build chamber 1127B may be rotated about the rotation axis 1126D in the rotation direction 1125 at a substantially constant velocity with a mover (not shown) during the manufacturing process relative to at least a portion of the top assembly. Alternatively, at least a portion of the top assembly may be rotated relative to the support platform 1127A and the build chamber 1127B. Still alternatively, instead of the support surface 1127E including the elevator platform that moves down, the support platform 1127A may be controlled to move downward along the rotation axis 1126D during fabrication and/or the top assembly may be controlled to move upward along the rotation axis 1126D during fabrication.

[00207] With the present design, the problem of building a practical and low cost three dimensional printer 1110 for high volume 3D printing of metal parts 1111 is solved by providing a rotating turntable 1127A that supports a large annular build chamber 1127B suitable for continuous deposition of myriad small parts 1111 or individual large parts that fit in the annular region.

[00208] In Figure 11, the irradiation device 1122 again includes multiple (e.g. three) separate irradiation energy sources 1122C (each illustrated as a circle) that are positioned along the irradiation axis 1122B. In this embodiment, the three energy sources 1122C are arranged in a line along the irradiation axis 1122B so that together

they may cover the full radial width of the build chamber 1127B. Because the exposure area covers the entire radial dimension of the desired build volume, every point in the required build volume may be reached by at least one of the irradiation beams. Alternatively, a single irradiation energy source 1122C may be utilized with a scanning irradiation beam.

[00209] As provided herein, this processing machine 1110 requires no back and forth motion (no turn motion), so throughput may be maximized. Many parts 1111 may be built in parallel in the build chamber 1127B. Very large parts that fit within the annular shape may be fabricated. There are many applications that require large round parts with a central hole, so this capability may be valuable in some applications (such as jet engines).

[00210] Figure 12 is a simplified side illustration of a portion of yet another embodiment of the processing machine 1210. In this embodiment, the processing machine 1210 includes (i) the build platform 1226 that supports the powder 1211; and (ii) the irradiation device 1222. It should be noted that the processing machine 1210 may include the powder depositor, pre-heat device, the cooler device, the measurement device, and the control system, that have been omitted from Figure 12 for clarity. The powder depositor, the irradiation device 1222, the pre-heat device, the cooler device, and the measurement device may collectively be referred to as the top assembly.

[00211] In this embodiment, the irradiation device 1222 generates the irradiation energy beam 1222D to selectively heat the powder 1211 in each subsequent powder layer 1213 to form the part. In the embodiment of Figure 12, the energy beam 1222D may be selectively steered to any direction within a cone shaped workspace. In Figure 12 three possible directions for the energy beam 1222D are represented by three arrows.

[00212] Additionally, in Figure 12, the support surface 1226B of the build platform 1226 is uniquely designed to have a concave, curved shape. As a result thereof, each powder layer 1213 will have a curved shape.

[00213] As provided herein scanning the energy beam 1222D across a large angle at a planar powder surface would create focus errors because the distance from the

deflection center to the powder changes with the cosine of the deflection angle. To avoid focus errors, in one embodiment of the system shown in Figure 12, the support surface 1226B and each powder layer 1213 have a spherical shape with the center of the sphere at the center of deflection 1223 of the energy beam 1222D. As a result thereof, the energy beam 1222D is properly focused at every point on the spherical surface of the powder 1211, and the energy beam 1222D has a constant beam spot shape at the powder layer 1213. In Figure 12, the powder 1211 is spread on the concave support surface 1226B centered at a beam deflection center 1223. For a processing machine 1210 having a single irradiation energy source as illustrated in Figure 12, the powder 1211 may be spread over the single concave support surface 1226B. Alternatively, for a processing machine 1210 having multiple, irradiation energy sources, the powder 1211 may optionally be spread on multiple curved surfaces, each centered on the deflection center 1223 of the respective energy sources.

[00214] For an alternative embodiment of the processing machine 1210 that uses linear scanning of the build platform 1226 (or the column) into and out of the page, the curved support surface 1226B would be cylindrical shape. Alternatively, for an embodiment where the build platform 1226 is rotated about a rotation axis, the curved surface support surface 1226B would be designed to have a spherical shape.

[00215] In these embodiments, the size and shape of the curved support surface 1226B is designed to correspond to (i) the beam deflection of the energy beam 1222D at the top powder layer 1213, and (ii) the type or relative movement between the energy beam 1222D and the powder layer 1213. Stated in another fashion, the size and shape of the curved support surface 1226B is designed so that the energy beam 1222D has a substantially constant focal distance to the top powder layer 1213 during relative movement between the energy beam 1222D and the powder layer 1213. As used herein the term substantially constant focus distance shall mean variations in the focal distance of less than five percent. In alternative embodiments, the term substantially constant focus distance shall mean the focus distance changes no more than ten, five, four, three, two, or one percent.

[00216] In Figure 12, the problem of building a three dimensional printer 1210 with focus variations caused by a large beam deflection angle is solved by providing at least

one cylindrical or spherical, bowl-shaped support surface 1226B that maintains a constant focal distance for the irradiation energy beam 1222D. In other words, the embodiment of the Figure 12 comprises the support device which includes a non-flat (e.g. the curved) support surface, the powder supply device which supplies the powder to the support device and which forms the curved powder layer, and the irradiation device which irradiates the curved powder layer. In this situation, the irradiation device sweeps the energy beam in at least a swept plane (paper plane of Figure 12) which includes a swept direction. And the curved support surface includes a curvature in the swept plane. The non-flat support surface may be a part of polygonal shape (a shape made of a plurality of straight lines which cross each other).

[00217] Figure 13A is a simplified side illustration of a portion of yet another embodiment of the processing machine 1310. In this embodiment, the processing machine 1310 includes (i) the build platform 1326 that supports the powder 1311; and (ii) the irradiation device 1322. It should be noted that the processing machine 1310 may include the powder depositor, pre-heat device, the cooler device, the measurement device, and the control system, that have been omitted from Figure 13A for clarity. The powder depositor, the irradiation device 1322, the pre-heat device, and the measurement device may collectively be referred to as the top assembly.

[00218] In this embodiment, the irradiation device 1322 includes multiple (e.g. three) irradiation energy sources 1322C that each generates a separate irradiation energy beam 1322D that may be steered (scanned) to selectively heat the powder 1311 in each subsequent powder layer 1313 to form the part. In Figure 13A, each energy beam 1322D may be controllably steered throughout a cone shaped workspace that diverges from the respective energy source 1322C. In Figure 13A, the possible directions of each energy beam 1322D are each represented by three arrows.

[00219] In Figure 13A, the support surface 1326B of the build platform 1326 is uniquely designed to have three concave, curved shaped regions 1326E. Stated in another fashion, the support surface 1326B includes a separate curved shaped region 1326E for each irradiation energy source 1322C. As a result thereof, each powder layer 1313 will have a dimpled curved shape.

[00220] As provided above, scanning each energy beam 1322D across a large angle

would create focus errors if the surface of the powder 1311 were a flat plane because the distance from the deflection center to the powder 1311 would change with the cosine of the deflection angle. In the embodiment illustrated in Figure 13A, however, the powder 1311 is spread on the three lobed, curved support surface 1326B and the distance between the deflection center of each energy beam 1322D and the surface of the powder 1311 is constant so there are no significant focus errors.

[00221] In certain embodiments, such as a system where the powder support surface 1326B is rotating in a manner similar to the previously described embodiments, it may be more practical to distribute the powder across a single curved spherical surface. In this case, the columns providing each energy beam 1322D may be offset from each other in the vertical direction to more closely align the focal surface of each energy beam 1322D with the powder surface. In other words, the shape of the surface of the powder 1311 is not precisely matched to the focal distance of each energy beam 1322D, but the deviations from optimal focus are small enough with respect to the depth of focus of each energy beam 1322D that the proper part geometry may be formed in the powder 1311.

[00222] The processing machine 1310 illustrated in Figure 13A, may be used with a linear scanning build platform 1326, or a rotating build platform 1326. For a rotating system, it may be preferable to distribute the multiple columns across the build platform 1326 radius, not its diameter. In this case, the build platform axis of rotation would be at the right edge of the diagrams.

[00223] In these embodiments, the size and shape of the curved support regions 1326E are designed to correspond to (i) the beam deflection of each energy beam 1322D at the top powder layer 1313, and (ii) the type of relative movement between the energy beam 1322D and the powder layer 1313. Stated in another fashion, the size and shape of each curved support region 1326E is designed so that the energy beam 1322D has a substantially constant focus distance at the top powder layer 1313 during relative movement between the energy beam 1322D and the powder layer 1313. Stated in yet another fashion, the shape of the support region 1326E, and the position of the energy beams 1322D are linked to the type of relative movement between the support region 1326E and the energy beams 1322D so that the energy beams 1322D

have a substantially constant focus distance at the top powder layer 1313.

[00224] For example, Figure 13B is a top view of a build platform 1326 in which the curved support regions 1326E are shaped into linear rows. In this embodiment, there is linear relative movement along a movement axis 1325 between the build platform 1326 and the irradiation device 1322 (illustrated in Figure 13A) while maintaining a substantially constant focus distance. A sweep (scan) direction 1323 of each beam 1322D (illustrated in Figure 13A) is illustrated with a two headed arrow in Figure 13B.

[00225] Alternatively, for example, Figure 13C is a top view of a build platform 1326 in which the curved support regions 1326E are shaped into annular rows. In this embodiment, there is rotational relative movement along a movement axis 1325 between the build platform 1326 and the irradiation device 1322 (illustrated in Figure 13A) while maintaining a substantially constant focus distance. A sweep (scan) direction 1323 of each beam 1322D (illustrated in Figure 13A) is illustrated with a two headed arrow in Figure 13C.

[00226] As provided herein, maintaining a constant focal distance will improve the part quality by controlling aberrations and the beam spot size.

[00227] Referring back Figure 13A, in this embodiment, (i) the build platform 1326 has a non-flat support region (support surface) 1326E, (ii) the powder supply device (not shown in Figure 13A) supplies the powder 1311 to the build platform 1326 to form the curved powder layer 1313; and (iii) the irradiation device 1322 irradiates the layer 1313 with an energy beam 1322D to form the built part (not shown in Figure 13A) from the powder layer 1313. In this embodiment, the non-flat support surface 1326E may have a curvature. Further, the irradiation device 1322 may sweep the energy beam 1322D back and forth along a swept direction 1323, and wherein the curved support surface 1326E includes the curvature in a plane where the energy beam 1322D pass through.

[00228] Figure 14 is a simplified side illustration of a portion of still another embodiment of the processing machine 1410. In this embodiment, the processing machine 1410 includes (i) the build platform 1426 that supports the powder 1411; and (ii) the irradiation device 1422 that are somewhat similar to the corresponding components described above and illustrated in Figure 19A. It should be noted that the

processing machine 1410 may include the powder depositor, pre-heat device, the cooler device, the measurement device, and the control system, that have been omitted from Figure 14 for clarity. The powder depositor, the irradiation device 1422, the pre-heat device, and the measurement device may collectively be referred to as the top assembly.

[00229] In this embodiment, the irradiation device 1422 includes multiple (e.g. three) irradiation energy sources 1422C that each generates a separate irradiation energy beam 1422D that may be steered (scanned) to selectively heat the powder 1411 in each subsequent powder layer 1413 to form the part. In Figure 14, each energy beam 1422D may be controllably steered throughout a cone shaped workspace that diverges from the respective energy source 1422C. In Figure 14, the possible directions of each energy beam 1422D are each represented by three arrows.

[00230] In Figure 14, the support surface 1426B of the build platform 1426 is uniquely designed to have large concave curved surface. Stated in another fashion, the support surface 1426B is curved shaped.

[00231] As provided above, scanning each energy beam 1422D across a large angle would create focus errors if the surface of the powder 1411 were a flat plane because the distance from the deflection center to the powder 1411 would change with the cosine of the deflection angle. In the embodiment illustrated in Figure 14, however, the powder 1411 is spread on the curved support surface 1426B, and the irradiation energy sources 1422C are tilted relative to each other so that the distance between the deflection center of each energy beam 1422D and the surface of the powder 1411 is substantially constant so there are no significant focus errors.

[00232] In the embodiment illustrated in Figure 14, the powder support surface 1426B is rotating in a manner similar to the previously described embodiments, and the powder 1411 is distributed across a single curved spherical surface 1426B. In this case, the columns providing each energy beam 1422D may be offset from each other in the vertical direction (and angled) to more closely align the focal surface of each energy beam 1422D with the powder surface. In other words, the shape of the surface of the powder 1411 is not precisely matched to the focal distance of each energy beam 1422D, but the deviations from optimal focus are small enough with respect to the

depth of focus of each energy beam 1422D that the proper part geometry may be formed in the powder 1411.

[00233] The processing machine 1410 illustrated in Figure 14, may be used with a linear scanning build platform 1426, or a rotating build platform 1426. In these embodiments, the size and shape of the curved support surface 1426B is designed and the irradiation energy sources 1422C are oriented and positioned (i) so that each energy beam 1422D has a substantially constant focus distance at the top powder layer 1413, and (ii) to match the type of relative movement between the energy beam 1422D and the powder layer 1413. Stated in yet another fashion, the shape of the support region 1426E, and the position of the energy beams 1422D are linked to the type of relative movement between the support region 1426E and the energy beams 1422D so that the energy beams 1422D have a substantially constant focus distance at the top powder layer 1413.

[00234] Figure 15 is a simplified side perspective illustration of a portion of yet another embodiment of the processing machine 1510 for making a three dimensional part 1511. In this embodiment, the processing machine 1510 is a wire feed, three dimensional printer that includes (i) the material bed assembly 1514 that supports the three dimensional part 1511; and (ii) a material depositor 1550.

[00235] In Figure 15, the material bed assembly 1514 includes the build platform 1526 and a device mover 1528 that rotates the build platform 1526 about the support rotation axis 1526D.

[00236] Further, in Figure 15, the material depositor 1550 includes (i) an irradiation device 1552 that generates an irradiation energy beam 1554; and (ii) a wire source 1556 that provides a continuous feed of wire 1558. In this embodiment, the irradiation energy beam 1554 illuminates and melts the wire 1558 to form molten material 1560 that is deposited onto the build platform 1526 to make the part 1511.

[00237] As provided herein, the problem of manufacturing high precision rotationally symmetric parts 1511 by three dimensional printing is solved by using a rotating material bed 1526 (build platform), the wire source 1556 (wire feed mechanism) that supplies the wire 1558, and the irradiation energy beam 1554 for melting the wire 1558.

[00238] In one embodiment, as the build platform 1526 is rotated about the rotation

axis 1526D, the material depositor 1550 may provide the molten material 1560 to form the part 1511. Further, material depositor 1550 (irradiation device 1552 and wire source 1556) may be moved transversely (e.g. along arrow 1562) with a depositor mover 1564 relative to the rotating build platform 1526 to build the part 1511. Further, the build platform 1526 and/or the material depositor 1550 may be moved vertically (e.g. by one of the movers 1528, 1564) to maintain the desired height between the material depositor 1550 and the part 1511.

[00239] Alternatively, the depositor mover 1564 may be designed to rotate the material depositor 1550 about a rotation axis and move the material depositor 1550 transversely to the rotation axis relative to the stationary build platform 1526. Still alternatively, the depositor mover 1564 may be designed to rotate the material depositor 1550 about a rotation axis relative to the build platform 1526, and the build platform 1526 may be moved transversely to the rotation axis with the device mover 1528.

[00240] Round, substantially rotationally symmetric parts 1511 may be built by rotating the build platform 1526 and depositing metal by using the energy beam 1554 to melt the wire feed 1558. The basic operation is analogous to a normal metal cutting lathe, except that the "tool" is depositing metal 1560 instead of removing it.

[00241] It is understood that although a number of different embodiments of the processing machine 10 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.

[00242] While a number of exemplary aspects and embodiments of the processing machine 10 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 an object from powder particles, the processing machine comprising:

a build platform that supports the powder particles on a support surface;

an excitation system that directs an excitation light at at least a portion of the powder particles; and

an electron beam irradiation device that irradiates at least a portion of the powder particles with an electron beam.

2. The processing machine of claim 1, wherein at least a portion of the powder particles are irradiated with the electron beam to form at least a portion of the object from the powder particles.

3. The processing machine of one of claims 1 or 2, wherein the excitation light increases electrical conductivity of the powder particles via photoconductivity.

4. The processing machine of claim 3, wherein each powder particles has an outer layer, and wherein the excitation light increases the electrical conductivity of the outer layer of a plurality of the powder particles via photoconductivity.

5. The processing machine of any one of claims 1 to 4, wherein the excitation light increases an electrical conductivity of a plurality of the powder particles at least fifty percent compared to the powder particles before the excitation light is directed at the plurality of the powder particles.

6. The processing machine of any one of claims 1 to 5, wherein the excitation light has a wavelength that is below a predetermined wavelength determined based upon a type of material of the powder particles.

7. The processing machine of any one of claims 1 to 6, further comprising a material identification system that is configured to identify the type of material of the powder particles.

8. The processing machine of claim 7, wherein the material identification system determines the type of material of the powder particles based at least in part on one of a powder particles weight and a powder particles specific gravity of the powder particles.

9. The processing machine of any one of claims 1 to 8, further comprising an input interface that is configured to receive input including information about the type of material of the powder particles.

10. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below an infrared range.

11. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below six hundred nanometers.

12. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below five hundred nanometers.

13. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below four hundred nanometers.

14. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below three hundred nanometers.

15. The processing machine of any one of claims 1 to 9, wherein the excitation light has a wavelength that is below two hundred nanometers.

16. The processing machine of any one of claims 1 to 15, wherein the excitation system directs a plurality of spaced apart excitation lights at at least a portion of the powder particles on the support surface.

17. The processing machine of any one of claim 1 to 16, wherein the excitation light has a wavelength that excites electrons in the powder particles.

18. The processing machine of any one of claims 1 to 17, wherein the powder particles are made of Ti-6AL-4V, and the excitation light has a wavelength of less than 178 nanometers.

19. The processing machine of any one of claims 1 to 17, wherein the powder particles are made of copper, and the excitation light has a wavelength of less than 572 nanometers.

20. The processing machine of any one of claims 1 to 17, wherein the powder particles are made of stainless steel, and the excitation light has a wavelength of less than 249 nanometers.

21. The processing machine of any one of claims 1 to 20, wherein the excitation system can irradiate the powder particles with the excitation light having two or more different wavelengths.

22. The processing machine of any one of claims 1 to 21, wherein the excitation system irradiates the powder particles using only the excitation light having an optimum wavelength that is based upon on the type of material of the powder particles.

23. The processing machine of any one of claims 1 to 22, wherein the excitation system has multiple excitation light sources, each of the multiple excitation light sources having a different wavelength.

24. The processing machine of any one of claims 1 to 23, wherein the excitation system has a wavelength converter.

25. The processing machine of any one of claims 1 to 24, wherein the excitation system has multiple excitation light sources.

26. The processing machine of any one of claims 1 to 25, wherein the excitation system has one of a beam splitter and a spatial light modulator to divide excitation light from a single excitation light source into multiple excitation lights.

27. The processing machine of any one of claims 1 to 26, wherein the excitation light changes a temperature of the powder particles less than five hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles.

28. The processing machine of any one of claims 1 to 27, wherein the excitation light changes a temperature of the powder particles less than two hundred fifty degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles.

29. The processing machine any one of claims 1 to 28, wherein the excitation light changes a temperature of the powder particles less than one hundred degrees Kelvin prior to the electron beam irradiation device directing the electron beam at the powder particles.

30. The processing machine of any one of claims 1 to 29, further comprising a build chamber having a chamber window, wherein the support surface is arranged inside the build chamber, the excitation light source is arranged outside the build chamber, and the excitation light from the excitation light source is irradiated to the powder particles through the chamber window.

31. The processing machine of any one of claims 1 to 29, further comprising a build chamber having a cooling system, wherein the support surface is arranged inside the build chamber, the excitation light source is arranged inside the build chamber, and the excitation light source is cooled by the cooling system.

32. The processing machine of any one of claims 1 to 31, wherein the excitation light is directed at the powder particles before the electron beam irradiates the powder particles.

33. The processing machine of claim 32, wherein the electron beam irradiates at least a portion of the powder particles having the increased electrical conductivity.

34. The processing machine of one of claim 32 or 33, wherein the electron beam irradiates at least a portion of the powder particles having the electrical conductivity of the powder particles that has been increased at least fifty percent.

35. The processing machine of any one of claims 1 to 34, wherein the excitation light irradiates a plurality of the powder particles in parallel with the irradiation of the powder particles with the electron beam.

36. The processing machine of any one of claims 1 to 35, wherein the excitation light irradiates a plurality of the powder particles in a time period as the at least a portion of the object is formed from the powder particles by irradiations of the electron beam.

37. The processing machine of any one of claims 1 to 36, wherein the excitation light irradiates a plurality of the powder particles after the electron beam irradiates the powder particles.

38. The processing machine of any one of claims 1 to 37, wherein the excitation system irradiates a plurality of the powder particles with the excitation light before the powder particles are supplied to the support surface.

39. The processing machine of any one of claims 1 to 38, wherein the excitation system irradiates a plurality of the powder particles with the excitation light after the powder particles are supplied to the support surface.

40. The processing machine of any one of claims 1 to 39, wherein the excitation system can change an irradiation direction of the excitation light.

41. The processing machine of claim 40, wherein the excitation system includes a position control mechanism to change a position of an excitation light-emitting port.

42. The processing machine of one of claims 40 or 41, wherein the excitation system increases an area of the powder particles that is irradiated by the excitation light by changing the irradiation direction.

43. The processing machine of any one of claims 1 to 42, further comprising a first mover that moves the support surface, wherein the excitation system irradiates a plurality of the powder particles with the excitation light before the support surface is moved such that the electron beam can irradiate the powder particles.

44. The processing machine of claim 43, wherein the excitation system changes the irradiation direction of the excitation light according to the movement of the support surface on which the powder particles are supplied.

45. The processing machine of claim 43, wherein the excitation system changes the position of the excitation light-emitting port according to the movement of the support surface on which the powder particles are supplied.

46. The processing machine of one of claims 44 or 45, wherein the excitation system increases the area of the powder particles that is irradiated by the excitation light by changing the irradiation direction.

47. The processing machine of any one of claims 43 to 46, wherein the first mover moves the support surface parallel to the support surface.

48. The processing machine of any one of claims 43 to 47, the first mover moves the support surface by rotating the support surface about a first axis intersecting the support surface.

49. The processing machine of any one of claims 43 to 48, further comprising a second mover that moves the support surface.

50. The processing machine of any one of claims 43 to 49, wherein the second mover rotates the support surface by rotating the support surface about a second axis intersecting the support surface.

51. The processing machine of any one of claims 43 to 50, wherein the second mover rotates the support surface to the contrary direction to the direction that the support surface is rotated by the first mover.

52. The processing machine of any one of claims 43 to 51, wherein the second mover rotates the support surface to maintain the attitude of the support surface against the rotation of the support surface by the first mover.

53. The processing machine of any one of claims 1 to 52, wherein the support surface supports the powder particles in layers and the excitation system directs the excitation light over the outer layer of the powder particles.

54. The processing machine of any one of claims 1 to 53, wherein the excitation light includes a light beam.

55. The processing machine of any one of claims 1 to 54, further comprising a control system that identifies an area where irradiation is required on the support surface and instructs the excitation system to direct the excitation light to the area.

56. A processing machine for building an object from powder particles, the powder particles having an outer layer, the processing machine comprising:

a build platform that supports the powder particles;

an excitation system that directs an excitation light at a plurality of the powder particles on the build platform, the excitation light increasing electrical conductivity of the outer layer of the plurality of powder particles at least fifty percent via photoconductivity; and

an electron beam system that directs an electron beam at the powder particles having the increased electrical conductivity to form at least a portion of the object from the powder particles, the excitation light changing a temperature of the powder particles less than five hundred degrees Kelvin prior to the electron beam system directing the electron beam at the powder particles.

57. The processing machine of claim 56, wherein the excitation light has a wavelength that is below an infrared range.

58. The processing machine of claim 57, wherein the excitation light has a wavelength that is below six hundred nanometers.

59. The processing machine of any one of claims 56 to 58, wherein the excitation light includes a light beam.

60. A method for building an object from powder particles, the method comprising the steps of:

supporting the powder particles on a support surface of a build platform;

directing an excitation light at a plurality of the powder particles with an excitation system; and

irradiating at least a portion of the powder particles with an electron beam of an electron beam irradiation device.

61. The method of claim 60, wherein the step of irradiating includes irradiating at least a portion of the powder particles with the electron beam to form at least a portion of the object from the powder particles.

62. The method of one of claims 60 or 61, wherein the step of directing includes the excitation light increasing electrical conductivity of the plurality of powder particles via photoconductivity.

63. The method of claim 62, wherein each of the powder particles has an outer layer, and wherein the step of directing includes the excitation light increasing the electrical conductivity of the outer layer of the plurality of powder particles via photoconductivity.

64. The method of any one of claims 60 to 63, wherein the step of directing includes the excitation light increasing an electrical conductivity of the plurality of powder particles at least fifty percent compared to the powder particles before the excitation light is directed at the plurality of the powder particles.

65. The method of any one of claims 60 to 64, wherein the step of directing includes the excitation light having a wavelength that is below a predetermined wavelength determined based upon a type of material of the powder particles.

66. The method of any one of claims 60 to 65, further comprising the step of identifying the type of material of the powder particles with a material identification system.

67. The method of claim 66, wherein the step of identifying includes determining the type of material of the powder particles with the material identification system based at least in part on one of a powder particles weight and a powder particles specific gravity of the powder particles.

68. The method of any one of claims 60 to 67, further comprising the step of receiving input via an input interface including information about the type of material of the powder particles.

69. The method of any one of claims 60 to 68, wherein the step of directing includes the excitation light having a wavelength that is below an infrared range.

70. The method of any one of claims 60 to 68, wherein the step of directing includes the excitation light having a wavelength that is below six hundred nanometers.

71. The method of any one of claims 60 to 68, wherein the step of directing includes the excitation light having a wavelength that is below four hundred nanometers.

72. The method of any one of claims 60 to 68, wherein the step of directing includes the excitation light having a wavelength that is below two hundred nanometers.

73. The method of any one of claims 60 to 72, wherein the step of directing includes directing a plurality of spaced apart excitation lights at the plurality of powder particles on the support surface with the excitation system.

74. The method of any one of claim 60 to 73, wherein the step of directing includes the excitation light having a wavelength that excites electrons in the powder particles.

75. The method of any one of claims 60 to 74, wherein the powder particles are made of Ti-6AL-4V, and wherein the step of directing includes the excitation light having a wavelength of less than 178 nanometers.

76. The method of any one of claims 60 to 74, wherein the powder particles are made of copper, and wherein the step of directing includes the excitation light having a wavelength of less than 572 nanometers.

77. The method of any one of claims 60 to 74, wherein the powder particles are made of stainless steel, and wherein the step of directing includes the excitation light having a wavelength of less than 249 nanometers.

78. The method of any one of claims 60 to 77, wherein the step of directing includes the excitation system irradiating the powder particles with the excitation light having two or more different wavelengths.

79. The method of any one of claims 60 to 78, wherein the step of directing includes the excitation system irradiating the powder particles using only the excitation light having an optimum wavelength that is based upon on the type of material of the powder particles.

80. The method of any one of claims 60 to 79, wherein the step of directing includes the excitation system having multiple excitation light sources, each of the multiple excitation light sources having a different wavelength.

81. The method of any one of claims 60 to 80, wherein the step of directing includes the excitation system having a wavelength converter.

82. The method of any one of claims 60 to 81, wherein the step of directing includes the excitation system having multiple excitation light sources.

83. The method of any one of claims 60 to 82, further comprising the step of dividing excitation light from a single excitation light source into multiple excitation lights with one of a beam splitter and a spatial light modulator of the excitation system.

84. The method of any one of claims 60 to 83, wherein the step of directing includes changing a temperature of the powder particles less than five hundred degrees Kelvin with the excitation light prior to the electron beam irradiation device directing the electron beam at the powder particles.

85. The method of any one of claims 60 to 84, further comprising the step of arranging the support surface inside a build chamber having a chamber window, and wherein the step of directing includes arranging the excitation light source outside the build chamber, and irradiating the powder particles with the excitation light from the excitation light source through the chamber window.

86. The method of any one of claims 60 to 84, further comprising the step of arranging the support surface inside a build chamber having a cooling system, and wherein the step of directing includes arranging the excitation light source inside the build chamber, and cooling the excitation light source with the cooling system.

87. The method of any one of claims 60 to 86, wherein the step of directing includes directing the excitation light at the powder particles before the electron beam irradiates the powder particles.

88. The method of claim 87, wherein the step of irradiating includes irradiating at least a portion of the powder particles having the increased electrical conductivity with the electron beam.

89. The method of any one of claims 60 to 88, wherein the step of directing includes the excitation light irradiating the powder particles in parallel with the irradiation of the powder particles with the electron beam.

90. The method of any one of claims 60 to 89, wherein the step of directing includes irradiating the powder particles with the excitation light in a time period as the at least a portion of the object is formed from the powder particles by irradiations of the electron beam.

91. The method of any one of claims 60 to 90, wherein the step of directing includes irradiating the powder particles with the excitation light after the electron beam irradiates the powder particles.

92. The method of any one of claims 60 to 91, wherein the step of directing includes irradiating the powder particles with the excitation light before the powder particles are supplied to the support surface.

93. The method of any one of claims 60 to 92, wherein the step of directing includes irradiating the powder particles with the excitation light after the powder particles are supplied to the support surface.

94. The method of any one of claims 60 to 93, wherein the step of directing includes changing an irradiation direction of the excitation light with the excitation system.

95. The method of claim 94, wherein the step of directing includes changing a position of an excitation light-emitting port with a position control mechanism of the excitation system.

96. The method of one of claims 94 or 95, wherein the step of directing includes increasing an area of the powder particles that is irradiated by the excitation light by changing the irradiation direction.

97. The method of any one of claims 60 to 96, further comprising the step of moving the support surface with a first mover, wherein the step of directing includes irradiating the powder particles with the excitation light before the support surface is moved such that the electron beam can irradiate the powder particles.

98. The method of claim 97, wherein the step of directing includes changing the irradiation direction of the excitation light with the excitation system according to the movement of the support surface on which the powder particles are supplied.

99. The method of claim 97, wherein the step of directing includes changing the position of the excitation light-emitting port with the excitation system according to the movement of the support surface on which the powder particles are supplied.

100. The method of one of claims 98 or 99, wherein the step of directing includes increasing the area of the powder particles that is irradiated by the excitation light by changing the irradiation direction.

101. The method of any one of claims 97 to 100, wherein the step of moving includes moving the support surface parallel to the support surface with the first mover.

102. The method of any one of claims 97 to 101, wherein the step of moving includes rotating the support surface about a first axis intersecting the support surface with the first mover.

103. The method of any one of claims 97 to 102, further comprising the step of moving the support surface with a second mover.

104. The method of any one of claims 97 to 103, wherein the step of moving the support surface with the second mover includes the second mover rotating the support surface about a second axis intersecting the support surface.

105. The method of any one of claims 97 to 104, wherein the step of moving the support surface with the second mover includes the second mover rotating the support surface to the contrary direction to the direction that the support surface is rotated by the first mover.

106. The method of any one of claims 97 to 105, wherein the step of moving the support surface with the second mover includes the second mover rotating the support surface to maintain the attitude of the support surface against the rotation of the support surface by the first mover.

107. The method of any one of claims 60 to 106, wherein the step of supporting includes supporting the powder particles in layers with the support surface, and wherein the step of directing includes directing the excitation light over the outer layer of the powder particles with the excitation system.

108. The method of any one of claims 60 to 107, wherein the step of directing includes the excitation light including a light beam.

109. The method of any one of claims 60 to 108, further identifying an area where irradiation is required on the support surface with a control system, and instructing the excitation system with the control system to direct the excitation light to the area.

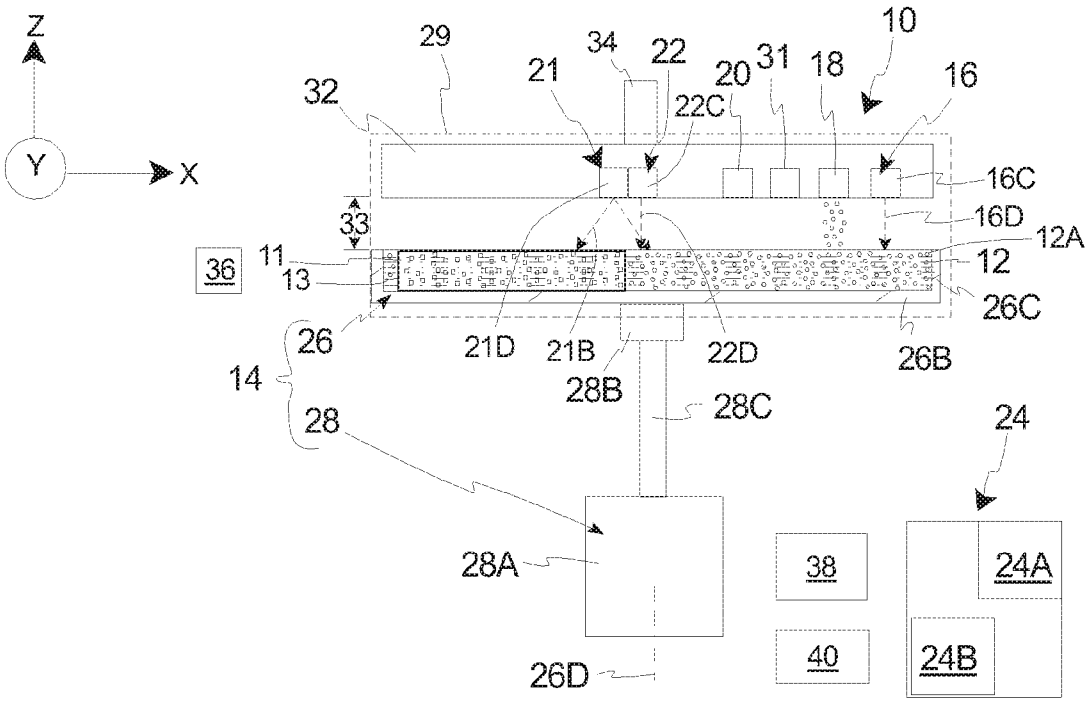

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Fig. 1A

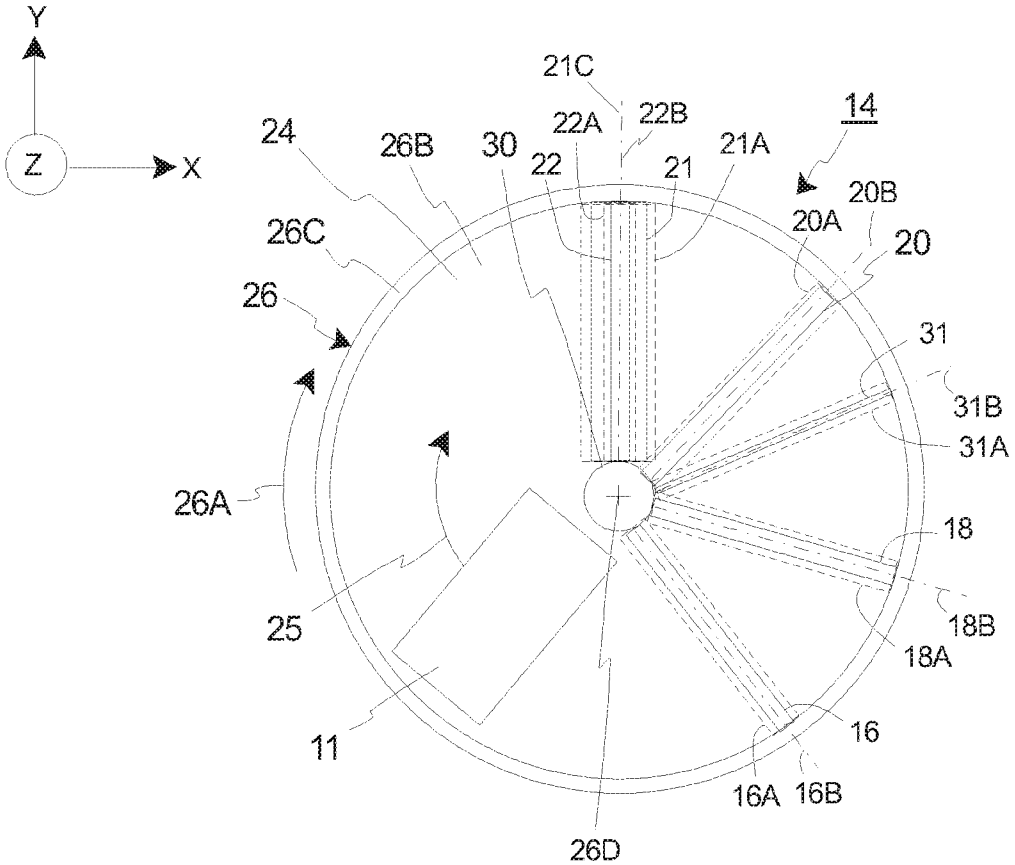

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Fig. 1B

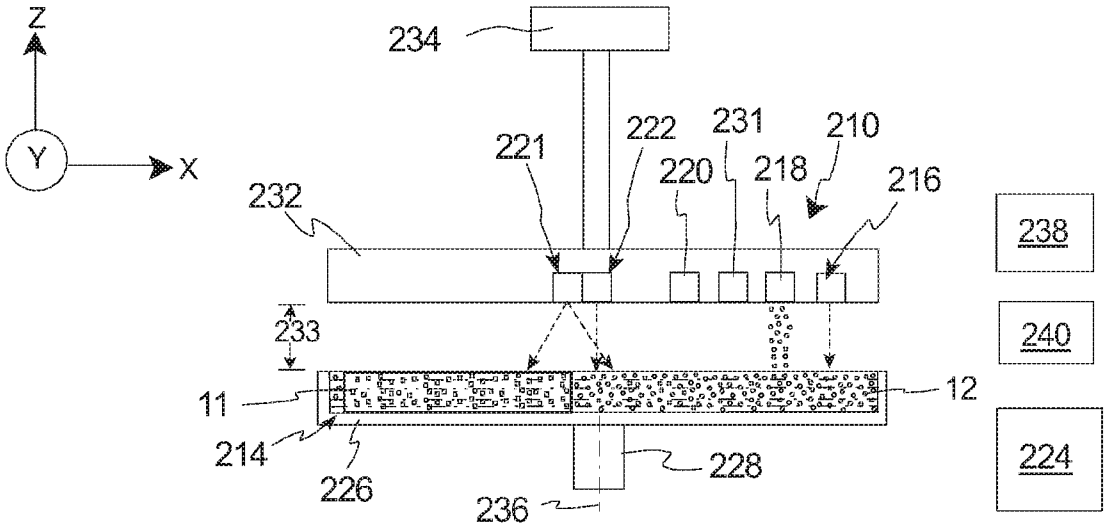

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Fig. 2

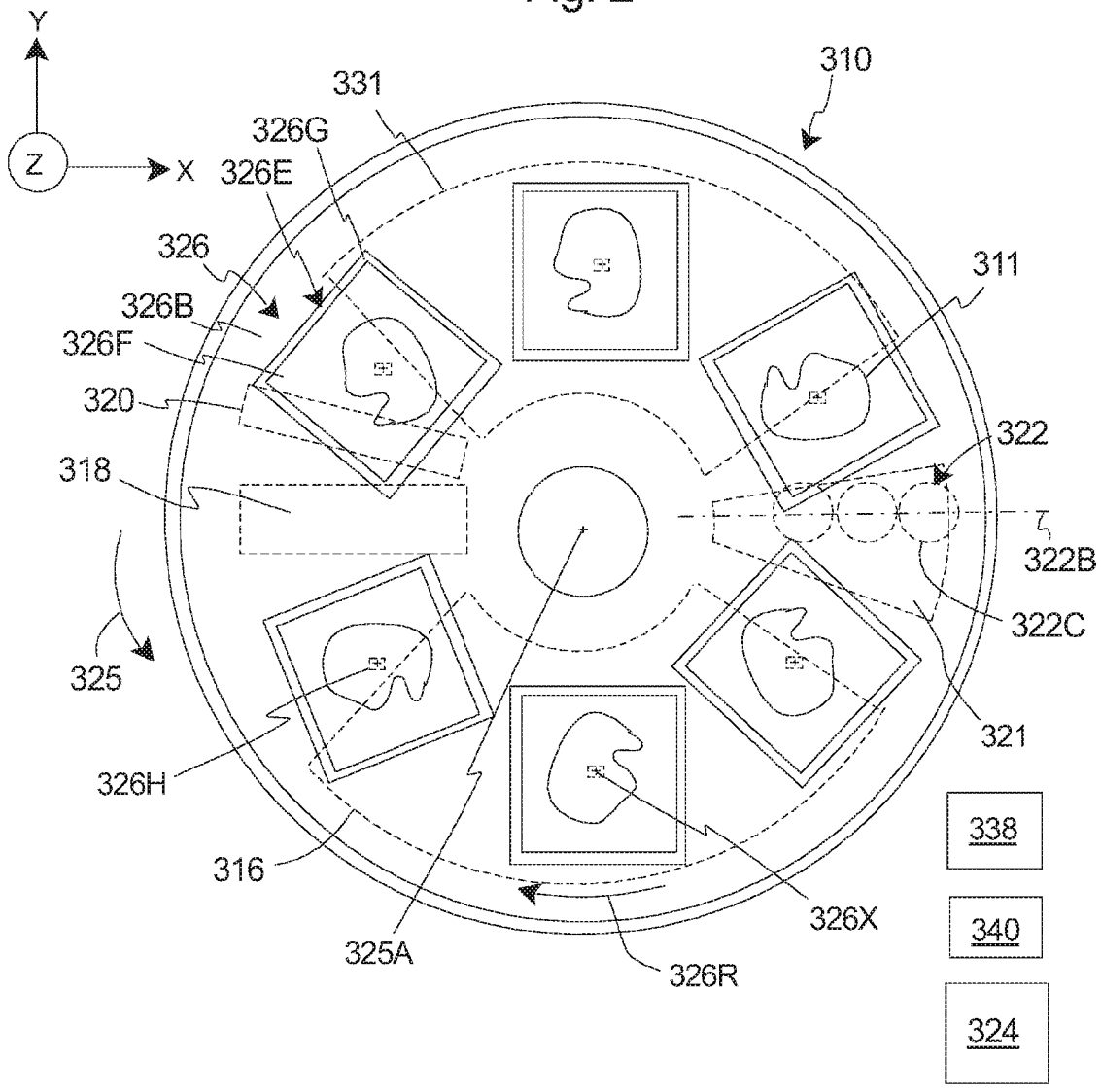

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Fig. 3

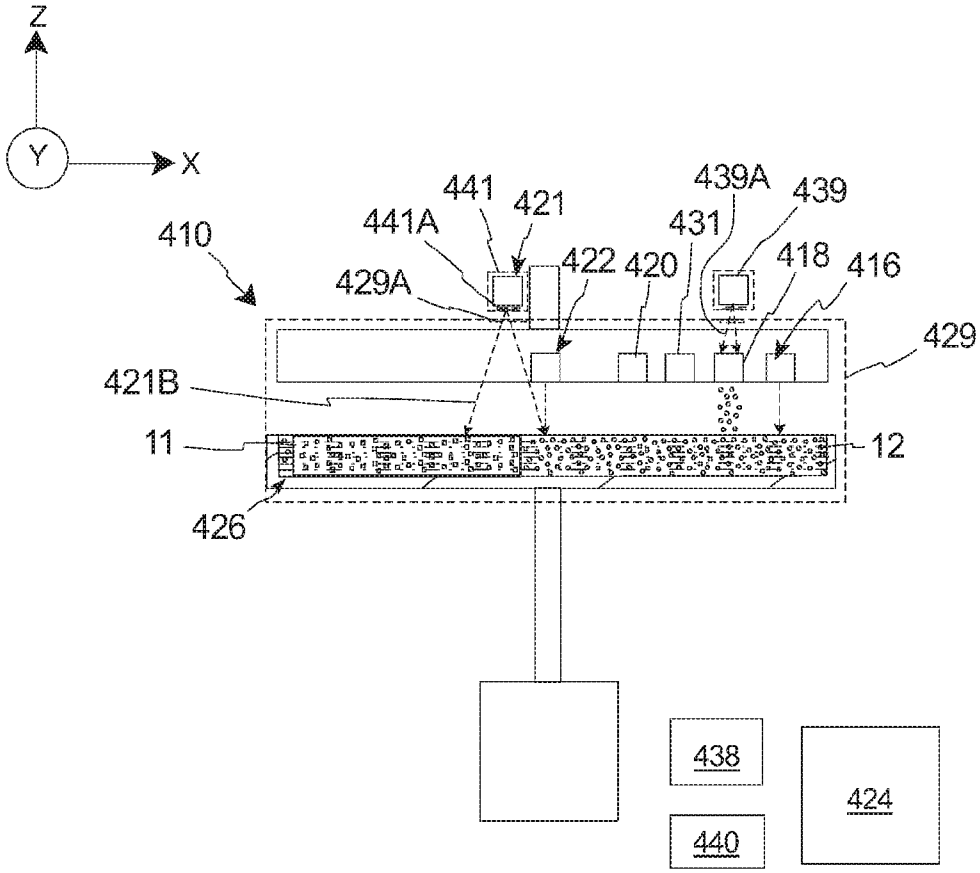

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Fig. 4

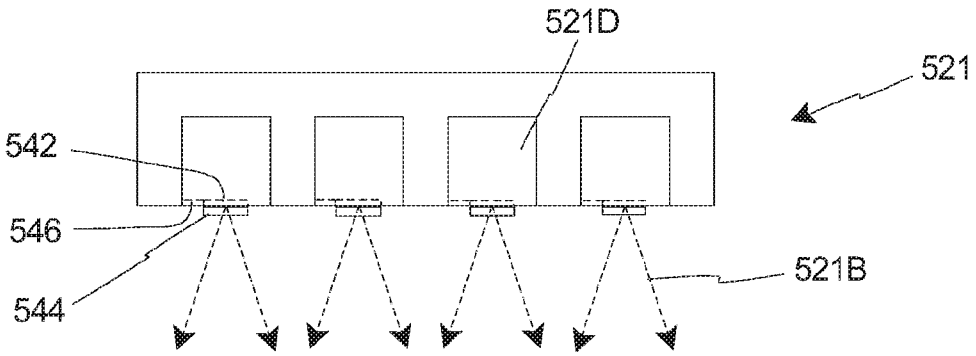


Fig. 5

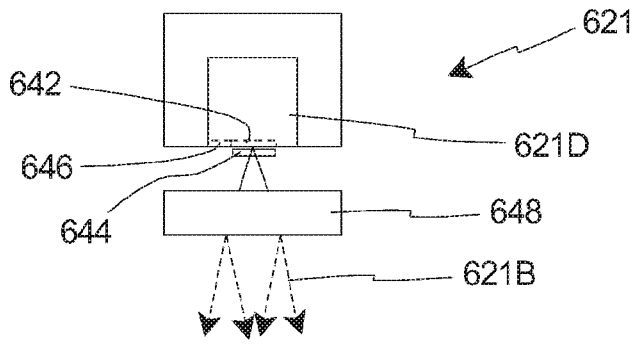


Fig. 6

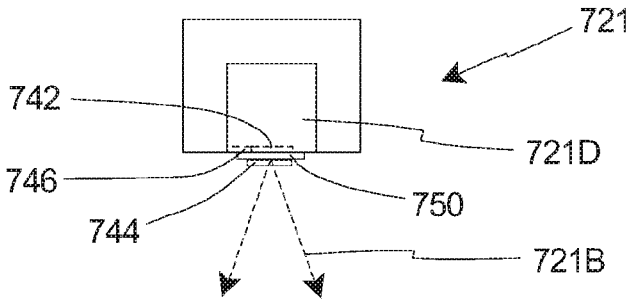


Fig. 7

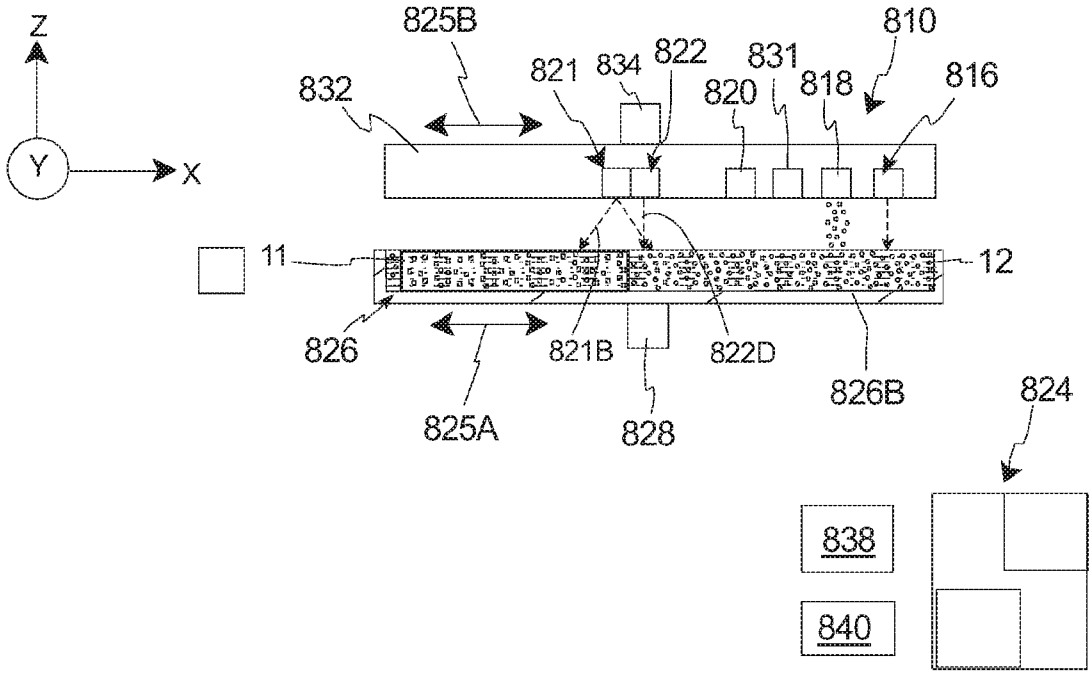

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Fig. 8

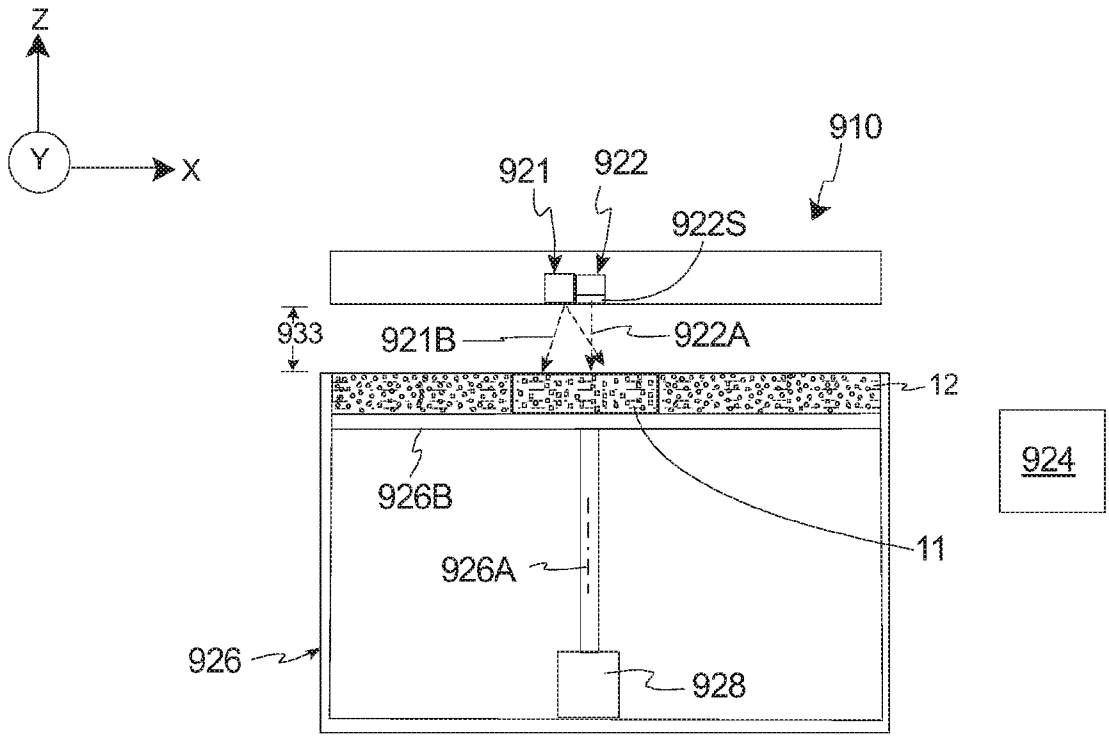

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Fig. 9

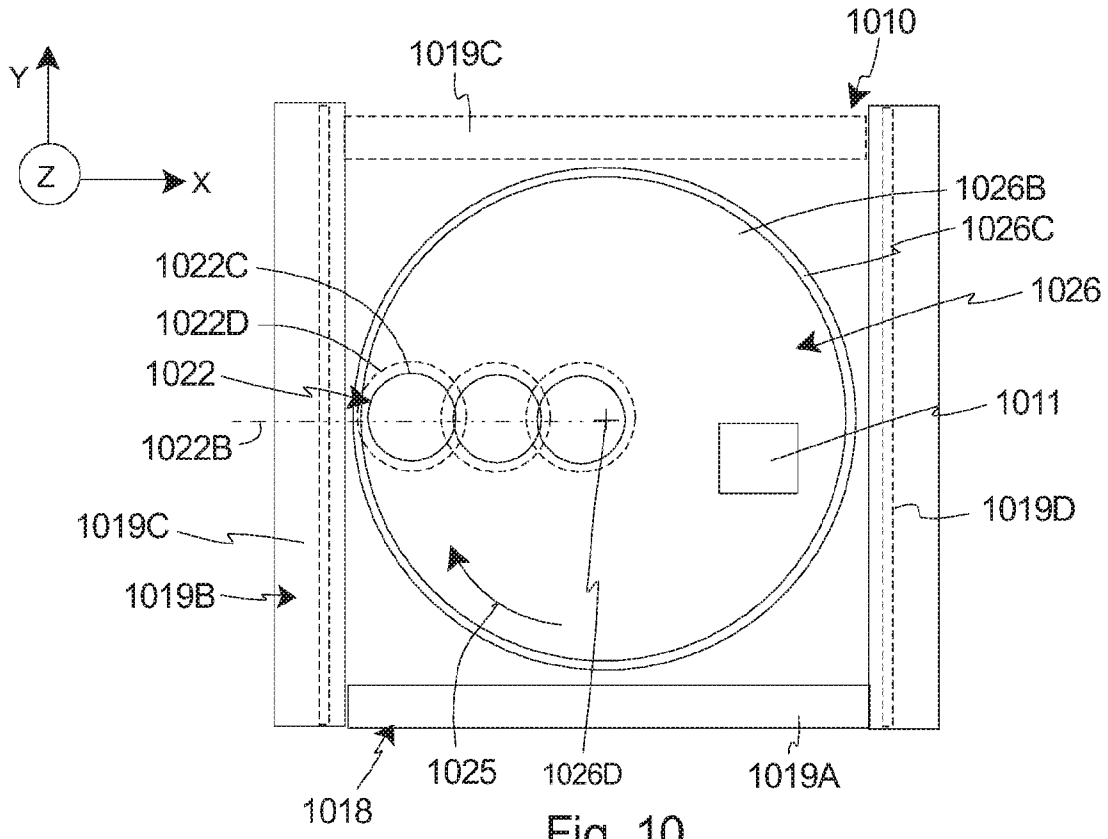

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Fig. 10

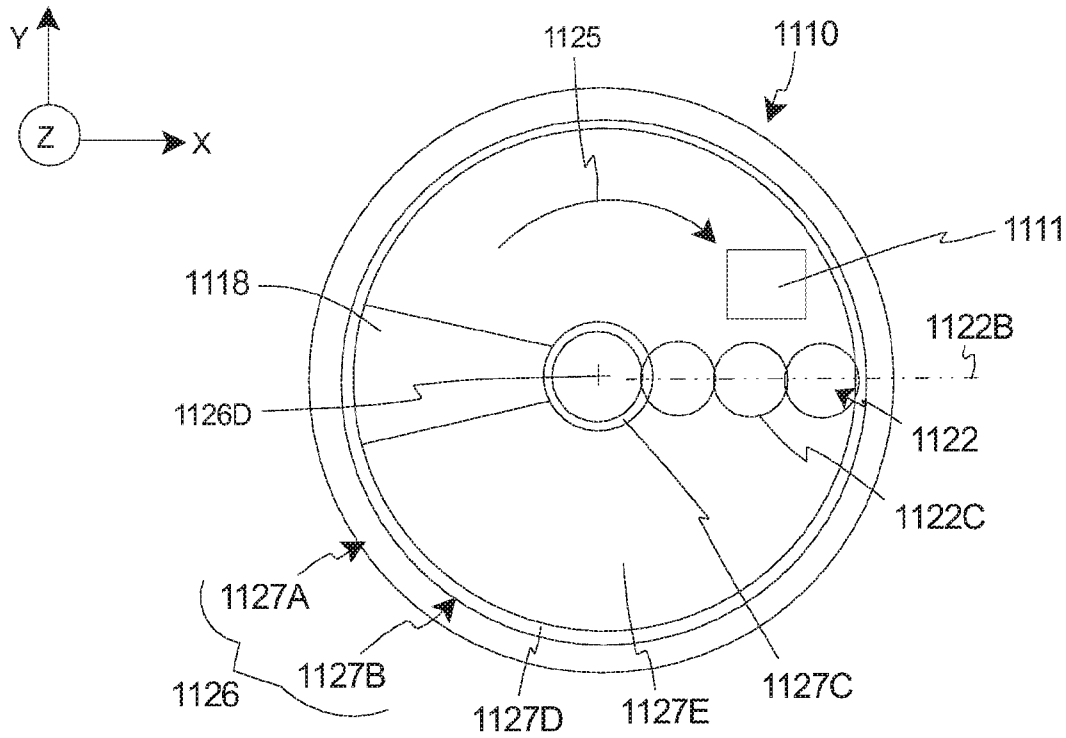

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Fig. 11

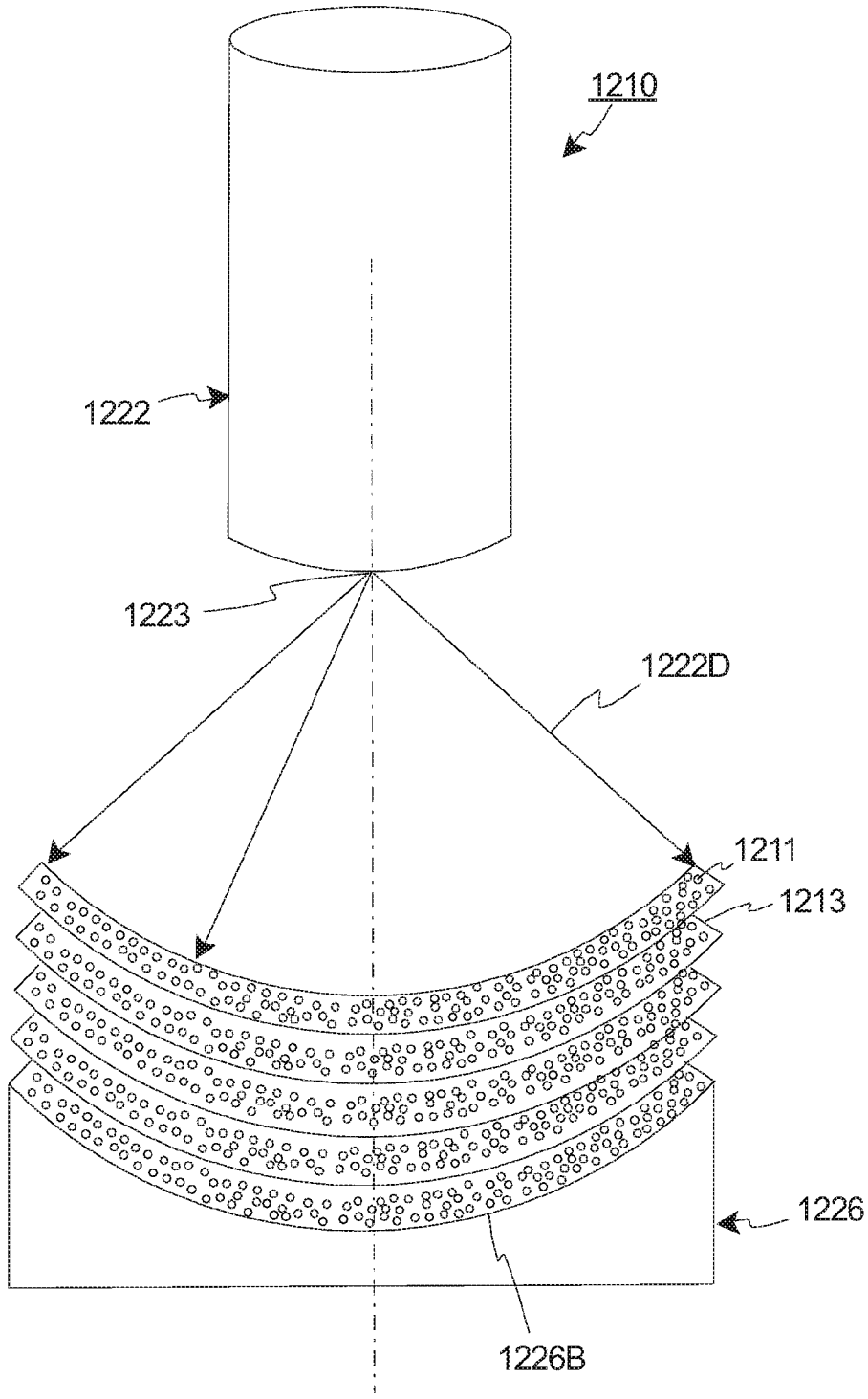


Fig. 12

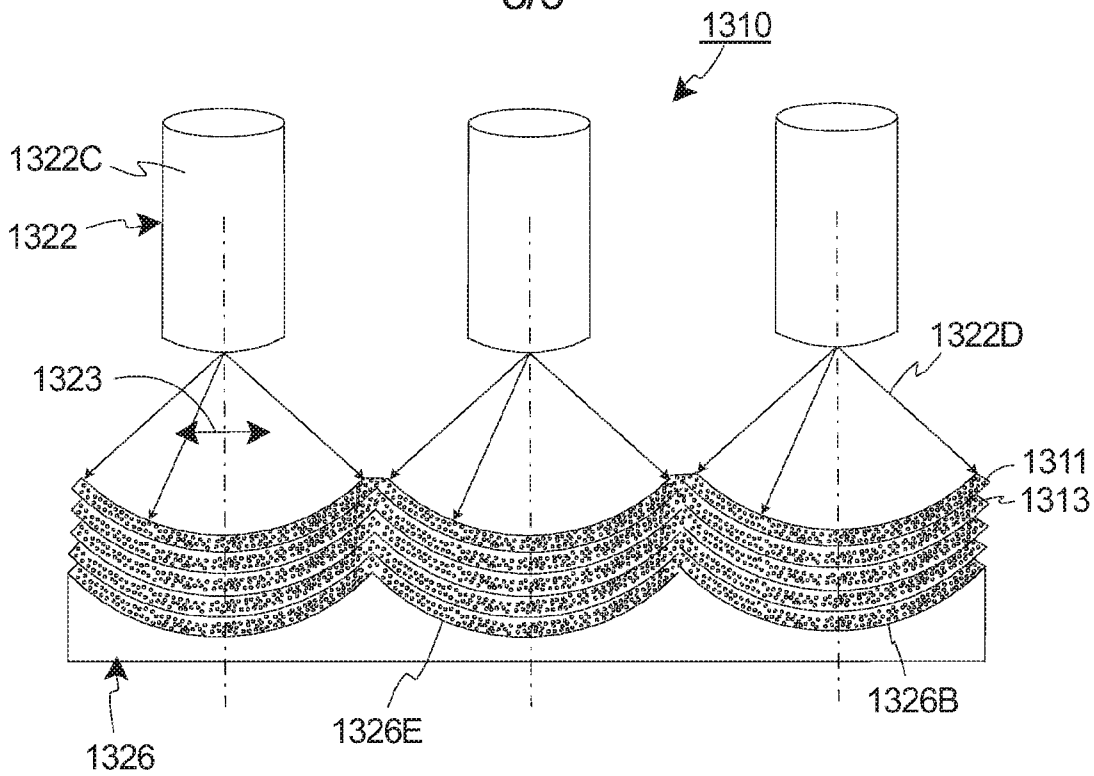


Fig. 13A

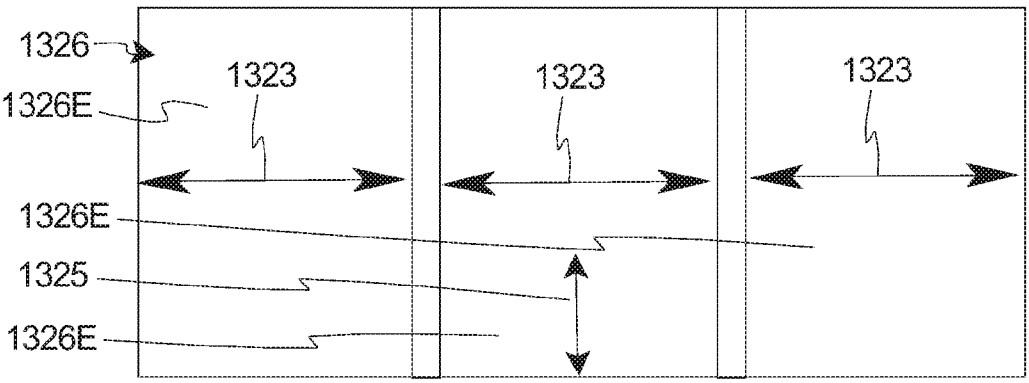


Fig. 13B

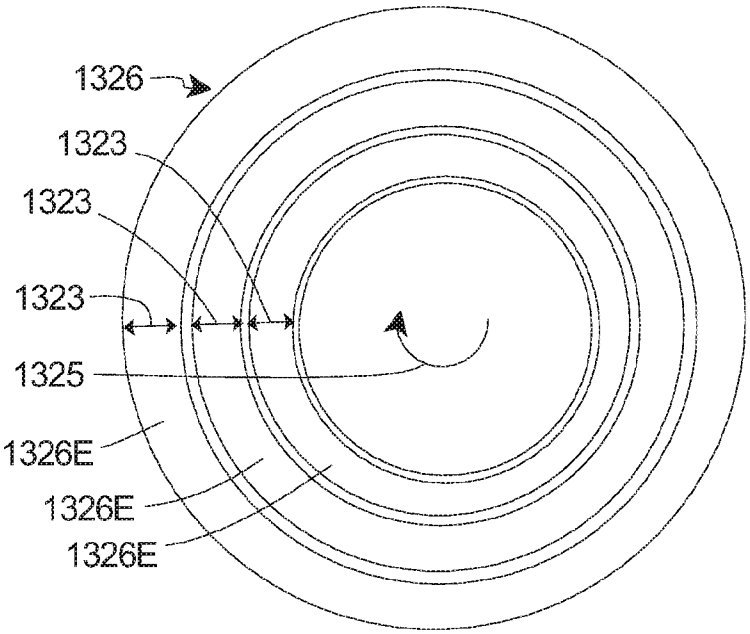


Fig. 13C

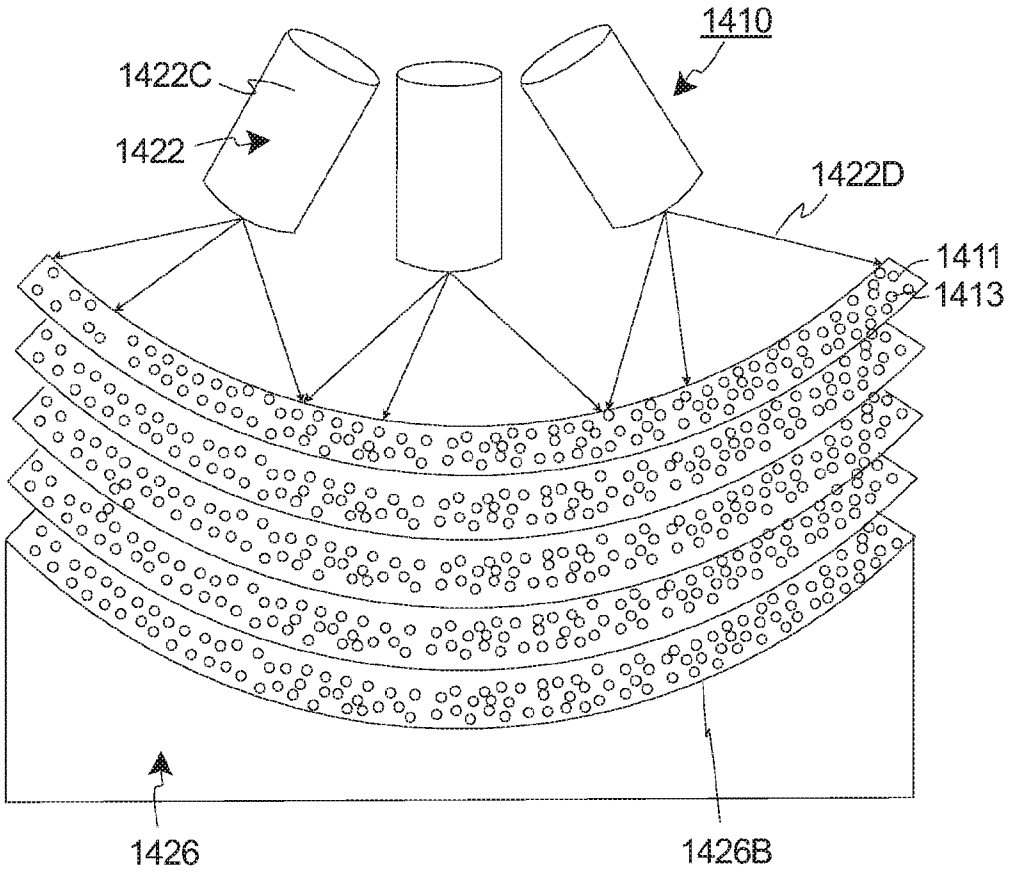

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Fig. 14

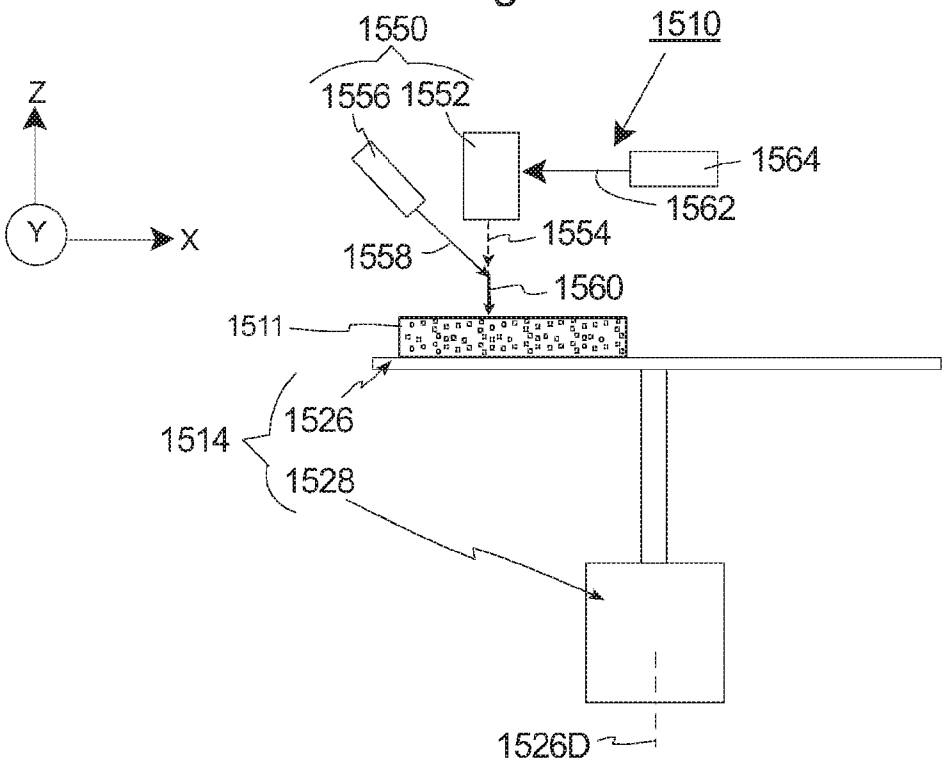

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Fig. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/040472

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22F3/105 B29C64/153 B29C64/236 B29C64/241 B29C64/245
B29C64/268 B29C64/291 B29C64/295 B29C64/393 B33Y10/00
B33Y30/00 B33Y50/02 B23K15/00 G01B9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22F B29C B33Y C22C B23K G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 3 269 473 A1 (UNIV TSINGHUA [CN]) 17 January 2018 (2018-01-17)	1-25, 27-42, 54-82, 84-96, 107-109
Y	paragraph [0040] - paragraph [0041] figure 3 paragraph [0051] - paragraph [0052] paragraph [0062]	26, 43-52, 83, 97-106

X	EP 2 937 163 A1 (JEOL LTD [JP]) 28 October 2015 (2015-10-28)	1-25, 27-42, 53-82, 84-96
Y	figures 1,2,3a,3b,3c paragraph [0011] - paragraph [0015] paragraph [0027] - paragraph [0030] paragraph [0032] - paragraph [0040]	26, 43-52, 83, 97-106

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 October 2020	30/10/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Godino Martinez, M

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/040472

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 2016/167160 A1 (HELLESTAM CALLE [SE]) 16 June 2016 (2016-06-16) paragraph [0060] figure 1	43-52, 97-106
A,P	WO 2019/185642 A1 (FREEMELT AB [SE]) 3 October 2019 (2019-10-03) figures 1,2,3,4 page 4, line 14 - line 29 page 5, line 10 - line 29 page 9, line 11 - line 23 claim 3 page 4, line 20 - page 7, line 20	1-109
A,P	WO 2019/136523 A1 (FLEW SOLUTIONS AUSTRALIA LTD [AU]) 18 July 2019 (2019-07-18) figures 1,2, 3a,3b,3c,3d claims 1-12	1-109

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2020/040472

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