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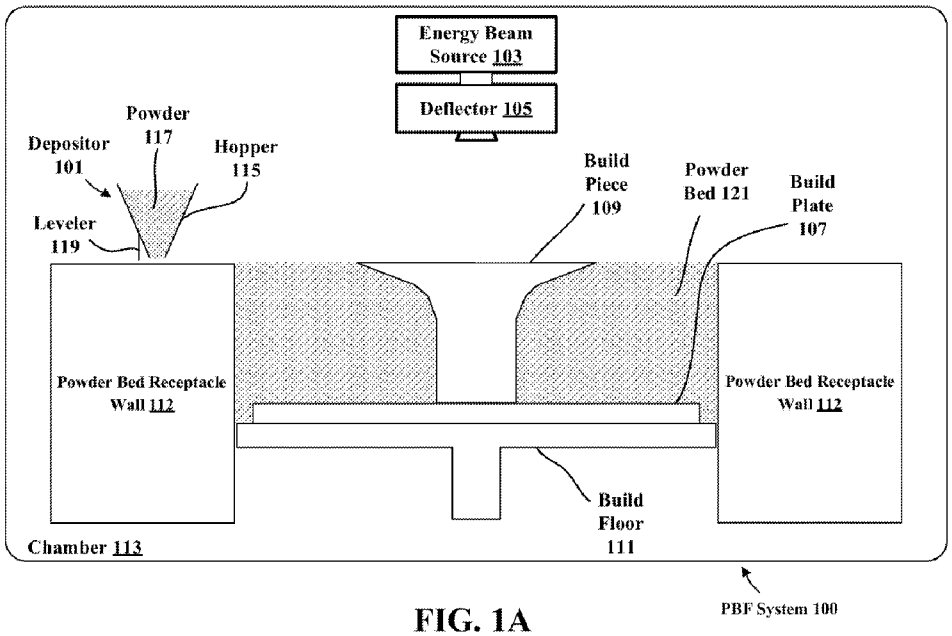


FIG. 1A

(57) Abstract: According to some configurations of the present disclosure, an alloy may include a composition that includes magnesium (Mg) that is approximately 1 to 5% by weight of the composition; silicon (Si) that is approximately 1 to 3% by weight of the composition; cobalt (Co) that is approximately 0.2 to 1% by weight of the composition; and aluminum (Al) that is a balance of the composition. In one configuration, the composition may further include one or more of nickel (Ni); titanium (Ti); zinc (Zn); zirconium (Zr); and/or manganese (Mn).

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ALUMINUM ALLOY COMPOSITIONS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/794,509, entitled "HIGH-PERFORMANCE ALUMINUM ALLOY" and filed on January 18, 2019, and U.S. Patent Application No. 16/526,679, entitled "ALUMINUM ALLOY COMPOSITIONS" and filed on July 30, 2019, which are expressly incorporated by reference herein in their entirety.

Technical Field

[0002] The present disclosure relates generally to alloys, and more specifically to aluminum alloys.

Description of the Related Technology

[0003] Additive Manufacturing (AM) processes involve the use of a stored geometrical model for accumulating layered materials on a "build plate" to produce three-dimensional (3-D) objects having features defined by the model. AM techniques are capable of printing complex components using a wide variety of materials. A 3-D object is fabricated based on a computer-aided design (CAD) model. The AM process can manufacture a solid three-dimensional object directly from the CAD model without additional tooling.

[0004] One example of an AM process is powder bed fusion (PBF), which uses a laser, electron beam, or other source of energy to sinter or melt metallic powder deposited on a powder bed, thereby consolidating powder particles together in targeted areas to produce a 3-D structure having the desired geometry. Different materials or combinations of materials, such as metals, plastics, and ceramics, may be used in PBF to create the 3-D object. Other more advanced AM techniques, including those discussed further below, are also available or under current development, and each may be applicable to the present disclosure.

[0005] Another example of an AM process is called Binder Jet (BJ) process that uses a powder bed (similar to PBF) in which metallic powder is spread in layers and bonded by using an organic binder. The resulting part is a green part which requires burning off the binder and sintering to consolidate the layers into full density. The metallic powder material can have the same chemical composition and similar physical characteristics as PBF powders.

[0006] Another example of an AM process is called Directed Energy Deposition (DED). DED is an AM technology that uses a laser, electron beam, plasma, or other method of energy supply, such as those in Tungsten Inert Gas (TIG), or Metal Inert Gas (MIG) welding to melt the metallic powder, wire, and/or rod, thereby transforming it into a solid metal object. Unlike many AM technologies, DED is not based on a powder bed. Instead, DED uses a feed nozzle to propel the powder or mechanical feed system to deliver wire and/or rod into the laser beam, electron beam, plasma beam or other energy stream. The powdered metal, wire, or rod are then fused by the respective energy beam. While supports or a freeform substrate may in some cases be used to maintain the structure being built, almost all the raw material (powder, wire, or rod) in DED is transformed into solid metal, and consequently, little waste powder is left to recycle. Using a layer by layer strategy, the print head, comprised of the energy beam or stream and the raw material feed system, can scan the substrate to deposit successive layers directly from a CAD model.

[0007] PBF, BJ, DED, and other AM processes may use various raw materials such as metallic powders, wires, or rods. The raw material may be made from various metallic materials. Metallic materials may include, for example, aluminum, or alloys of aluminum. It may be advantageous to use alloys of aluminum that have properties that improve functionality within AM processes. For example, particle shape, powder size, packing density, melting point, flowability, stiffness, porosity, surface texture, density electrostatic charge, as well as other physical and chemical properties may impact how well an aluminum alloy performs as a material for AM. Similarly, raw materials for AM processes can be in the form of wire or rod whose chemical composition and physical characteristics may impact the performance of the material. Some alloys may impact one or more of these or other traits that affect the performance of the alloy for AM.

[0008] One or more aspects of the present disclosure may be described in the context of the related technology. None of the aspects described herein are to be construed as an admission of prior art, unless explicitly stated herein.

SUMMARY

[0009] Several aspects of one or more alloys and compositions of alloys, as well as methods of making and/or using the same, are described herein. For example, one or more alloys or compositions thereof may be aluminum alloys. The one or more alloys may

be used in three-dimensional (3-D) printing and/or additive manufacturing to produce additively manufactured structures with the one of more alloys. Illustratively, an alloy may include a composition including a plurality of materials (e.g., elements, metals, etc.).

[0010] According to some configurations of the present disclosure, an alloy may comprise: a composition that includes: magnesium (Mg) that is approximately 1 to 5% by weight of the composition; silicon (Si) that is approximately 1 to 3% by weight of the composition; cobalt (Co) that is approximately 0.2 to 1% by weight of the composition; and aluminum (Al) that is a balance of the composition. In one configuration, the composition may further include at least one selected from: nickel (Ni); titanium (Ti); zinc (Zn); zirconium (Zr); and manganese (Mn). In one configuration, the composition includes up to approximately 5% by weight of the Ni. In one configuration, the composition includes at least approximately 1% by weight of the Ni. In one configuration, the composition includes up to approximately 0.5% by weight of the Ti. In one configuration, the composition includes at least 0.05% by weight of the Ti. In one configuration, the composition includes up to approximately 2% by weight of the Zn. In one configuration, the composition includes at least 0.1% by weight of the Zn. In one configuration, the composition includes up to approximately 0.5% by weight of the Zr. In one configuration, the composition includes at least 0.05% by weight of the Zr. In one configuration, the composition includes up to approximately 1% by weight of the Mn. In one configuration, the composition includes at least 0.2% by weight of the Mn. In one configuration, the composition includes all of the elements listed above (Al, Mg, Si, Co, Ni, Ti, Zn, Zr, and Mn). In one configuration, the balance of the Al of the composition includes up to approximately 0.1% by weight of trace impurities.

[0011] It will be understood that other aspects of alloys will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only several embodiments by way of illustration. As will be realized by those skilled in the art, the manufactured structures and the methods for manufacturing these structures are capable of other and different embodiments, and its several details are capable of modification in various other respects, all without departing from the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Various aspects of alloys that may be used for additive manufacturing, for example, in automotive, aerospace, and/or other engineering contexts are presented in the detailed description by way of example, and not by way of limitation, in the accompanying drawings, wherein:

[0013] FIGs. 1A-D illustrate respective side views of an exemplary 3-D printer system.

DETAILED DESCRIPTION

[0014] The detailed description set forth below in connection with the appended drawings is intended to provide a description of various exemplary embodiments of aluminum alloys are not intended to represent the only embodiments in which the invention may be practiced. The term "exemplary" used throughout this disclosure means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other embodiments presented in this disclosure. The detailed description includes specific details for the purpose of providing a thorough and complete disclosure that fully conveys the scope of the invention to those skilled in the art. However, the techniques and approaches of the present disclosure may be practiced without these specific details. In some instances, well-known structures and components may be shown in block diagram form, or omitted entirely, in order to avoid obscuring the various concepts presented throughout this disclosure.

[0015] AlSi10Mg (AA 4046) is an aluminum alloy that may be used for Additive Manufacturing (AM) techniques, such as Selective Laser Melting (SLM) and/or Powder Bed Fusion (PBF). However, AA 4046 is primarily a welding alloy for joining automotive aluminum parts. When processed by additive manufacturing, this alloy yields moderate strength but poor ductility. AA 4046 has good welding properties where the weld pool is large and cooling rate is relatively slow. Additionally, AA 4046 may be used in cases where a joint design can tolerate poor properties. For example, some environments may cause a reduction in fatigue life of a component due to a corrosive environment compared to the performance of the component in air. The reduction in fatigue life may be referred to as a knockdown factor. However, in AM, the whole part is built with micro-welds with extremely small weld pools and rapid melting and cooling.

[0016] Accordingly, with AM, there should be little or no compromise through design knockdown. Extremely high attention has been placed on the improvement of properties of AA 4046, resulting in a voluminous array of investigations without significant property improvements for engineering applications that require high performance and reliability. Still, the tested mechanical properties of AA 4046 may be inferior to those commonly used in wrought and cast form for high-strength applications. In addition, some aluminum alloys are unavailable and/or impractical for commercial use in AM, such as aluminum alloys in the 6000 and 7000 series.

[0017] Some high-performance aluminum alloys have been developed that may differ from AA 4046, aluminum alloys in the 6000 and 7000 series, and/or other commercially available aluminum alloys. Such high-performance alloys may include Scalmalloy® and A205. However, the applications of various high-performance aluminum alloys, including Scalmalloy® and A205, may be economically prohibitive in AM contexts.

[0018] In view of the foregoing, there exists a need for alloys that are high performance and economically feasible for AM in various automotive, aerospace, and/or other engineering applications. The present disclosure describes alloys that may be implemented in AM processes, such as SLM, PBF, DED, and others. In this way, for example, additively manufactured structures of the alloys disclosed in this invention may be produced. The alloys of the present disclosure may provide improved properties for AM in automotive, aerospace, and/or other engineering applications. The alloys may yield improved performance in AM contexts, such as one or more of high strength (e.g., yield strength), ductility, fracture toughness, fatigue strength, corrosion resistance, elevated temperature strength, percent elongation, and/or any combination thereof. Furthermore, application of the alloys of the present disclosure may be economically feasible, for example, in a commercial context and/or production scale for AM in automotive, aerospace, and/or other engineering applications.

[0019] In an aspect, high-performance aluminum alloys are described. Crashworthiness is a combination of tensile, shear, and compression strengths that make up a material's crash performance. The analytical and experimental data are utilized by a variety of industries (e.g., automotive) while designing and engineering structures incorporating the materials.

[0020] High-performance aluminum alloys processed with conventional techniques (e.g., non-AM processes) may obtain various properties through one or combination of the

following processes: solid solution strengthening, strain hardening, precipitation strengthening, and/or dispersion strengthening. The processes of solid solution strengthening, strain hardening, precipitation strengthening, grain or phase boundary strengthening, and/or dispersion strengthening may take place during solidification, subsequent thermal processing, intermediate cold working, or some combination of these.

[0021] Solidification processes and subsequent cooling in solid state in AM may differ from those processes occurring through conventional techniques. For example, the solidification in PBF processing occurs on a microscale, layer by layer, with each layer undergoing one or more melting, solidification, and cooling cycles. In such a process, melting may begin at approximately 610°C and may conclude at approximately 696°C. Due to the small size of the melt pool, the cooling rate is extremely high relative to conventional techniques – e.g., the cooling rate may be from approximately 10^3 °C/second (s) to approximately 10^6 °C/s. Therefore, non-equilibrium thermodynamics and phase transformation kinetics may become the dominant drivers during AM, thereby making alloys exhibit different properties with AM, such as through inheriting element supersaturation and alloy partitioning.

[0022] Not all alloys (e.g., AA 4046, etc.) may be suitable for the rapid solidification through AM, which may include relatively small weld pools (and may include a rate of approximately 10^3 °C/ s to approximately 10^6 °C/s). The present disclosure describes alloys that may provide high performance with AM, e.g., in comparison to currently available alloys. The performance of these alloys of the present disclosure may be improved in the as-printed state, e.g., after undergoing thermal processing (post AM), or some combination of both in the as-printed state and after undergoing thermal processing.

[0023] In one exemplary configuration, one or more alloys of the present disclosure may be tailored for superior strengthening where the one or more alloys would have high ultimate and tensile strength at room and elevated temperature. In another exemplary configuration, one or more of the alloys of the present disclosure may be designed for superior ductility where the one or more alloys would have high elongation at room and elevated temperatures.

[0024] The nominal chemical composition of the common AA 4046 includes 11% silicon (Si), 0.55% iron (Fe), 0.45% manganese (Mn), 0.45% magnesium (Mg), and balance aluminum (Al). The as-printed tensile properties of AA 4046 are up to 6% elongation,

up to 301 megapascal (MPa) yield strength, and up to 459 MPa ultimate tensile strength. High-performance aluminum alloys, such as Scalmalloy®, have nominal chemical compositions of 4.5% Mg, 0.7% scandium (Sc), 0.3% zirconium (Zr), 0.5% Mn, with heat-treated properties of up to 13% elongation, up to 469 MPa yield strength, and up to 495 MPa ultimate tensile strength. However, the aforementioned high-performance aluminum alloys are economically infeasible for production scale and/or commercial consumer applications (e.g., automotive applications).

[0025] According to some configurations, one or more alloys of the present disclosure may be configured with elongation percentage exceeding that of some existing aluminum alloys, such as AA 4046. While the advertised and tested elongation percentage of AA 4046 is approximately 6% and 4%, respectively, an elongation of one or more alloys of the present disclosure may be approximately 8%. Therefore, one or more alloys described herein may exceed the elongation percentage of the conventional AA 4046 by approximately 2%, e.g., in the as-printed condition. Post-processing techniques, such as heat treatment and/or surface (shot) peening, may further increase the elongation percentage of the one or more alloys described herein. For example, heat treatment may include treating an aluminum alloy as described herein at a temperature between approximately 100°C to approximately 400°C for a time of approximately 30 minutes to approximately 30 hours.

[0026] In addition, the strength(s) of the one or more alloys described herein may exceed that of some existing aluminum alloys. For example, one or more alloys described herein may have an average yield strength of 363 MPa. This average yield strength may exceed some aluminum alloys of the 7000 series (e.g., Al 7075) in AM. The alloying elements in the aluminum matrix may create strengthening mechanisms intrinsic to chemistry and, through AM, the resultant material including the alloying elements of the present disclosure may be approximately 80% stronger than AA 4046. One or more alloys of the present disclosure may derive strength(s) through solid solution strengthening, micro-precipitation hardening, nano-precipitation hardening, reduced grain size, and/or strain hardening.

[0027] One or more alloys of the present disclosure may be specifically designed in order to accommodate the rapid melting, solidification, and/or cooling experienced by alloys in AM (e.g., PBF process). For example, the alloying elements and concentrations thereof may be configured such that intermetallics may be formed with other alloying elements during rapid cooling. Further, the alloying elements and concentrations

thereof may be configured based on the liquid and/or solid solubilities of the alloying elements in the aluminum matrix. The alloying elements and concentrations thereof may be configured such that the alloying elements may form supersaturated solid solutions and/or nano-precipitates after rapid solidification and cooling during AM (e.g., PBF process). The alloying elements and the concentrations thereof may be configured to form intermetallics and the phases thereof during subsequent thermal processing, for example, including precipitation heat treatment and/or Hot Isostatic Pressing (HIP). Finally, the alloying elements and concentrations thereof may be configured to form intermetallics during rapid solidification and cooling such that the phases formed thereby may enhance the performance of the one or more alloys of the present disclosure. Additionally, the configurations of the alloying elements and the concentrations thereof may result in the formation of phases during subsequent thermal processing that improves the mechanical performance of the one or more alloys of the present disclosure.

[0028] Example elements that may be used to form aluminum alloys in some examples may include cobalt (Co), silicon (Si), Mg, and balance Al. In some further configurations, example elements that may be used to form aluminum alloys in some further examples may include nickel (Ni), titanium (Ti), zinc (Zn), Zr, Mn, or some combination of these elements (or other elements as discussed here). Configuring one or more alloys of the present disclosure with Co may contribute to precipitation hardening of the one or more alloys. Exemplary concentrations of Co may be 0.2-1% by weight of an alloy described herein. Configuring one or more alloys of the present disclosure with Si may contribute to precipitation hardening. Exemplary concentrations of Si may be 1-3% by weight of an alloy described herein. Configuring one or more alloys of the present disclosure with Zr may contribute to precipitation hardening. Exemplary concentrations of Zr may be 0.05-0.5% by weight of an alloy described herein. Configuring one or more alloys of the present disclosure with Ti may contribute to solid solution strengthening. Exemplary concentrations of Ti may be 0.05-0.5% by weight of an alloy described herein. Configuring one or more alloys of the present disclosure with Mg may contribute to solid solution strengthening. Exemplary concentrations of Mg may be 1-5% by weight of an alloy described herein. Configuring one or more alloys of the present disclosure with Zn may contribute to solid solution strengthening. Exemplary concentrations of Zn may be 0.1-2% by weight of an alloy described herein. Configuring one or more alloys of the present

disclosure with Mn may contribute to solid solution strengthening. Exemplary concentrations of Mn may be 0.2-1% by weight of an alloy described herein. One or more alloys of the present disclosure may include a balance of Al, which may include at most 0.1% by weight of trace elements.

[0029] AM processes may use various metallic powders, such as aluminum alloys. FIGs. 1A-D illustrate respective side views of an exemplary 3-D printer system. In this example, the 3-D printer system is a powder-bed fusion (PBF) system 100. FIGs. 1A-D show PBF system 100 during different stages of operation. It should also be noted that elements of FIGs. 1A-D and the other figures in this disclosure are not necessarily drawn to scale, but may be drawn larger or smaller for the purpose of better illustration of concepts described herein.

[0030] The particular embodiments illustrated in FIGs. 1A-D are some suitable examples of a PBF system employing principles of this disclosure. Specifically, one or more of the aluminum alloys described herein may be used in at least one PBF system 100 described in FIGs. 1A-D. While one or more aluminum alloys described in the present disclosure may be suitable for various AM processes (e.g., using a PBF system, as shown in FIGs. 1A-D), it will be appreciated that one or more aluminum alloys of the present disclosure may be suitable for other applications, as well. For example, one or more aluminum alloys described herein may be used in other fields or areas of manufacture without departing from the scope of the present disclosure. Accordingly, AM processes employing the one or more aluminum alloys of the present disclosure are to be regarded as illustrative, and are not intended to limit the scope of the present disclosure.

[0031] According to some examples of the present disclosure, an aluminum alloy used in PBF system 100 may be a composition that includes a balance of Al, Mg that is 0 to 5% by weight of the composition, Si that is 0.5 to 4% by weight of the composition, and Co that is 0.2 to 5% by weight of the composition. In a specific configuration, the Mg may be 1 to 5% by weight of the composition, Si may be 1 to 3% by weight of the composition, and Co may be 0.2 to 1% by weight of the composition.

[0032] In some further configurations, the composition may further include at least one selected from a group of Ni, Ti, Zn, Zr, and/or Mn. In one example, the composition may include Ti that is least 0.05% by weight of the composition. The composition may include up to 0.5% by weight of Ti. In another example, the composition may include Zr that is at least 0.05% by weight of the composition. The composition may

include up to 0.5% by weight of Zr. In a further example, the composition may include Mn that is up to 1% by weight of the composition. The composition may include at least 0.2% by weight of Mn. In still another example, the composition may include Ni that is 1 to 5% by weight of the composition. In yet a further example, the composition may include Zn that is 0.1 to 2% by weight of the composition. In some examples, the composition may include up to approximately 0.1% by weight of trace impurities cumulatively, and 0.01% individually (e.g., in each individual element that is alloyed with the balance of Al).

[0033] Prior to use in PBF system 100, the elements of an aluminum alloy may be combined into a composition according to one of the examples/configurations described herein. For example, the elements in respective concentrations described in one of the examples/configurations of the present disclosure may be combined when the elements are molten. The composition may be mixed while the elements are molten, e.g., in order to promote even distribution of each element with the balance of Al. The molten composition may be cooled and atomized. Atomization of the composition may yield a metallic powder that includes the elements of the one of the examples/configurations of the present disclosure, and can be used in additive manufacturing systems such as PBF system 100.

[0034] PBF system 100 can include a depositor 101 that can deposit each layer of metal powder, an energy beam source 103 that can generate an energy beam, a deflector 105 that can apply the energy beam to fuse the powder material, and a build plate 107 that can support one or more build pieces, such as a build piece 109. PBF system 100 can also include a build floor 111 positioned within a powder bed receptacle. The walls 112 of the powder bed receptacle generally define the boundaries of the powder bed receptacle, which is sandwiched between the walls 112 from the side and abuts a portion of the build floor 111 below. Build floor 111 can progressively lower build plate 107 so that depositor 101 can deposit a next layer. The entire mechanism may reside in a chamber 113 that can enclose the other components, thereby protecting the equipment, enabling atmospheric and temperature regulation and mitigating contamination risks. Depositor 101 can include a hopper 115 that contains a powder 117, such as a metal powder, and a leveler 119 that can level the top of each layer of deposited powder.

[0035] Referring specifically to FIG. 1A, this figure shows PBF system 100 after a slice of build piece 109 has been fused, but before the next layer of powder has been

deposited. In fact, FIG. 1A illustrates a time at which PBF system 100 has already deposited and fused slices in multiple layers, e.g., 150 layers, to form the current state of build piece 109, e.g., formed of 150 slices. The multiple layers already deposited have created a powder bed 121, which includes powder that was deposited but not fused.

[0036] FIG. 1B shows PBF system 100 at a stage in which build floor 111 can lower by a powder layer thickness 123. The lowering of build floor 111 causes build piece 109 and powder bed 121 to drop by powder layer thickness 123, so that the top of the build piece and powder bed are lower than the top of powder bed receptacle wall 112 by an amount equal to the powder layer thickness. In this way, for example, a space with a consistent thickness equal to powder layer thickness 123 can be created over the tops of build piece 109 and powder bed 121.

[0037] FIG. 1C shows PBF system 100 at a stage in which depositor 101 is positioned to deposit the powder 117 in a space created over the top surfaces of build piece 109 and powder bed 121 and bounded by powder bed receptacle walls 112. In this example, depositor 101 progressively moves over the defined space while releasing the powder 117 from hopper 115. Leveler 119 can level the released powder to form a powder layer 125 that has a thickness substantially equal to the powder layer thickness 123 (*see* FIG. 1B). Thus, the powder in a PBF system can be supported by a powder material support structure, which can include, for example, a build plate 107, a build floor 111, a build piece 109, walls 112, and the like. It should be noted that the illustrated thickness of powder layer 125 (i.e., powder layer thickness 123 (FIG. 1B) is greater than an actual thickness used for the example involving 150 previously-deposited layers discussed above with reference to FIG. 1A.

[0038] FIG. 1D shows PBF system 100 at a stage in which, following the deposition of powder layer 125 (FIG. 1C), energy beam source 103 generates an energy beam 127 and deflector 105 applies the energy beam to fuse the next slice in build piece 109. In various exemplary embodiments, energy beam source 103 can be an electron beam source, in which case, energy beam 127 constitutes an electron beam. Deflector 105 can include deflection plates that can generate an electric field or a magnetic field that selectively deflects the electron beam to cause the electron beam to scan across areas designated to be fused. In various embodiments, energy beam source 103 can be a laser, in which case, the energy beam 127 is a laser beam. Deflector 105 can include

an optical system that uses reflection and/or refraction to manipulate the laser beam to scan selected areas to be fused.

[0039] In various embodiments, the deflector 105 can include one or more gimbals and actuators that can rotate and/or translate the energy beam source to position the energy beam. In various embodiments, energy beam source 103 and/or deflector 105 can modulate the energy beam, e.g., turn the energy beam on and off as the deflector scans so that the energy beam is applied only in the appropriate areas of the powder layer. For example, in various embodiments, the energy beam can be modulated by a digital signal processor (DSP).

[0040] An alloy may be a substance composed of two or more materials (e.g., metals or nonmetals). The two or more materials may be combined together by being merged together, for example, when molten.

[0041] In some configurations, one or more alloys of the present disclosure may be a composition that may be mixed to include a balance of Al and the following materials: (1) Mg that is approximately 1-5% by weight of the composition; (2) Si that is approximately 1-3% by weight of the composition; (3) Co that is 0.2-1% by weight of the composition. In some configurations, the balance of Al may include up to 0.1% of trace elements.

[0042] In some other configurations, one or more alloys of the present disclosure may be the aforementioned composition of Al, Mg, Si, and Co, and the composition may include at least one of the following other materials: Ni, Ti, Zn, Zr, and/or Mn. When an alloy of the present disclosure is a composition that includes Ni, Ni may be 1-5% by weight of the composition. When an alloy of the present disclosure is a composition that includes Ti, Ti may be 0.05-0.5% by weight of the composition. When an alloy of the present disclosure is a composition that includes Zn, Zn may be 0.1-2% by weight of the composition. When an alloy of the present disclosure is a composition that includes Zr, Zr may be 0.05-0.5% by weight of the composition. When an alloy of the present disclosure is a composition that includes Mn, Mn may be 0.2-1% by weight of the composition. In various configurations, the one or more alloys of the present disclosure may include all, none, or some of the other materials Ni, Ti, Zn, Zr, and/or Mn.

[0043] An exemplary alloy of the present disclosure may include the elements in the amounts as shown in Table 1.

Element	Co	Ti	Si	Mg	Zn	Zr	Mn	Al
Weight%	0.2-0.5	0.05-0.3	1.8-2.2	2-5	0.05-0.3	0.1-0.5	0.3-0.8	Balance

Table 1

[0044] The example alloy may include specific amounts of Co, Ti, Si, Mg, Zn, Zr, Mn, and the balance of Al. Example I of Table 2 shows an example configuration.

Example I:

Element	Co	Ti	Si	Mg	Zn	Zr	Mn	Al
Weight%	.29	0.152	1.77	3.64	0.124	0.3	0.56	Balance

Table 2

[0045] The example alloy (Example I) may be processed with the L-PBF method to print test bars. The tensile properties obtained are shown in Table 3.

Property	% Elongation	YS (MPa)	UTS (MPa)
Value	8	362	440

Table 3

[0046] By way of illustration, the properties of AA 4046 in an as-printed condition may be given by Table 4, which illustrates a set of properties obtained from a set of tests of as-printed AA 4046 (note the last row illustrates the average value of the property across the set of tests).

Property	% Elongation	YS (MPa)	UTS (MPa)
Value 1	4	270	375
Value 2	5.3	322	434

Value 3	7.2	311	391
Value 4	5.4	300	455
Value 5	1.2	255	377
Average	4.62	291.6	406.4

Table 4

[0047] The aluminum alloy may be formed into a powder, wire, or rod, e.g., for use in AM. AM raw materials may be manufactured by powder making processes as well as other methods, such as ingot metallurgy (I/M) in which a solid ingot is manufactured by melting the metal along with added alloying elements and solidifying in a mold (e.g., ingot). The molded solid or ingot is then deformed by various wrought material production methods, such as rolling, extrusion, drawing, etc. The ingots, wires, and rods are either melted and atomized to make powders or fed directly into the laser, electron, plasma beams, or electrical arc, such as TIG, MIG, to melt the metal layer by layer for the manufacture of AM products.

[0048] Powder characteristics may be important for successful fusion within an AM machine such as PBF and/or DMD. Some aspects of alloy powders that may be advantageous for use with AM may include but are not limited to, good flow, close packing of particles and spherical particle shape. These aspects may lead to consistent and predictable layers.

[0049] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these exemplary embodiments presented throughout this disclosure will be readily apparent to those skilled in the art, and the concepts disclosed herein may be applied to aluminum alloys. Thus, the claims are not intended to be limited to the exemplary embodiments presented throughout the disclosure but are to be accorded the full scope consistent with the language claims. All structural and functional equivalents to the elements of the exemplary embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C.

§112(f), or analogous law in applicable jurisdictions, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

WHAT IS CLAIMED IS:

1. An alloy comprising:
a composition that includes:
magnesium (Mg) that is 0 to 5% by weight of the composition;
silicon (Si) that is 0.5 to 4% by weight of the composition;
cobalt (Co) that is 0.2 to 5% by weight of the composition; and
aluminum (Al) that is a balance of the composition.

2. The alloy of claim 1, wherein the composition includes:
Mg that is 1 to 5% by weight of the composition;
Si that is 1 to 3% by weight of the composition;
Co that is 0.2 to 1% by weight of the composition.

3. The alloy of claim 1, wherein the composition further includes at least one of:
nickel (Ni);
titanium (Ti);
zinc (Zn);
zirconium (Zr); or
manganese (Mn).

4. The alloy of claim 3, wherein the composition includes:
Ti that is least 0.05% by weight of the composition;
Zr that is at least 0.05% by weight of the composition; and
Mn that is up to 1% by weight of the composition.

5. The alloy of claim 3, wherein composition includes up to 5% by weight of the Ni.

6. The alloy of claim 5, wherein the composition includes at least 1% by weight of the Ni.

7. The alloy of claim 3, wherein composition includes up to 0.5% by weight of the Ti.

8. The alloy of claim 7, wherein the composition includes at least 0.05% by weight of the Ti.

9. The alloy of claim 3, wherein composition includes up to 2% by weight of the Zn.

10. The alloy of claim 9, wherein the composition includes at least 0.1% by weight of the Zn.

11. The alloy of claim 3, wherein composition includes up to 0.5% by weight of the Zr.

12. The alloy of claim 11, wherein the composition includes at least 0.05% by weight of the Zr.

13. The alloy of claim 3, wherein composition includes up to 1% by weight of the Mn.

14. The alloy of claim 13, wherein the composition includes at least 0.2% by weight of the Mn.

15. The alloy of claim 1, wherein the balance of the Al of the composition includes up to 0.1% by weight of trace impurities.

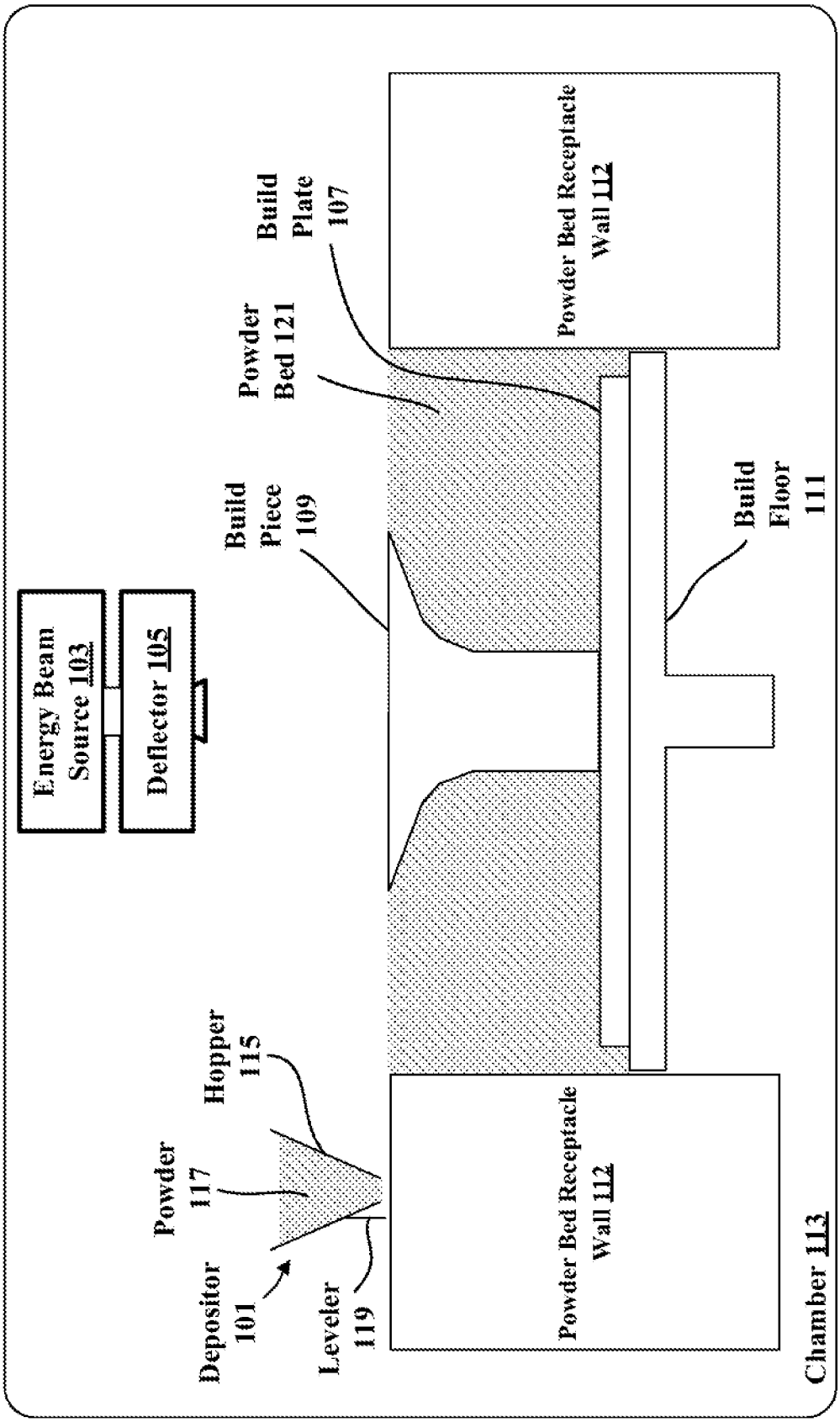

PBF System 100
Chamber 113
Powder Bed Receptacle Wall 112
Powder Bed Receptacle Wall 112
Build Floor 111
Build Piece 109
Powder Bed 121
Build Plate 107
Energy Beam Source 103
Deflector 105
Hopper 115
Powder 117
Depositor 101
Leveler 119

FIG. 1A

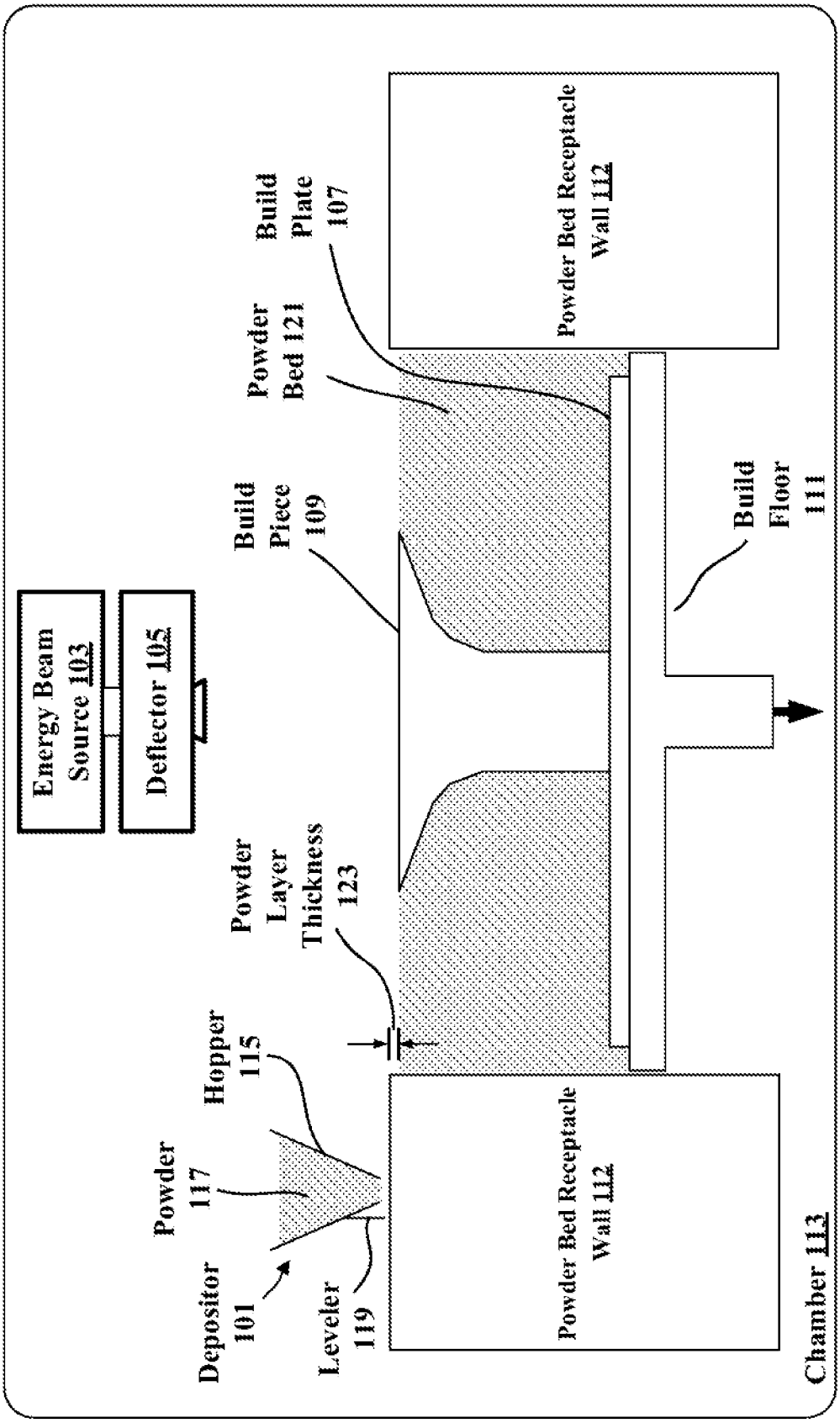

Energy Beam Source 103
Deflector 105
Build Piece 109
Powder Bed 121
Build Plate 107
Powder Bed Receptacle Wall 112
Build Floor 111
PBF System 100
Powder Layer Thickness 123
Hopper 115
Powder 117
Depositor 101
Leveler 119
Powder Bed Receptacle Wall 112
Chamber 113

FIG. 1B

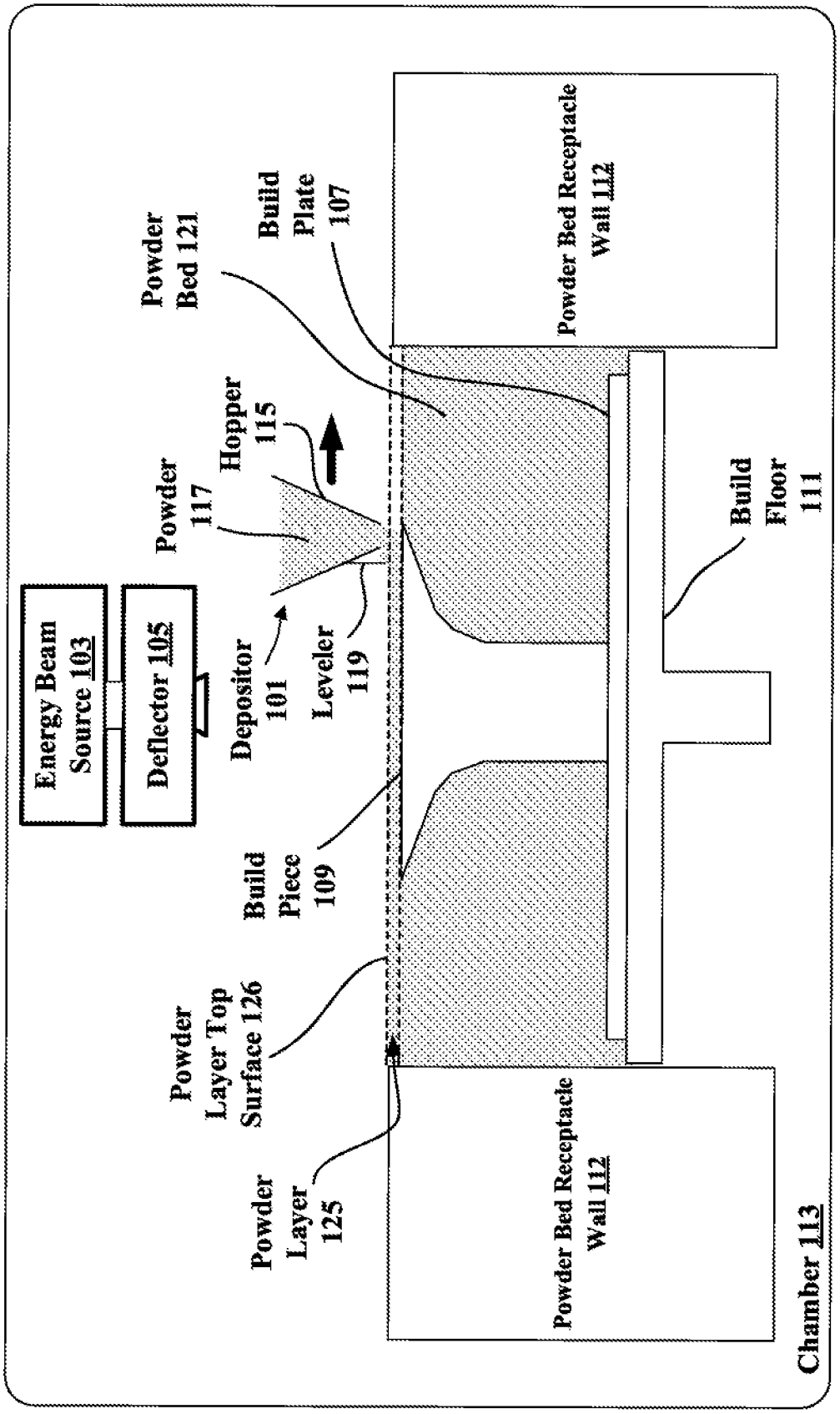

Energy Beam Source 103
Deflector 105
Depositor 101
Leveler 119
Powder 117
Hopper 115
Powder Bed 121
Build Plate 107
Powder Bed Receptacle Wall 112
PBF System 100
Build Floor 111
Build Piece 109
Powder Layer Top Surface 126
Powder Layer 125
Powder Bed Receptacle Wall 112
Chamber 113

FIG. 1C

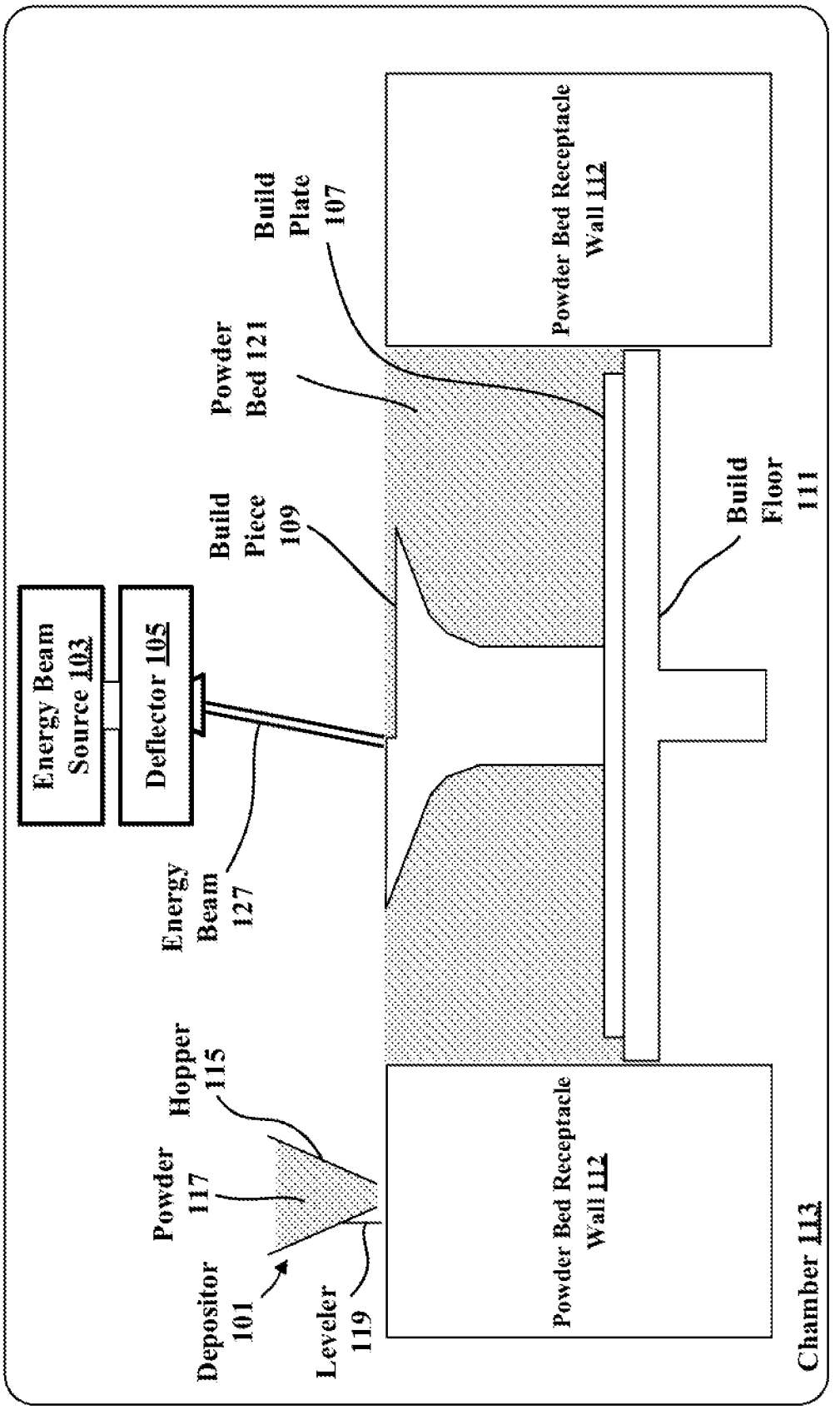

Energy Beam Source 103
Deflector 105
Energy Beam 127
Build Piece 109
Powder Bed 121
Build Plate 107
Powder Bed Receptacle Wall 112
Build Floor 111
PBF System 100
Hopper 115
Powder 117
Depositor 101
Leveler 119
Powder Bed Receptacle Wall 112
Chamber 113

FIG. 1D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/12726

A. CLASSIFICATION OF SUBJECT MATTER

IPC - C22C 21/00; C23C 10/30; C23C 2/12 (2020.01)

CPC - B32B 15/01; C22C 21/00; C23C 10/30; C23C 2/12

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)
See Search History document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/0198152 A1 (THYSSENKRUPP STEEL EUROPE AG et al.) 13 July 2017 (13.07.2017) entirety of document especially claims 19-20	1-15
X	US 2017/0069403 A1 (FURUKAWA ELECTRIC CO., LTD. et al.) 09 March 2017 (09.03.2017) entirety of document esp. para [0017]	1-5, 7-8, 11-15
X	US 2008/0175750 A1 (ZI LIi et al.) 24 July 2008 (24.07.2008) entirety of document especially para [0015]	1-15
A	US 4,021,271 A (ROBERTS, S.) 03 May 1977 (03.05.1977) entirety of document	1-15
A	US 3,958,987 A (CHIA E. H. et al.) 25 May 1976 (25.05.1976) entirety of document	1-15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 February 2020	02 APR 2020
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300