US 20140010951A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2014/0010951 A1**

(43) **Pub. Date: Jan. 9, 2014**

Vargas et al.

(54) **POROUS METAL IMPLANTS MADE FROM CUSTOM MANUFACTURED SUBSTRATES**

(71) Applicant: **Zimmer, Inc.**, Warsaw, IN (US)

(72) Inventors: **Joseph R. Vargas**, Garnerville, NY (US); **Steven Seelman**, Montclair, NJ (US); **Emmanuel L. Uzuyem**, Union, NJ (US); **Joseph P. Zitelli**, River Edge, NJ (US)

(21) Appl. No.: **13/926,658**

(22) Filed: **Jun. 25, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/664,241, filed on Jun. 26, 2012.

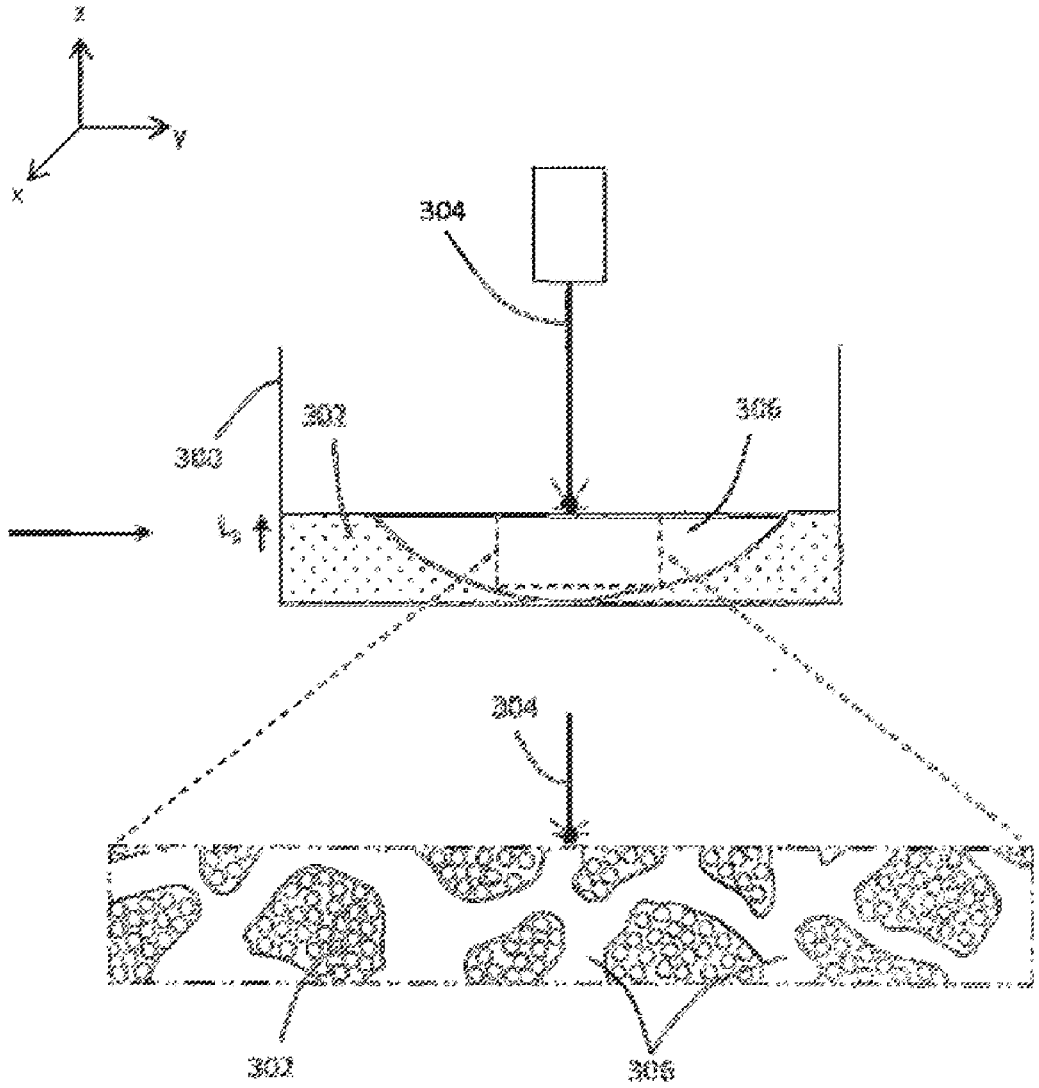
Publication Classification

(51) **Int. Cl.**
C23C 16/06 (2006.01)

(52) **U.S. Cl.**
CPC *C23C 16/06* (2013.01)
USPC **427/2.26**

(57) **ABSTRACT**

A porous metal implant and method of manufacturing the same are disclosed. The method involves rapidly manufacturing a porous substrate layer-by-layer. The method can include the steps of depositing a first layer of a material and depositing a second layer of the material on top of the first layer. In this manner, a porous substrate having a plurality of ligaments or struts, which define a plurality of pores, can be built. The method can also include coating the porous substrate with a biocompatible metal to strengthen and stabilize the porous substrate for implantation.



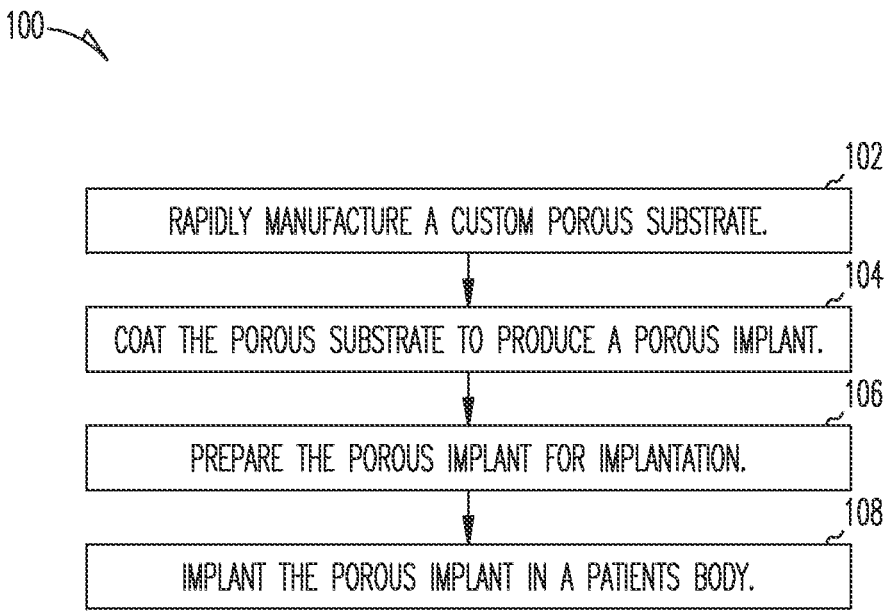

100
102
RAPIDLY MANUFACTURE A CUSTOM POROUS SUBSTRATE.
104
COAT THE POROUS SUBSTRATE TO PRODUCE A POROUS IMPLANT.
106
PREPARE THE POROUS IMPLANT FOR IMPLANTATION.
108
IMPLANT THE POROUS IMPLANT IN A PATIENTS BODY.

FIG. 1

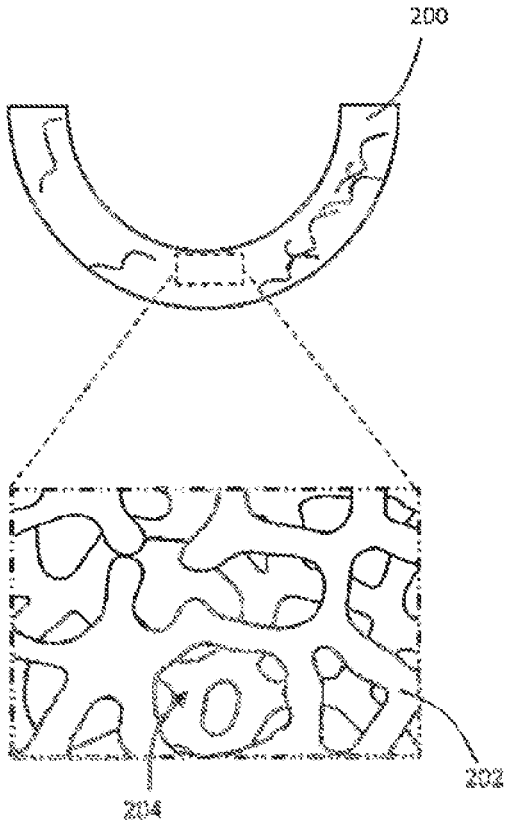


FIG. 2

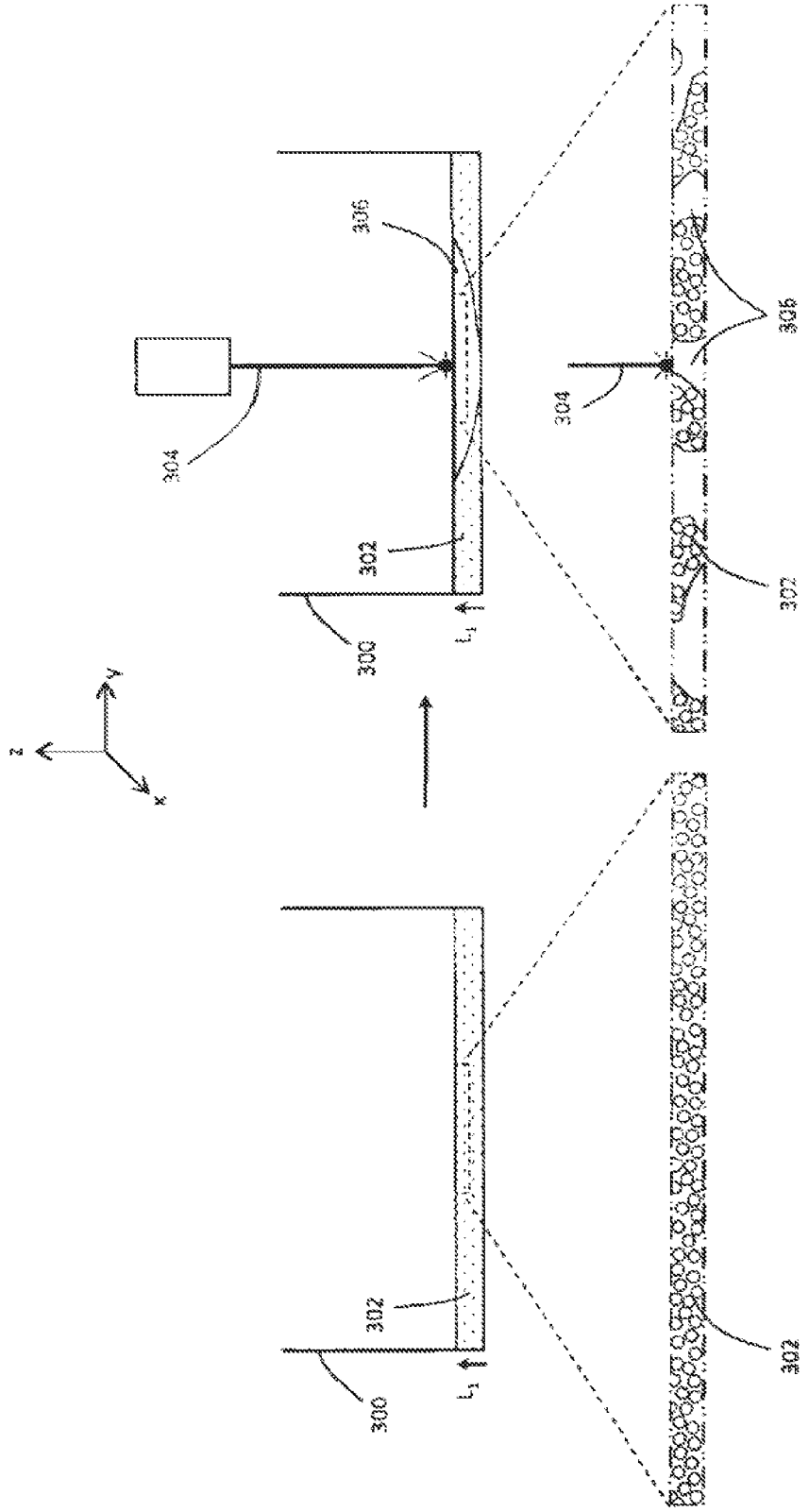


FIG. 3

FIG. 4

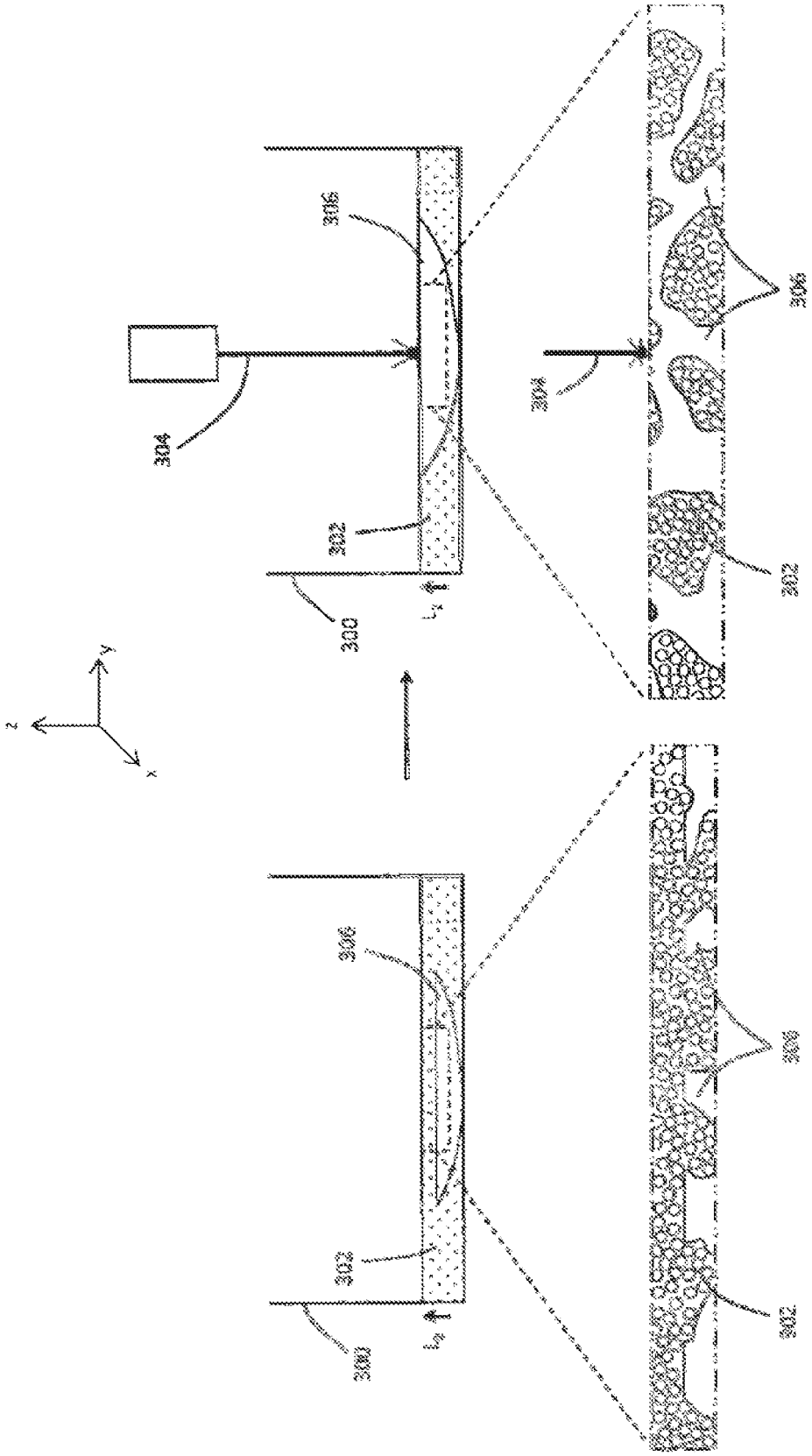


FIG. 6

FIG. 5

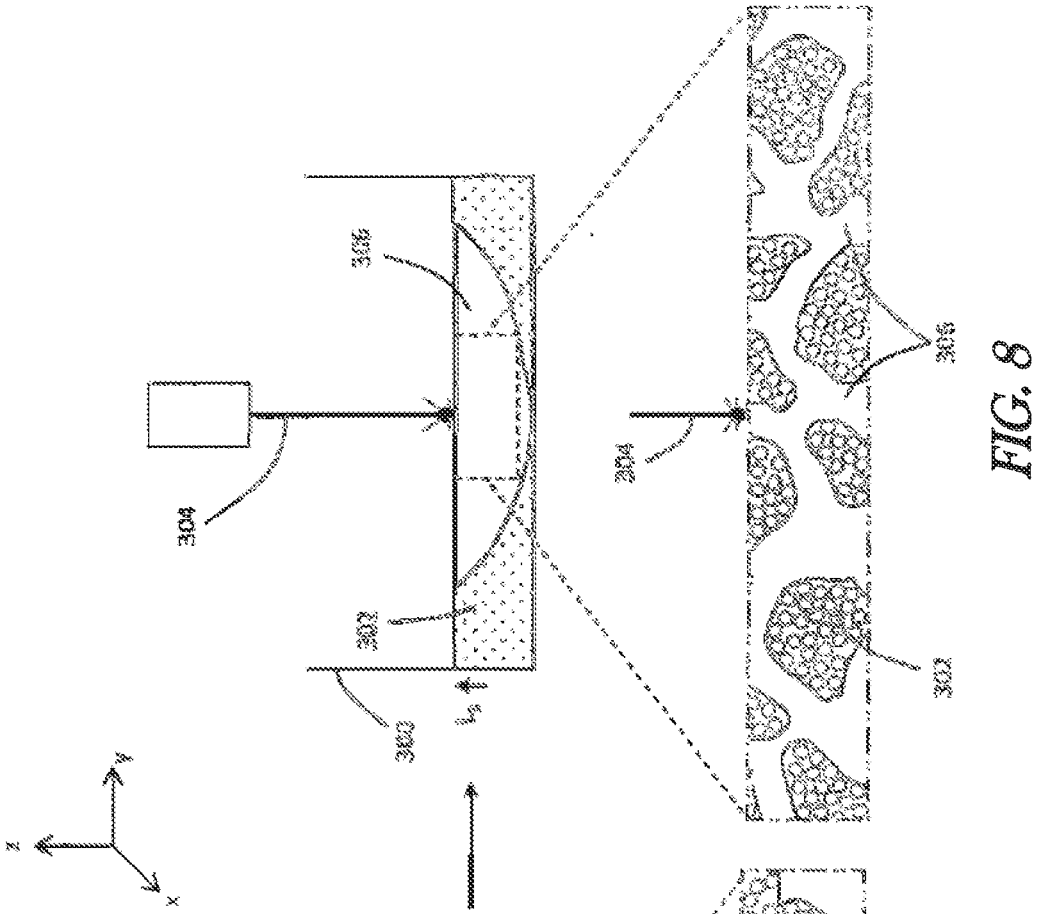


FIG. 8

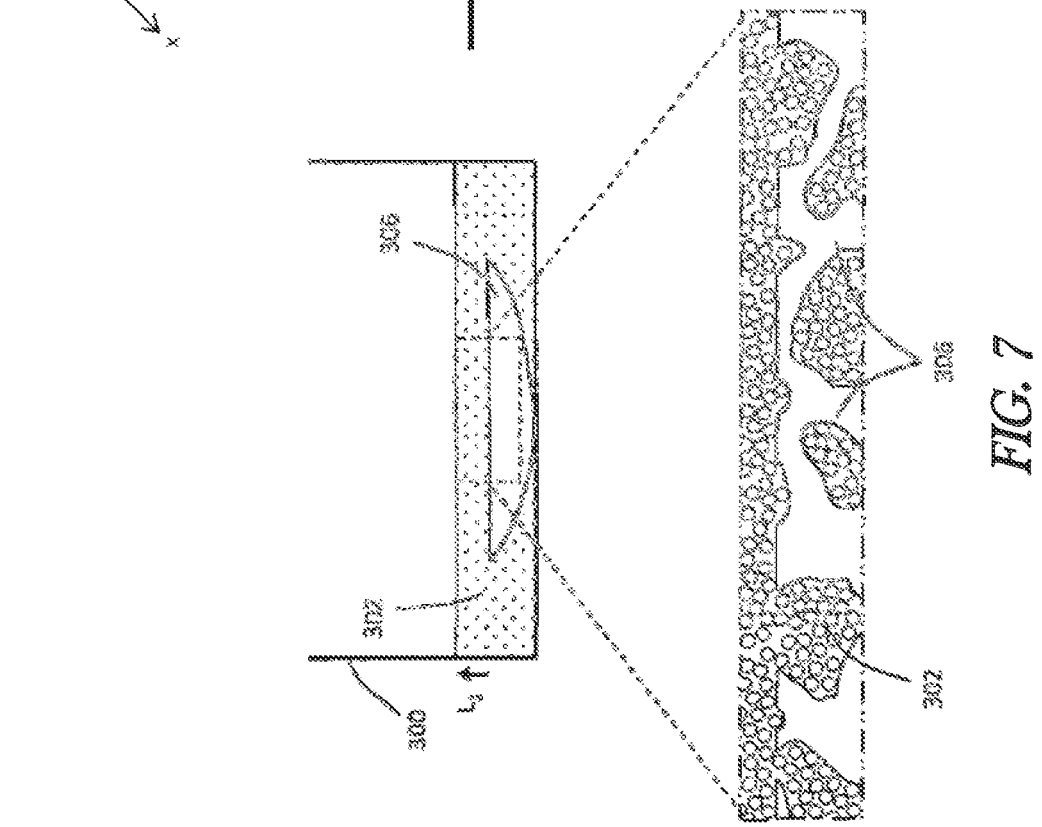


FIG. 7

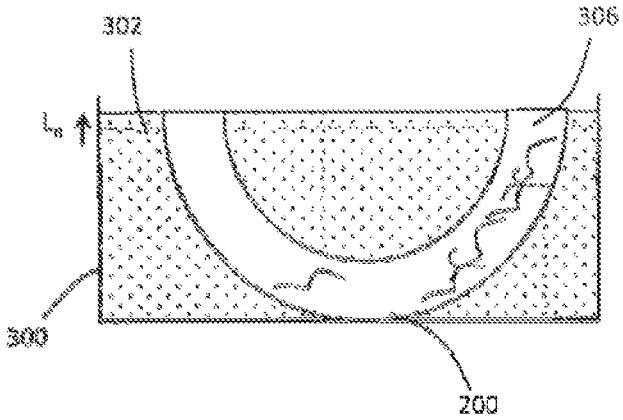


FIG. 9

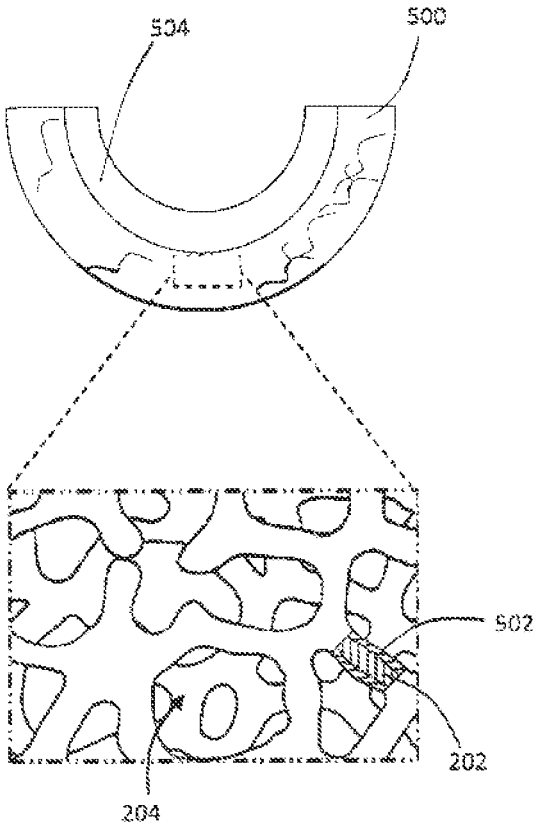


FIG. 10

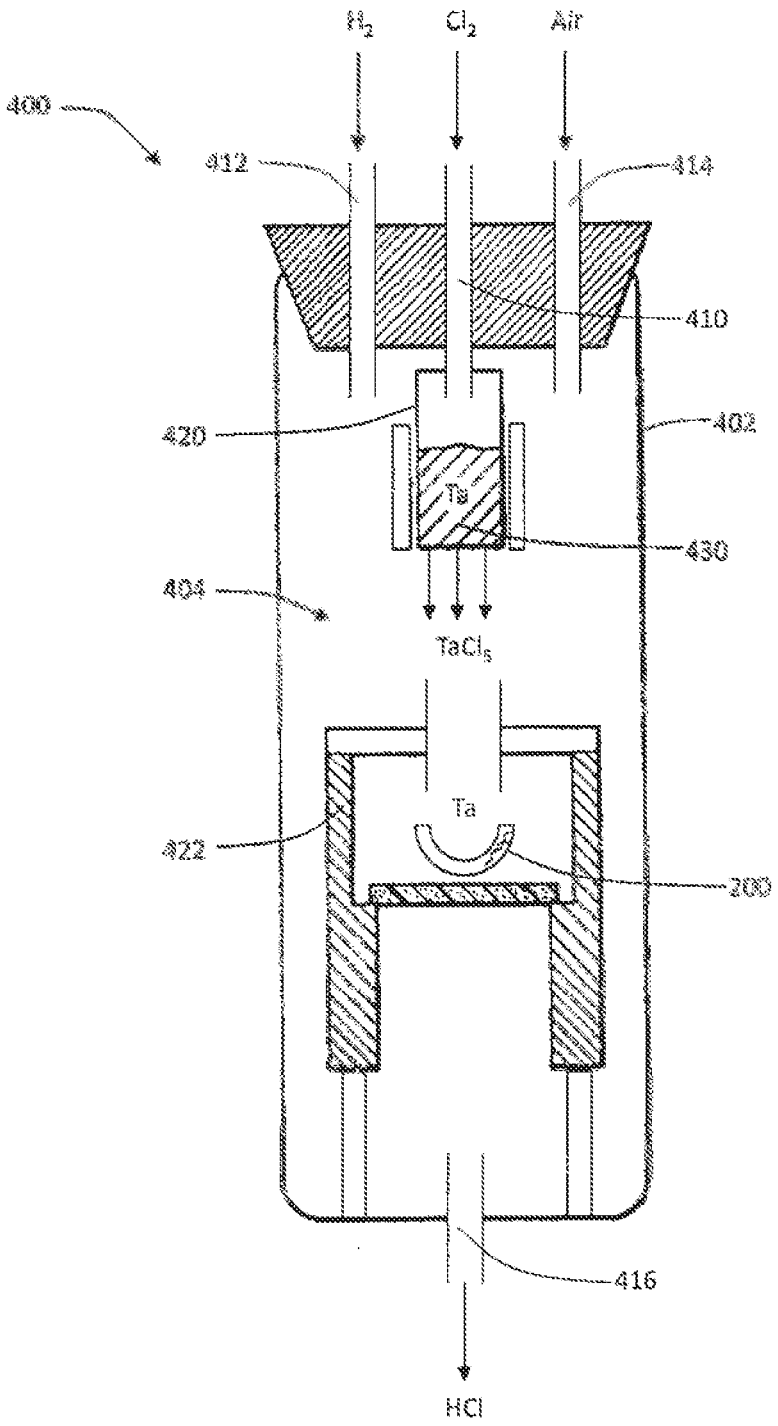

H_2
Cl_2
Air
400
412
414
410
420
402
Ta
430
404
$TaCl_5$
Ta
422
200
416
HCl

FIG. 11

POROUS METAL IMPLANTS MADE FROM CUSTOM MANUFACTURED SUBSTRATES

CLAIM OF PRIORITY

[0001] This patent matter claims the benefit of priority under 35 U.S.C. §119(e) of U.S. Provisional Patent Application Ser. No. 61/664,241, entitled "POROUS METAL IMPLANTS MADE FROM CUSTOM MANUFACTURED SUBSTRATES," filed on Jun. 26, 2012, which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to porous metal implants.

BACKGROUND

[0003] Prosthetic orthopaedic implants are commonly used to replace at least a portion of a patient's bone following traumatic injury or deterioration due to aging, illness, or disease, for example.

[0004] When implanted into a joint, the prosthetic orthopaedic implant may be configured to articulate with an adjacent orthopaedic component. For example, a prosthetic orthopaedic implant that is implanted into a patient's hip joint may be socket-shaped to receive and articulate with an adjacent femoral component.

[0005] The prosthetic orthopaedic implant may be at least partially porous to promote ingrowth of the patient's surrounding bone and/or soft tissue. Such ingrowth may enhance the fixation between the implant and the patient's surrounding bone and/or soft tissue.

[0006] An example of a porous implant material is produced using Trabecular Metal™ technology generally available from Zimmer, Inc., of Warsaw, Ind. Trabecular Metal™ is a trademark of Zimmer, Inc. Such a material may be formed by converting a polymer foam into a reticulated vitreous carbon (RVC) foam, and then coating and infiltrating the RVC foam substrate with a biocompatible metal in the manner disclosed in U.S. Pat. No. 5,282,861 to Kaplan, the entire disclosure of which is expressly incorporated herein by reference. The polymer foam may be provided in a bulk shape (e.g., a block or a sheet), so that the RVC foam or the metal-coated foam may require shaping of the bulk shape (e.g., machining) to arrive at a shape that is suitable or desirable for implantation.

OVERVIEW

[0007] The present disclosure provides a porous metal implant and method of manufacturing the same. The method can involve rapidly manufacturing a porous substrate layer-by-layer. The method can also involve coating the porous substrate with a biocompatible metal to strengthen and stabilize the porous substrate for implantation.

[0008] According to an example embodiment of the present disclosure, a method is provided for manufacturing a porous implant. The method can include the steps of depositing a first layer of a material, depositing a second layer of the material on top of the first layer to build a porous substrate having a plurality of ligaments or struts that define pores, the first and second layers of material cooperating to form at least one of the plurality of ligaments or struts of the porous substrate, and coating the plurality of ligaments or struts of the porous substrate with a biocompatible metal coating.

[0009] To better illustrate the porous metal implants disclosed herein, a non-limiting list of embodiments is provided here:

[0010] In Embodiment 1, a method of manufacturing a porous implant comprising the steps of depositing a first layer of material, depositing a second layer of material on top of the first layer of material to build a porous substrate with a plurality of ligaments or struts that define pores, the first and second layers of material cooperating to form at least one of the plurality of ligaments or struts of the porous substrate; and coating the plurality of ligaments or struts of the porous substrate with a biocompatible metal coating.

[0011] In Embodiment 2, the method of claim **1** can optionally be modified such that the first and second layers of material are deposited with the material in a powdered state, the method further comprising the step of converting the material from the powdered state to a solid state.

[0012] In Embodiment 3, the method of any one or any combination of Embodiments 1 or 2 can optionally be modified to further comprise the step of applying an energy source to the second layer of material to couple the second layer of material to the first layer of material.

[0013] In Embodiment 4, the method of any one or any combination of Embodiments 1 to 3 can optionally be modified such that the coating step comprises performing a chemical vapor deposition process.

[0014] In Embodiment 5, the method of any one or any combination of Embodiments 1 to 4 can optionally be modified to further comprise the step of allowing the first and second layers of material to harden before the coating step.

[0015] In Embodiment 6, the method of any one or any combination of Embodiments 1 to 5 can optionally be modified such that the first and second layers of material in the porous substrate comprise titanium or a titanium alloy and the biocompatible metal coating comprises tantalum or a tantalum alloy.

[0016] In Embodiment 7, the method of any one or any combination of Embodiments 1 to 6 can optionally be modified such that the first and second layers of material comprise a metal different from the biocompatible metal coating.

[0017] In Embodiment 8, the method of any one or any combination of Embodiments 1 to 7 can optionally be modified such that the depositing steps build the porous substrate in a net shape that is suitable for implantation.

[0018] In Embodiment 9, the method of any one or any combination of Embodiments 1 to 8 can optionally be modified such that the porous substrate has a porosity of at least about 55%,

[0019] In Embodiment 10, the method of any one or any combination of Embodiments 1 to 9 can optionally be modified such that the porous substrate has an average pore size between about 100 μm and about 1,000 μm.

[0020] In Embodiment 11, the method of any one or any combination of Embodiments 1-10 can optionally be configured such that all elements or options recited are available to use or select from.

[0021] These and other examples and features of the present methods are set forth in part in the following Detailed Description. This Overview is intended to provide non-limiting examples of the present subject matter—it is not intended to provide an exclusive or exhaustive explanation. The Detailed Description below is included to provide further information about the present subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The above-mentioned and other features and advantages of this disclosure, and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

[0023] FIG. **1** is a flow chart of an example method for manufacturing a porous metal implant from a custom porous substrate;

[0024] FIG. **2** is a schematic view of a porous substrate of the present disclosure;

[0025] FIG. **3** is a schematic diagram showing a first layer of metal powder applied across a build chamber;

[0026] FIG. **4** is another schematic diagram showing a laser selectively converting the first layer of metal powder from FIG. **3** to solid metal;

[0027] FIG. **5** is another schematic diagram showing a second layer of metal powder applied across the first layer;

[0028] FIG. **6** is another schematic diagram showing the laser selectively converting the second layer of metal powder from FIG. **5** to solid metal;

[0029] FIG. **7** is another schematic diagram showing a third layer of metal powder applied across the second layer;

[0030] FIG. **8** is another schematic diagram showing the laser selectively converting the third layer of metal powder from FIG. **7** to solid metal;

[0031] FIG. **9** is another schematic diagram showing a final layer of metal powder converted to solid metal to arrive at the porous substrate of FIG. **2**;

[0032] FIG. **10** is a schematic view of a porous implant of the present disclosure made by coating the porous substrate of FIG. **2**, a portion of the porous implant being depicted in cross-section to show the coating on the porous substrate; and

[0033] FIG. **11** is a schematic view of a chemical vapor deposition (CVD) apparatus for coating the porous substrate of FIG. **2**.

[0034] Corresponding reference characters indicate corresponding parts throughout the several views. The examples set out herein illustrate exemplary embodiments of the invention and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION

[0035] FIG. **1** provides an example method **100** for manufacturing a porous metal implant.

[0036] Beginning at step **102** of method **100** (FIG. **1**), a custom porous substrate is manufactured. An example porous substrate **200** is shown in FIG. **2** with a large plurality of struts or ligaments **202** that define open spaces or pores **204** therebetween. Pores **204** between struts or ligaments **202** may form a matrix of continuous channels having no dead ends, such that growth of cancellous bone and/or soft tissue through porous substrate **200** is uninhibited. Thus, porous substrate **200** may provide a matrix into which cancellous bone and/or soft tissue may grow to provide fixation of porous substrate **200** to the patient's bone.

[0037] During the manufacturing step **102** (FIG. **1**), porous substrate **200** may be fabricated to virtually any desired porosity (pore density), pore orientation, and/or location within the porous substrate, pore shape, and pore size in order to selectively tailor porous substrate **200** for a particular application, such as for a specific implant device, implantation procedure or surgical or implant site. For example, porous substrate **200** may be fabricated to a porosity as low as about 55%, 65%, or 75%, and as high as about 80%, 85%, 90%, or more, or within any range delimited by any pair of the forgoing values. Also, porous substrate **200** may be fabricated to an average pore size as low as about 100 μm, 300 μm, or 500 μm, and as high as about 700 μm, 900 μm, or 1,000 μm, or within any range delimited by any pair of the forgoing values.

[0038] In an embodiment, the porous metal implant can be specifically configured and customized (e.g., through pore density, pore size, pore shape and/or pore location, orientation and/or direction within the substrate) such that the modulus or strength of the porous metal implant is optimized for a specific implant type, or implantation procedure, or surgical or implantation site. In yet another embodiment, the porous implant can include a porous substrate that can be specifically configured and customized (e.g., through pore density, pore size, pore shape and/or pore location, orientation and/or direction within the substrate) to positively or negatively influence the stress exerted on, or the remodeling of, a bone adjacent to the implantation site of the porous metal implant. For example, the porous metal implant can be custom manufactured such that it has a modulus that is substantially the same as, or slightly less than the modulus of the adjacent bone, thereby having a positive influence on the stress exerted on, or remodeling of, the bone. Alternatively, the porous metal implant can be custom manufactured such that it has a modulus that is greater than the modulus of the adjacent bone, thereby having a negative influence on the stress exerted on, and remodeling of, the adjacent bone.

[0039] For example, a distal end of a primary hip stem implant designed for proximal stem fixation can be custom manufactured such that the pores if the implant are configured (e.g., through pore density, pore size, pore shape and/or pore location, orientation and/or direction within the substrate) to resist bone bridging adjacent the distal tip when the hip stem implant is implanted. In an alternate example, such as a revision hip stem intended for implantation adjacent proximal bone of poor quality, the revision hip stein implant can be custom manufactured such that the pores can be designed or configured (e.g., through pore density, pore size, pore shape and/or pore location, orientation and/or direction within the substrate) to encourage fixation of the distal end of the hip stem implant to the bone.

[0040] In certain embodiments, the implant is manufactured so that the implant includes a gradation in the pore density or pore size, or a variation in pore shape or orientation, from the bone/porous implant interface to the interior of the porous implant or from the proximal to distal end of the porous metal implant, to customize the modulus or strength of the porous metal implant for a specific implant type, a specific implantation procedure, a specific surgical or implantation site, or for a specific patient anatomy based on medical imaging, pre-operation evaluations of the patient (e.g., joint kinematics, anatomical defects or deficiencies, and lifestyle or other factors that may affect joint kinematics, bone density or bone health) and/or medical history.

[0041] In still other embodiments, the implant is manufactured in such a way that there is a gradation in pore orientation to customize the modulus or strength of the porous metal implant. In an example, a hemispherical acetabular shell can be custom manufactured to include a tapered conical pore design having a virtual initiation point of all of the tapers

originating at the center of rotation of the femoral head that would be articulating within porous metal acetabular shell implant.

[0042] The porous structure and the overall implant is designed, manufactured in layers, and treated with a final coating layer according the the methods described herein, based on input from appropriate measurements of the surgical site, bone quality adjacent the surgical site, joint kinematics, patient health and medical history, and projected reconstruction.

[0043] Additionally, during the manufacturing step **102** (FIG. **1**), porous substrate **200** may be fabricated in a desired shape and size that is suitable for implantation in a patient's body (i.e., a net shape). The illustrative porous substrate **200** of FIG. **2**, for example, is provided in a hollow hemispherical shape and in a size that is suitable for implantation in a patient's hip joint as a prosthetic acetabular component. It is also within the scope of the present disclosure that the porous substrate may be shaped and sized for use as a prosthetic femoral component, a prosthetic tibial component, a prosthetic humeral component, a prosthetic spinal component, a prosthetic dental component, or another prosthetic orthopaedic component, for example. It is also within the scope of the present disclosure that porous substrate **200** may be manufactured in a near net shape and then undergo subsequent shaping (e.g., machining) before implantation.

[0044] An example porous substrate **200** is constructed of metal, such as titanium, a titanium alloy (e.g., Ti-6Al-4V), cobalt, or a cobalt-chromium alloy. However, other materials may be used to construct porous substrate **200** if such materials are capable of withstanding the necessary anatomical forces when implanted.

[0045] According to an example embodiment of the present disclosure, the manufacturing step **102** (FIG. **1**) is performed using a rapid manufacturing process, more specifically a rapid additive manufacturing process. Rapid additive manufacturing processes build struts or ligaments **202** of porous substrate **200** by laying down and solidifying material layer-by-layer. Suitable rapid additive manufacturing processes may include, for example, 3-D printing, selective laser sintering (SLS), direct metal laser sintering (DMLS), selective laser melting (SLM), electron beam melting (EBM), fused deposition modeling (FDM), stereolithography (SLA), and laser engineered net shaping (LENS).

[0046] Advantageously, such rapid additive manufacturing processes allow porous substrate **200** to be built in desired shapes and sizes. The overall size and shape of porous substrate **200** may be controlled, which enables construction of porous substrates **200** in net shapes or near net shapes with little or no subsequent shaping required. The ability to control the overall size and shape of porous substrate **200** also enables construction of porous substrates **200** have highly complex geometries for patient-specific applications, for example. In addition to controlling the overall size and shape of porous substrate **200**, the size, shape, and placement of each individual ligament **202** of porous substrate **200** may be controlled, which enables control over the number or density, the shape and size of pores **204** located between ligaments or struts **202**, and the location, orientation and/or direction of the pores **204** within the porous metal implant.

[0047] Also advantageously, such rapid additive manufacturing processes allow porous substrate **200** to be built in a rapid, automated manner for efficiency and reproducibility. Furthermore, such processes allow porous substrate **200** to include both porous areas with pores **204** and solid areas without pores, where the solid areas may serve as supports, bearing surfaces for articulation, or attachment surfaces for mechanical fasteners, for example.

[0048] An example rapid additive manufacturing process will now be described with reference to FIGS. **3-9**. The illustrative process involves laying down successive layers of metal powder, and then applying energy to certain areas of each metal powder layer to selectively sinter and/or melt the metal powder. The sintered or melted metal powder fuses together with surrounding material in the same layer and in adjacent layers to form ligaments or struts **202** of porous substrate **200** (FIG. **2**).

[0049] A suitable build chamber **300** is shown in FIG. **3**. Build chamber **300** may be evacuated and flushed with an inert gas (e.g., argon) to avoid oxidation. Build chamber **300** may be equipped with a heater (not shown), if necessary. Also, build chamber **300** may be equipped with a leveling mechanism, such as a roller (not shown), which is discussed further below.

[0050] The illustrative rapid additive manufacturing process begins by depositing a first layer L_1 of metal powder **302** into build chamber **300**, as shown in FIG. **3**. As mentioned above, metal powder **302** may include, for example, titanium powder, a titanium alloy (e.g., Ti-6Al-4V) powder, cobalt powder, or a cobalt-chromium alloy powder. In an example embodiment, the first layer L_1 of metal powder **302** (and each subsequent layer of metal powder **302**) is about 20 micrometers to about 30 micrometers thick. After depositing the first layer L_1 of metal powder **302** (and each subsequent layer of metal powder **302**) into build chamber **300**, metal powder **302** may be leveled by rolling a roller (not shown) across build chamber **300**, by vibrating build chamber **300**, or by another suitable leveling technique.

[0051] The illustrative rapid additive manufacturing process continues by exposing select areas of the first layer L_1 of metal powder **302** to an energy source **304**, as shown in FIG. **4**. The energy source **304** may be focused and high-powered to cause localized sintering or melting of metal powder **302** particles, which converts select areas of metal powder **302** to solid metal **306**. If metal powder **302** is a Ti-6Al-4V powder, for example, the energy applied by the source **304** may cause select areas of metal powder **302** to approach and/or reach its melting point of about 1,700° C. to achieve localized sintering or melting. The energy source **304** may be in the form of a laser (e.g., a ytterbium fiber optic laser), an electron beam, or another suitable energy source. When cooled and hardened, each newly-formed region of solid metal **306** may bond to surrounding regions of solid metal **306**, as shown in FIG. **4**. In this manner, solid metal **306** is selectively and rapidly formed in build chamber **300**.

[0052] The energy source **304** may be automatically controlled using a suitable computer processor having, for example, computer-aided design (CAD) software and/or computer-aided manufacturing (CAM) software installed thereon. Such software can be used to rapidly create computer numerical control (CNC) code that will control each individual pass of the energy source **304** across build chamber **300**. For example, after the first layer L_1 of metal powder **302** (and each subsequent layer of metal powder **302**) is deposited into build chamber **300** (i.e., along the z-axis), the CNC code may automatically direct the energy source **304** side-to-side across build chamber **300** (i.e., along the y-axis) and back-and-forth across build chamber **300** (i.e., along the x-axis). To

convert select areas of metal powder **302** to solid metal **306**, the energy source **304** may be activated at select xy-coordinates. To leave other areas of metal powder **302** as is, without forming solid metal **306**, the energy source **304** may be deactivated at other xy-coordinates or may avoid traveling to those xy-coordinates altogether. In this manner, the energy source **304** is able to form solid metal **306** in the first layer L_1 (and in each subsequent layer) in a predetermined pattern.

[0053] As shown in FIGS. **5-9**, the above-described steps of the rapid additive manufacturing process are repeated to deposit successive layers $L_2, L_3, \ldots L_n$ of metal powder **302** into build chamber **300** atop the first layer L_1 and to convert additional areas of metal powder **302** to solid metal **306**. In some areas, the pattern of solid metal **306** in adjacent layers $L_1, L_2, L_3, \ldots L_n$ may differ. For example, a region of solid metal **306** in the second layer L_2 may overlap a region of metal powder **302** in the first layer L_1. In other areas, the pattern of solid metal **306** in adjacent layers $L_1, L_2, L_3, \ldots L_n$ may overlap. When cooled and hardened, the overlapping areas of solid metal **306** in adjacent layers $L_1, L_2, L_3, \ldots L_n$ will couple together and cooperate to form ligaments or struts **202** of porous substrate **200** (FIG. **2**). As discussed above, the ability to convert select areas of metal powder **302** to solid metal **306** allows the overall size and shape of porous substrate **200** to be customized, as well as the size, shape, and placement of each individual ligament **202** of porous substrate **200** and the pores **204** located therebetween.

[0054] After solid metal **306** is allowed to sufficiently harden, the porous substrate **200** of FIG. **9** may be removed from build chamber **300**, leaving behind metal powder **302** that was not converted to solid metal **306**. Excess metal powder **302** that is captured in pores **204** between ligaments or struts **202** (FIG. **2**) may be removed by shaking porous substrate **200** and/or by blowing pressurized air into porous substrate **200**, for example. Constructing open pores **204** that communicate with one another facilitates the escape of metal powder **302** from porous substrate **200**.

[0055] In the illustrated rapid additive manufacturing process of FIGS. **3-9**, the metal powder particles are sintered and/or melted after being laid down across build chamber **300**. It is also within the scope of the present disclosure to sinter and/or melt the metal powder particles before or while laying down the particles. For example, the above-mentioned LENS process involves delivering metal powder particles to a deposition head, directing a laser beam through the deposition head to melt the metal powder particles, and then laying down the molten particles in select areas. Regardless of the state or type of material being laid, the rapid additive manufacturing processes of the present disclosure allow porous substrate **200** to be built layer-by-layer.

[0056] Returning to method **100** of FIG. **1**, the custom, porous substrate **200** from the rapid manufacturing step **102** is coated in step **104** to produce a custom, porous implant **500**, as shown in FIG. **10**. More specifically, the ligaments or struts **202** of the custom, porous substrate **200** are coated in step **104**, such that the underlying ligaments or struts **202** serve as a skeleton for the coating **502** that is applied during step **104**.

[0057] The coating step **104** allows a first metal or other material to be used for the rapid manufacturing step **102** and a different, second metal to be used for the coating step **104**. In an example embodiment, the first metal has a relatively low melting point to facilitate conversion of metal powder **302** to solid metal **306** during the rapid manufacturing step **102**, and the second metal is strong and highly biocompatible to facilitate implantation after the coating step **104**. For example, the first metal from the rapid manufacturing step **102** may include titanium or a titanium alloy (e.g., Ti-6Al-4V), and the second metal from the coating step **104** may include tantalum or a tantalum alloy.

[0058] According to an example embodiment of the present disclosure, the coating step **104** (FIG. **1**) is performed by chemical vapor deposition (CVD). The CVD process may enable the coating **502** to both surround and infiltrate porous substrate **200**, coating both exterior ligaments or struts **202** of porous substrate **200** and interior struts or ligaments **202** within porous substrate **200**, as shown in FIG. **10**. As indicated above, the coating **502** may strengthen porous substrate **200** and improve the biocompatibility of porous substrate **200** for implantation.

[0059] An example CVD apparatus **400** is shown in FIG. **11**, but it is understood that the design of apparatus **400** may vary. Apparatus **400** includes housing **402** that defines an internal reaction chamber **404**. Apparatus **400** includes a chlorine (Cl_2) gas input **410**, a hydrogen (H_2) gas input **412**, and an air input **414** into reaction chamber **404**, each having a suitable flow control valve (not shown). Apparatus **400** also includes an exhaust gas output **416** from reaction chamber **404**. Within reaction chamber **404**, apparatus **400** includes a heated chlorination chamber **420** and a heated deposition chamber or furnace **422**. A supply of tantalum **430** or another biocompatible metal is located within chlorination chamber **420**. The rapidly manufactured porous substrate **200** is placed within deposition chamber **422**.

[0060] In operation, Cl_2 gas is injected via input **410** and H_2 gas is injected via input **412** into reaction chamber **404**, which may be held under vacuum at a pressure of 1.0 to 2.0 Torr. Once inside the heated chlorination chamber **420**, which may be resistance-heated to a temperature of approximately 500° C., the Cl_2 gas reacts with tantalum **430** to form tantalum chloride gas, such as $TaCl_5$ gas. The $TaCl_5$ gas then mixes with the injected H_2 gas and travels into the heated deposition chamber **422**, which may be induction-heated to a temperature of approximately 900° C.-1,100° C., and more specifically to a temperature of approximately 900° C.-970° C. Once inside the heated deposition chamber **422**, the $TaCl_5$ and H_2 gases flow around and into the porous substrate **200**. Then, upon contact with the heated surfaces of porous substrate **200**, the $TaCl_5$ and H_2 gases react to deposit tantalum metal and to liberate hydrogen chloride (HCl) gas. The liberated tantalum metal is deposited as a thin, substantially uniform film or coating **502** onto exterior and interior ligaments or struts **202** of porous substrate **200** (FIG. **10**). The HCl gas is then exhausted via exhaust gas output **416** from reaction chamber **404**, along with excess reactant gases. Additional information regarding the CVD process is set forth in the above-incorporated U.S. Pat. No. 5,282,861 to Kaplan.

[0061] To promote even metal deposition and infiltration, the porous substrate **200** may be flipped and/or rotated in apparatus **400** during the CVD process or between individual cycles of the CVD process. Also, porous substrate **200** may be moved to different locations in apparatus **400**, especially when multiple porous substrates **200** are coated simultaneously in apparatus **400**. For example, when apparatus **400** contains a stack of porous substrates **200**, a certain substrate may be located on top of the stack during a first CVD cycle and then may be moved to the bottom of the stack during a second CVD cycle.

[0062] In certain embodiments, the coating of the plurality of struts and ligaments **202** of the porous substrate with a biocompatible metal coating is designed to produce a specific macro-, micro- or nano-topography to modify a biological response to the porous metal implant when implanted in the body. In still other embodiments, the macro-, micro- or nano-topography of the layered metals comprising the porous structure, and the macro-, micro-, or nano-topography of the biocompatible metal coating are each adjusted to modify a biological response to the porous metal implant when implanted in the body. Such modified biological response can include a modified cellular migration, cellular adhesion to the porous metal implant and/or cell proliferation therein. In some embodiments, the response can be a positive response, wherein one or more of cell migration, cell adhesion and cell proliferation are promoted. In other embodiments, the response can be a negative response, wherein one or more of cell migration, cell adhesion and cell proliferation are inhibited or disrupted. In certain embodiments, the biological response is the response of a human cell, while in other embodiments the biological response is the response of a bacterial cell.

[0063] In certain embodiments, the coating of the porous substrate with a biocompatible metal coating is configured or designed to produce a specific nano-topography to enhance the bone or soft tissue integration to the implant when the porous metal implant is implanted in the body. In alternate embodiments, the coating of the porous substrate with a biocompatible metal coating is configured or designed to produce a specific nano-topography to disrupt or inhibit bone or soft tissue integration to the porous metal implant when implanted in the body. In still other embodiments, the coating of the porous substrate with a biocompatible metal coating is configured or designed to produce a specific nano-topography to create an antimicrobial surface on the porous metal implant when implanted in the body.

[0064] In certain embodiments, the coating step **104** is optional. For example, if the first metal that is used to produce porous substrate **200** during the rapid manufacturing step **102** is suitable for direct implantation (e.g., tantalum), the coating step **104** can be avoided. In such embodiments, porous substrate **200** can be considered a porous implant **500** that is ready for implantation after the rapid manufacturing step **102**, even without the coating step **104**.

[0065] Returning to method **100** of FIG. **1**, the porous implant **500** from the manufacturing step **102** or the optional coating step **104** may be prepared for implantation in step **106**. The preparing step **106** can include any necessary shaping, processing, sterilizing, or packaging steps. For example, a polymeric bearing component **504** may be secured onto the porous implant **500**, as shown in FIG. **10**, to form an articulating, joint replacement implant. Example methods for attaching a polymeric bearing component to a highly porous material are described in U.S. Patent Application Publication No. 2009/0112315 to Fang et al., the entire disclosure of which is expressly incorporated herein by reference. As another example, porous implant **500** may be coupled to a solid metal substrate (not shown), such as by sintering or diffusion bonding. Example methods for attaching a highly porous material to a solid metal substrate are described in U.S. Pat. No. 7,918,382 to Charlebois et al. and in U.S. Pat. No. 7,686,203 to Rauguth et al., the entire disclosures of which are expressly incorporated herein by reference. Another example method for coupling porous implant **500** to a solid metal substrate is resistance welding, which is described in U.S. Patent Application Publication No. 2012/0125896 to Vargas et al., the entire disclosure of which is expressly incorporated herein by reference.

[0066] Finally, in step **108** of method **100** (FIG. **1**), porous implant **500** is implanted into the patient's body. The illustrative porous implant **500** of FIG. **10** is hemispherical in shape and is configured to be implanted into the patient's hip joint as a prosthetic acetabular component. It is also within the scope of the present disclosure that porous implant **500** may be a prosthetic proximal femoral component for use in the patient's hip joint, a prosthetic distal femoral component for use in the patient's knee joint, a prosthetic tibial component for use in the patient's knee joint, a prosthetic humeral component for use in the patient's shoulder joint, a prosthetic spinal component, or a prosthetic dental component, for example. Porous implant **500** may also be in the shape of a plate, plug, or rod, for example. Porous implant **500** may be secured in place using suitable fasteners (e.g., bone screws) or bone cement, for example. Over time, porous implant **500** will facilitate ingrowth of the patient's surrounding bone and/or soft tissue.

[0067] The above Detailed Description includes references to the accompanying drawings, which form a part of the Detailed Description. The drawings show, by way of illustration, specific embodiments in which various methods can be practiced. These embodiments are also referred to herein as "examples."

[0068] While this invention has been described with reference to certain examples, the present invention can be further modified within the spirit and scope of this disclosure. This patent matter is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this patent matter is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

[0069] The above Detailed Description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more elements thereof) can be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. Also, various features or elements can be grouped together. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter can lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

[0070] In the event of inconsistent usages between this document and any document so incorporated by reference, the usage in this document controls.

[0071] In this document, the terms "a" or "an" are used to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated.

[0072] In the appended claims, the terms "having," "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." The

terms "having", "including" and "comprising" are open-ended, that is, an apparatus, system, kit, or method that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc, are used merely as labels, and are not intended to impose numerical requirements on their objects.

[0073] The Abstract is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

What is claimed is:

1. A method of manufacturing a porous implant, comprising:

depositing a first layer of material;

depositing a second layer of material on top of the first layer of material to build a porous substrate with a plurality of ligaments that define pores, the first and second layers of material cooperating to form at least one of the plurality of ligaments of the porous substrate; and

coating the plurality of ligaments of the porous substrate with a biocompatible metal coating.

2. The method of claim **1**, wherein the first and second layers of material are deposited with the material in a powdered state, the method further comprising converting the material from the powdered state to a solid state.

3. The method of claim **2**, further comprising applying an energy source to the second layer of material to couple the second layer of material to the first layer of material.

4. The method of claim **1**, wherein coating the plurality of ligaments comprises performing a chemical vapor deposition process.

5. The method of claim **1**, further comprising allowing the first and second layers of material to harden before coating.

6. The method of claim **1**, wherein the first and second layers of material in the porous substrate comprise titanium or a titanium alloy and the biocompatible metal coating comprises tantalum or a tantalum alloy.

7. The method of claim **1**, wherein the first and second layers of material comprise a metal different from the biocompatible metal coating.

8. The method of claims **1**, wherein depositing the first and second layers of material includes building the porous substrate in a net shape that is suitable for implantation.

9. The method of claim **1**, wherein the porous substrate has a porosity of at least about 55%.

10. The method of claim **1**, wherein the porous substrate has an average pore size between about 100 μm and about 1,000 μm.

* * * * *