



- (51) **International Patent Classification:**  
*B29C 67/00* (2006.01)
- (21) **International Application Number:**  
PCT/EP2013/076912
- (22) **International Filing Date:**  
17 December 2013 (17.12.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**  
61/738,309 17 December 2012 (17.12.2012) US
- (71) **Applicant:** MATERIALISE N.V. [BE/BE]; Technologie-  
laan 15, B-3001 Leuven (BE).
- (72) **Inventor:** COECK, Sam; c/o Materialise N.V., Technolo-  
gielaan 15, B-3001 Leuven (BE).
- (74) **Agent:** EIP; Fairfax House, 15 Fulwood Place, London  
Greater London WC1V 6HU (GB).

(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title:** GRADED MATERIALS FORMED WITH THREE DIMENSIONAL PRINTING

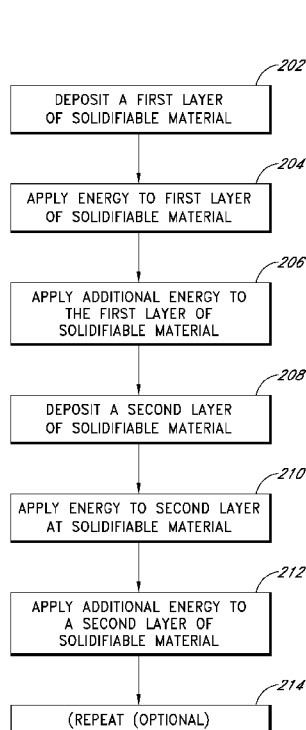


FIG. 2

(57) **Abstract:** This disclosure relates to three-dimensional printing techniques such as stereolithography ("SLA") and/or selective laser sintering ("SLS"). The techniques disclosed herein may allow for the mechanical properties of objects formed using SLA and/or SLS to be altered and/or optimized by increasing the energy delivered to sections of the layers of material used to form the object. In some embodiments, increased energy is applied in a grid-like pattern to each layer that forms the object. As such, graded materials, having varied internal structure and/or composition, may be formed using SLA and/or SLS. In some embodiments, controlling the amount and location of the energy delivered to each cross-section of an object formed with a three dimensional printing technique results in less shrinkage and/or deformation from, for example, a digital rendering of the object and may allow for more accurately sized and shaped objects to be formed.



---

**Published:**

— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

## GRADED MATERIALS FORMED WITH THREE DIMENSIONAL PRINTING

### BACKGROUND

#### Field

[0001] This application relates generally to three dimensional printing and/or additive manufacturing techniques such as stereolithography and selective laser sintering. In particular, this application relates to systems and methods for forming objects comprising graded materials and/or materials with enhanced mechanical properties using stereolithography and/or selective laser sintering techniques.

#### Description of the Related Art

[0002] Three dimensional printing and/or additive manufacturing techniques include stereolithography and selective laser sintering. Stereolithography (“SLA”) is a rapid prototyping and manufacturing technique. In general, three dimensional printing allows for fabrication of three dimensional objects directly from computer generated CAD files. In a typical SLA process, the object to be formed is divided into a stack of successive layers. These layers represent the three-dimensional object as closely as possible, and are typically generated using SLA modeling software executed by a computing device. The object is then constructed using SLA machines based on the computer-generated layers.

[0003] The object formation process typically includes several steps. First a layer of resin is deposited over the entire building area. Next, sections of the building area that are part of the object to be constructed are illuminated. This illumination causes the resin on the illuminated areas to polymerize and harden. Upon completion of the layer a new layer of resin is deposited and the process is repeated until the each layer has been deposited. The solidified object may be removed from the resin and processed further if so desired. SLA provides the ability to quickly manufacture both simple and complex parts without tooling.

[0004] Selective laser sintering (“SLS”) is a similar manufacturing technique that uses a high power laser to fuse small particles. The high power laser may, for example, be a carbon dioxide laser. The small particles typically are made of plastic, metal (direct metal laser sintering), ceramic, or glass powders. The fusion of these particular yields an object

that has a desired three-dimensional shape. In a typical SLS process, the laser selectively fuses powdered material by scanning cross-sections generated from a digital three-dimensional (“3D”) description of the desired part on the surface of a powder bed. The 3D description may be provided by a computer assisted design (“CAD”) file or from scan data inputted into a computing device. After each cross-section is scanned, the powder bed is often lowered by one layer of thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

### SUMMARY

[0005] The devices, systems, and methods of the present disclosure have several features, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this invention as expressed by the claims which follow, its more prominent features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled “Detailed Description of Certain Inventive Embodiments” one will understand how the features of this invention provide several advantages over traditional three dimensional printing systems and methods.

[0006] One aspect of the subject matter described in the disclosure provides a method for altering the mechanical properties of an object formed by three dimensional printing. The method may include depositing a first layer of solidifiable material, applying energy to the first layer of solidifiable material to at least partially solidify the first layer, applying additional energy to portions of the first layer to increase the stiffness of the portions of the first layer, depositing a second layer of solidifiable material applying energy to the second layer of solidifiable material to at least partially solidify the second layer, and applying additional energy to portions of the second layer to increase the stiffness of the portions of the second layer. In some embodiments, this method is repeated to form for additional layers until a three-dimensional object is formed. The energy may be applied using a programmable laser. Additional energy may be applied in a grid like pattern.

[0007] Another aspect of the subject matter described in the disclosure provides for three-dimensional object to be made by depositing a first layer of solidifiable material, applying energy to the first layer of solidifiable material to solidify the first layer, applying additional energy to portions of the first layer to increase the stiffness of the portions of the

first layer, depositing a second layer of solidifiable material on the first layer of solidifiable material, and applying energy to the second layer of solidifiable material to solidify the second layer to form a three dimensional object. In some embodiments, the process includes applying additional energy to portions of the second layer to increase the stiffness of the portions of the second layer.

[0008] Another aspect of the subject matter described in the disclosure provides for a three-dimensional printing device. The device may include a vessel configured to hold a solidifiable material and an energy source disposed over the vessel and configured to solidify the solidifiable material. The device may include a controller coupled to the energy source and configured to control the energy source such that the energy source delivers energy to the solidifiable material to solidify a cross section of an object to be formed. The energy source may be controlled and/or instructed to deliver additional energy to one or more portions of the cross section to increase the stiffness of the portion relative to the cross section.

[0009] Another aspect of the subject matter described in the disclosure provides for a method of forming an object. The method may include forming a first cross-section of the object by applying energy to a first amount of solidifiable material, forming at least one reinforcement structure in the first cross-section by applying additional of energy to at least a portion of the first cross section, contacting a second amount of solidifiable material with the first cross-section, and forming a second cross-section of the object by applying energy to the first second amount of solidifiable material. In some embodiments, the method includes forming at least one reinforcement structure in the second cross-section by applying additional of energy to at least a portion of the second cross section.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and other features, aspects, and advantages of the invention disclosed herein are described below with reference to the drawings of preferred embodiments, which are intended to illustrate and not to limit the invention. Additionally, from figure to figure, the same reference numerals have been used to designate the same components of an illustrated embodiment. The following is a brief description of each of the drawings.

[0011] FIG. 1 is a schematic illustration of one example of a 3D printing machine that may be used to perform the techniques disclosed herein.

[0012] FIG. 2 illustrates a process, according to one embodiment, for manufacturing a 3D object having enhanced mechanical properties.

[0013] FIG. 3 is a schematic illustration of an object formed by a process, according to one embodiment, for manufacturing a 3D object having enhanced mechanical properties.

[0014] FIG. 4 is a schematic illustration of an object formed by a process, according to another embodiment, for manufacturing a 3D object having enhanced mechanical properties

[0015] FIG. 5 is a topside perspective view illustrating a portion of an object formed by techniques disclosed herein.

[0016] FIG. 6 is a topside perspective view illustrating another embodiment of an object formed by techniques disclosed herein.

[0017] FIG. 7 is a topside perspective view illustrating another embodiment of an object formed by techniques disclosed herein.

[0018] FIG. 8 is a topside perspective view illustrating another embodiment of an object formed by techniques disclosed herein.

[0019] FIG. 9 is a topside perspective view illustrating another embodiment of an object formed by techniques disclosed herein.

[0020] FIG. 10 is a topside perspective view illustrating another embodiment of an object formed by techniques disclosed herein.

#### DETAILED DESCRIPTION OF CERTAIN INVENTIVE EMBODIMENTS

[0021] The following description and the accompanying figures describe and show various embodiments and are made to demonstrate several possible configurations that the objects formed by the techniques described herein may take to include various disclosed aspects and features. The illustrations of the objects in any particular context are not intended to limit the disclosed aspects and features to the specified embodiment or to any particular usage. Those of skill in the art will recognize that the disclosed aspects and features are not limited to any particular embodiments, which may or may not include one or

more of the inventive aspects and features herein described. The devices, systems, and methods described herein and may be designed and optimized for use in a variety fields.

[0022] The present invention will be described with respect to particular embodiments but the invention is not limited thereto but only by the claims.

[0023] As used herein, the singular forms “a”, “an”, and “the” include both singular and plural referents unless the context clearly dictates otherwise.

[0024] The terms “comprising,” “comprises” and “comprised of” as used herein are synonymous with “including,” “includes” or “containing,” “contains,” and are inclusive or open-ended and do not exclude additional, non-recited members, elements or method steps. The terms “comprising,” “comprises,” and “comprised of” when referring to recite components, elements or method steps also include embodiments which “consist of” said recited components, elements or method steps.

[0025] Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order, unless specified. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

[0026] Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to a person skilled in the art from this disclosure, in one or more embodiments. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the appended claims, any of the features of the claimed embodiments can be used in any combination.

[0027] One of skill in the art will recognize that the techniques and methods described herein may be performed with various additive manufacturing and/or 3D printing systems. Similarly, the products formed by the techniques and methods described herein may be formed using various additive manufacturing and/or 3D printing systems and materials. Such additive manufacturing systems include, but are not limited to various implementations of SLA and SLS technology. Materials used may include, but are not limited to, polyurethane, polyamide, polyamide with additives such as glass or metal particles, resorbable materials such as polymer-ceramic composites, etc. Examples of commercially available materials include: DSM Somos® series of materials 7100, 8100, 9100, 9420, 10100, 11100, 12110, 14120 and 15100 from DSM Somos; Accura Plastic, DuraForm, CastForm, Laserform and VisiJet line of materials from 3-Systems; Aluminium, CobaltChrome and Stainless Steel materials; Maranging Steel; Nickel Alloy; Titanium; the PA line of materials, PrimeCast and PrimePart materials and Alumide and CarbonMide from EOS GmbH.

[0028] In some embodiments, the mechanical properties of objects formed using SLA and/or SLS may be altered and/or optimized by increasing the energy delivered to sections of the layers of material used to form the object. In some embodiments, the increased energy is applied in a grid-like pattern to each layer. In other words, the stiffness of the objects or sections thereof may be controlled by applying additional energy to specific sections of the layers of material and/or applying additional energy in specific patterns to the layers of material as the object is formed. As such, graded materials, having varied internal structure and/or composition, may be formed using SLA and/or SLS. This varied structure may result in corresponding changes to the mechanical properties of the material. Utilizing these techniques, materials may then be designed for specific function and applications. For example, unitary objects having both rigid sections and flexible sections may be formed using the techniques described herein.

[0029] The inventors have recognized that objects formed using SLA and/or SLS have a tendency to distort from the designed dimensions of the object. For example, material used to form the object often shrinks when the material hardens. Various sections of a given object may shrink to various extents, giving rise to differential shrinkage and inaccurate objects or portions thereof.

[0030] In SLA for example, applying additional energy applied to the material used to form the object can lead to additional curing and additional stiffness of the object that is formed. Similarly, applying additional energy in SLS, can cause a higher melt pool temperature which results in decreased porosity and increased stiffness. However, these benefits typically come with a cost. The application of additional energy may lead to longer manufacturing times and/or cause additional heat that may be detrimental to the shape and stability of the object. Thus, it is beneficial to apply additional energy to only selected areas of each layer in order to increase the stiffness of the object without causing excess shrinkage or the other problems referenced above. Accordingly, the techniques disclosed herein may be used to form accurately sized objects with varying mechanical properties. In sum, applying increased energy in a pre-determined or pre-programmed grid or in a random pattern across one or more cross-sections of the object allows for SLA or SLS manufacturing systems to form a precise object, and having custom designed mechanical properties, while avoiding problems associated with applying higher energy over the entire object, such as part deformation.

[0031] Furthermore, disclosed herein is a method of forming an object with 3D printing that results in an accurately sized and shaped object. For example, applying the same energy in a uniform or substantially uniform manner to each layer of an object may result in some shrinkage and/or deformation of the object in comparison with the designed parameters as explained above. Applying less total energy to each layer may reduce the amount of shrinkage applying less total energy to each layer but may also result in an object that lacks the desired strength and/or stiffness characteristics. Applying less total energy to each layer may also reduce the ability of each layer to adhere to and or bond with adjacent layers. Thus, distributing how and where the energy is distributed in each layer may result in less shrinkage and/or deformation from, for example, a digital rendering of the object and may allow for a more accurately sized and shaped object to be formed without applying less total energy. Distributing how and where the energy is distributed in each layer may also result in layers that adhere to one another and/or have the desired mechanical properties and/or characteristics. Accordingly, distributing the same total amount of energy in a varied manner may result in less shrinkage and/or deformation of the object or portions thereof from the object as modeled and designed.

[0032] Additionally, in some embodiments, a 3D object is formed by construction individual cross-sections and combining the cross-sections to form the 3D object. Each cross-section or layer of the object can be the same thickness or each cross-section or layer of the object can have varying thickness. According to one embodiment of the present disclosure, one or more cross-section or layers include reinforcements or fiber-like structures formed therein. Reinforcement areas may be formed by delivering more energy to the desired area than delivered to the remainder of the cross-section. Similarly, fiber-like structures, lines or patterns of lines for example, may be formed in one or more cross sections by delivering more energy to selected portions of the cross-section in comparison to the remainder of the cross-section. Thus, distributing proportionally energy higher levels to one or more portions of a cross-section may form reinforcements and/or fibers within the cross-section.

[0033] In some implementations, the techniques disclosed herein may be used to form patient-specific surgical devices, tools, guides, and/or implants designed for an individual patient's anatomy. Thus, patient-specific devices, tools, guides, and/or implants may be manufactured to have a custom fit or functioning in a unique, customized manner for a particular individual patient. The use of patient-specific devices, tools, guides, and/or implants may allow for improved or optimized surgical interventions, orthopedic structures, and/or kinematics for the patient. Similar benefits may be obtained when such patient-specific devices are used in combination with standard implants, tools, devices, surgical procedures, and/or other methods.

[0034] Various aspects will now be described with reference to specific forms or embodiments selected for the purpose of illustration. It will be appreciated that the spirit and scope of the objects disclosed herein is not limited to the selected forms. Moreover, it is to be noted that the figures provided herein are not drawn to any particular proportion or scale, and that many variations may be made to the illustrated embodiments. Brief introductions to some of the features, which may be common to embodiments disclosed herein are now described.

[0035] FIG. 1 shows a schematic illustration of one example of a 3D printing machine 100 that may be used to perform the techniques disclosed herein and may be used to form objects having customizable mechanical properties. The 3D printing machine 100 may

include a vessel 105 of liquid polymer 107 that hardens when the liquid polymer is struck by one or more computer controlled laser beams. The laser may be a programmable laser. A controller 120 may control the laser 110.

[0036] In some embodiments, a digital representation of the 3D object to be formed is input to the controller 120. Generally, the digital representation is sliced into a series of cross-sectional layers which can be overlaid to form the object as a whole. The controller 105 may use this data for building the object on a layer-by-layer basis. The cross-sectional data representing the layer data of the 3D object may be generated using a computer system and computer aided design and manufacturing (CAD/CAM) software.

[0037] Starting from the digital representation of the 3D object, supports for overhangs and cavities may be automatically generated for the particular object to be formed by the controller and/or other hardware and/or software. The support and object files may be divided into thin horizontal slices and programmed into the 3D printing machine 100 which may use a computer controlled laser 110 to draw a cross-section onto the surface of the liquid polymer 107. The object may then be lowered along with the resin level of the vessel 105 to a depth corresponding to the next cross-section's desired thickness. A small reservoir holding additional liquid polymer (not shown) may then move over the vessel 105 and deposit an additional liquid polymer 107 over the object and the vessel 105. The computer controlled laser 110 may then draw the next cross-section directly on top of the previous one. This may be repeated until the part is finished.

[0038] For one or more layers, the computer controlled laser 110 may draw grids or different shapes or patterns across the cross section or portions of the cross section. In this way, additional energy is applied to portions of one or more cross sections that form the object. As such, portions of the cross section will experience additional curing and additional stiffness. Thus, the object that is formed may have unique and controllable mechanical properties.

[0039] FIG. 2 illustrates a process 200 for manufacturing a 3D object having enhanced mechanical properties. The process 200 may begin at step 202 by depositing a first layer of solidifiable material. The first layer of solidifiable material can be any suitable thickness and may comprise a liquid polymer. The liquid polymer may solidify when exposed to light. The light may be a laser light. The process can continue at step 204 by

applying energy to the first layer of solidifiable material. The energy may solidify the solidifiable material. The energy may be delivered in the form of a laser beam. The laser may be configured to supply varying intensities such that energy delivered by the beam can be controlled. In general, the more energy that is supplied to the solidifiable material, the more solid and stiff the solidifiable material becomes. The laser may be configured to expose an entire cross section of an object that is to be formed. In this way, one cross section of the solid three dimensional object may be formed.

[0040] The process 200 may continue at step 206 by applying additional energy to portions of the first layer so as to increase the stiffness of certain portions of the first layer. In general, there is a maximum amount of energy that can be applied to each cross-section. However, maximum energy delivery to across an entire cross-section often results in maximum shrinkage and/or deformation of the cross-section from the designed and/or desired shape. Applying additional energy to portions of the cross-section allows for a method to increase the stiffness of the cross-section, or portions thereof, while avoiding shrinkage and/or deformation from the desired shape. Applying additional energy to select portions of the cross-section can also allow for selective stiffness.

[0041] The process 200 may continue at step 208 by depositing a second layer of solidifiable material on top of the first layer of solidifiable material. The second layer of solidifiable material can be any suitable thickness and may comprise a liquid polymer. The liquid polymer may solidify when exposed to light. The light may be a laser light. The process 200 can continue at step 210 by applying energy to the second layer of solidifiable material. The energy may solidify the solidifiable material. The energy may be delivered in the form of a laser beam. The laser may be configured to supply varying intensities such that energy delivered by the beam can be controlled.

[0042] The process 200 may continue at step 212 by applying additional energy to portions of the second layer so as to increase the stiffness of certain portions of the second layer. Such a process can lead to variation in composition and structure over the entire volume of the object to be formed. The patterns of additional energy may result in corresponding changes in the properties of the material. In this way, the materials can be designed for specific function and applications. The process 200 may continue at step 214

by depositing additional layers of solidifiable material and applying energy to each layer. Additional energy can be applied as desired in order to alter the mechanical properties.

[0043] Turning to FIG. 3, a schematic illustration of an object 310 formed by a process, according to one embodiment, for manufacturing a 3D object having enhanced mechanical properties is shown. In the embodiment illustrated in FIG. 3, additional energy was applied at sections 308 in each layer 301, 302, and 303 that forms the object 310. In other words, additional energy was applied in the same pattern to each layer 301, 302, and 303. This results in an object with stiffer fiber-like sections 312 that run through the object. However, the additional energy need not be applied in the same pattern for each layer. For example, as shown in FIG. 4, in some embodiments, additional energy may be applied in a staggered manner when forming an object 410. In other words, each layer may have additional energy applied in a different pattern or in a similar pattern that is offset from the pattern in the layer above and/or below. In this way, the mechanical properties of the object can be altered and customized in three dimensions.

[0044] To assist in the description of the objects formed by the techniques disclosed herein, the following coordinate terms may be used. As shown in FIGS. 5–10, a “lateral axis” may extend across a top surface of the object extending away from the viewer. A “longitudinal axis” may be approximately normal (i.e. at approximately a 90° angle to) to the transverse axis and extends across a top surface of the object. A “transverse axis” may extend approximately normal to both the longitudinal and lateral axes.

[0045] FIG. 5 illustrates a portion of an object 500 formed according to one embodiment. The illustrated object 500 was formed using a modified SLA technique. As shown, increased energy was applied to each layer of the material used to form the object 500 in an array or grid-like pattern of lines. In FIG. 5, increased energy was applied to each layer in a series of substantially parallel lines 505 of uniform thickness in the lateral direction. In addition, increased energy was applied to each layer in a series of substantially parallel lines 509 of uniform thickness at about 45° from the lateral direction. Increased energy was also applied to each layer in a series of substantially parallel lines 511 of uniform thickness roughly normal to lines 509 forming a diamond shaped cross-hatched pattern. The process involved minimal shrinkage to the object 500 and the tensile strength of the object 500 increased in comparison to embodiments that did not apply increased energy doses. In

other words, the application of increased energy in a consistent manner throughout the layering results in stiffer fiber-like portions that run in a grid-like pattern throughout the three dimensional structure of the object and stiffer object overall.

**[0046]** FIG. 6 illustrates a portion of an object 600 formed according to another embodiment. Object 600 was formed in a substantially similar manner as object 500. However, in the embodiment of FIG. 6, increased energy was applied to each layer in a series of substantially parallel lines 611 of uniform thickness in the longitudinal direction. In addition, increased energy was applied to each layer in a series of substantially parallel lines 605 of uniform thickness at about 45° from the lateral direction. Increased energy was also applied to each layer in a series of substantially parallel lines 607 of uniform thickness roughly normal to lines 605 forming a diamond shaped cross-hatched pattern. The process involved minimal shrinkage to the object 600 and the tensile strength of the object 600 increased in comparison to embodiments that did not apply increased energy doses. IN some embodiments, the grid like patterns are staggered or offset from one another in the transverse direction. In these staggered or offset embodiments, the mechanical properties of the object can be altered and/or optimized for each direction in three dimensional space. Further, while the increased energy was applied in lines of uniform thickness, the lines of increased energy may be applied in lines of verifying thickness and length and pattern that is desired.

**[0047]** FIG. 7 illustrates a portion of an object 700 formed according to another embodiment. The illustrated object 700 was formed using a modified SLA technique. In some embodiments increased energy may be applied to each layer of the material used to form the object 700 in a random manner. As shown in FIG. 7, increased energy was applied in a random pattern of straight lines to each layer of the material while the object was formed. The process involved minimal shrinkage to the object 700 and the tensile strength of the object 300 increased in comparison to embodiments that did not apply increased energy doses.

**[0048]** FIG. 8 illustrates a portion of an object 800 formed according to another embodiment. As shown, increased energy was applied in a series of hexagonal shapes 816 to each layer of the material used to form the object 800. Again, the process involved minimal shrinkage to the object 800 and the tensile strength of the object 800 increased in comparison to embodiments that did not apply increased energy doses.

[0049] FIG. 9 illustrates a portion of an object 900 formed according to another embodiment. As shown, increased energy was applied in a two dimensional pattern to each layer of the material used to form the object 900. As shown in FIG. 9, increased energy was applied to each layer in a series of substantially parallel lines 815 of uniform thickness in the longitudinal direction and in a thinner lined grid like pattern 820 in between the substantially parallel lines 815 of uniform thickness in the longitudinal direction. Once again, the process involved minimal shrinkage to the object 900 and the tensile strength of the object 900 increased in comparison to embodiments that did not apply increased energy doses.

[0050] FIG. 10 illustrates a portion of an object 1000 formed according to another embodiment. As shown in FIG. 10, increased energy was applied to each layer in a series of substantially parallel lines 1005 of uniform thickness in the longitudinal direction and in a series of substantially parallel lines 1006 in the lateral direction to form a grid like pattern. Once again, the process involved minimal shrinkage to the object 1000 and the tensile strength of the object 1000 increased in comparison to embodiments that did not apply increased energy doses.

[0051] As will be understood by one of skill in the art, in some embodiments, additional energy can be applied by delivering energy to certain portions of a layer for longer periods of time than to other portions, for example at the same or similar intensity levels. In some embodiments, additional energy can be applied by delivering energy to certain portions of a layer at increased intensity levels relative to other portions. In some embodiments, energy can be applied by moving a laser or other energy source over the surface of a layer in a pattern, optionally with varying speeds and/or varying intensity levels to generate relatively stiffer portions in the pattern. In some embodiments, energy can be applied by projecting one or more energy sources onto a layer to generate a pattern (e.g., a two-dimensional pattern) at once. For example, energy can be applied in a first pattern to at least partially solidify certain portions of a layer, and then energy can be applied in a second pattern to increase the stiffness of the portions of the layer falling within the second pattern. Also for example, in some embodiments, varying levels of energy can be applied at once using multiple energy sources, using, for example, one or more lasers, an array of fixed or movable LEDs, and/or digital light processing controlled illumination.

[0052] It is to be noted that many variations may be made to the illustrated embodiments. Those of skill in the art will recognize that the disclosed aspects and features shown herein are not limited to any particular object formed by three dimensional printing techniques known in the art. Three dimensional printing techniques that include one or more of the features herein described may be designed for use with a variety of objects, tools, guides, devices that may be formed.

[0053] The various embodiments of the techniques described above in accordance with the present invention thus provide a means to form precise objects with SLA or SLS having customizable mechanical properties. Of course, it is to be understood that not necessarily all objects or advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0054] Those of skill would further appreciate that any of the various illustrative logical blocks, modules, cores, processors, controllers, means, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware (e.g., a digital implementation, an analog implementation, or a combination of the two, which may be designed using source coding or some other technique), various forms of program or design code incorporating instructions (which may be referred to herein, for convenience, as “software” or a “software module”), or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[0055] The invention disclosed herein may be implemented as a method, apparatus, or article of manufacture using standard programming or engineering techniques to produce software, firmware, hardware, or any combination thereof. Code or logic may be

implemented in hardware or non-transitory computer readable media such as optical storage devices, and volatile or non-volatile memory devices or transitory computer readable media such as signals, carrier waves, etc. Such hardware may include, but is not limited to, field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), complex programmable logic devices (CPLDs), programmable logic arrays (PLAs), microprocessors, or other similar processing devices.

**[0056]** It should be understood that any reference to an element herein using a designation such as “first,” “second,” and so forth does not generally limit the quantity or order of those elements. Rather, these designations may be used herein as a convenient method of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements may be employed there or that the first element must precede the second element in some manner. Also, unless stated otherwise a set of elements may comprise one or more elements.

**[0057]** Furthermore, the skilled artisan will recognize the interchangeability of various features from different embodiments. In addition to the variations described herein, other known equivalents for each feature may be mixed and matched by one of ordinary skill in this art to construct objects in accordance with principles of the present invention.

**[0058]** Although this invention has been disclosed in the context of certain embodiments and examples, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the invention and obvious modifications and equivalents thereof. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiments described above.

## CLAIMS

## WHAT IS CLAIMED IS:

1. A method for altering the mechanical properties of an object formed by three dimensional printing, the method comprising:
  - depositing a first layer of solidifiable material;
  - applying energy to the first layer of solidifiable material to at least partially solidify the first layer;
  - applying additional energy to portions of the first layer to increase the stiffness of the portions of the first layer relative to other portions of the first layer;
  - depositing a second layer of solidifiable material;
  - applying energy to the second layer of solidifiable material to at least partially solidify the second layer; and
  - applying additional energy to portions of the second layer to increase the stiffness of the portions of the second layer relative to other portions of the second layer.
2. The method of claim 1, further comprising repeating the steps for additional layers until a three-dimensional object is formed.
3. The method of claim 1, wherein the solidifiable material is a photosensitive resin.
4. The method of claim 1, wherein the solidifiable material is a curable photopolymer resin.
5. The method of claim 1, wherein the solidifiable material comprises small fusible particles.
6. The method of claim 5, wherein the small fusible particles are selected from the group consisting of plastic powders, metal powders, ceramic powders, and glass powders.
7. The method of claim 1, wherein the energy is applied with a programmable laser.
8. The method of claim 1, wherein the additional energy is applied with a programmable laser.

9. The method of claim 1, wherein the additional energy is applied in a grid like pattern.
10. The method of claim 1, wherein the additional energy is applied in a random pattern of lines.
11. The method of claim 9, wherein the grid like pattern is the same for each layer.
12. The method of claim 9, wherein the grid like pattern is different for each layer.
13. The method of claim 2, wherein the three-dimensional object is a medical device.
14. A three-dimensional object made by the following process:
  - depositing a first layer of solidifiable material;
  - applying energy to the first layer of solidifiable material to solidify the first layer;
  - applying additional energy to portions of the first layer to increase the stiffness of the portions of the first layer relative to other portions of the first layer;
  - depositing a second layer of solidifiable material on the first layer of solidifiable material; and
  - applying energy to the second layer of solidifiable material to solidify the second layer and form a three dimensional object.
15. The three-dimensional object made by the process of claim 14, wherein the process further comprises applying additional energy to portions of the second layer to increase the stiffness of the portions of the second layer.
16. A three-dimensional printing device comprising:
  - a vessel configured to hold a solidifiable material;
  - an energy source disposed over the vessel and configured to solidify the solidifiable material; and
  - a controller coupled to the energy source and configured to control the energy source such that the energy source delivers energy to the solidifiable material to solidify a cross section of an object to be formed and delivers additional energy to

one or more portions of the cross section to increase the stiffness of the portion relative to other portions of the cross section.

17. A method of forming an object comprising:

forming a first cross-section of the object by applying energy to a first amount of solidifiable material;

forming at least one reinforcement structure in the first cross-section by applying additional energy to at least a portion of the first cross section; and

contacting a second amount of solidifiable material with the first cross-section, and

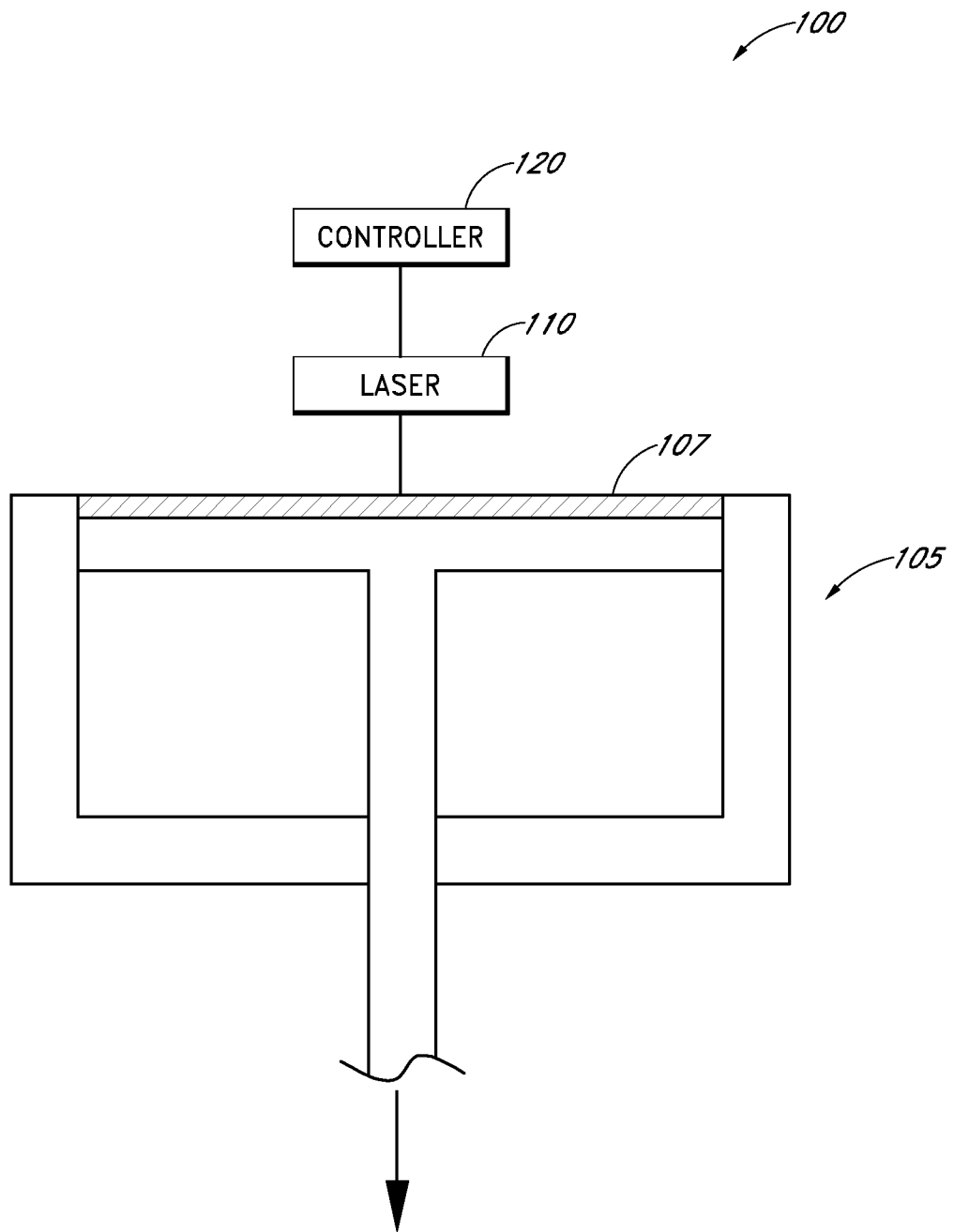
forming a second cross-section of the object by applying energy to the first second amount of solidifiable material.

18. The method of Claim 17, further comprising forming at least one reinforcement structure in the second cross-section by applying additional of energy to at least a portion of the second cross section.

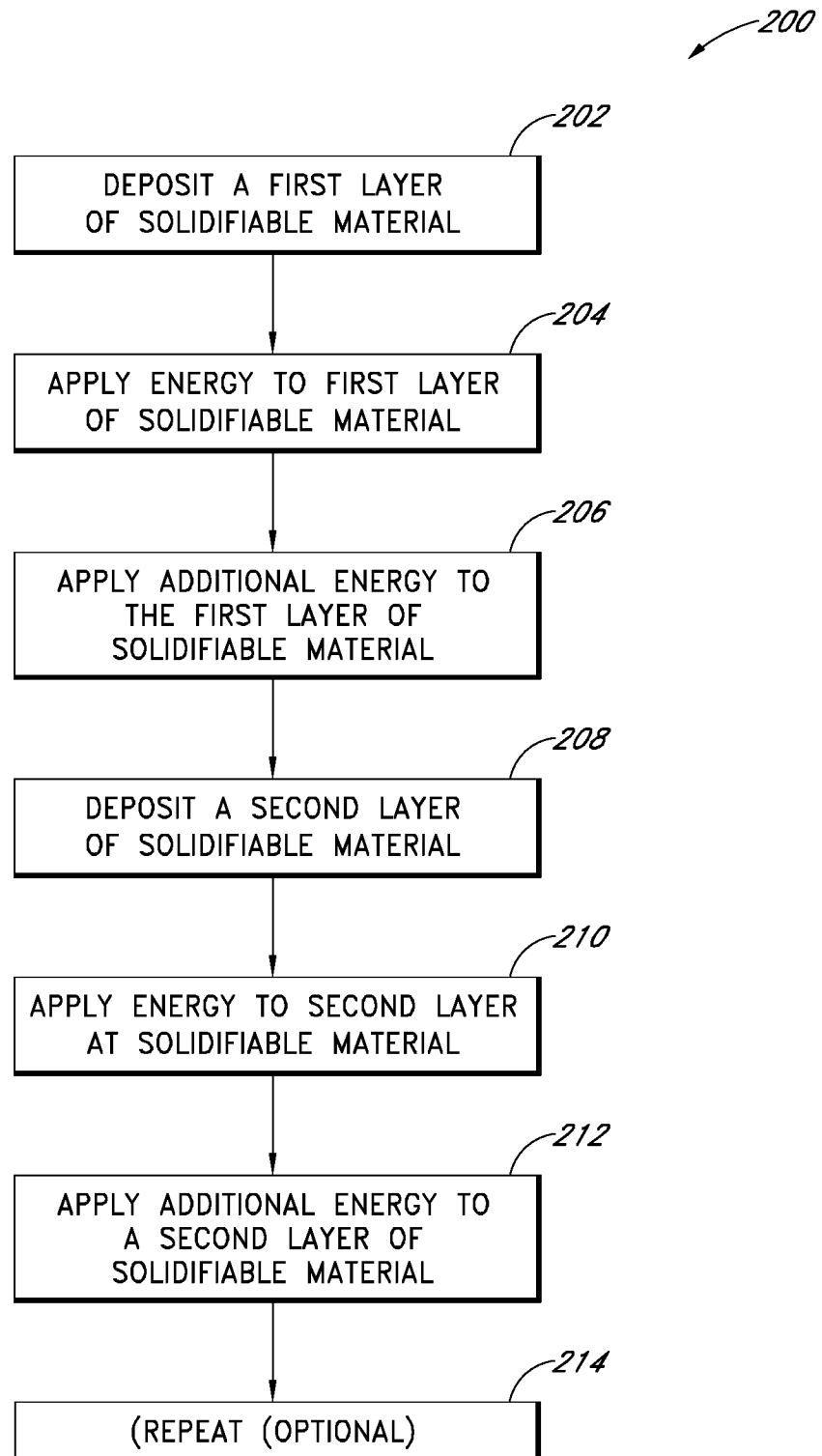
19. The method of Claim 17, further comprising receiving a digital rendering of the object.

20. The method of Claim 19, wherein the object formed is sized and shaped substantially the same as the digital rendering.

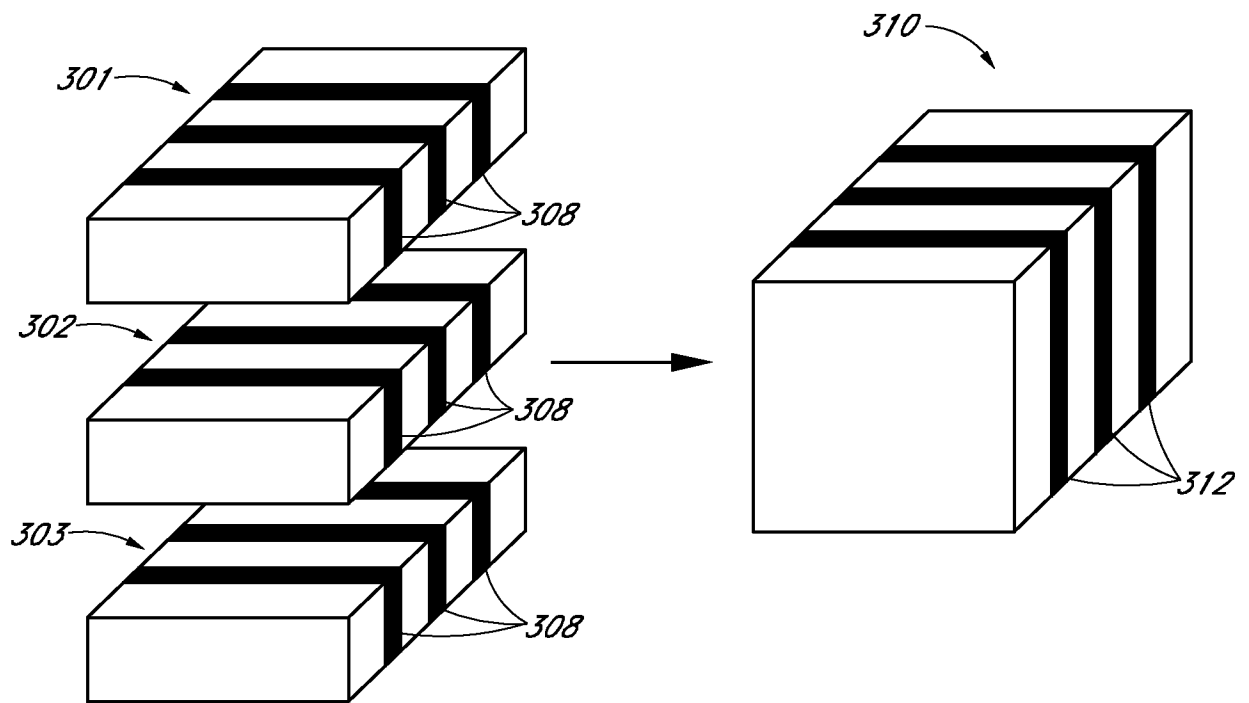
1/6

*FIG. 1*

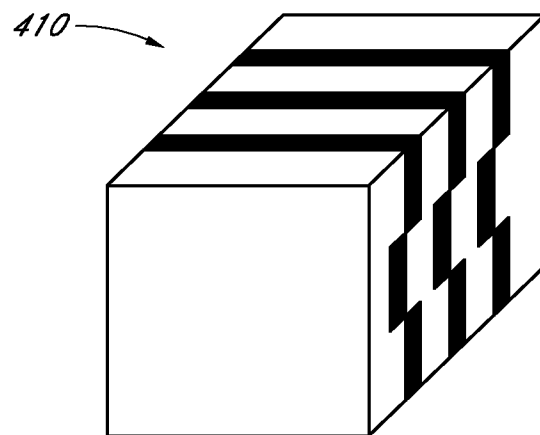
2/6

*FIG. 2*

3/6

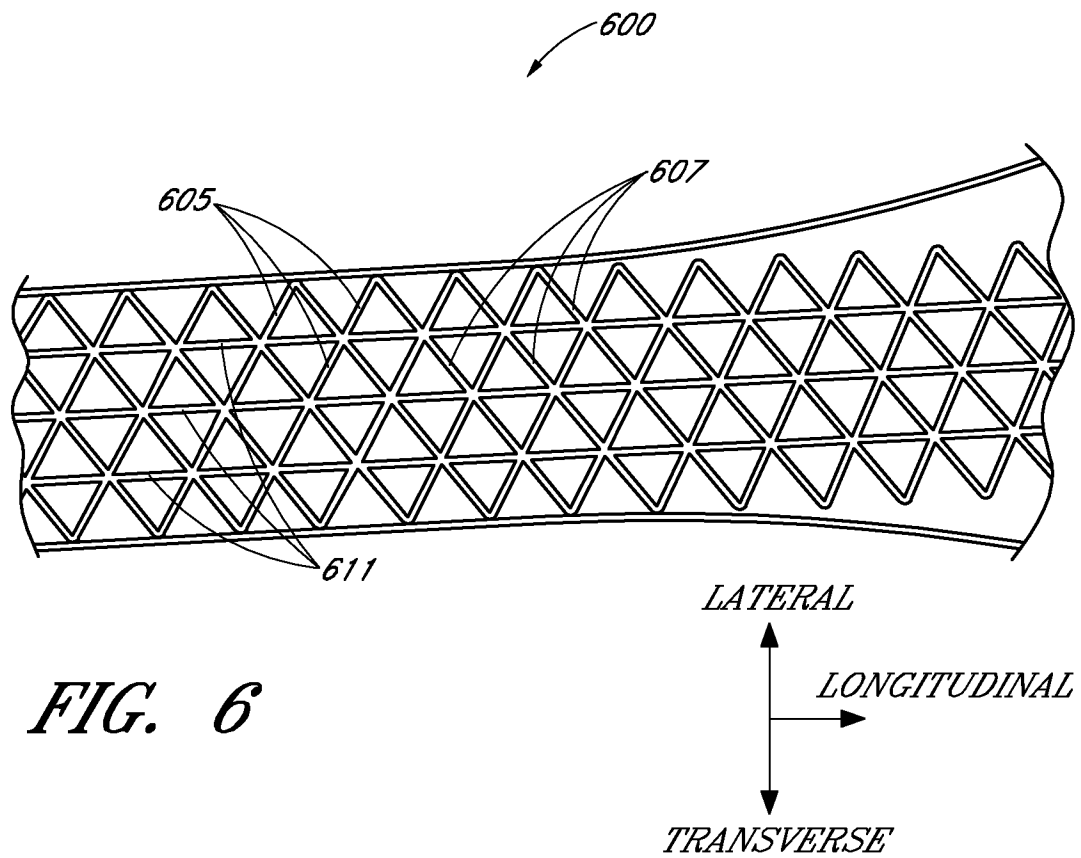
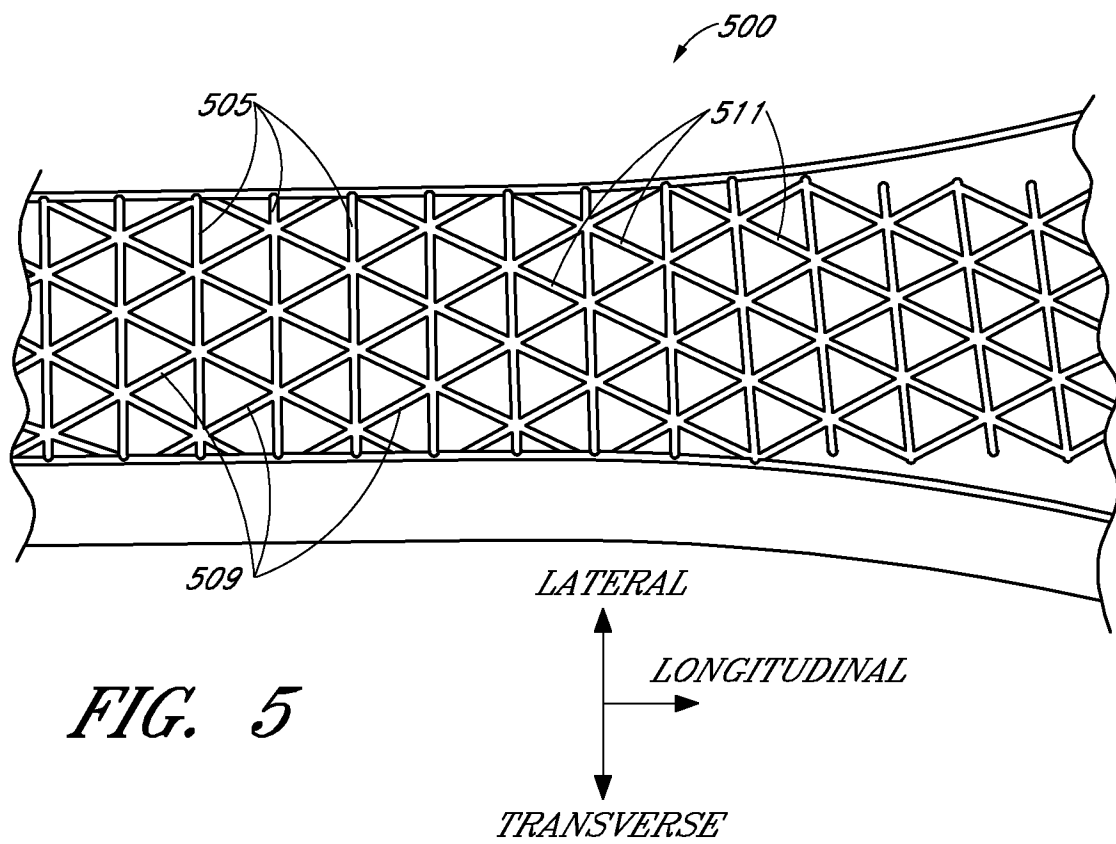


*FIG. 3*

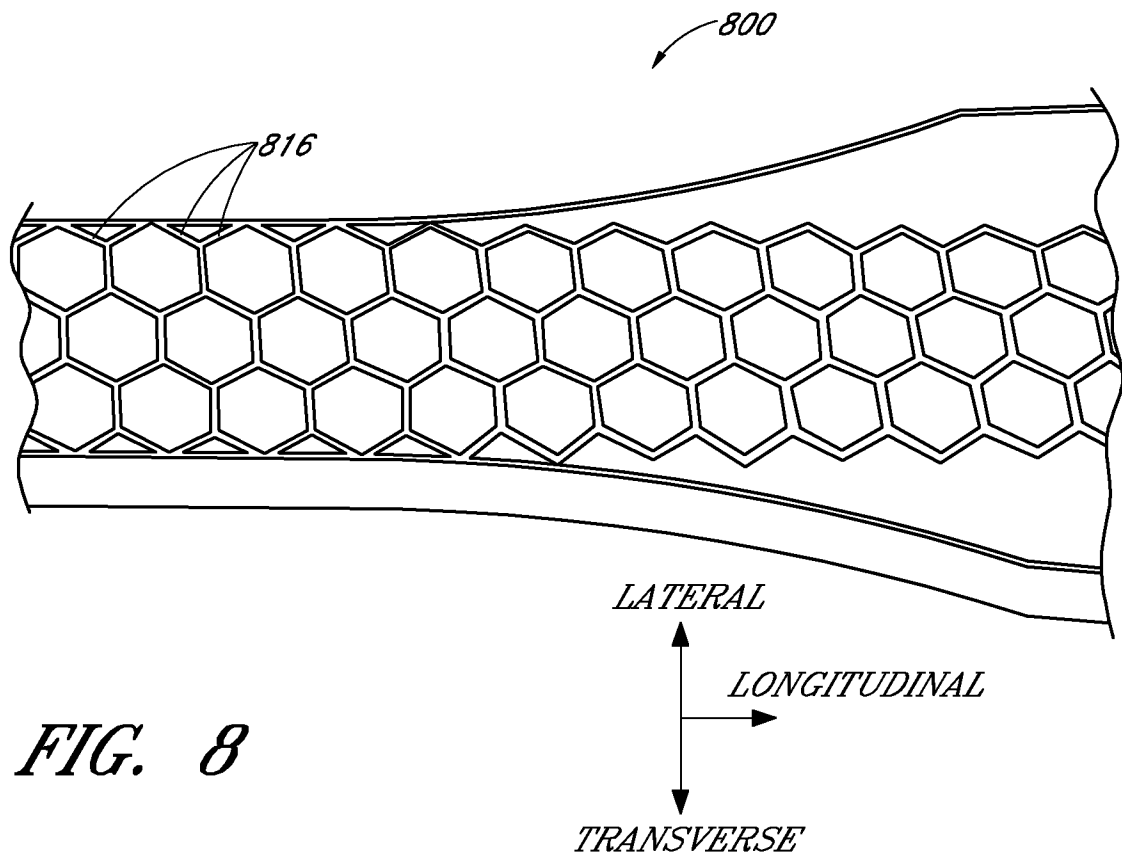
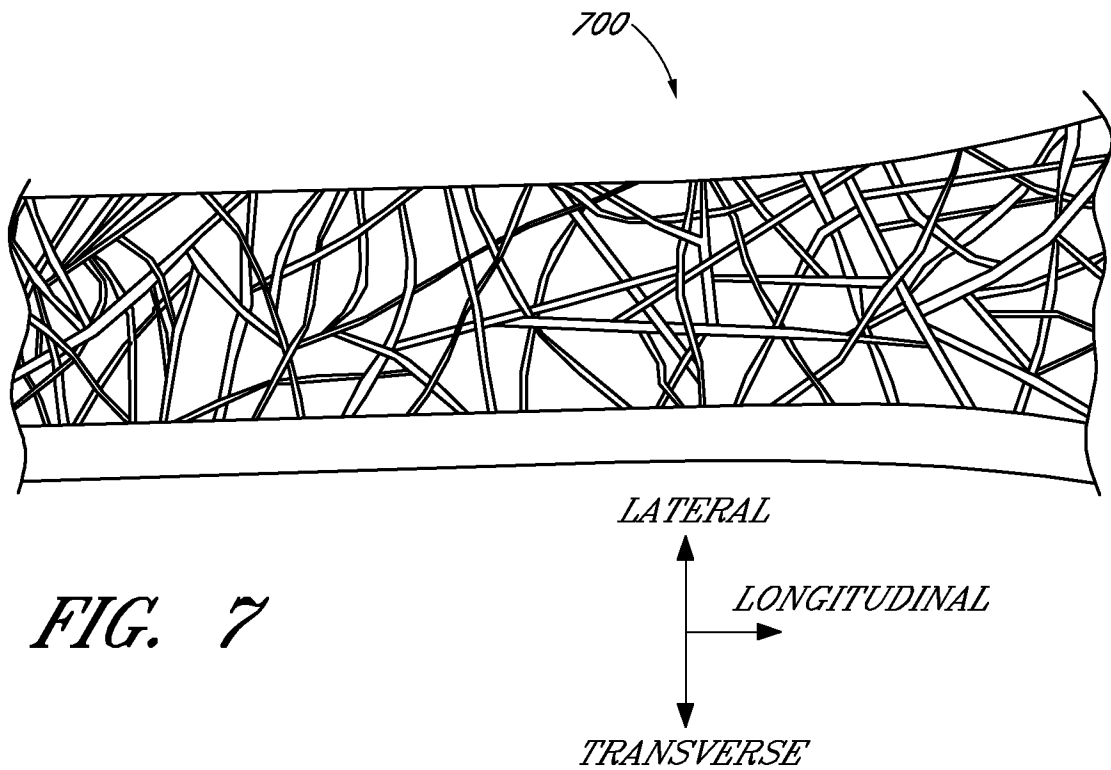


*FIG. 4*

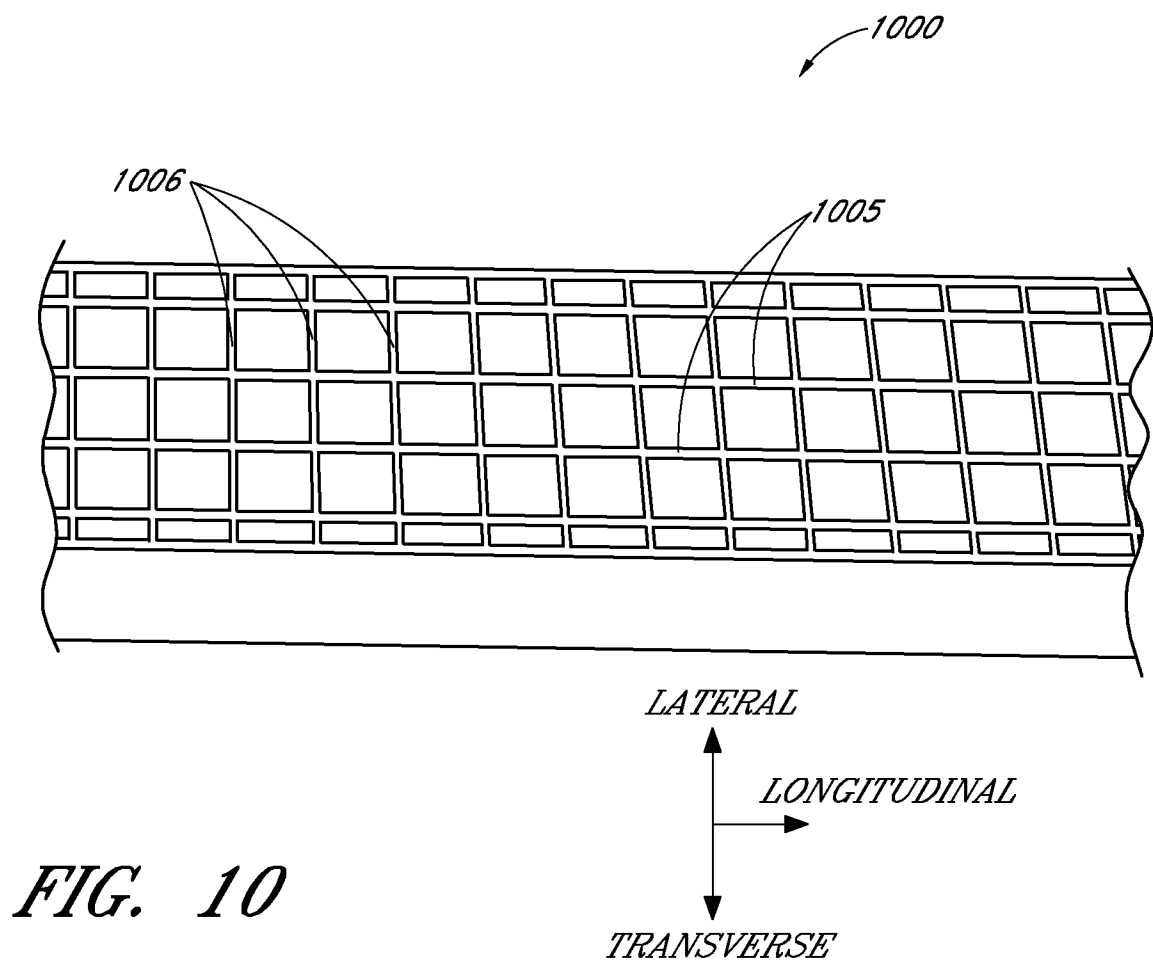
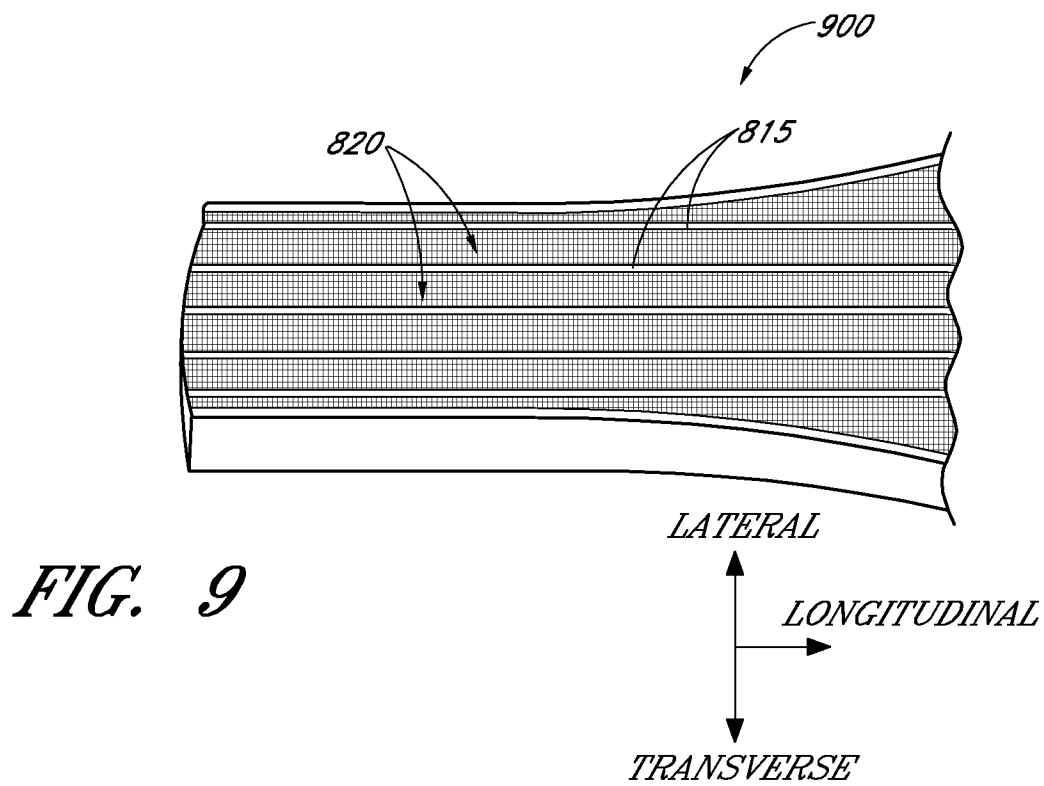
4/6



5/6



6/6



## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2013/076912

A. CLASSIFICATION OF SUBJECT MATTER  
INV. B29C67/00  
ADD.

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)  
B29C

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 1 151 849 A1 (3D SYSTEMS INC [US])<br>7 November 2001 (2001-11-07)<br>paragraph [0001]<br>paragraph [0007] - paragraph [0023]<br>paragraph [0031] - paragraph [0036]<br>paragraph [0041] - paragraph [0044]<br>paragraph [0048]<br>figures 1,3 | 1-20                  |
| X         | WO 96/11790 A1 (EOS ELECTRO OPTICAL SYST<br>[DE]; FRUTH CARL [DE]; LANGER HANS J [DE])<br>25 April 1996 (1996-04-25)<br>page 5, paragraph 3 - page 6, paragraph 3<br>page 7, line 1 - page 8, line 9<br>figures<br>-----<br>-/-                   | 1-20                  |



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

"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

8 April 2014

Date of mailing of the international search report

17/04/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

Whelan, Natalie

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2013/076912

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                     |                       |
|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                  | Relevant to claim No. |
| X                                                    | US 2010/262272 A1 (SHKOLNIK ALEXANDR [US]<br>ET AL) 14 October 2010 (2010-10-14)<br>claims<br>paragraph [0112]<br>figures 1A,2A,8,12A-12D,14C-14F<br>-----                          | 1-20                  |
| X                                                    | US 2010/095556 A1 (JARVIS KELLY B [US])<br>22 April 2010 (2010-04-22)<br>paragraph [0020] - paragraph [0022]<br>paragraph [0045] - paragraph [0047]<br>figure 2<br>-----            | 1-15                  |
| X                                                    | WO 2008/074287 A1 (CL<br>SCHUTZRECHTSVERWALTUNGS GMB [DE]; HERZOG<br>FRANK [DE]) 26 June 2008 (2008-06-26)<br>page 3, line 7 - page 5, line 8<br>page 8, line 19 - line 23<br>----- | 1-15                  |
| X                                                    | EP 2 052 693 A1 (ENVISIONTEC GMBH [DE])<br>29 April 2009 (2009-04-29)<br>claims<br>-----                                                                                            | 1-20                  |
| X                                                    | DE 10 2010 040261 A1 (EOS ELECTRO OPTICAL<br>SYST [DE]) 8 March 2012 (2012-03-08)<br>figures<br>the whole document<br>-----                                                         | 1-6,9-15              |
| X                                                    | US 5 198 159 A (NAKAMURA YOSHIMITSU [US]<br>ET AL) 30 March 1993 (1993-03-30)<br>the whole document<br>-----                                                                        | 1,14,16,<br>17        |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/076912

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date           |
|-------------------------------------------|---------------------|----------------------------|-------------------------------|
| EP 1151849                                | A1                  | 07-11-2001                 | DE 60115136 D1 29-12-2005     |
|                                           |                     |                            | DE 60115136 T2 17-08-2006     |
|                                           |                     |                            | EP 1151849 A1 07-11-2001      |
|                                           |                     |                            | JP 3556923 B2 25-08-2004      |
|                                           |                     |                            | JP 2002001827 A 08-01-2002    |
|                                           |                     |                            | US 6574523 B1 03-06-2003      |
| WO 9611790                                | A1                  | 25-04-1996                 | DE 4436695 C1 21-12-1995      |
|                                           |                     |                            | DE 19538257 A1 18-04-1996     |
|                                           |                     |                            | DE 59504444 D1 14-01-1999     |
|                                           |                     |                            | EP 0785859 A1 30-07-1997      |
|                                           |                     |                            | JP H09511705 A 25-11-1997     |
|                                           |                     |                            | US 5897825 A 27-04-1999       |
|                                           |                     |                            | WO 9611790 A1 25-04-1996      |
| US 2010262272                             | A1                  | 14-10-2010                 | EP 2241430 A1 20-10-2010      |
|                                           |                     |                            | EP 2419258 A2 22-02-2012      |
|                                           |                     |                            | US 2010262272 A1 14-10-2010   |
|                                           |                     |                            | WO 2010120839 A2 21-10-2010   |
| US 2010095556                             | A1                  | 22-04-2010                 | CN 102448340 A 09-05-2012     |
|                                           |                     |                            | EP 2429325 A2 21-03-2012      |
|                                           |                     |                            | JP 2012525289 A 22-10-2012    |
|                                           |                     |                            | KR 20120047848 A 14-05-2012   |
|                                           |                     |                            | US 2010095556 A1 22-04-2010   |
|                                           |                     |                            | US 2012117826 A1 17-05-2012   |
|                                           |                     |                            | WO 2010126708 A2 04-11-2010   |
| WO 2008074287                             | A1                  | 26-06-2008                 | DE 102006059851 A1 03-07-2008 |
|                                           |                     |                            | WO 2008074287 A1 26-06-2008   |
| EP 2052693                                | A1                  | 29-04-2009                 | CN 101917925 A 15-12-2010     |
|                                           |                     |                            | CN 101918199 A 15-12-2010     |
|                                           |                     |                            | DK 2052693 T3 11-11-2013      |
|                                           |                     |                            | EP 2052693 A1 29-04-2009      |
|                                           |                     |                            | EP 2217429 A1 18-08-2010      |
|                                           |                     |                            | EP 2224874 A1 08-09-2010      |
|                                           |                     |                            | JP 2011500382 A 06-01-2011    |
|                                           |                     |                            | US 2009130449 A1 21-05-2009   |
|                                           |                     |                            | US 2009146344 A1 11-06-2009   |
|                                           |                     |                            | US 2011260365 A1 27-10-2011   |
|                                           |                     |                            | WO 2009053099 A1 30-04-2009   |
|                                           |                     |                            | WO 2009053100 A1 30-04-2009   |
| DE 102010040261                           | A1                  | 08-03-2012                 | CN 103118858 A 22-05-2013     |
|                                           |                     |                            | DE 102010040261 A1 08-03-2012 |
|                                           |                     |                            | EP 2440387 A1 18-04-2012      |
|                                           |                     |                            | JP 2013536774 A 26-09-2013    |
|                                           |                     |                            | US 2013171019 A1 04-07-2013   |
|                                           |                     |                            | WO 2012028747 A1 08-03-2012   |
| US 5198159                                | A                   | 30-03-1993                 | NONE                          |