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(71) Applicant *(for all designated States except US)*: **BOSTON SCIENTIFIC SCIMED, INC.** [US/US]; One Scimed Place, Maple Grove, MN 55311-1566 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **CHANDRASEKARAN, Chandru** [US/US]; 2433 84th Avenue SE, Mercer Island, WA 98040 (US). **RADHAKRISHNAN, Rajesh** [IN/US]; 2716 204th Street SE, Bothell, WA 98012 (US).

(74) Agents: **STERN, Gidon, D.** et al.; Jones Day, 222 East 41st Street, New York, NY 10017-6702 (US).

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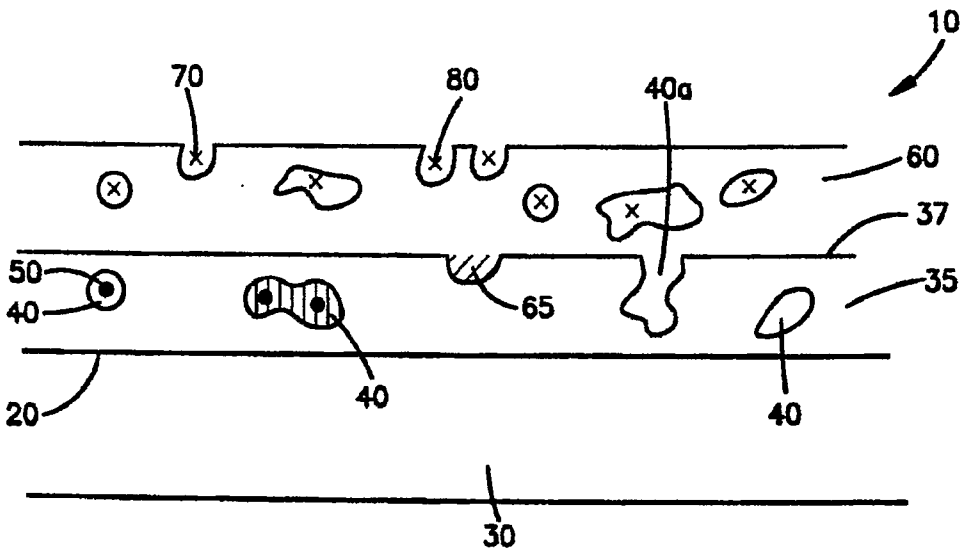
(54) **Title:** MEDICAL DEVICES COMPRISING A POROUS METAL OXIDE OR METAL MATERIAL AND A POLYMER COATING FOR DELIVERING THERAPEUTIC AGENTS



(57) **Abstract:** The invention relates generally to a medical device, such as an intravascular stent, for delivering a therapeutic agent to the body tissue of a patient, and a method for making such a medical device. More particularly, the invention pertains to a medical device having a metal oxide or metal material with a plurality of pores therein disposed on the surface of the medical device and a polymer disposed on the metal oxide or metal material. The invention also relates to medical devices having a surface and an outer region comprising a metal oxide or metal material having a plurality of pores therein and a polymer disposed on the metal oxide or metal material.

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MEDICAL DEVICES COMPRISING A POROUS METAL OXIDE OR METAL MATERIAL AND A POLYMER COATING FOR DELIVERING THERAPEUTIC AGENTS

FIELD OF THE INVENTION

[0001] The invention relates generally to a medical device for delivering a therapeutic agent to the body tissue of a patient, and a method for making such a medical device. More particularly, the invention pertains to a medical device having a metal oxide or metal material with a plurality of pores therein disposed on the surface of the medical device and a polymer disposed on the metal oxide or metal material. The invention also relates to medical devices having a surface and an outer region comprising a metal oxide or metal material having a plurality of pores therein and a polymer disposed on the metal oxide or metal material.

BACKGROUND OF THE INVENTION

[0002] Medical devices, such as implantable stents, have been used to deliver therapeutic agents directly to body tissue of a patient, particularly for treating restenosis. In particular, therapeutic agents can be incorporated into the medical device structure itself or incorporated into a coating that is disposed on the surface of the medical device.

[0003] In some instances it is desirable to increase the amount of therapeutic agent to be delivered by the medical device. However, the surface area of the medical device may limit the amount of therapeutic agent that can be delivered or incorporated into or onto the medical device. Thus, it may be desirable to have a medical device or a coating for a medical device with a greater surface area so that a greater amount of therapeutic agent can be incorporated into or onto the medical device.

[0004] Furthermore, in some instances, it is desirable to control the rate of release of the therapeutic agent from the medical device. For example, it may be desirable to have a constant rate of release of a therapeutic agent for an extended period of time. To ensure a constant rate of release, the amount of therapeutic agent that is loaded on to the implantable medical device must be above a certain amount and, at the same time, be able to be released from the medical device. In addition to ensuring an adequate amount of therapeutic agent is disposed on the medical device in order to achieve a constant release rate, it also desirable to prevent the therapeutic agent from being released from the medical device to the targeted tissue too rapidly, *e.g.*, to avoid a burst effect.

[0005] Accordingly, there is a need for a medical device that can deliver the desired amount or dosage of a therapeutic agent. Furthermore, there is a need for a method of making a medical device with a greater surface area that can incorporate a desired amount of a therapeutic agent that will release from the medical device. Also, there is also a need for a medical device that can deliver the desired amount of a therapeutic agent at a desired rate or in a controlled manner over time.

SUMMARY OF THE INVENTION

[0006] These and other objectives are accomplished by the present invention. The present invention is directed towards an implantable medical device such as a stent, which has increased surface area and a controllable release rate of a therapeutic agent.

[0007] The medical device of the present invention comprises a porous surface which increases the surface area of the medical device, allowing a greater amount of therapeutic agent to be loaded onto the medical device. In addition, by controlling the amount or concentration of the therapeutic agent within the pores or disposed on the surface of the medical device, as well as, controlling the size, depth, location and number of the pores, the release rate of the therapeutic agent can be controlled.

[0008] Additionally, the medical device of the present invention can comprise a porous coating, over the surface of the medical device. The release rate of the therapeutic agent can further be controlled by controlling the thickness and porosity of the coating.

[0009] The present invention, in one embodiment, provides an implantable medical device comprising: (a) a surface; (b) a coating disposed on the surface comprising: (i) a first material comprising a metal oxide or a metal having a plurality of pores therein disposed on at least a portion of the surface, wherein a first therapeutic agent is disposed in at least some of the pores of the first metal oxide or metal material; and (ii) a first polymer disposed on at least a portion of the first metal oxide or metal material, wherein the first polymer has a plurality of pores therein.

[0010] The medical device, of the present invention, can further comprise an outer region adjacent to the surface, wherein the outer region comprises a second material comprising a metal oxide or a metal having a plurality of pores therein, and a second therapeutic agent disposed in at least some of the pores of the second metal oxide or metal material. The first metal oxide or metal material and the second metal oxide or metal material can be the same.

[0011] Additionally, the medical device, of the present invention can further comprise an inner region adjacent to the outer region, wherein the inner region is substantially non-porous.

[0012] Also, the medical device, of the present invention, can further comprise a second polymer disposed in at least some of the pores of the first metal oxide or metal material. Additionally, the first and second polymers can be the same.

[0013] Suitable polymers include, but are not limited to, ethylene-vinylacetate copolymers, such as, polyethylene-co-vinyl acetate; polymethacrylates, such as, poly(n-butyl methacrylate); styrene-isobutylene copolymers, such as, poly(styrene-b-. isobutylene-b-styrene); and polylactic acids, such as, polylactic-glycolic acid.

[0014] In accordance with the present invention, the first metal oxide or metal material can be in the form of a layer. Also, the first polymer can be in the form of a layer.

[0015] Suitable metal materials include, but are not limited to, gold, platinum, stainless steel, titanium, tantalum, iridium, molybdenum, niobium, palladium or chromium.

[0016] Suitable metal oxide materials comprise an oxide of a transitional metal. Suitable metal oxides include, but are not limited to, tantalum oxide, titanium oxide, iridium oxide, niobium oxide, zirconium oxide, tungsten oxide, or rhodium oxide. Additionally, the metal oxide or metal material can be radiopaque.

[0017] The pores in the first metal oxide or metal material can be micropores, nanopores or a combination thereof. The pores in the first metal oxide or metal material can have an average width or diameter of between about 1 nm and about 10 μm. Additionally, the pore size can be designed or engineered to suit the size of the therapeutic agent that is disposed in the pores.

[0018] The first therapeutic agent can comprise an anti-restenosis agent, anti-thrombogenic agent, anti-angiogenesis agent, anti-proliferative agent, antibiotic agent, growth factor, immunosuppressant or radiochemical. Preferably, the therapeutic agent comprises an anti-restenosis agent. Suitable therapeutic agents include, but are not limited to, paclitaxel, sirolimus, tacrolimus, pimecrolimus or everolimus. Additionally, the first therapeutic agent and the second therapeutic agent can be the same.

[0019] In another embodiment, the present invention provides an implantable medical device comprising: (a) a surface and an outer region adjacent to the surface, wherein the surface and the outer region comprise a material comprising a metal oxide or a metal having a plurality of pores therein, and a therapeutic agent disposed in at least some of the pores in the metal oxide or metal material; (b) an inner region adjacent to the outer region, wherein the

inner region is substantially non-porous; and (c) a first polymer disposed on at least a portion of the surface, wherein the first polymer has a plurality of pores therein. The first polymer can also be in the form of a layer.

[0020] The first polymer can also comprise a second therapeutic agent dispersed in the pores of the first polymer, and wherein the first therapeutic agent and the second therapeutic agent are the same.

[0021] The medical device can further comprise a second polymer disposed in at least some of the pores of the metal oxide or metal material. Additionally, the first and second polymers can be the same. Suitable polymers include, but are not limited to, ethylene-vinylacetate copolymers, such as, polyethylene-co-vinyl acetate; polymethacrylates, such as, poly(n-butyl methacrylate); styrene-isobutylene copolymers, such as, poly(styrene-b-. isobutylene-b-styrene); and polylactic acids, such as, polylactic-glycolic acid.

[0022] Suitable metal materials include but are not limited to, gold, platinum, stainless steel, titanium, tantalum, iridium, molybdenum, niobium, palladium or chromium.

[0023] The metal oxide material can comprise an oxide of a transitional metal. Suitable metal oxide materials include, but are not limited to, tantalum oxide, titanium oxide, iridium oxide, niobium oxide, zirconium oxide, tungsten oxide, or rhodium oxide. Additionally, the metal oxide or metal material can be radiopaque.

[0024] The pores in the metal oxide or metal material can be micropores, nanopores or a combination thereof. The pores in the metal oxide or metal material have an average width or diameter of between about 1 nm and about 10 μm.

[0025] The therapeutic agent can comprise an anti-restenosis agent, anti-thrombogenic agent, anti-angiogenesis agent, anti-proliferative agent, antibiotic agent, growth factor, immunosuppressant or radiochemical. Preferably, the therapeutic agent comprises an anti-restenosis agent. Suitable therapeutic agent, include but are not limited to, paclitaxel, sirolimus, tacrolimus, pimecrolimus or everolimus.

[0026] In yet another embodiment, the present invention provides an intravascular stent comprising: (a) a metallic sidewall stent structure designed for implantation into a blood vessel of a patient, wherein the sidewall stent structure comprises a plurality of struts and openings in the sidewall stent structure, wherein at least one strut has a surface; (b) a coating disposed on the surface comprising: (i) a first material comprising a metal oxide or a metal having a plurality of pores therein disposed on at least a portion of the surface of the strut, wherein a first therapeutic agent disposed in at least some of the pores of the first metal oxide

or metal material; and (ii) a first polymer disposed on at least a portion of the first metal oxide or metal material, wherein the first polymer has a plurality of pores therein.

[0027] The first metal oxide or metal material and the first polymer can conform to the surface to preserve the openings in the sidewall stent structure. Also, the sidewall stent structure can be balloon-expandable.

[0028] The therapeutic agent can comprise an antibiotic and the polymer can comprise an ethylene vinyl acetate copolymer.

[0029] In yet another embodiment, the present invention also provides an intravascular stent comprising:(a) a metallic open lattice sidewall stent structure designed for implantation into a blood vessel of a patient, wherein the sidewall stent structure comprises a plurality of struts and openings in the sidewall stent structure, and wherein at least one strut has (i) a surface and an outer region adjacent to the surface, wherein the surface and the outer region comprise a material comprising a metal oxide or a metal having a plurality of pores therein, and a therapeutic agent disposed in at least some of the pores in the metal oxide or metal material; and (ii) an inner region adjacent to the outer region, wherein the inner region is substantially non-porous; and (b) a first polymer disposed on at least a portion of the first metal oxide or metal material, wherein the first polymer has a plurality of pores therein.

[0030] The first polymer can conform to the surface to preserve the openings in the sidewall stent structure. Also, the sidewall stent structure can be balloon-expandable.

[0031] The therapeutic agent can comprise an antibiotic and the polymer can comprise an ethylene vinyl acetate copolymer.

[0032] The present invention is also directed to methods for making the medical device of the present invention. In one embodiment the present invention provides a method of making an implantable medical device comprising: (a) providing a medical device having a surface; (b) forming a coating comprising a first material comprising a metal oxide or a metal having a plurality of pores therein on at least a portion of the surface, (c) depositing a first therapeutic agent in at least some of the pores of the first metal oxide or metal material; and (d) forming a coating of a first polymer disposed on at least a portion of the first metal oxide or metal material, wherein the first polymer has a plurality of pores therein.

[0033] The forming of the coating of the first metal oxide or metal material having a plurality of pores therein can comprise the steps of (i) applying a composition comprising the first metal oxide or metal material and a secondary phase material to at least a portion of the surface and (ii) removing the secondary phase material to form the plurality of pores in the first metal oxide or metal material.

[0034] Suitable secondary phase materials include, but are not limited to, carbon, aluminum, nickel or a combination thereof. Other suitable secondary phase materials include polymers. Preferably, the polymers can be leached out.

[0035] The secondary phase material can be removed by annealing or chemical etching.

[0036] Additionally, the forming of the coating of the first metal oxide or metal material having a plurality of pores therein can comprise applying a composition comprising the first metal oxide or metal material to at least a portion of the surface by sputtering, electroplating, e-beam evaporation or thermal evaporation.

[0037] The first therapeutic agent can be deposited in at least some of the pores of the first metal oxide or metal material by vacuum impregnation or electrophoretic transport.

[0038] The forming of the first polymer coating having a plurality of pores can comprise the steps of (i) applying a composition comprising the first polymer and a secondary phase material to the coating of the first metal oxide or metal material and (ii) removing the secondary phase material to form the plurality of pores in the first polymer.

[0039] Suitable secondary phase materials include, but are not limited to polymers or metals that can be removed by dissolution or leaching. Suitable polymers include, but are not limited to, polymers containing styrene, such as, polystyrene. Suitable metals include, but are not limited, aluminum, nickel or a combination thereof.

[0040] The secondary phase material can be removed by selectively dissolving or leaching out the second phase material.

[0041] In another embodiment, the present invention also provides a method of making an implantable medical device comprising: (a) providing a medical device having (i) a surface and an outer region adjacent to the surface, wherein the surface and the outer region comprise a material comprising a metal oxide or a metal having a plurality of pores therein, and (ii) an inner region adjacent to the outer region, wherein the inner region is substantially non-porous; (b) depositing a therapeutic agent in at least some of the pores in the metal oxide or metal material; (c) forming a coating of a first polymer disposed on at least a portion of the surface, wherein the first polymer has a plurality of pores.

[0042] The method, of the present invention can also comprise the step of forming the pores in the metal oxide or metal material of the surface and outer region. The pores can be formed by micro-roughening the medical device.

[0043] The therapeutic agent can be deposited in at least some of the pores of the metal oxide or metal material by vacuum impregnation or electrophoretic transport.

[0044] Additionally, the forming of the polymer coating having a plurality of pores can comprise the steps of (i) applying a composition comprising the first polymer and a secondary phase material to the surface and (ii) removing the secondary phase material to form the plurality of pores in the first polymer.

[0045] Suitable secondary phase materials include, but are not limited to polymers or metals that can be dissolved or leached out. Suitable polymers include, but are not limited to, polystyrene. Suitable metals include, but are not limited, aluminum, nickel or a combination thereof.

[0046] The secondary phase material can be removed by selectively dissolving or leaching out the second phase material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] The present invention will be explained with reference to the following drawings.

[0048] **FIG. 1** is a cross-sectional view of an embodiment of the present invention that includes a material comprising a metal oxide or metal disposed on the surface of the medical device.

[0049] **FIG. 2** is a cross-sectional view of another embodiment of the present invention that includes a material comprising a metal oxide or metal disposed on the surface of the medical device.

[0050] **FIG. 3** is a cross-sectional view of an embodiment of the present invention in which the medical device has a surface and an outer region that comprises a material comprising a metal oxide or metal.

[0051] **FIG. 4** is a cross-sectional view of a strut of a stent in which a material comprising a metal oxide or metal has been disposed on the surface of the strut.

[0052] **FIG. 5** is a perspective view of a portion of an intravascular stent.

DETAILED DESCRIPTION

[0053] In one embodiment of the present invention, a material comprising a metal oxide or metal having a plurality of pores therein is disposed on at least a portion of the surface of the medical device. **FIG. 1** shows an example of such an embodiment of the invention. In this embodiment, a medical device **10** has a surface **20** that is adjacent to an outer region **30** of the medical device **10**. The outer region **30** is adjacent to an inner region (not shown) of the medical device **10**. A material that comprises a metal oxide or metal **35** is

disposed on at least a portion of the surface **20**. This material can be in the form of a layer. A plurality of pores **40** are present in the metal oxide or metal material **35**. Preferably, at least some of the pores **40** are interconnected. Also, at least some of the pores **40** contain a first therapeutic agent **50**. The first therapeutic agent **50** can be in particulate form. In addition, the first therapeutic agent **50** can partially or entirely fill a pore **40**.

[0054] Disposed on the first metal oxide or metal material **35** of **FIG. 1** is a first polymer **60**, which forms a coating thereon. The polymer can be in the form of a layer. The polymer **60** has a plurality of pores **70** therein. In this embodiment, the pores in the polymer **60** include a second therapeutic agent **80**, which can be the same as or different from the first therapeutic agent **50**. In other embodiments, the pores **70** in the polymer **60** can be free of a therapeutic agent or substantially free of a therapeutic agent, *i.e.* a therapeutic agent occupies less than 5% of the volume of the pores.

[0055] In some embodiments, the pores **40** of the metal oxide or metal material **35** can also include a second polymer **65** in addition to the polymer **60**. The second polymer **65** can be the same as or different from the first polymer **60**.

[0056] Another embodiment of the present invention is shown in **FIG. 2**. Like the embodiment shown in **FIG. 1**, this embodiment comprises a first material that comprises a metal oxide or metal material **35** that is disposed on at least a portion of the surface **20** of a medical device **10**. A plurality of pores **40** are present in the first metal oxide or metal material **35**. A therapeutic agent **50** and optionally a second polymer **65** is present in at least some of the pores **40**. A first polymer **60** having a plurality of pores **70** therein is disposed on the first metal oxide or metal material **35**. The pores **70** in the first polymer **60** can include a second therapeutic agent **80**.

[0057] In this embodiment of **FIG. 2**, the surface **20** is adjacent to an outer portion **30** of the medical device **10**, which in turn is adjacent to an inner portion **32** of the medical device **10**. The outer portion **30** is comprised of a second material that comprises a metal oxide or metal **90** having a plurality of pores **95** therein. This second material **90** can be the same as or different from the first metal oxide or metal material **35**. A therapeutic agent **100** that can be the same as or different from the first therapeutic agent **50** or second therapeutic agent **80** can be deposited in the pores **95** of the second metal oxide or metal material **90**. The inner portion **32** of the medical device **10** is substantially non-porous, *i.e.* less than 5% of the volume of the inner portion **32** is occupied by pores. Although the inner portion **32** is substantially non-porous, it can be made of the same metal oxide or metal material that is used to form the outer portion **30**.

[0058] **FIG. 3** shows a cross-sectional view of another embodiment of the present invention. In this embodiment, a medical device **10** comprises a surface **20**, an outer region **30** that is adjacent to the surface **20**, and an inner region **32** that is adjacent to the outer region **30**. The outer region **30** is comprised of a material comprising a metal oxide or metal **90** having a plurality of pores **95** therein. The pores **95** in the metal oxide or metal material **90** contain a therapeutic agent **100** and optionally a polymer **105**. The inner portion **32** of the medical device **10** is substantially non-porous, *i.e.* less than 5% of the volume of the inner portion **32** is occupied by pores. Disposed on the surface **20** is a quantity of another polymer **60**, which can be the same as or different from the polymer **105** disposed in the pores **95**. The quantity of polymer **60** can include pores **70** therein. The pores **70** in the quantity of polymer **60** can include a second therapeutic agent **80**.

[0059] **FIG. 4** shows a cross-sectional view of a stent strut **150** having an inner region **32** that is adjacent to an outer region **30**. The strut **150** also has a surface **20** that is adjacent to the outer region **30**. Similar to the embodiment shown in **FIG. 1**, a material that comprises a metal oxide or metal **35** having a plurality of pores **40** therein is disposed on at least a portion of the surface **20**. At least some of the pores **40** contain a first therapeutic agent **50**. Disposed on the first metal oxide or metal material **35** is a first polymer **60**, which forms a coating thereon. The polymer **60** comprises a plurality of pores **70** therein. In this embodiment, the pores in the polymer **60** include a second therapeutic agent **80**, which can be the same as or different from the first therapeutic agent **50**.

[0060] Preferably the metal oxide or metal material having a plurality of pores is biocompatible. Suitable metal oxides include transition metal oxides. These include, but are not limited to, tantalum oxide, titanium oxide, iridium oxide, niobium oxide, zirconium oxide, tungsten oxide, rhodium oxide and combinations thereof. Suitable metals include but are not limited to, gold, platinum, stainless steel, tantalum, titanium, iridium, molybdenum, niobium, palladium, or chromium.

[0061] Also, it may be preferably that the metal oxide or metal material be radiopaque so that the medical device is visible under x-ray or fluoroscopy. Suitable radiopaque materials include without limitation gold, tantalum, platinum, bismuth, iridium, zirconium, iodine, titanium, barium, silver, tin, or alloys of these metals.

[0062] Some or all of the pores in the metal oxide or metal material can be interconnected to other pores. In some embodiments, the pores may be discrete or disposed in a pattern. Also, some or all of the pores in the metal oxide or metal material may be in communication with the outer surface of the metal oxide or metal material. For example, in

FIGS. 1-2, the pores **40a** are in communication with the outer surface **37** of the metal oxide or metal material. Such communication with the outer surface can facilitate release of the therapeutic agent from the medical device. Additionally, once drug elution is complete, having the pores in communication with the outer surface can aid in vascularization and cell coverage for long term non-inflammation.

[0063] In addition, the pores in the metal oxide or metal material may have any shape. For example, the pores can be shaped like channels, void pathways or microscopic conduits. Additionally, the pores in the metal oxide or metal material may have any size or range of sizes. In some instances, the pores can be micropores or nanopores. Also, in some embodiments, it may be preferable that the average width or diameter of the pores is between about 1 nm and about 10 μm.

[0064] The size of the pores can also be used to control the release rate of the therapeutic agent. For example, pores having larger average width will allow the therapeutic agent to be released more quickly than pores with a smaller average width. Also, the number of pores in the metal oxide or metal material can be adjusted to better control the release rate of the therapeutic agent. For example, the presence of more pores per unit volume or weight of the metal oxide or metal material can allow for a higher release rate of the therapeutic agent than a material having fewer pores therein.

[0065] The metal oxide or metal material having pores therein applied to the surface can be any thickness. In some embodiments, it is preferable that the average thickness of the material be about 1.0 to about 50 microns. Similarly, the outer region of the medical device that comprises the metal oxide or metal material having pores therein can be of any thickness. In some embodiments, it is preferable that this outer region be about 1 to about 10 percent of the thickness of the portion of the medical device that includes this outer region. In the instance where the portion of the medical device is a strut of a stent, it is preferable that the outer region of the strut that comprises the porous metal oxide or metal material be about 1 to about 10 percent of the thickness of the strut.

[0066] The polymer disposed on the metal oxide or metal material can be any thickness needed to achieve the desired release rate of the therapeutic agent. A thicker or thinner coating of the polymer may be preferred to affect the rate at which the therapeutic agent is released. In some cases, the polymer preferably has a thickness of about 1 to about 20 microns.

[0067] Also the polymer may have a plurality of pores therein. The polymer may also comprise a therapeutic agent in the pores that may be the same or a different from that in

the pores of the metal oxide or metal material. The size and number of the pores can be adjusted in order to control the release rate of the therapeutic agent that may be dispersed in the pores of the polymer.

A. Medical Devices

[0068] Suitable medical devices for the present invention include, but are not limited to, stents, surgical staples, catheters, such as central venous catheters and arterial catheters, guide wires, cannulas, cardiac pacemaker leads or lead tips, cardiac defibrillator leads or lead tips, implantable vascular access ports, blood storage bags, blood tubing, vascular or other grafts, intra-aortic balloon pumps, heart valves, cardiovascular sutures, total artificial hearts and ventricular assist pumps, extra-corporeal devices such as blood oxygenators, blood filters, hemodialysis units, hemoperfusion units or plasmapheresis units.

[0069] Medical devices which are particularly suitable for the present invention include any stent for medical purposes, which are known to the skilled artisan. Suitable stents include, for example, vascular stents such as self-expanding stents and balloon expandable stents. Examples of self-expanding stents are illustrated in U.S. Patent Nos. 4,655,771 and 4,954,126 issued to Wallsten and 5,061,275 issued to Wallsten *et al.* Examples of appropriate balloon-expandable stents are shown in U.S. Patent No. 5,449,373 issued to Pinchasik *et al.* In preferred embodiments, the stent suitable for the present invention is an Express stent. More preferably, the Express stent is an Express™ stent or an Express2™ stent (Boston Scientific, Inc. Natick, Mass.).

[0070] **FIG. 5** shows an example of a medical device that is suitable for use in the present invention. This figure shows a portion of an implantable intravascular stent **200** comprising a sidewall **210** which comprises a plurality of struts **230** and at least one opening **250** in the sidewall **210**. Generally, the opening **250** is disposed between adjacent struts **230**. This embodiment is an example of a stent where the struts and openings of the stent define an open lattice sidewall stent structure. Also, the sidewall **210** may have a first sidewall surface **260** and an opposing second sidewall surface, which is not shown in **FIG. 5**. The first sidewall surface **260** can be an outer sidewall surface, which faces the body lumen wall when the stent is implanted, or an inner sidewall surface, which faces away from the body lumen wall. Likewise, the second sidewall surface can be an outer sidewall surface or an inner sidewall surface. In a stent having a sidewall stent structure with openings therein, in certain embodiments, it is preferable that the coating applied to the stent conforms to the surface of

the stent so that the openings in the sidewall stent structure is preserved, *e.g.* the openings are not entirely or partially occluded with coating material.

[0071] The framework of the suitable stents may be formed through various methods as known in the art. The framework may be welded, molded, laser cut, electro-formed, or consist of filaments or fibers which are wound or braided together in order to form a continuous structure.

[0072] Medical devices that are suitable for the present invention may be fabricated from metallic, ceramic, or polymeric materials, or a combination thereof. Preferably, the materials are biocompatible. Metallic material is more preferable. Suitable metallic materials include metals and alloys based on titanium (such as nitinol, nickel titanium alloys, thermo-memory alloy materials), stainless steel, tantalum, nickel-chrome, or certain cobalt alloys including cobalt-chromium-nickel alloys such as Elgiloy® and Phynox®. Metallic materials also include clad composite filaments, such as those disclosed in WO 94/16646.

[0073] Suitable ceramic materials include, but are not limited to, oxides, carbides, or nitrides of the transition elements such as titanium oxides, hafnium oxides, iridium oxides, chromium oxides, aluminum oxides, and zirconium oxides. Silicon based materials, such as silica, may also be used.

[0074] Suitable polymeric materials for forming the medical devices may be biostable. Also, the polymeric material may be biodegradable. Suitable polymeric materials include, but are not limited to, styrene isobutylene styrene, polyetheroxides, polyvinyl alcohol, polyglycolic acid, polylactic acid, polyamides, poly-2-hydroxy-butyrate, polycaprolactone, poly(lactic-co-clycolic)acid, and Teflon.

[0075] Polymeric materials may be used for forming the medical device in the present invention include without limitation isobutylene-based polymers, polystyrene-based polymers, polyacrylates, and polyacrylate derivatives, vinyl acetate-based polymers and its copolymers, polyurethane and its copolymers, silicone and its copolymers, ethylene vinyl-acetate, polyethylene terephtalate, thermoplastic elastomers, polyvinyl chloride, polyolefins, cellulosics, polyamides, polyesters, polysulfones, polytetrafluorethylenes, polycarbonates, acrylonitrile butadiene styrene copolymers, acrylics, polylactic acid, polyglycolic acid, polycaprolactone, polylactic acid-polyethylene oxide copolymers, cellulose, collagens, and chitins.

[0076] Other polymers that are useful as materials for medical devices include without limitation dacron polyester, poly(ethylene terephthalate), polycarbonate, polymethylmethacrylate, polypropylene, polyalkylene oxalates, polyvinylchloride,

polyurethanes, polysiloxanes, nylons, poly(dimethyl siloxane), polycyanoacrylates, polyphosphazenes, poly(amino acids), ethylene glycol I dimethacrylate, poly(methyl methacrylate), poly(2-hydroxyethyl methacrylate), polytetrafluoroethylene poly(HEMA), polyhydroxyalkanoates, polytetrafluorethylene, polycarbonate, poly(glycolide-lactide) co-polymer, polylactic acid, poly(γ-caprolactone), poly(γ -hydroxybutyrate), polydioxanone, poly(γ -ethyl glutamate), polyiminocarbonates, poly(ortho ester), polyanhydrides, alginate, dextran, chitin, cotton, polyglycolic acid, polyurethane, or derivatized versions thereof, i.e., polymers which have been modified to include, for example, attachment sites or cross-linking groups, e.g., RGD, in which the polymers retain their structural integrity while allowing for attachment of cells and molecules, such as proteins, nucleic acids, and the like.

[0077] Medical devices may also be made with non-polymeric materials. Examples of useful non-polymeric materials include sterols such as cholesterol, stigmasterol, β -sitosterol, and estradiol; cholesteryl esters such as cholesteryl stearate; C_{12} -C_{24} fatty acids such as lauric acid, myristic acid, palmitic acid, stearic acid, arachidic acid, behenic acid, and lignoceric acid; C_{18} -C_{36} mono-, di- and triacylglycerides such as glyceryl monooleate, glyceryl monolinoleate, glyceryl monolaurate, glyceryl monodocosanoate, glyceryl monomyristate, glyceryl monodicenoate, glyceryl dipalmitate, glyceryl didocosanoate, glyceryl dimyristate, glyceryl didecenoate, glyceryl tridocosanoate, glyceryl trimyristate, glyceryl tridecenoate, glycerol tristearate and mixtures thereof; sucrose fatty acid esters such as sucrose distearate and sucrose palmitate; sorbitan fatty acid esters such as sorbitan monostearate, sorbitan monopalmitate and sorbitan tristearate; C_{16} -C_{18} fatty alcohols such as cetyl alcohol, myristyl alcohol, stearyl alcohol, and cetostearyl alcohol; esters of fatty alcohols and fatty acids such as cetyl palmitate and cetearyl palmitate; anhydrides of fatty acids such as stearic anhydride; phospholipids including phosphatidylcholine (lecithin), phosphatidylserine, phosphatidylethanolamine, phosphatidylinositol, and lysoderivatives thereof; sphingosine and derivatives thereof; sphingomyelins such as stearyl, palmitoyl, and tricosanyl sphingomyelins; ceramides such as stearyl and palmitoyl ceramides; glycosphingolipids; lanolin and lanolin alcohols; and combinations and mixtures thereof. Preferred non-polymeric materials include cholesterol, glyceryl monostearate, glycerol tristearate, stearic acid, stearic anhydride, glyceryl monooleate, glyceryl monolinoleate, and acetylated monoglycerides.

B. Therapeutic Agents

[0078] The term "therapeutic agent" as used in the present invention encompasses drugs, genetic materials, and biological materials and can be used interchangeably with "biologically active material". In one embodiment, the therapeutic agent is an anti-restenotic agent. In other embodiments, the therapeutic agent inhibits smooth muscle cell proliferation, contraction, migration or hyperactivity. Non-limiting examples of suitable therapeutic agent include heparin, heparin derivatives, urokinase, dextrophenylalanine proline arginine chloromethylketone (PPack), enoxaprin, angiopeptin, hirudin, acetylsalicylic acid, tacrolimus, everolimus, rapamycin (sirolimus), pimecrolimus, amlodipine, doxazosin, glucocorticoids, betamethasone, dexamethasone, prednisolone, corticosterone, budesonide, sulfasalazine, rosiglitazone, mycophenolic acid, mesalamine, paclitaxel, 5-fluorouracil, cisplatin, vinblastine, vincristine, epothilones, methotrexate, azathioprine, adriamycin, mutamycin, endostatin, angiostatin, thymidine kinase inhibitors, cladribine, lidocaine, bupivacaine, ropivacaine, D-Phe-Pro-Arg chloromethyl ketone, platelet receptor antagonists, anti-thrombin antibodies, anti-platelet receptor antibodies, aspirin, dipyridamole, protamine, hirudin, prostaglandin inhibitors, platelet inhibitors, trapidil, liprostin, tick antiplatelet peptides, 5-azacytidine, vascular endothelial growth factors, growth factor receptors, transcriptional activators, translational promoters, antiproliferative agents, growth factor inhibitors, growth factor receptor antagonists, transcriptional repressors, translational repressors, replication inhibitors, inhibitory antibodies, antibodies directed against growth factors, bifunctional molecules consisting of a growth factor and a cytotoxin, bifunctional molecules consisting of an antibody and a cytotoxin, cholesterol lowering agents, vasodilating agents, agents which interfere with endogenous vasoactive mechanisms, antioxidants, probucol, antibiotic agents, penicillin, cefoxitin, oxacillin, tobranycin, angiogenic substances, fibroblast growth factors, estrogen, estradiol (E2), estriol (E3), 17-beta estradiol, digoxin, beta blockers, captopril, enalopril, statins, steroids, vitamins, paclitaxel (as well as its derivatives, analogs or paclitaxel bound to proteins, *e.g.* Abraxane™) 2'-succinyl-taxol, 2'-succinyl-taxol triethanolamine, 2'-glutaryl-taxol, 2'-glutaryl-taxol triethanolamine salt, 2'-O-ester with N-(dimethylaminoethyl) glutamine, 2'-O-ester with N-(dimethylaminoethyl) glutamide hydrochloride salt, nitroglycerin, nitrous oxides, nitric oxides, antibiotics, aspirins, digitalis, estrogen, estradiol and glycosides. In one embodiment, the therapeutic agent is a smooth muscle cell inhibitor or antibiotic. In a preferred embodiment, the therapeutic agent is taxol (*e.g.*, Taxol®), or its analogs or derivatives. In another preferred embodiment, the therapeutic agent is paclitaxel, or its analogs or

derivatives. In yet another preferred embodiment, the therapeutic agent is an antibiotic such as erythromycin, amphotericin, rapamycin, adriamycin, etc.

[0079] The term "genetic materials" means DNA or RNA, including, without limitation, of DNA/RNA encoding a useful protein stated below, intended to be inserted into a human body including viral vectors and non-viral vectors.

[0080] The term "biological materials" include cells, yeasts, bacteria, proteins, peptides, cytokines and hormones. Examples for peptides and proteins include vascular endothelial growth factor (VEGF), transforming growth factor (TGF), fibroblast growth factor (FGF), epidermal growth factor (EGF), cartilage growth factor (CGF), nerve growth factor (NGF), keratinocyte growth factor (KGF), skeletal growth factor (SGF), osteoblast-derived growth factor (BDGF), hepatocyte growth factor (HGF), insulin-like growth factor (IGF), cytokine growth factors (CGF), platelet-derived growth factor (PDGF), hypoxia inducible factor-1 (HIF-1), stem cell derived factor (SDF), stem cell factor (SCF), endothelial cell growth supplement (ECGS), granulocyte macrophage colony stimulating factor (GM-CSF), growth differentiation factor (GDF), integrin modulating factor (IMF), calmodulin (CaM), thymidine kinase (TK), tumor necrosis factor (TNF), growth hormone (GH), bone morphogenic protein (BMP) (*e.g.*, BMP-2, BMP-3, BMP-4, BMP-5, BMP-6 (Vgr-1), BMP-7 (PO-1), BMP-8, BMP-9, BMP-10, BMP-11, BMP-12, BMP-14, BMP-15, BMP-16, etc.), matrix metalloproteinase (MMP), tissue inhibitor of matrix metalloproteinase (TIMP), cytokines, interleukin (*e.g.*, IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12, IL-15, etc.), lymphokines, interferon, integrin, collagen (all types), elastin, fibrillins, fibronectin, vitronectin, laminin, glycosaminoglycans, proteoglycans, transferrin, cytotactin, cell binding domains (*e.g.*, RGD), and tenascin. Currently preferred BMP's are BMP-2, BMP-3, BMP-4, BMP-5, BMP-6, BMP-7. These dimeric proteins can be provided as homodimers, heterodimers, or combinations thereof, alone or together with other molecules. Cells can be of human origin (autologous or allogeneic) or from an animal source (xenogeneic), genetically engineered, if desired, to deliver proteins of interest at the transplant site. The delivery media can be formulated as needed to maintain cell function and viability. Cells include progenitor cells (*e.g.*, endothelial progenitor cells), stem cells (*e.g.*, mesenchymal, hematopoietic, neuronal), stromal cells, parenchymal cells, undifferentiated cells, fibroblasts, macrophage, and satellite cells.

[0081] Other non-genetic therapeutic agents include:

- anti-thrombogenic agents such as heparin, heparin derivatives, urokinase, and PPack (dextrophenylalanine proline arginine chloromethylketone);
- anti-proliferative agents such as enoxaprin, angiopeptin, or monoclonal antibodies capable of blocking smooth muscle cell proliferation, hirudin, acetylsalicylic acid, tacrolimus, everolimus, amlodipine and doxazosin;
- anti-inflammatory agents such as glucocorticoids, betamethasone, dexamethasone, prednisolone, corticosterone, budesonide, estrogen, sulfasalazine, rosiglitazone, mycophenolic acid and mesalamine;
- anti-neoplastic/anti-proliferative/anti-miotic agents such as paclitaxel, 5-fluorouracil, cisplatin, vinblastine, vincristine, epothilones, methotrexate, azathioprine, adriamycin and mutamycin; endostatin, angiostatin and thymidine kinase inhibitors, cladribine, taxol and its analogs or derivatives;
- anesthetic agents such as lidocaine, bupivacaine, and ropivacaine;
- anti-coagulants such as D-Phe-Pro-Arg chloromethyl ketone, an RGD peptide-containing compound, heparin, antithrombin compounds, platelet receptor antagonists, anti-thrombin antibodies, anti-platelet receptor antibodies, aspirin (aspirin is also classified as an analgesic, antipyretic and anti-inflammatory drug), dipyridamole, protamine, hirudin, prostaglandin inhibitors, platelet inhibitors, antiplatelet agents such as trapidil or liprostin and tick antiplatelet peptides;
- DNA demethylating drugs such as 5-azacytidine, which is also categorized as a RNA or DNA metabolite that inhibit cell growth and induce apoptosis in certain cancer cells;
- vascular cell growth promoters such as growth factors, vascular endothelial growth factors (VEGF, all types including VEGF-2), growth factor receptors, transcriptional activators, and translational promoters;
- vascular cell growth inhibitors such as anti-proliferative agents, growth factor inhibitors, growth factor receptor antagonists, transcriptional repressors, translational repressors, replication inhibitors, inhibitory antibodies, antibodies directed against growth factors, bifunctional molecules consisting of a growth factor and a cytotoxin, bifunctional molecules consisting of an antibody and a cytotoxin;
- cholesterol-lowering agents, vasodilating agents, and agents which interfere with endogenous vasoactive mechanisms;
- anti-oxidants, such as probucol;

- antibiotic agents, such as penicillin, cefoxitin, oxacillin, tobranycin, rapamycin (sirolimus);
- angiogenic substances, such as acidic and basic fibroblast growth factors, estrogen including estradiol (E2), estriol (E3) and 17-beta estradiol;
- drugs for heart failure, such as digoxin, beta-blockers, angiotensin-converting enzyme (ACE) inhibitors including captopril and enalopril, statins and related compounds; and
- macrolides such as sirolimus or everolimus.

Preferred biological materials include anti-proliferative drugs such as steroids, vitamins, and restenosis-inhibiting agents. Preferred restenosis-inhibiting agents include microtubule stabilizing agents such as Taxol®, paclitaxel (*i.e.*, paclitaxel, paclitaxel analogs, or paclitaxel derivatives, and mixtures thereof). For example, derivatives suitable for use in the present invention include 2'-succinyl-taxol, 2'-succinyl-taxol triethanolamine, 2'-glutaryl-taxol, 2'-glutaryl-taxol triethanolamine salt, 2'-O-ester with N-(dimethylaminoethyl) glutamine, and 2'-O-ester with N-(dimethylaminoethyl) glutamide hydrochloride salt.

Other suitable therapeutic agents include tacrolimus; halofuginone; inhibitors of HSP90 heat shock proteins such as geldanamycin; microtubule stabilizing agents such as epothilone D; phosphodiesterase inhibitors such as cliostazole; Barkct inhibitors; phospholamban inhibitors; and Serca 2 gene/proteins.

Other preferred therapeutic agents include nitroglycerin, nitrous oxides, nitric oxides, aspirins, digitalis, estrogen derivatives such as estradiol and glycosides.

In one embodiment, the therapeutic agent is capable of altering the cellular metabolism or inhibiting a cell activity, such as protein synthesis, DNA synthesis, spindle fiber formation, cellular proliferation, cell migration, microtubule formation, microfilament formation, extracellular matrix synthesis, extracellular matrix secretion, or increase in cell volume. In another embodiment, the therapeutic agent is capable of inhibiting cell proliferation and/or migration.

In certain embodiments, the therapeutic agents for use in the medical devices of the present invention can be synthesized by methods well known to one skilled in the art. Alternatively, the therapeutic agents can be purchased from chemical and pharmaceutical companies.

[0082] In some embodiments, the therapeutic agent comprises at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least

80%, at least 90%, at least 95%, at least 97%, at least 99% or more by weight of the porous metal oxide or metal material. Preferably, the therapeutic agent is about 0.1 to about 10 percent by weight of the porous metal oxide or metal material that contains the therapeutic agent. More preferably, the therapeutic agent is about 0.5 to about 10 percent by weight of the porous metal oxide or metal material that contains the therapeutic agent.

C. **Polymers**

[0083] Polymers useful as the quantity of polymer disposed on the porous metal oxide or metal material to form a coating thereon should be ones that are biocompatible, particularly during insertion or implantation of the device into the body and avoids irritation to body tissue. Examples of such polymers include, but not limited to, polyurethanes, polyisobutylene and its copolymers, silicones, and polyesters. Other suitable polymers include polyolefins, polyisobutylene, ethylene-alphaolefin copolymers, acrylic polymers and copolymers, vinyl halide polymers and copolymers such as polyvinyl chloride, polyvinyl ethers such as polyvinyl methyl ether, polyvinylidene halides such as polyvinylidene fluoride and polyvinylidene chloride, polyacrylonitrile, polyvinyl ketones, polyvinyl aromatics such as polystyrene, polyvinyl esters such as polyvinyl acetate; copolymers of vinyl monomers, copolymers of vinyl monomers and olefins such as ethylene-methyl methacrylate copolymers, acrylonitrile-styrene copolymers, ABS resins, ethylene-vinyl acetate copolymers, polyamides such as Nylon 66 and polycaprolactone, alkyd resins, polycarbonates, polyoxyethylenes, polyimides, polyethers, epoxy resins, polyurethanes, rayon-triacetate, cellulose, cellulose acetate, cellulose butyrate, cellulose acetate butyrate, cellophane, cellulose nitrate, cellulose propionate, cellulose ethers, carboxymethyl cellulose, collagens, chitins, polylactic acid, polyglycolic acid, and polylactic acid-polyethylene oxide copolymers.

[0084] When the polymer is being applied to a part of the medical device, such as a stent, which undergoes mechanical challenges, e.g. expansion and contraction, the polymers are preferably selected from elastomeric polymers such as silicones (e.g. polysiloxanes and substituted polysiloxanes), polyurethanes, thermoplastic elastomers, ethylene vinyl acetate copolymers, polyolefin elastomers, and EPDM rubbers. The polymer is selected to allow the coating to better adhere to the surface of the strut when the stent is subjected to forces or stress. Furthermore, although the coating can be formed by using a single type of polymer, various combinations of polymers can be employed.

[0085] Generally, when a hydrophilic therapeutic agent is used then a hydrophilic polymer having a greater affinity for the therapeutic agent than another material that is less hydrophilic is preferred. When a hydrophobic therapeutic agent is used then a hydrophobic polymer having a greater affinity for the therapeutic agent is preferred. However, in some embodiments, a hydrophilic therapeutic agent can be used with a hydrophobic polymer and a hydrophobic therapeutic agent can be used with a hydrophilic polymer.

[0086] Examples of suitable hydrophobic polymers or monomers include, but not limited to, polyolefins, such as polyethylene, polypropylene, poly(1-butene), poly(2-butene), poly(1-pentene), poly(2-pentene), poly(3-methyl-1-pentene), poly(4-methyl-1-pentene), poly(isoprene), poly(4-methyl-1-pentene), ethylene-propylene copolymers, ethylene-propylene-hexadiene copolymers, ethylene-vinyl acetate copolymers, blends of two or more polyolefins and random and block copolymers prepared from two or more different unsaturated monomers; styrene polymers, such as poly(styrene), poly(2-methylstyrene), styrene-acrylonitrile copolymers having less than about 20 mole-percent acrylonitrile, and styrene-2,2,3,3,-tetrafluoropropyl methacrylate copolymers; halogenated hydrocarbon polymers, such as poly(chlorotrifluoroethylene), chlorotrifluoroethylene-tetrafluoroethylene copolymers, poly(hexafluoropropylene), poly(tetrafluoroethylene), tetrafluoroethylene, tetrafluoroethylene-ethylene copolymers, poly(trifluoroethylene), poly(vinyl fluoride), and poly(vinylidene fluoride); vinyl polymers, such as poly(vinyl butyrate), poly(vinyl decanoate), poly(vinyl dodecanoate), poly(vinyl hexadecanoate), poly(vinyl hexanoate), poly(vinyl propionate), poly(vinyl octanoate), poly(heptafluoroisopropoxyethylene), poly(heptafluoroisopropoxypropylene), and poly(methacrylonitrile); acrylic polymers, such as poly(n-butyl acetate), poly(ethyl acrylate), poly(1-chlorodifluoromethyl)tetrafluoroethyl acrylate, poly di(chlorofluoromethyl)fluoromethyl acrylate, poly(1,1-dihydroheptafluorobutyl acrylate), poly(1,1-dihydropentafluoroisopropyl acrylate), poly(1,1-dihydropentadecafluorooctyl acrylate), poly(heptafluoroisopropyl acrylate), poly 5-(heptafluoroisopropoxy)pentyl acrylate, poly 11-(heptafluoroisopropoxy)undecyl acrylate, poly 2-(heptafluoropropoxy)ethyl acrylate, and poly(nonafluoroisobutyl acrylate); methacrylic polymers, such as poly(benzyl methacrylate), poly(n-butyl methacrylate), poly(isobutyl methacrylate), poly(t-butyl methacrylate), poly(t-butylaminoethyl methacrylate), poly(dodecyl methacrylate), poly(ethyl methacrylate), poly(2-ethylhexyl methacrylate), poly(n-hexyl methacrylate), poly(phenyl methacrylate), poly(n-propyl methacrylate), poly(octadecyl methacrylate), poly(1,1-dihydropentadecafluorooctyl methacrylate), poly(heptafluoroisopropyl methacrylate), poly(heptadecafluorooctyl

methacrylate), poly(1-hydrotetrafluoroethyl methacrylate), poly(1,1-dihydrotetrafluoropropyl methacrylate), poly(1-hydrohexafluoroisopropyl methacrylate), and poly(t-nonafluorobutyl methacrylate); polyesters, such a poly(ethylene terephthalate) and poly(butylene terephthalate); condensation type polymers such as and polyurethanes and siloxane-urethane copolymers; polyorganosiloxanes, i.e., polymeric materials characterized by repeating siloxane groups, represented by Ra SiO 4-a/2, where R is a monovalent substituted or unsubstituted hydrocarbon radical and the value of a is 1 or 2; and naturally occurring hydrophobic polymers such as rubber.

[0087] Examples of suitable hydrophilic polymers or monomers include, but not limited to; (meth)acrylic acid, or alkaline metal or ammonium salts thereof; (meth)acrylamide; (meth)acrylonitrile; those polymers to which unsaturated dibasic, such as maleic acid and fumaric acid or half esters of these unsaturated dibasic acids, or alkaline metal or ammonium salts of these dibasic adds or half esters, is added; those polymers to which unsaturated sulfonic, such as 2-acrylamido-2-methylpropanesulfonic, 2-(meth)acryloylethanesulfonic acid, or alkaline metal or ammonium salts thereof, is added; and 2-hydroxyethyl (meth)acrylate and 2-hydroxypropyl (meth)acrylate.

[0088] Polyvinyl alcohol is also an example of hydrophilic polymer. Polyvinyl alcohol may contain a plurality of hydrophilic groups such as hydroxyl, amido, carboxyl, amino, ammonium or sulfonyl (-SO3). Hydrophilic polymers also include, but are not limited to, starch, polysaccharides and related cellulosic polymers; polyalkylene glycols and oxides such as the polyethylene oxides; polymerized ethylenically unsaturated carboxylic acids such as acrylic, mathacrylic and maleic acids and partial esters derived from these acids and polyhydric alcohols such as the alkylene glycols; homopolymers and copolymers derived from acrylamide; and homopolymers and copolymers of vinylpyrrolidone.

[0089] Other suitable polymers include without limitation: polyurethanes, silicones (*e.g.*, polysiloxanes and substituted polysiloxanes), and polyesters, styrene-isobutylene-copolymers. Other polymers which can be used include ones that can be dissolved and cured or polymerized on the medical device or polymers having relatively low melting points that can be blended with biologically active materials. Additional suitable polymers include, but are not limited to, thermoplastic elastomers in general, polyolefins, polyisobutylene, ethylene-alphaolefin copolymers, acrylic polymers and copolymers, vinyl halide polymers and copolymers such as polyvinyl chloride, polyvinyl ethers such as polyvinyl methyl ether, polyvinylidene halides such as polyvinylidene fluoride and polyvinylidene chloride, polyacrylonitrile, polyvinyl ketones, polyvinyl aromatics such as

polystyrene, polyvinyl esters such as polyvinyl acetate, copolymers of vinyl monomers, copolymers of vinyl monomers and olefins such as ethylene-methyl methacrylate copolymers, acrylonitrile-styrene copolymers, ABS (acrylonitrile-butadiene-styrene) resins, ethylene-vinyl acetate copolymers, polyamides such as Nylon 66 and polycaprolactone, alkyd resins, polycarbonates, polyoxymethylenes, polyimides, polyethers, polyether block amides, epoxy resins, rayon-triacetate, cellulose, cellulose acetate, cellulose butyrate, cellulose acetate butyrate, cellophane, cellulose nitrate, cellulose propionate, cellulose ethers, carboxymethyl cellulose, collagens, chitins, polylactic acid, polyglycolic acid, polylactic acid-polyethylene oxide copolymers, EPDM (ethylene-propylene-diene) rubbers, fluoropolymers, fluorosilicones, polyethylene glycol, polysaccharides, phospholipids, and combinations of the foregoing.

D. Methods of Making Coatings

[0090] In embodiments of the medical device of the present invention where the surface and outer region of the medical device comprises a metal oxide or metal material having a plurality of pores (such as those in **FIG.s 2** and **3**), the pores in some instances can be created by micro-roughing techniques involving the use of reactive plasmas or ion bombardment electrolyte etching. The pores can also be created by other methods such as sand blasting, laser etching or chemical etching.

[0091] In embodiments where the medical device comprises a coating of a metal oxide or metal material having a plurality of pores (such as in **FIG.s 1** and **2**), such a coating can be formed in a number of ways. In some instances, the coating can be formed by depositing the material in a particular manner so that pores form in the material. For example, the metal oxide or metal material can be made porous by a deposition process such as sputtering and adjusting the deposition condition. Deposition conditions that can be adjusted or varied include, but are not limited to, chamber pressure, substrate temperature, substrate bias, substrate orientation, sputter rate, or a combination thereof.

[0092] In an alternative method, the coating having a plurality of pores may be formed on the surface of the medical device using vacuum plasma spraying of a spray composition comprising a metal oxide or metal under certain process parameters that promote the formation of pores.

[0093] In addition, the porous coating of metal oxide or metal material can be formed by a co-deposition technique. In such a technique the metal oxide or metal material is combined with a secondary phase material to form a composition. The secondary phase

material can be a metal, such as carbon, aluminum, nickel or a non-metal. Preferably non-metal secondary materials include polymers that are capable of being leached off, such as polystyrene. The secondary phase material can be in the form of particles such as hollow spheres or chopped tubes of various sizes. The size of the pores formed will be determined by the size of the secondary phase material used. For example, if a hollow sphere of a second metal used as the secondary phase material, the size of the spheres will determine the size of the pores formed.

[0094] In some embodiments, the composition can contain a metal used to form the porous coating and a metal that is used as the secondary phase material. The two metals can form an alloy such as a gold/silver alloy, where gold is the metal used to form the porous coating and silver is the secondary phase material. Also, the two metals can be in the form of a mixture or a composite. As discussed below, the secondary phase material is removed to form the pores in the coating. Thus, if two metals are used in the composition, the metals should have different chemical or physical properties to facilitate removal of the metal that is used as the secondary phase material. For example, the metal that will be removed should be more electrochemically active, *e.g.*, less corrosion-resistant than the metal used to form the porous coating. In some embodiments, the metal that will be removed should have a lower melting point than the metal used to form the porous coating. In yet another embodiment, the metal that will be removed should have a higher vapor pressure than the metal used to form the coating. Also, in another embodiment, the metal that is removed is more susceptible to being dissolved in a chosen solvent than the metal used to form the coating.

[0095] The composition containing the metal oxide or metal material is combined with a secondary phase material is applied to the surface of the medical device. Suitable application methods include but are not limited to, dipping, spraying, painting, electroplating, evaporation, plasma-vapor deposition, cathodic-arc deposition, sputtering, ion implantation, electrostatically, electroplating, electrochemically, a combination of the above, or the like.

[0096] Afterwards, the secondary phase material is removed from the composition to form a porous coating. For example, the secondary phase material may be removed from the composition by a dealloying process such as selective dissolution of the secondary phase material. In this method, the composition is exposed to an acid which removes the secondary phase material. Thus, the metal oxide or metal used to form the coating is preferably one that will not dissolve when exposed to the acid, while the secondary phase material is one that will dissolve in the acid. Any suitable acid can be used to remove the secondary phase material. One of ordinary skill in the art would recognize the appropriate concentration and

reaction conditions to use. For example, if the secondary phase material is silver, nitric acid may be used at a concentration of up to 35% and a temperature up to 120°F. Also, a nitric acid and sulfuric acid mixture (95%/5%) immersion process at 80°F may be used. The reaction conditions may be varied to vary the geometry, distribution, and depth of the coating.

[0097] Alternatively, the second metal can be removed anodically. For example, when silver is used as the secondary phase material, the silver may be removed from the composition applied to the surface anodically using a dilute nitric acid bath comprising up to 15% nitric acid, wherein the anode is the medical device, and the cathode comprises platinum. Voltages up to 10V DC can be applied across the electrodes. The bath chemistry, temperature, applied voltage, and process time may be varied to vary the geometry, distribution, and depth of the coating.

[0098] Furthermore, if the secondary phase material has a lower melting point than the metal oxide or metal used in the porous coating, the device coated with the composition containing the metal oxide or metal and the secondary phase material can be heated to a temperature such that the secondary phase material becomes a liquid and is removable from the metal oxide or metal. Examples of suitable metals for the porous coating include one of the higher melting point first metals: platinum, gold, stainless steel, titanium, tantalum, and iridium, in combination with a lower melting point secondary phase material such as: aluminum, barium, and bismuth.

[0099] In another embodiment, the secondary phase material has a higher vapor pressure than the metal oxide or metal used to form the porous coating. When the composition applied to the surface of the medical device is heated under vacuum the secondary phase material becomes vaporized and is removed from the metal oxide or metal.

[00100] A therapeutic agent is deposited in the pores of the metal oxide or metal material by any suitable method, such as, but not limited to dip coating, spray coating, spin coating, plasma deposition, condensation, electrochemically, electrostatically, evaporation, plasma vapor deposition, cathodic arc deposition, sputtering, ion implantation, or use of a fluidized bed. In order to dispose the molecules of the therapeutic agent in the pores, it may be necessary to modify the size of the pores in the coating or in the surface and outer region of the medical device. The pore size may be modified by any suitable method, such as heat treatment. If a polymer is also deposited in the pores, the polymer can be combined with the therapeutic agent and optionally a solvent. A composition containing the polymer and

therapeutic agent can be deposited in the pores. Alternatively, the polymer and therapeutic agent can be deposited in the pores separately.

[00101] The polymer can be applied to the porous metal oxide or metal material by any method. Examples of suitable methods include, but are not limited to, spraying such as by conventional nozzle or ultrasonic nozzle, dipping, rolling, electrostatic deposition, and a batch process such as air suspension, pan coating or ultrasonic mist spraying. Also, more than one coating method can be used. To facilitate the application of the polymer to the porous metal oxide or metal material, the polymer can be dispersed or dissolved in a solvent. After the composition comprising the solvent and the polymer is applied, the solvent is removed. Pores can be formed in the polymer by bubbling gas through the polymer, or by adding a second phase material to the solvent and polymer composition and dissolving the second phase material. In addition, a therapeutic agent can be loaded into the pores of the polymer by methods described above for loading a therapeutic agent into the pores of the metal oxide or metal material.

[00102] The description contained herein is for purposes of illustration and not for purposes of limitation. Changes and modifications may be made to the embodiments of the description and still be within the scope of the invention. Furthermore, obvious changes, modifications or variations will occur to those skilled in the art. Also, all references cited above are incorporated herein, in their entirety, for all purposes related to this disclosure.

THE CLAIMS

What is claimed is:

1. An implantable medical device comprising:

(a) a surface;

(b) a coating disposed on the surface comprising:

(i) a first material comprising a metal oxide or a metal having a plurality of pores therein disposed on at least a portion of the surface, wherein a first therapeutic agent is disposed in at least some of the pores of the first metal oxide or metal material; and

(ii) a first polymer disposed on at least a portion of the first metal oxide or metal material, wherein the first polymer has a plurality of pores therein.

2. The device of claim 1 further comprising an outer region adjacent to the surface, wherein the outer region comprises a second material comprising a metal oxide or a metal having a plurality of pores therein, and a second therapeutic agent disposed in at least some of the pores of the second metal oxide or metal material.

3. The device of claim 2 further comprising an inner region adjacent to the outer region, wherein the inner region is substantially non-porous.

4. The device of claim 2, wherein the first metal oxide or metal material and the second metal oxide or metal material are the same.

5. The device of claim 1 further comprising a second polymer disposed in at least some of the pores of the first metal oxide or metal material.

6. The device of claim 1, wherein the polymer comprises ethylene-vinylacetate copolymers, polymethacrylates, styrene-isobutylene copolymers and polylactic acids.

7. The device of claim 1, wherein the first metal oxide or metal material is in the form of a layer.

8. The device of claim 1, wherein the first polymer is in the form of a layer.

9. The device of claim 1, wherein the metal material comprises gold, platinum, stainless steel, titanium, tantalum, iridium, molybdenum, niobium, palladium or chromium.

10. The device of claim 1, wherein the metal oxide material comprises an oxide of a transitional metal.

11. The device of claim 1, wherein the metal oxide material comprises tantalum oxide, titanium oxide, iridium oxide, niobium oxide, zirconium oxide, tungsten oxide, or rhodium oxide.

12. The device of claim 1, wherein the pores in the first metal oxide or metal material have an average width of between about 1 nm and about 10 μm.

13. The device of claim 1, wherein the first therapeutic agent comprises an anti-restenosis agent, anti-thrombogenic agent, anti-angiogenesis agent, anti-proliferative agent, antibiotic agent, growth factor, immunosuppressant or radiochemical.

14. The device of claim 1, wherein the therapeutic agent comprises an anti-restenosis agent.

15. The device of claim 1, wherein the therapeutic agent comprises paclitaxel.

16. The device of claim 1, wherein the therapeutic agent comprises sirolimus, tacrolimus, pimecrolimus or everolimus.

17. An implantable medical device comprising:

(a) a surface and an outer region adjacent to the surface, wherein the surface and the outer region comprise a material comprising a metal oxide or a metal having a plurality of pores therein, and a therapeutic agent disposed in at least some of the pores in the metal oxide or metal material;

(b) an inner region adjacent to the outer region, wherein the inner region is substantially non-porous; and

(c) a first polymer disposed on at least a portion of the surface, wherein the first polymer has a plurality of pores therein.

18. The device of claim 17 further comprising a second polymer disposed in at least some of the pores of the metal oxide or metal material.

19. The device of claim 17 wherein the first and second polymers are the same.

20. The device of claim 17, wherein the polymer comprises polyethylene-co-vinyl acetate, poly(n-butyl methacrylate), poly(styrene-b-. isobutylene-b-styrene) and polylactic-glycolic acid.

21. The device of claim 17, wherein the first polymer is in the form of a layer.

22. The device of claim 17, wherein the metal material comprises gold, platinum, stainless steel, titanium, tantalum, iridium, molybdenum, niobium, palladium or chromium.

23. The device of claim 17, wherein the metal oxide material comprises an oxide of a transitional metal.

24. The device of claim 17, wherein the metal oxide material comprises tantalum oxide, titanium oxide, iridium oxide, niobium oxide, zirconium oxide, tungsten oxide, or rhodium oxide.

25. The device of claim 17, wherein the pores in the metal oxide or metal material have an average width of between about 1 nm and about 10 μm.

26. The device of claim 17, wherein the first polymer comprises a second therapeutic agent dispersed in the pores of the first polymer, and wherein the first therapeutic agent and the second therapeutic agent are the same.

27. The device of claim 17, wherein the therapeutic agent comprises an anti-restenosis agent, anti-thrombogenic agent, anti-angiogenesis agent, anti-proliferative agent, antibiotic agent, growth factor, immunosuppressant or radiochemical.

28. The device of claim 27, wherein the therapeutic agent comprises an anti-restenosis agent.

29. The device of claim 17, wherein the therapeutic agent comprises paclitaxel.

30. The device of claim 17, wherein the therapeutic agent comprises sirolimus, tacrolimus, pimecrolimus or everolimus.

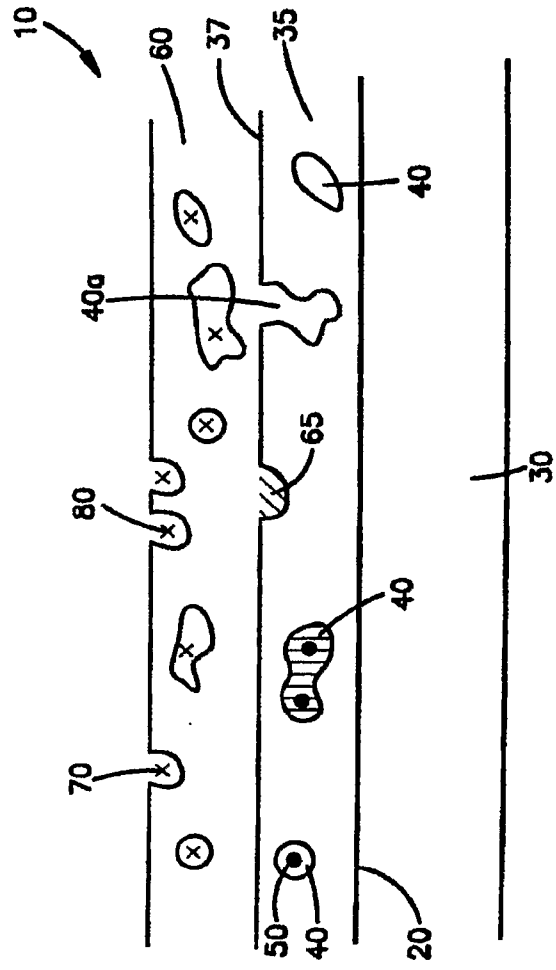

Fig. 1

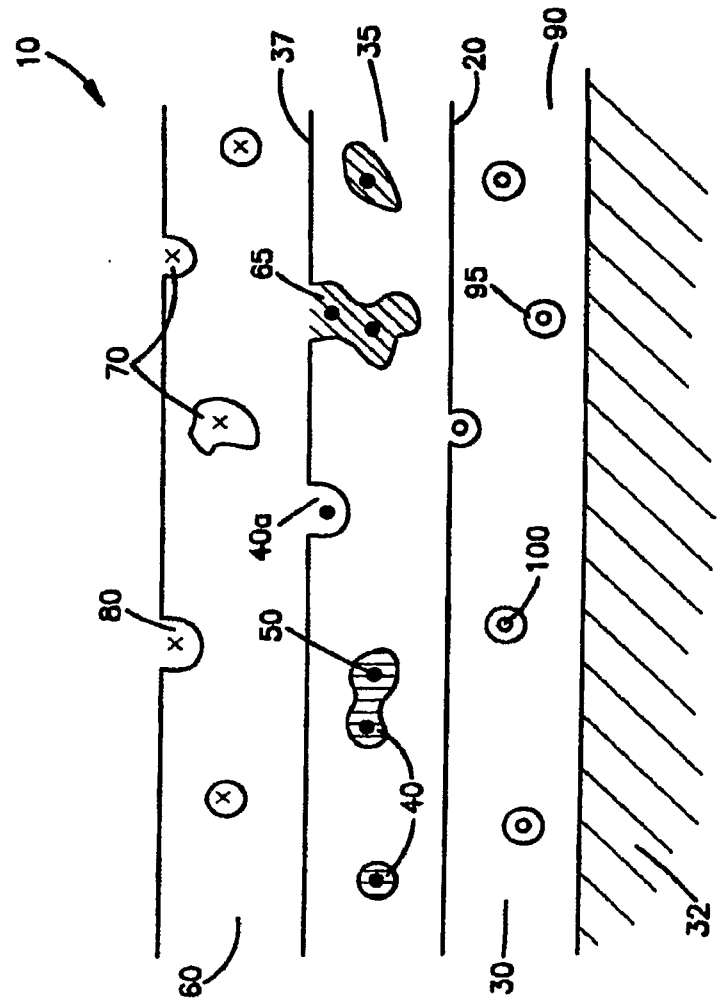

Fig. 2

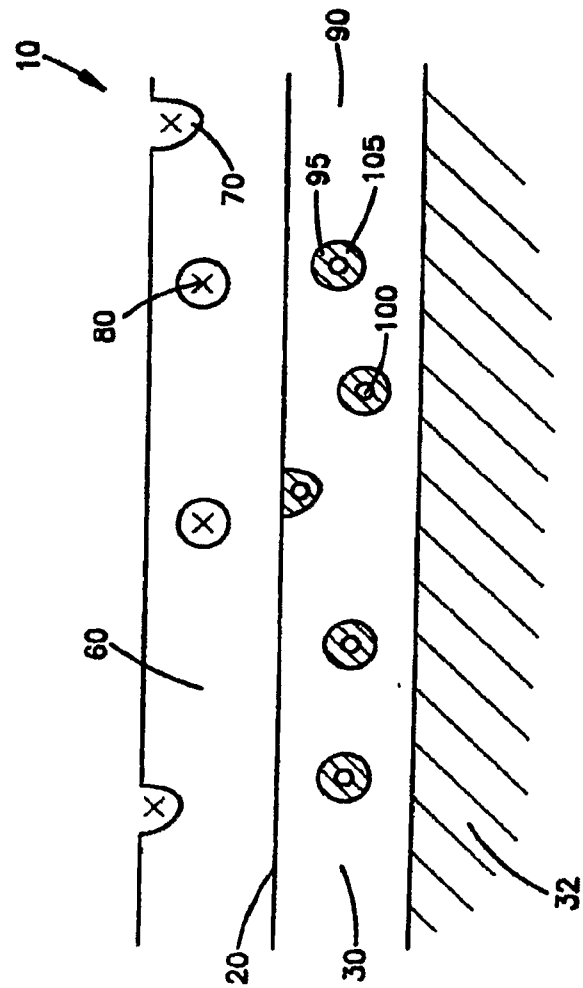

Fig. 3

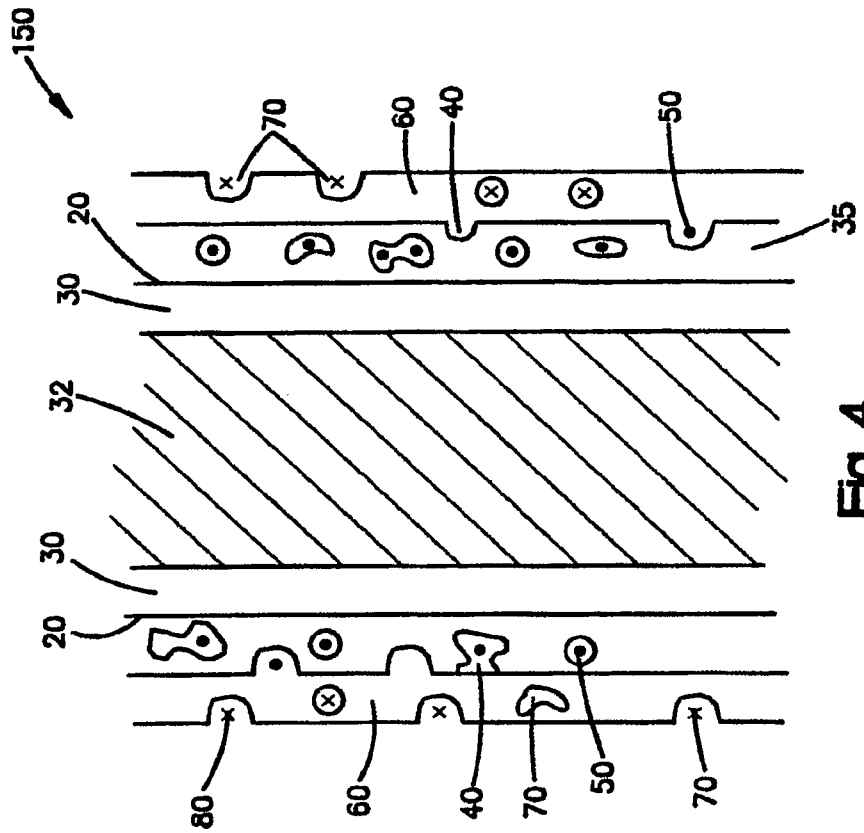

Fig. 4

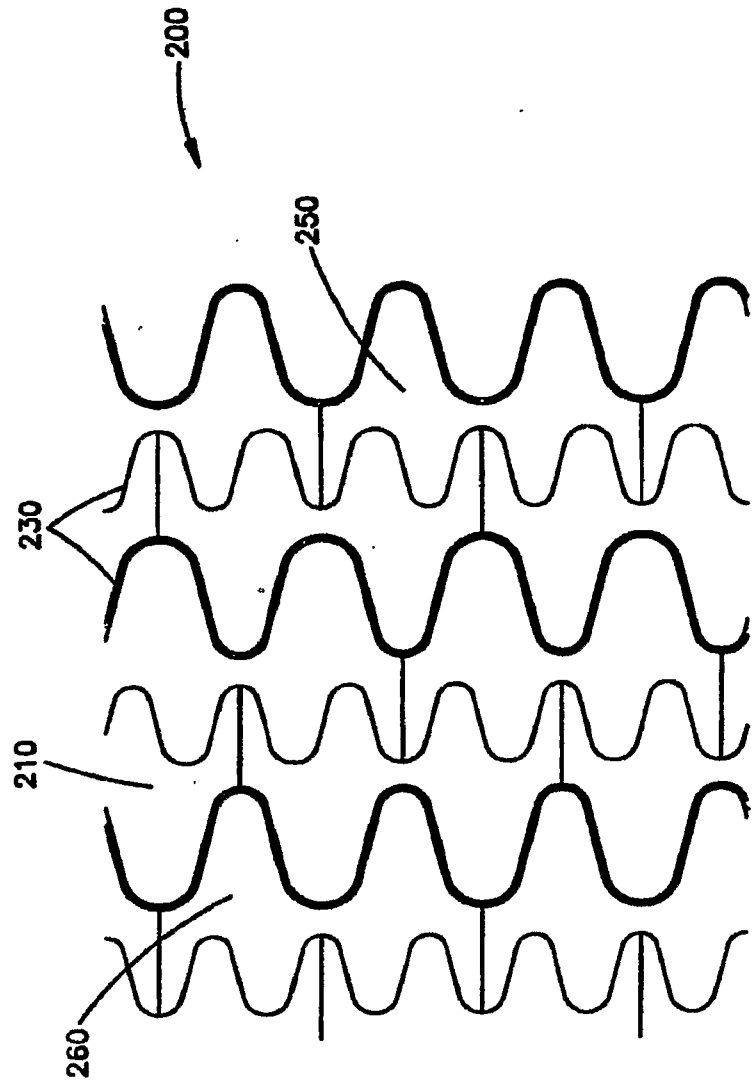

Fig. 5