(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 973 479 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
28.09.2016 Bulletin 2016/39

(21) Application number: **06844319.1**

(22) Date of filing: **09.11.2006**

(51) Int Cl.:
A61M 37/00 *(2006.01)*

(86) International application number:
PCT/US2006/043754

(87) International publication number:
WO 2007/081430 (19.07.2007 Gazette 2007/29)

(54) **MICRONEEDLE ARRAY, PATCH, AND APPLICATOR FOR TRANSDERMAL DRUG DELIVERY**

MIKRONADELANORDNUNG, PFLASTER UND APPLIKATOR FÜR DIE TRANSDERMALE ARZNEIABGABE

RESEAU DE MICRO-AIGUILLES, PIECE ET APPLICATEUR POUR ADMINISTRATION TRANSDERMIQUE DE MEDICAMENT

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR

(30) Priority: **10.01.2006 US 328813**

(43) Date of publication of application:
01.10.2008 Bulletin 2008/40

(73) Proprietor: **Yuzhakov, Vadim V.**
Alameda CA 94501 (US)

(72) Inventor: **Yuzhakov, Vadim V.**
Alameda CA 94501 (US)

(74) Representative: **Johnson, Yvonne Catherine**
Barker Brettell LLP
100 Hagley Road
Edgbaston
Birmingham
B16 8QQ (GB)

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Description

Background of the Invention

[0001] This invention is generally in the field of devices for the administration of drugs to patients through the skin. More particularly, this invention relates to microneedle arrays for transdermal drug delivery.

[0002] Transdermal drug delivery provides several advantages over other routes for administering a drug formulation to a patient. For example, oral administration of some drugs may be ineffective because the drug is destroyed in the gastrointestinal tract or eliminated by the liver, both of which are avoided by transdermal drug delivery. Parenteral injection with a conventional hypodermic needle also has drawbacks, as it is often painful and inconvenient. Although transdermal drug delivery avoids these problems, there are obstacles to its use. In particular, the transport of drug molecules through the intact stratum corneum, the outer layer of the skin, is often quite difficult due to the barrier properties of the stratum corneum. These barrier properties only allow relatively small molecules to be transported through the intact stratum corneum, and many useful drugs are too large to pass through the stratum corneum without some type of modification of the stratum corneum or other transport enhancement. Various transdermal enhancement methods are known, including those based on iontophoresis, ultrasound, and chemical penetration enhancers. However, these methods may be inadequate to assist in the delivery of many medications through an intact skin layer and/or they may be inconvenient or undesirably complicated to use.

[0003] Several methods have been recently proposed for making small pores in the stratum corneum in order to overcome its barrier properties. Document WO03/048031 A2, upon which the preamble of claim 1 is based, describes one known prior art device to achieve this. Further, patents to Altea Therapeutics disclose the use of arrays of micro-heaters for creating tiny holes in the stratum corneum, as well as the use of miniature pyramidal projections to porate the stratum corneum. See, e.g., U.S. Patent No. 6,142,939 to Eppstein et al. and U.S. Patent No. 6,183,434 to Eppstein. Others, including Procter & Gamble, Alza Corporation, and scientists and engineers at the University of California, Berkeley and at the Georgia Institute of Technology, have been working on the development of microneedle arrays that would make a large number of tiny holes in the stratum corneum. See, e.g., U.S. Patent No. 6,611,707 to Prausnitz et al. and U.S. Patent No. 6,334,856 to Allen et al.

[0004] These known microneedle array generally fall into one of two design categories: (1) solid microneedles and (2) microneedles with a central hollow bore, which are similar to conventional hypodermic needle. Solid microneedle arrays are essentially arrays of projections that are used to make holes in the stratum corneum and are subsequently removed before a drug is applied to the skin. If solid microneedle arrays are kept in the skin, then the drug cannot readily flow into and through the holes in the skin because the holes remain plugged by the microneedles. In an apparent effort to work around this problem, Alza Corporation discloses a method of depositing a drug directly on the surface of these solid microneedles. However, the deposition process is unreliable, and the thin layer of drug formulation on the microneedle could be easily chipped off of the microneedle during storage, transport, or administration (insertion) of the microneedles. Moreover, application of a thicker and stronger layer of drug formulation was found to be undesirable because it reduced the sharpness of the microneedles and therefore made insertion more difficult and painful. In response to this deficiency with the thicker drug coating, Alza Corporation disclosed a special insertion device, because patients are unable to insert the microneedle array by their selves without it. It therefore would be desirable to provide a microneedle array for drug delivery that avoids the disadvantages associated with known solid microneedle array designs.

[0005] Other microstructures devices are designed to disrupt the stratum corneum but are generally unsuitable for use in adhesive patch-type drug delivery devices. For example, U.S. Patent Application Publication No. 2002/0177858 discloses microstructures that are designed to have sharp edges (rather than sharp tips) which are intended to be rubbed against the skin, for example, to facilitate spreading of a lotion on the upper skin surface. These microstructures cannot be inserted or kept in the skin, because of the inability of these microstructures to pierce the skin and the absence of any means for attachment to the skin. These microstructures cannot not maintain their penetrated position in the stratum corneum at a discrete location to form a fluid channel communicating between a drug reservoir and the dermis or other tissues beneath the stratum corneum. It would be desirable to provide an improved drug delivery patch having a microneedle array for drug delivery over an extended period.

[0006] Conventional hollow microneedles with a central bore are expensive to make and require exotic and expensive microfabrication methods. In particular, it is difficult to make sharp tips on hollow microneedles. Consequently, insertion of the microneedles into a patient's skin can be difficult and often painful. In addition, the central bore of the microneedle is quite small and may be easily plugged by skin tissue during the insertion process, thereby blocking the drug delivery conduit. Furthermore, because the length of microneedle central bore is much greater than its diameter, the diffusional transport of the drug through the central bore may be unacceptably slow. It may be even slower than the diffusion of the drug through the intact stratum corneum in the absence of the microneedle. It therefore would be desirable to provide a microneedle array for drug delivery that avoids the disadvantages associated with known hollow microneedle array designs.

[0007] U.S. Patent Application Publication No. 2003/0028125 discloses devices and methods for piercing the skin and accessing and collecting a physiological fluid sample therein. The disclosed device is unsuitable for drug delivery to the stratum corneum, in particular because the needle design is too large for such applications.

[0008] In summary, there is a need for a simple, effective, and economically desirable device for transdermal administration of a variety of drug types to a patient.

Summary of the Invention

[0009] The invention is defined in appended independent claim 1. Preferred embodiments are described in the dependent claims.

[0010] Microneedle arrays and drug delivery devices incorporating the microneedle arrays are provided, along with methods of making microneedle arrays.

[0011] In one aspect, a microneedle array device is provide which includes a substantially planar substrate having an array of spaced apertures therein; and a plurality of microneedles projecting at angle from the plane in which the planar substrate lies, the microneedles having a base portion integrally connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween, wherein at least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate. In a preferred embodiment, the at least one of the microneedles has a substantially rectangular cross-sectional shape in a plane parallel to the substrate. In one specific variation of this embodiment, the at least one channel is open to two opposing surfaces of the microneedle.

[0012] In another embodiment, the tip end portion of the microneedle is tapered. In a specific embodiment, the channel extends into the tapered tip portion of the microneedle.

[0013] In a preferred embodiment, the substrate and the microneedles comprise at least one biocompatible metal, such as a stainless steel. In another embodiment, the substrate and the microneedles comprise at least one biocompatible polymer.

[0014] In one embodiment, the length of the at least one microneedle may be between 10 μm and 1000 μm, preferably between 100 μm and 500 μm. In another embodiment, the at least one microneedle has a maximum width dimension of 500 μm.

[0015] In one embodiment, the body portion of the at least one microneedle is rectangular with a centrally located channel extending through the opposed longer sides of the body portion. In one particular embodiment, the rectangular body portion has a long side cross-sectional dimension between 1 and 500 μm and a short side cross-sectional dimension between 1 and 200 μm.

[0016] In one example, the apertures in the substrate are polygonal in shape, each aperture being defined by three or more interior side surfaces in the substrate. In one example, the base portion of the at least one microneedle includes a curved portion that extends from at least one of the interior side surfaces of the substrate. In one embodiment, a proximal end of the at least one channel extends to or into the at least one of the interior side surfaces of the substrate.

[0017] In another aspect, a device for transdermal administration of a drug is provided, which includes a substantially planar substrate having an array of spaced apertures therein; a plurality of microneedles projecting at angle from the plane in which the planar substrate lies, the microneedles having a base portion integrally connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween, wherein at least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate; and at least one drug storage element, which contains a drug formulation, positioned adjacent to the planar substrate. In a preferred embodiment, the at least one of the microneedles has a substantially rectangular cross-sectional shape in a plane parallel to the substrate. The at least one channel may be open to two opposing surfaces of the microneedle.

[0018] In one embodiment, the drug storage element is attached to a first surface of the planar substrate, said first surface being opposed to a second surface of the planar substrate of the microneedle array, wherein the microneedles project from said second surface.

[0019] In another embodiment, the device further includes a release mechanism for releasing the drug formulation from the drug storage element to permit the drug formulation to be transported into and through the at least one channel of the at least one microneedle. The release mechanism may utilize a mechanical force, heat, a chemical reaction, an electric field, a magnetic field, a pressure field, ultrasonic energy, vacuum, pressure, or a combination thereof.

[0020] In one exemplary modification, the drug storage element includes a porous material, wherein the drug formulation is stored in pores of the porous material. In another embodiment, the drug storage element includes at least one sealed reservoir. In one variation of this embodiment, the device further includes at least one puncturing barb extending from the first surface of the planar substrate, wherein the puncturing barb can be used to puncture the sealed reservoir.

[0021] In a preferred embodiment, the device further includes a backing structure and adhesive surface suitable for securing the device to the skin of a patient during administration of the drug formulation to the patient.

[0022] In still another aspect, a method is provided for manufacturing a microneedle array. In one embodiment,

the method includes the steps of forming a substantially planar substrate having an array of spaced apertures therein; and forming a plurality of microneedles projecting at angle from the plane in which the planar substrate lies, the microneedles having a base portion integrally connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween, wherein at least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate. In various embodiments, the step of forming the plurality of microneedles comprises embossing, injection molding, casting, photochemical etching, electrochemical machining, electrical discharge machining, precision stamping, high-speed computer numerically controlled milling, Swiss screw machining, soft lithography, directional chemically assisted ion etching, or a combination thereof.

[0023] In a preferred embodiment, a method for manufacturing a microneedle array is provided that includes the steps of providing a substantially planar substrate material; forming a plurality of first apertures in the substrate material, wherein the interior surface of at least one of the first apertures defines a microneedle having a tip, a base, and a body portion therebetween; forming a plurality of second apertures in the substrate material, which at least one of the second apertures defines a channel located in the body portion of the microneedle; and bending said microneedle near its base such that the tip projects out of the plane of the substrate material. In one embodiment, the step of forming the first apertures, the forming the second apertures, or the forming both the first and second apertures includes removing portions of the substrate material by a process comprises embossing, injection molding, casting, photochemical etching, electrochemical machining, electrical discharge machining, precision stamping, high-speed computer numerically controlled milling, Swiss screw machining, soft lithography, directional chemically assisted ion etching, or a combination thereof. In one embodiment, the bending of the microneedle comprises direct or indirect application of a compressive force, heat, or a combination thereof, to the microneedle and/or substrate.

[0024] In still another aspect, an exemplary method is provided for administering a drug to a patient in need thereof, which includes the steps of inserting into the skin of the patient the microneedles of the microneedle devices described above, and causing the drug formulation to be transported from the drug storage element through the at least one channel of the microneedle and through the stratum corneum of the skin. The transport of the drug formulation may be driven or assisted by capillary force, gravitational force, overpressure, vacuum, an electric field, a magnetic field, iontophoresis, a molecular concentration gradient, or a combination thereof.

[0025] In a further aspect, an applicator device is provided for applying a microneedle array to skin. In one embodiment, the applicator device includes a housing having a substantially planar application side and an opposed top side; a recess in the housing in which a drug delivery device that includes a microneedle array can be stored; and a button on the top side of the housing, which button can be depressed to drive the drug delivery device out of the recess with the microneedles oriented substantially perpendicular to the planar application side. In one embodiment, the housing further comprises a roller disposed partially in a cavity on the planar application side of the housing.

[0026] In a preferred embodiment, the applicator device further includes one or more of the drug delivery devices described above that includes a microneedle array, wherein the device comprises a substantially planar substrate having an array of spaced apertures therein; a plurality of microneedles projecting at angle from the plane in which the planar substrate lies, the microneedles having a base portion integrally connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween, wherein at least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate; and at least one drug storage element, which contains a drug formulation, positioned adjacent to the planar substrate.

Brief Description of the Figures

[0027]

FIG. 1 is an exploded, perspective view of one embodiment of a transdermal drug delivery device comprising an array of microneedles and a drug storage element.

FIG. 2 is a close-up view of part of one embodiment of a microneedle array.

FIG. 3 is a plan view of one embodiment of an intermediate structure used in forming the microneedle array, wherein the microneedles of the intermediate structure are formed, and still are, in-plane with the substrate.

FIG. 4 is a close-up view of part of the intermediate microneedle structure shown in **FIG. 3.**

FIGS. 5A-B are perspective views of one embodiment of an applicator device for applying a microneedle drug delivery device to a patient's skin. **FIG. 5A** shows the application side, and **FIG. 5B** shows the actuation side.

Detailed Description of the Preferred Embodiment

[0028] Improved microneedle arrays and transdermal drug delivery devices have been developed. The microneedles of the array combine the advantages of prior

solid microneedles and prior microneedles with a central hollow bore, and avoid disadvantages of each. In particular, the present microneedles advantageously have both a strong, small solid tip and a channel for drug to flow through the stratum corneum and into the patient's lower skin tissues (e.g., epidermis, dermis, or subcutaneous skin layers) while the microneedle remains inserted in the patient's skin during drug delivery. Consequently, drug delivery rates can be maintained relatively constant because the created pores are kept open by the microneedles inserted into the patient's stratum corneum, and pain from insertion of the microneedles can be minimized since the tip portion of the microneedle can be made to have a smaller cross-section and sharper tip than conventional drug-coated solid microneedles or hollow microneedles with a central bore. In addition, mass transport using the present microneedles can be increased relative to similarly dimensioned hollow or solid conventional microneedles. A still further advantage of the present array design is that it may be fabricated using relatively easy and relatively inexpensive techniques, compared to those techniques required to make conventional hollow microneedles having a central bore.

[0029] Applicator devices have also been developed for applying the microneedle drug delivery devices (e.g., patches) to a patient's skin.

[0030] As used herein, the terms "comprise," "comprising," include," and "including" are intended to be open, non-limiting terms, unless the contrary is expressly indicated.

Microneedle Array

[0031] The microneedle array comprises at least one substrate and a plurality of microneedles projecting at an angle from the at least one substrate. In one embodiment, a microneedle array device is provided which includes a substantially planar substrate having an array of spaced apertures therein. A plurality of microneedles project at angle from the plane in which the planar substrate lies. The microneedles have a base portion connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween.

[0032] At least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate.

[0033] Generally, the microneedle can be in any elongated shape suitable for providing the skin piercing and fluid conduit functions, with minimal pain to the patient. In various embodiments, the microneedle is substantially cylindrical, wedge-shaped, cone-shaped, or triangular (e.g., blade-like). The cross-sectional shape (cut along a plane approximately parallel to the planar substrate or approximately perpendicular to the longitudinal axis of the microneedle) of the microneedle, or at least the portion of microneedle that is penetrable into the skin, may take a variety of forms, including rectangular, square, oval, circular, diamond, triangular, or star-shaped.

[0034] In a preferred embodiment, the base portion of the at least one of the microneedles has a substantially rectangular cross-sectional shape in a plane parallel to the substrate. Preferably, this base portion is untapered and the tip end portion which extends from the base portion is tapered, the combination of which is believed to provide a good combination of strength, manufacturing ease, and drug delivery performance. The channel desirably extends from the substrate through the base portion and into the tip portion, to facilitate delivery of the drug well beneath the skin surface. In one specific variation of this embodiment, the channel is open to two opposing surfaces of the microneedle. In one embodiment, each microneedle in an array has a rectangular cross-sectional shape, an untapered base portion, a tapered tip end portion, and a channel which is open to two opposing surfaces of the microneedle and extends from an aperture in the substrate, through the body portion, and into the tapered tip portion.

[0035] The tip portion of the microneedle is designed to pierce a biological barrier, e.g., to pierce the stratum corneum of the skin of a patient, to form a conduit through which a drug formulation can be transported into the patient's tissue. To provide minimal pain to the patient, the tip portion of the microneedle should be sufficiently small and sharp to enable piercing and penetration of the skin with minimal pain. In a preferred embodiment, the tip end portion of the microneedle is tapered from the body portion toward the tip end, defining a point or apex at the end of the microneedle. In a preferred embodiment, the channel extends from the planar substrate through the body portion and into the tip end portion. In an alternative embodiment, the channel may terminate in the body portion of the microneedle and not extend into the tapered tip portion. In various embodiments, the tapered tip portion may be in the form of an oblique angle at the tip, or a pyramidal or triangular shape.

[0036] The dimensions of the microneedles may vary depending on a variety of factors such as the type of drug to be delivered, the dosage of the drug to be delivered, and the desired penetration depth. Generally, the microneedles are constructed to provide skin-piercing and fluid delivery functions and thus will be designed to be sufficiently robust to withstand insertion into and withdrawal from the skin. Each microneedle has a length of about 1 micrometer (μm) to about 5000 micrometers (μm). More preferably, each microneedle has a length of about 1 μm to about 500 (μm. Still more preferably, each microneedle has a length of about 100 μm to about 500 μm. The penetration length of the microneedles into the biological barrier is about 50 μm to about 200 μm. In addition, each of the microneedles has a width of about 1 μm to about 500 μm. Furthermore, each microneedle has a thickness of about 1 μm to about 200 μm. It will be understood by one skilled in the art that the width and thickness of the

microneedle may vary along its length. For instance, the base portion may be wider (thicker) than the body portion, or the body portion may have a slight taper approaching the tip portion.

[0037] Importantly, the one or more channels in each microneedle provide a path for a drug formulation to flow from the apertures in the substrate through/into the biological barrier at the site of piercing. The channel preferably extends from the substrate toward the tip through a substantial portion of a length dimension of the microneedles. The channel does not extend all the way to the tip of the microneedle as a central bore would. The channel may comprise an opening through two surfaces of the microneedle. In alternate embodiments, the channel may comprise any shape suitable to deliver fluid proximal to the microneedle tip. For example, the channel may comprise a groove on one surface of the microneedle that is only open to the outside environment on one side of the microneedle. In addition, the channel may be dimensioned to provide a capillary force or effect upon the fluid to be delivered such that the capillary effect draws or wicks fluid into the base portion of the microneedle from the substrate aperture, through the body portion of the microneedle, and toward the tip portion of the microneedle. In other embodiments, each microneedle may have more than one channel, for example, two narrower channels in parallel.

[0038] The width of the channel may be constant along its length or may vary. The length of the channel will vary depending on a variety of factors, but will typically be about 50 to 99% of the length of the microneedle, and preferably is about 70 to 99% of the length of the microneedle. Nevertheless, it is possible that in certain embodiments the length of the channel will be between 1 to 50% of the length of the microneedle. As such, the length of the tip portion beyond the channel may vary, but usually is about 1 to 50% of the length of the microneedle, and more usually is about 1 to 30% of the length of the microneedle. It will be appreciated by one skilled in the art that the width of the channel, the length of the channel, and the length of the microneedle may be varied to increase or decrease the flow rate of the drug.

[0039] In one embodiment, the length of the at least one microneedle may be between 10 μm and 1000 μm, preferably between 100 μm and 500 μm. In another embodiment, the at least one microneedle has a maximum width dimension of 500 μm. In one embodiment, the body portion of the microneedle is rectangular with a centrally located channel extending through the opposed longer sides of the body portion. In one particular embodiment, the rectangular body portion has a long side cross-sectional dimension between 1 μm and 500 μm and a short side cross-sectional dimension between 1 μm and 200 μm.

[0040] In a preferred embodiment, the microneedle has an untapered, rectangular-shaped base portion having a longer side width of between 50 μm and 500 μm and a shorter side width of between 20 μm and 200 μm. The channel is centrally located in the microneedle and extends from the aperture in the substrate, through the base portion, and into a tapered tip portion, and is open to both of the longer sides of the base portion. In one embodiment, the width of the channel is substantially constant along its length in the base portion. In one case, the width of the channel is between about 40 μm and about 400 μm, e.g., between 100 and 250 μm. With a long side width of the microneedle between 50 μm and 500 μm and a channel width of between 40 μm and 400 μm, the width of the channel as a percentage of the width of the microneedle may be between 8% and 100%, for example between 20% and 100%, between 50% and 100%, between 8% and 80%, between 20% and 80%, between 50% and 80%, or between 20% and 50%.

[0041] The apertures in the planar substrate may be in essentially any shape. In exemplary embodiments, the apertures may be circular, semi-circular, oval, diamond, triangular, or a combination thereof. In a preferred embodiment, the apertures in the substrate are polygonal in shape, each aperture being defined by three or more interior side surfaces in the substrate. In one embodiment, the base portion of the at least one microneedle includes a curved portion that extends from at least one of the interior side surfaces of the substrate. In a preferred embodiment, the apertures occupy a substantial area of the substrate, in order to maximize the contact of the drug reservoir with skin and to facilitate adhesion of the microneedle patch device to the skin. As used herein, the term "substantial area of the substrate" means that in a plan view of the substrate of the microneedle device, the apertures compose more than about 40% (e.g., between 50% and 95%, between 60% and 85%) of the total area of the substrate from which the microneedles extend. In one embodiment, a proximal end of the at least one channel extends to or into the at least one of the interior side surfaces of the substrate. In preferred embodiments, the substrate, the microneedles, or both, are formed of, or coated with, a biocompatible material. The microneedles may be formed from the substrate material, or alternatively, the microneedles can include a material different from the substrate material. Representative examples of suitable materials of construction include metals and alloys such as stainless steels, palladium, titanium, and aluminum; plastics such as polyetherimide, polycarbonate, polyetheretherketone, polyimide, polymethylpentene, polyvinylidene fluoride, polyphenylsulfone, liquid crystalline polymer, polyethylene terephthalate (PET), polyethylene terephthalate-glycol modified (PETG), polyimide, and polycarbonate; and ceramics such as silicon and glass. The material preferably is selected such that the microneedle is strong enough at its designed dimensions for the microneedle to effectively pierce the biological barrier(s) of choice, without significant bending or breaking of the microneedle. The microneedle and substrate materials also should be non-reactive with the drug formulation being delivered through substrate apertures and microneedle channel(s). In a

preferred embodiment, the microneedles and substrate consist of a metal or alloy. In another embodiment, the microneedles comprise a biocompatible thermoplastic polymer.

[0042] The substrate, the microneedles, or both, optionally may further include secondary materials of construction embedded therein or coated thereon. For example, microparticles, nanoparticles, fibers, fibrids, or other particulate materials may be included. Examples of such materials include metals, carbon siliceous materials, glasses, and ceramics. These secondary materials may enhance one or more physical or chemical characteristics of the microneedle array. For example, the secondary material may be insulating layer or may improve the flow or transport of the drug formulation through the apertures and channels of the array. Representative examples of suitable insulating materials include PET, PETG, polyimide, polycarbonate, polystyrene, silicon, silicon dioxide, ceramic, glass, and the like. In a preferred embodiment, chemical vapor deposited silicon dioxide is used as an insulating layer on the microneedle array due to its hydrophilic nature, which may facilitate fluid delivery. In another embodiment, the channel of the microneedle may include one or more agents to facilitate fluid flow. For example, one or more hydrophilic agents may be present on the interior surfaces defining the channel. Examples of such hydrophilic agents include, but are not limited to, surfactants. Exemplary surfactants include MESA, Triton, Macol, Tetronic, Silwet, Zonyl, and Pluronic.

[0043] The surface of the substrate that is in contact with the surface of the biological barrier (e.g., the stratum corneum) may be coated, in whole or in part, with a bonding substance that can secure the microneedle patch to the biological barrier for an extended period of time, e.g., for a duration required to release all of the drug formulation to the biological barrier. Examples of such bonding agents include adhesives and bioactive films, which are activated by pressure, heat, light (UV, visible, or laser), electric, magnetic fields, biochemical and electrochemical reactions, or a combination thereof.

[0044] A representative embodiment of the microneedle array is shown in **FIG. 1** and **FIG. 2.** The microneedle array **12** includes a substantially planar substrate **14** and a plurality of microneedles **16** extending from the planar substrate **14.** The planar substrate **14** includes a plurality of spaced apertures **13.** The planar substrate **14** optionally may be coated with a bonding substance (not shown) to facilitate adhesion of the microneedle array **12** to a surface of a biological barrier. Each of the microneedles **16** has a base portion **15** connected to the planar substrate, a tip end portion **22** distal to the base portion **15,** and a body portion **17** therebetween. The base portion of the microneedle has a substantially rectangular cross-sectional shape in a plane parallel to the substrate. Each microneedle has an elongated channel **24** extending from the base portion **15** through at least a part of the body portion **17.** The channel **24** is open along the body portion, through two opposing surfaces of the body portion, and the channel **24** is in fluid communication with aperture **13** in the planar substrate. The channel **24** extends from the planar substrate through the body portion **17** and into the tip end portion **22.** The microneedles **16,** or at least the body and tip portions thereof, are substantially perpendicular to the planar substrate **14.** The apertures **13** in the substrate are hexagonal and defined by interior side surfaces **19** in the planar substrate. The base portion **15** of each of the microneedles includes a curved portion that is integrally connected to the planar substrate, extending from one of the interior side surfaces **19.**

Microneedle Drug Delivery Device

[0045] In preferred embodiments, the microneedle array described in the preceding section is part of a drug delivery device that includes a drug storage element. The drug storage element is a means for containing a drug formulation for release to and through the microneedle array, for transdermal administration of the formulation via the microneedle array. Preferably, the drug delivery device is in the form of a transdermal drug delivery patch.

[0046] In a preferred embodiment, the drug storage element is positioned adjacent to the planar substrate. For example, the drug storage element may be attached to a first surface of the planar substrate, wherein the first surface is opposed to a second surface of the planar substrate from which the microneedles project. In a preferred embodiment, the drug delivery device is in the form of a patch that can be adhered to the skin during transdermal administration of a drug formulation through the microneedle array. In one embodiment, the device, or patch, includes a backing structure and adhesive surface suitable for securing the device to the skin of a patient with the microneedles in an inserted position in the skin. In one embodiment, the drug storage completely fills the apertures and adheres to the skin after patch application. In a preferred embodiment, the adhesive surface and/or microneedles are protected by a release liner which is removed before administration of the drug delivery patch to the skin.

[0047] In a preferred embodiment, the drug storage element has at least one sealed reservoir, which can be selectively punctured or otherwise breached in a controlled manner to release a drug formulation contained therein. In one embodiment, the drug storage element includes a porous material, wherein the drug formulation is stored in pores of the porous material. Representative examples of suitable porous materials include open cell polymeric foams, sheets/mats of woven or non-woven fibers, combinations thereof, and the like. In another example, the drug storage element may be in the form of one or more substantially flat pouches, for example, made of two sheets of flexible thermoplastic polymeric film, sealed along the edges to define a reservoir therebetween.

[0048] The "drug formulation" refers to essentially any therapeutic or prophylactic agent known in the art (e.g.,

an active pharmaceutical ingredient, or API), and typically includes one or more physiological acceptable carriers or excipients to facilitate transdermal administration of the drug formulation. In one embodiment, the drug formulation is a fluid drug formulation, wherein the formulation can flow through apertures and channels in the microneedle array; it may be a solution, suspension, emulsion, or a combination thereof. In another embodiment, the drug formulation comprises a solid formulation, wherein the transport of drug through apertures and channels in the microneedle array involves diffusional transport mechanisms, with little or no bulk flow. The drug delivery device may include a drug formulation that includes a combination of liquid and solid components, wherein transport of the drug formulation involves both flow and mass diffusion.

[0049] The drug delivery device typically includes means for causing the drug formulation to be released from the drug storage element, permitting the drug formulation to flow into or otherwise be transported through the channel of the microneedle. The release typically is to and through the apertures in the planar substrate and thus to the base end of the channel in the microneedle. A wide variety of release mechanisms for releasing the drug formulation from the drug storage element can be envisioned by those skilled in the art. These release mechanisms may utilize a mechanical force, heat, a chemical reaction, an electric field, a magnetic field, a pressure field, ultrasonic energy, vacuum, pressure, or a combination thereof. In one embodiment, the release mechanism includes a means for applying a compressive force to a porous material to expel the drug formulation from the pores in the porous material. The means for applying a compressive force can be in the form of a spring-biased piston or button that can be manually depressed to apply a direct or leveraged force onto the back of the drug storage element. The same force optionally may cause the microneedles to be inserted into the skin of a patient and/or cause a pressure-sensitive adhesive surface on the device (e.g., inside the apertures and on the periphery of a backing material) to become adhered to the surface of the skin. In another embodiment, the drug delivery device includes at least one puncturing barb extending from the surface of the planar substrate (opposite the microneedle), wherein the puncturing barb can be used to puncture the sealed reservoir, e.g., upon application of a compressive force to the reservoir. This barb could be one or more microneedles bent in the opposite direction from the microneedles intended for skin insertion.

[0050] The flow of the drug formulation through the channels into the biological barrier may be passive, e.g., the result of capillary and gravitational forces. Alternatively, the flow may be actively assisted. In one embodiment, the drug delivery device may include means for actively driving the drug formulation through the microneedle channels and/or into the skin. For example, the flow of the drug formulation through the channels into the biological barrier may be aided by application of heat (e.g., generated by a series of microfabricated resistors), an electric field, a magnetic field, a pressure field, a concentration gradient, or any other physical force or energy. The application of an electric field can comprise electrophoresis, iontophoresis, electroosmosis, electroporation, or the like. The application of a magnetic field can comprise magnetophoresis or the like. The application of a pressure field can comprise pumping, applying ultrasonic energy, applying vacuum, pressure, or the like.

[0051] **FIG. 1** shows a transdermal drug delivery patch **10** comprising a microneedle array **12** and a drug storage element **18,** which is configured to store a drug formulation therein for subsequent release to the microneedle array.

Making the Microneedle Arrays

[0052] The microneedle arrays described herein can be made using or adapting a variety of fabrication techniques known in the art, depending upon the particular materials of construction and the particular microneedle/array design selected. In one embodiment, the microneedle array is made using one or more conventional microfabrication techniques. The microneedles may be formed individually or the whole array of microneedles and substrate may be formed in a single process. In a preferred embodiment, the microneedle arrays are formed in mass (i.e., commercial scale) quantities using inexpensive fabrication processes available in the art.

[0053] In one embodiment, the method for manufacturing a microneedle array includes the steps of forming a substantially planar substrate having an array of spaced apertures therein; and forming a plurality of microneedles projecting at angle from the plane in which the planar substrate lies, the microneedles having a base portion integrally connected to the substrate, a tip end portion distal to the base portion, and body portion therebetween, wherein at least one of the microneedles has at least one channel extending substantially from the base portion through at least a part of the body portion, the channel being open along at least part of the body portion and in fluid communication with at least one of the apertures in the substrate. In various embodiments, the step of forming the plurality of microneedles includes embossing, injection molding, casting, photochemical etching, electrochemical machining, electrical discharge machining, precision stamping, high-speed computer numerically controlled milling, Swiss screw machining, soft lithography, directional chemically assisted ion etching, or a combination thereof.

[0054] In one particular embodiment, the method for manufacturing a microneedle array includes the steps of providing a substantially planar substrate material; forming a plurality of first apertures in the substrate material, wherein the interior surface of at least one of the first apertures defines a microneedle having a tip, a base, and a body portion therebetween; forming a plurality of

second apertures in the substrate material, which at least one of the second apertures defines a channel located in the body portion of the microneedle; and bending said microneedle near its base such that the tip projects out of the plane of the substrate material. In particular variations of this embodiment, the forming of the first apertures, the forming of the second apertures, or the forming of both the first and second apertures includes removing portions of the substrate material, proximate to each of the plurality of microneedles to shape each microneedle. This process may include embossing, injection molding, casting, photochemical etching, electrochemical machining, electrical discharge machining, precision stamping, high-speed computer numerically controlled milling, Swiss screw machining, soft lithography, directional chemically assisted ion etching, or a combination thereof. In one embodiment, the step of bending the microneedle comprises direct or indirect application of a compressive force, heat, or a combination thereof, to the microneedle and/or substrate.

[0055] The forming of the microneedles may include forming the microneedles in-plane with the substrate and then bending the plurality of microneedles out-of-plane with the substrate, for example, to a position substantially perpendicular to the planar substrate surface. Alternatively, the microneedles may be fabricated originally out-of-plane with the substrate (i.e., with no intermediate in-plane structure). For example, directional chemically assisted ion etching can be used to fabricate the microneedles that are initially out-of-plane with the substrate. These various microneedle fabrication options allow the microneedle arrays to be fabricated from flexible substrates and/or inflexible substrates.

[0056] In a preferred embodiment, microneedles may be formed in-plane or out-of-plane with the substrate using a microreplication technique known in the art. Representative examples of suitable microreplication techniques include embossing, injection molding and casting processes. Such microreplication techniques, and in particular embossing techniques, may provide low cost manufacturing and also may advantageously enable the tip of the microneedle to be extremely small (near infinitesimally small cross-sectional area) and sharp. Furthermore, embossing techniques allow precise, consistent fabrication of the microneedles.

[0057] In a preferred embodiment, an embossing technique is used. In one process using an embossing technique, a planar substrate material, such as a suitable thermoplastic precursor material, is placed into an embossing apparatus, where such an apparatus includes a mold having features of a microneedle array as described herein. (The mold may have a negative image of the features of the microneedles.) The precursor material is then compressed by the mold under heat and a suitable compression force. In one embodiment, the planar substrate material has a thickness in the range of about 25 μm to about 650 μm, preferably from about 50 μm to about 625 μm, and more preferably from about 75 μm to about 600 μm. In one embodiment, the substrate material is heated temperature in the range of about 20 °C to 1500 °C, preferably from about 100 °C to 1000 °C, more preferably from about 200 °C to 500 °C. The heat is usually applied to the substrate material for about 0.1 seconds to 1000 seconds, preferably for about 0.1 seconds to 100 seconds, and more preferably about 0.1 seconds to 10 seconds. The compression force may range from about 1 GPa to 50 GPa, preferably from about 10 GPa to 40 GPa, and more preferably from about 20 GPa to 30 GPa. The compression force may be applied for about 0.01 seconds to 100 seconds, preferably for about 0.01 seconds to 10 seconds, and more preferably about 0.01 seconds to 1 second. The heat and compression force may be applied at the same time or different times. After the substrate material is cooled, it is removed from the embossing apparatus, yielding an embossed array of microneedles, which may be in-plane or out-of-plane. If the microneedles of the embossed array are in-plane with the substrate, then the microneedles subsequently are subjected to a bending step to fix them into an out-of-plane orientation relative to the substrate.

[0058] The step of bending in-plane microneedles of an intermediate structure into an out-of-plane position to form a microneedle array can be done using a variety of different methods, to effect application of a direct or indirect force that causes plastic and/or elastic deformation of the microneedles, preferably limited to the base portion thereof. In one example, the bending of the microneedles out-of-plane with the substrate may be facilitated by the use of a mold (e.g., a metal mold) having protrusions corresponding to the number and position of the microneedles in the intermediate structure, whereby the mold can be engaged (e.g., compressed) with the intermediate structure, the compressive force between the protrusions and the microneedles causing all of the microneedles to bend (at their base portions) simultaneously out-of-plane. In another example, the microneedle array can be pressed between a thick elastic film (e.g., rubber or polyurethane) and a mold having cavities corresponding to the number and position of the microneedles to bend the microneedles out-of-plane with the substrate simultaneously. The compressive force squeezes the thick elastic film into the cavities on the opposite side of the substrate, and the thick elastic film consequently bends the microneedles out-of-plane with the substrate and into the cavities.

[0059] Heat and/or various auxiliary pressures can be used in conjunction with the bending force to facilitate the bending of the microneedles. For example, a heated high-speed liquid or gas can be flowed in a direction substantially perpendicular to the plane of the substrate comprising plastic microneedles. The plastic microneedles are heated by the flowing fluid, undergo a plastic transition, and then are bent out-of plane with the substrate by the force of the high-speed fluid. In other embodiments, the step of bending the in-plane microneedles may include directly or indirectly applying an electric field or a

magnetic field to microneedles.

[0060] **FIG. 3** and **FIG. 4** illustrate one embodiment of an intermediate microneedle structure **30.** Structure **30** includes a planar substrate **34** and a plurality of microneedles **36** positioned in apertures **46** in the planar substrate **34.** The microneedles lie in the plane of the planar substrate. Each microneedle **36** has a base portion **37,** a tip end portion **42,** and a body portion **38** therebetween. Each microneedle **36** also has an elongated channel **44** in the base portion and body portion of each microneedle. To make a microneedle array for drug delivery from this intermediate structure, the microneedles **36** will be bent out-of-plane with the planar substrate **34.**

[0061] The microneedle arrays and drug storage elements can be made separately and then assembled using known techniques for connecting conventional microneedle arrays to a drug storage element, which preferably is done in an aseptic or sterile environment.

Drug Device Applicator and Use of the Microneedle Array Devices

[0062] Drug delivery devices comprising the microneedle arrays described herein preferably are used to deliver a drug formulation across a biological barrier. The biological barrier preferably is human or other mammalian skin, although other tissue surfaces may be envisioned. In a typical use, the drug formulation is released from the drug storage element, it flows to the microneedle array, where it passes through the apertures in the planar substrate of the array and then enters the channels of the microneedles at the base portions of the microneedles. The drug formulation then is transported through the channel, traversing the stratum corneum and then entering the epidermis, dermis, and/or subcutaneous skin tissues. After administration of the drug formulation is complete, the microneedles are removed from the skin.

[0063] In an exemplary method of administering a drug to a patient in need thereof includes the steps of inserting into the skin of the patient the microneedles of a drug delivery device that has a drug storage element containing a drug formulation, and then causing the drug formulation to be transported from the drug storage element, into and through at least one channel of at least one of the microneedle, and through the stratum corneum of the skin. The transport of the drug formulation can be passively or actively assisted. The drug formulation is transported under the influence or assistance of capillary forces, gravitational forces, overpressure, vacuum, an electric field, a magnetic field, iontophoresis, a molecular concentration gradient, or a combination thereof. One skilled in the art can utilize or readily adapt any of these means using technology known in the art.

[0064] The microneedles of the drug delivery device can be inserted into the skin by a variety of means, including direct manual application or with the aid of an applicator device to insure uniform and proper microneedle penetration, consistently within a single array and across different arrays. The applicator device may be completely mechanical or it may be electromechanical. The applicator device may include pressure sensors in communication with an electronically controlled release mechanism, to insure that a drug delivery device is applied to the skin with the desired force each time. Optionally, the applicator device may include hardware, software, and power source components to provide heat, electrical field, magnetic field, pressure, or other drug delivery assistance means known in the art. The applicator device may include one or more rollers for use in applying an even pressure to the drug delivery patch to ensure that it is completely secured to the skin. The roller may, for example, further secure a pressure sensitive adhesive surface around the periphery of the patch.

[0065] One example of a simple applicator device is shown in **FIGS. 5A-B.** Applicator device **50** includes a rigid housing **51** having a substantially planar application side **56** and an opposed actuation (top) side **58;** a recess **52** in the housing in which a drug delivery device (i.e., a patch) **60** that includes a microneedle array **62** is disposed; and a button **54** on the top side of the housing **51.** The button can be depressed to drive the drug delivery device **60** out of the recess **52** to and to drive the microneedles **62** into the skin (piercing the stratum corneum), when the application side is placed against the skin of a patient at the site for transdermal administration of the drug formulation. The housing further includes a roller **64** disposed partially in a cavity **66** on the application side of the housing. The roller **64** is used for completely inserting the microneedles **62** into the biological barrier as well as for establishing and facilitating a secure bond between the drug delivery device **60** and the surface of the biological barrier. The action of depressing the button **54** followed by application of the roller **64** also supplies a compressive force to the drug storage element (not shown) causing the drug formulation to be released from the drug storage element to the apertures and channels of the microneedle array. The roller **64** can also generate pressure, heat, light (e.g., UV, visible, or laser), electric, magnetic fields, biochemical and electrochemical reactions, or a combination thereof aimed to activate the bonding substance applied on the surface of the drug delivery device **60** which can hold the drug delivery device 60 attached to the biological barrier (not shown) for an extended period of time.

[0066] The foregoing description is presented for purposes of illustration and description. Modifications and variations are intended to come within the scope of the appended claims.

Claims

1. A microneedle array (12) for insertion into a biological tissue and delivering a fluid through a biological barrier, the array (12) comprising:

(a) a substantially planar substrate (14) having an array of spaced apertures (13) therein; and
(b) a plurality of microneedles (16) projecting at angle from the plane in which the planar substrate (14) lies, the microneedles (16) having a tip end, defining a point or apex at the end of the microneedle (16), a base portion (15) integrally connected to the substrate (14), a tip end portion (22) distal to the base portion (15), and a rectangular body portion (17) therebetween, said tip end portion (22) being tapered from the body portion (17) towards the tip end,

characterised in that

at least one of the microneedles (16) has at least one elongated channel (24), the channel (24) having a width that is substantially constant along its length and the channel extending through 50% to 99% of the length of the at least one microneedle (16) substantially from the planar substrate (14), through the base portion (15), and through at least a part of the body portion (17), and

wherein the channel (24): (i) is open along at least part of the body portion (17) and in fluid communication with at least one of the apertures (13) in the substrate (14), and (ii) forms an opening extending through the substrate (14), thereby providing a conduit between the tip end portion (22) of the microneedle (16) and the surface of the substrate (14) distal to the microneedle (16).

2. The microneedle array (12) of claim 1, wherein the at least one channel (24) is open to two opposing surfaces of the microneedle (16).

3. The microneedle array (12) of claim 1 or 2, wherein the substrate (14) and the microneedles (16) comprise at least one biocompatible metal, such as a stainless steel, or at least one biocompatible polymer.

4. The microneedle array (12) of claim 1 or 2, wherein the length of the at least one microneedle (16) is between 10 μm and 1000 μm, such as between 100 μm and 500 μm.

5. The microneedle array (12) of claim 1, wherein the rectangular body portion (17) has a long side cross-sectional dimension between 1 μm and 500 μm and a short side cross-sectional dimension between 1 μm and 200 μm.

6. A device (10) for transdermal administration of a drug, comprising:

the microneedle array (12) of claim 1 or any one of claims 2 to 5; and
at least one drug storage element (18), which contains a drug formulation, positioned adjacent to the planar substrate (14) of the microneedle array (12),
wherein the channel (24) of the microneedle array (12) in operation provides a conduit between the tapered tip end portion (22) of the microneedle (16) and the at least one drug storage element (18).

7. The device (10) of claim 6, wherein the drug storage element (18) is attached to a first surface of the planar substrate (14), said first surface being opposed to a second surface of the planar substrate (14) of the microneedle array (12), wherein the microneedles (16) project from said second surface.

8. The device (10) of claim 6 or 7, further comprising a release mechanism for releasing the drug formulation from the drug storage element (18) to permit the drug formulation to pass into and through the at least one channel (24) of the at least one microneedle (16), wherein the release mechanism utilizes a mechanical force, heat, a chemical reaction, an electric field, a magnetic field, a pressure field, ultrasonic energy, vacuum, pressure, or a combination thereof.

9. The device (10) of any one of claims 6 to 8, wherein the drug storage element (18) comprises at least one sealed reservoir.

10. The device (10) of claim 9, further comprising at least one puncturing barb extending from the first surface of the planar substrate (14), wherein the puncturing barb can be used to puncture the sealed reservoir.

11. The device (10) of any one of claims 6 to 8, further comprising a backing structure and adhesive surface suitable for securing the device (10) to the skin of a patient during administration of the drug formulation to the patient.

12. A method for manufacturing a microneedle array (12) comprising:

(a) forming a substantially planar substrate (14, 34) having an array of spaced apertures (13, 46) therein; and
(b) forming a plurality of microneedles (16, 36) projecting at an angle from the plane in which the planar substrate (14, 34) lies, the microneedles (16, 36) having a tip end, defining a point or apex at the end of the microneedle (16, 36), a base portion (15, 37) integrally connected to the substrate (14, 34), a tip end portion (22, 42) distal to the base portion (15, 37), and a rectan-

gular body portion (17, 38) therebetween, said tip end portion (22, 42) being tapered from the body portion (17, 38) towards the tip end,

characterised in that

at least one of the microneedles (16, 36) has at least one elongated channel (24, 44) extending through 50% to 99% of the length of the at least one microneedle (16, 36), substantially from the planar substrate (14, 34) through the base portion (15, 37), and through at least a part of the body portion (17, 38),
wherein the channel (24, 44): (i) is open along at least part of the body portion (17, 38) and in fluid communication with at least one ofthe apertures (13, 46) in the substrate (14, 34), and (ii) forms an opening extending through the substrate (14, 34), thereby providing a conduit between the tip end portion (22, 42) ofthe microneedle (16, 36) and the surface of the substrate (14, 34) distal to the microneedle (16, 36).

13. The method of claim 12, which comprises:

providing a substantially planar substrate material (14, 34);
forming a plurality of first apertures (13, 46) in the substrate material (14, 34), wherein the interior surface of at least one ofthe first apertures (13, 46) defines a microneedle (16, 36) having a tip (22, 42), a base (15, 37), and a body portion (17, 38) therebetween;
forming a plurality of second apertures in the substrate material, which at least one of the second apertures defines a channel (24, 44) located in the body portion ofthe microneedle (16, 36); and
bending said microneedle (16, 36) near its base (15, 37) such that the tip (22, 42) projects out of the plane of the substrate material (14, 34), wherein the bending of the microneedle (16, 36) comprises direct or indirect application of a compressive force, heat, or a combination thereof, to the microneedle (16, 36) and/or substrate (14, 34).

14. An applicator device (50) suitable for applying a microneedle array (12, 62) according to any one of claims 1 to 5 to skin, the applicator device (50) comprising:

a housing (51) having a substantially planar application side (56) and an opposed top side (58);
a recess (52) in the housing (51) in which a drug delivery device (60) can be stored, the drug delivery device (60) comprising the microneedle array (12, 62) of any one of claims 1 to 5;
a button (54) on the top side (58) of the housing (51), which button (54) can be depressed to drive the drug delivery device (60) out of the recess (52) with the microneedles (16, 62) oriented substantially perpendicular to the planar application side (56); and
a roller (64) disposed partially in a cavity (66) on the planar application side (56) of the housing (51).

15. The microneedle array (12) of claim 1, wherein the at least one elongated channel (24) is dimensioned to provide a capillary effect to wick the fluid into the base portion (15) of said microneedle (16) from the substrate aperture (13), through the body portion (17) of said microneedle (16), and toward the tip end portion (22) of said microneedle (16).

Patentansprüche

1. Eine Mikronadelanordnung (12) für die Einsetzung in ein biologisches Gewebe und Abgabe einer Flüssigkeit durch eine biologische Barriere, die Anordnung (12) weist dabei Folgendes auf:

(a) ein im Wesentlichen planares Substrat (14) mit einer Anordnung räumlich voneinander getrennter Öffnungen (13) darin; und
(b) eine Vielzahl von Mikronadeln (16), die in einem Winkel aus der Ebene herausragen, in der das planare Substrat (14) liegt, die Mikronadeln (16) haben dabei ein Spitzenende, das einen Punkt oder eine Kegelspitze am Ende der Mikronadel (16) definiert, einen Basis-Teil (15), der vollständig mit dem Substrat (14) verbunden ist, einen Spitzenende-Teil (22), der distal zum Basis-Teil (15) steht, und einen rechtwinkligen Gehäuse-Teil (17) dazwischen, der Spitzenende-Teil (22) verjüngt sich dabei vom Gehäuse-Teil (17) zum Spitzenende,

dadurch gekennzeichnet, dass

mindestens eine der Mikronadeln (16) mindestens einen Längskanal (24) und der Kanal (24) eine Breite hat, die im Wesentlichen konstant entlang seiner Länge ist, und der Kanal durch 50% bis 99% der Länge der mindestens einen Mikronadel (16) im Wesentlichen vom ebenen Substrat (14), durch das Basis-Teil (15) und durch mindestens einen Teil des Gehäuse-Teils (17) verläuft, und
wobei der Kanal (24): (i) entlang mindestens eines Teils des Gehäuse-Teils (17) offen ist und in Fluidverbindung mit mindestens einer der Öffnungen (13) im Substrat (14) steht, und (ii) eine Öffnung bildet, die durch das Substrat (14) ver-

läuft, und dadurch eine Leitung zwischen dem Spitzenende (22) der Mikronadel (16) und der Oberfläche des Substrats (14) distal zur Mikronadel (16) bereitstellt.

2. Die Mikronadelanordnung (12) gemäß Anspruch 1, wobei der mindestens eine Kanal (24) zu zwei gegenüberliegenden Oberflächen der Mikronadel (16) offen ist.

3. Die Mikronadelanordnung (12) gemäß Anspruch 1 oder 2, wobei das Substrat (14) und die Mikronadeln (16) mindestens ein biokompatibles Metall, wie beispielsweise Edelstahl, oder mindestens einen biokompatiblen Polymer aufweisen.

4. Die Mikronadelanordnung (12) gemäß Anspruch 1 oder 2, wobei die Länge der mindestens einen Mikronadel (16) zwischen 10 μm und 1000 μm, beispielsweise zwischen 100 μm und 500 μm, liegt.

5. Die Mikronadelanordnung (12) gemäß Anspruch 1, wobei das rechtwinklige Gehäuse-Teil (17) einen Längsseiten-Durchmesser zwischen 1 μm und 500 μm und einen Kurzseiten-Durchmesser zwischen 1 μm und 200 μm hat.

6. Eine Vorrichtung (10) für die transdermale Verabreichung eines Arzneimittels, die Folgendes aufweist:

die Mikronadelanordnung (12) gemäß Anspruch 1 oder gemäß eines der Ansprüche 2 bis 5; und
mindestens ein Arzneimittelaufnahme-Element (18), das ein Arzneimittelpräparat enthält, das am planaren Substrat (14) der Mikronadelanordnung (12) positioniert ist,
wobei der Kanal (24) der Mikronadelanordnung (12) im Einsatz eine Leitung zwischen dem sich verjüngenden Spitzenende-Teil (22) der Mikronadel (16) und dem mindestens einen Arzneimittelaufnahme-Element (18) bereitstellt.

7. Die Vorrichtung (10) gemäß Anspruch 6, wobei das Arzneimittelaufnahme-Element (18) mit einer ersten Oberfläche des planaren Substrats (14) verbunden ist, diese erste Oberfläche liegt dabei einer zweiten Oberfläche des planaren Substrats (14) der Mikronadelanordnung (12) gegenüber, wobei die Mikronadeln (16) aus der zweiten Oberfläche herausragen.

8. Die Vorrichtung (10) gemäß Anspruch 6 oder 7, die darüberhinaus einen Abgabemechanismus für die Abgabe des Arzneimittelpräparats aus dem Arzneimittelaufnahme-Element (18) aufweist, um das Arzneimittelpräparat in und durch den mindestens einen Kanal (24) der mindestens einen Mikronadel (16) laufen zu lassen, wobei der Abgabemechanismus eine mechanische Kraft, Wärme, eine chemische Reaktion, ein Kraftfeld, ein Magnetfeld, ein Druckfeld, Ultraschallenergie, Vakuum, Druck oder eine Kombination daraus nutzt.

9. Die Vorrichtung (10) gemäß eines der Ansprüche 6 bis 8, wobei das Arzneimittelaufnahme-Element (18) mindestens einen abgedichteten Behälter aufweist.

10. Die Vorrichtung (10) gemäß Anspruch 9, die darüberhinaus mindestens eine Durchstechspitze aufweist, die von der ersten Oberfläche des planaren Substrats (14) verläuft, wobei die Durchstechspitze verwendet werden kann, um den abgedichteten Behälter zu durchstechen.

11. Die Vorrichtung (10) gemäß eines der Ansprüche 6 bis 8, die darüberhinaus eine Stützstruktur und eine Klebestelle aufweist, mit der die Vorrichtung (10) an der Haut eines Patienten bei der Verabreichung des Arzneimittelpräparats an den Patienten befestigt werden kann.

12. Ein Verfahren für die Herstellung einer Mikronadelanordnung (12), die Folgendes aufweist:

(a) die Bildung eines im Wesentlichen planaren Substrats (14, 34) mit einer Anordnung räumlich voneinander getrennter Öffnungen (13, 46) darin; und
(b) die Bildung einer Vielzahl von Mikronadeln (16, 36), die in einem Winkel aus der Ebene herausragen, in der das planare Substrat (14, 34) liegt, die Mikronadeln (16, 36) haben dabei ein Spitzenende, das einen Punkt oder eine Kegelspitze am Ende der Mikronadel (16, 36) definiert, einen Basis-Teil (15, 37), der vollständig mit dem Substrat (14, 34) verbunden ist, einen Spitzenende-Teil (22, 42), der distal zum Basis-Teil (15, 37) steht, und ein rechtwinkliger Gehäuse-Teil (17, 38) dazwischen, der Spitzenende-Teil (22, 42) verjüngt sich dabei vom Gehäuse-Teil (17, 38) zum Spitzenende,

dadurch gekennzeichnet, dass

mindestens eine der Mikronadeln (16, 36) mindestens einen Längskanal (24, 44) hat, der durch 50% bis 99% der Länge der mindestens einen Mikronadel (16, 36), im Wesentlichen vom planaren Substrat (14, 34), durch das Basis-Teil (15, 37) und durch mindestens einen Teil des Gehäuse-Teils (17, 38) verläuft,
wobei der Kanal (24, 44): (i) entlang mindestens eines Teils des Gehäuse-Teils (17, 38) offen ist und in Fluidverbindung mit mindestens einer der Öffnungen (13, 46) im Substrat (14, 34) steht,

und (ii) eine Öffnung bildet, die durch das Substrat (14, 34) verläuft, und dadurch eine Leitung zwischen dem Spitzenende-Teil (22, 42) der Mikronadel (16, 36) und der Oberfläche des Substrats (14, 34) distal zur Mikronadel (16, 36) bereitstellt.

13. Das Verfahren gemäß Anspruch 12, das Folgendes aufweist:

die Bereitstellung eines im Wesentlichen planaren Substrat-Materials (14, 34);
die Bildung einer Vielzahl von ersten Öffnungen (13, 46) im Substrat-Material (14, 34), wobei die Innenfläche mindestens einer der ersten Öffnungen (13, 46) eine Mikronadel (16, 36) mit einer Spitze (22, 42), einer Basis (15, 37) und einem Gehäuse-Teil (17, 38) dazwischen definiert;
die Bildung einer Vielzahl von zweiten Öffnungen im Substrat-Material, wobei mindestens eine der zweiten Öffnungen einen Kanal (24, 44) definiert, der am Gehäuse-Teil der Mikronadel (16, 36) positioniert ist; und
die Biegung der Mikronadel (16, 36) nahe ihrer Basis (15, 37), so dass die Spitze (22, 42) aus der Ebene des Substrat-Materials (14, 34) herausragt, wobei die Biegung der Mikronadel (16, 36) eine direkte oder indirekte Anwendung einer Druckkraft, Wärme oder einer Kombination daraus auf die Mikronadel (16, 36) und/oder das Substrat (14, 34) aufweist.

14. Eine Applikatorvorrichtung (50), die geeignet ist, eine Mikronadelanordnung (12, 62) gemäß eines der Ansprüche 1 bis 5 auf die Haut anzuwenden, die Applikatorvorrichtung (50) weist dabei Folgendes auf:

ein Gehäuse (51) mit einer im Wesentlichen planaren Applikations-Seite (56) und einer gegenüberliegenden Oberseite (58);
eine Vertiefung (52) im Gehäuse (51), in die eine Arzneimittelabgabevorrichtung (60) eingesetzt werden kann, die Arzneimittelabgabevorrichtung (60) weist dabei die Mikronadelanordnung (12, 62) gemäß eines der Ansprüche 1 bis 5 auf;
eine Taste (54) an der Oberseite (58) des Gehäuses (51), diese Taste (54) kann gedrückt werden, um die Arzneimittelabgabevorrichtung (60) aus der Vertiefung (52) herauszudrücken, wobei die Mikronadeln (16, 62) im Wesentlichen senkrecht zur planaren Applikations-Seite (56) ausgerichtet sind; und
eine Rolle (64), die teilweise in einer Vertiefung (66) an der planaren Applikations-Seite (56) des Gehäuses (51) angebracht ist.

15. Die Mikronadelanordnung (12) gemäß Anspruch 1, wobei der mindestens eine Längskanal (24) so dimensioniert ist, dass er einen Kapillareffekt bereitstellt, der die Flüssigkeit in den Basis-Teil (15) der besagten
Mikronadel (16) aus der Substrat-Öffnung (13), durch den Gehäuse-Teil (17) der Mikronadel (16) und zum Spitzenende-Teil (22) der Mikronadel (16) zieht.

Revendications

1. Un réseau de micro-aiguilles (12) destiné à une insertion dans un tissu biologique et à l'administration d'un fluide au travers d'une barrière biologique, le réseau (12) comprenant :

(a) un substrat sensiblement plan (14) possédant un réseau d'ouvertures espacées (13) dans celui-ci, et
(b) une pluralité de micro-aiguilles (16) faisant saillie à un angle à partir du plan dans lequel le substrat plan (14) se situe, les micro-aiguilles (16) possédant une extrémité en pointe définissant un point ou un sommet à l'extrémité de la micro-aiguille (16), une partie base (15) raccordée d'un seul tenant au substrat (14), une partie extrémité en pointe (22) distale de la partie base (15) et une partie corps rectangulaire (17) entre celles-ci, ladite partie extrémité en pointe (22) étant biseautée à partir de la partie corps (17) vers l'extrémité en pointe,

caractérisé en ce que

au moins une des micro-aiguilles (16) possède au moins un canal allongé (24), le canal (24) possédant une largeur qui est sensiblement constante le long de sa longueur et le canal s'étendant sur 50% à 99% de la longueur de la au moins une micro-aiguille (16) sensiblement à partir du substrat plan (14) au travers de la partie base (15) et au travers d'au moins une partie de la partie corps (17), et
où le canal (24) : (i) est ouvert le long d'au moins une partie de la partie corps (17) et en communication fluidique avec au moins une des ouvertures (13) dans le substrat (14), et (ii) forme une ouverture s'étendant au travers du substrat (14), fournissant ainsi un conduit entre la partie extrémité en pointe (22) de la micro-aiguille (16) et la surface du substrat (14) distale de la micro-aiguille (16).

2. Le réseau de micro-aiguilles (12) selon la Revendication 1, où le au moins un canal (24) est ouvert vers deux surfaces opposées de la micro-aiguille (16).

3. Le réseau de micro-aiguilles (12) selon la Revendication 1 ou 2, où le substrat (14) et les micro-aiguilles (16) contiennent au moins un métal biocompatible, tel qu'un acier inoxydable, ou au moins un polymère biocompatible.

4. Le réseau de micro-aiguilles (12) selon la Revendication 1 ou 2, où la longueur de la au moins une micro-aiguille (16) se situe entre 10 μm et 1000 μm, par exemple entre 100 μm et 500 μm.

5. Le réseau de micro-aiguilles (12) selon la Revendication 1, où la partie corps rectangulaire (17) possède une dimension en section transversale côté long entre 1 μm et 500 μm et une dimension en section transversale côté court entre 1 μm et 200 μm.

6. Un dispositif (10) destiné à une administration transdermique d'un médicament, comprenant :

le réseau de micro-aiguilles (12) selon la Revendication 1 ou selon l'une quelconque des Revendications 2 à 5, et
au moins un élément de stockage de médicament (18), qui contient une formulation de médicament, positionné adjacent au substrat plan (14) du réseau de micro-aiguilles (12),
où le canal (24) du réseau de micro-aiguilles (12) en fonctionnement fournit un conduit entre la partie extrémité en pointe biseautée (22) de la micro-aiguille (16) et le au moins un élément de stockage de médicament (18).

7. Le dispositif (10) selon la Revendication 6, où l'élément de stockage de médicament (18) est fixé à une première surface du substrat plan (14), ladite première surface étant opposée à une deuxième surface du substrat plan (14) du réseau de micro-aiguilles (12), où les micro-aiguilles (16) font saillie à partir de ladite deuxième surface.

8. Le dispositif (10) selon la Revendication 6 ou 7, comprenant en outre un mécanisme de libération destiné à la libération de la formulation de médicament à partir de l'élément de stockage de médicament (18) de façon à permettre à la formulation de médicament de passer dans et au travers du au moins un canal (24) de la au moins une micro-aiguille (16), où le mécanisme de libération utilise une force mécanique, de la chaleur, une réaction chimique, un champ électrique, un champ magnétique, un champ de pression, une énergie ultrasonique, le vide, une pression, ou une combinaison de ceux-ci.

9. Le dispositif (10) selon l'une quelconque des Revendications 6 à 8, où l'élément de stockage de médicament (18) comprend au moins un réservoir scellé.

10. Le dispositif (10) selon la Revendication 9, comprenant en outre au moins une barbule de perforation s'étendant à partir de la première surface du substrat plan (14), où la barbule de perforation peut être utilisée pour perforer le réservoir scellé.

11. Le dispositif (10) selon l'une quelconque des Revendications 6 à 8, comprenant en outre une structure de renfort et une surface adhésive adaptée de façon à fixer le dispositif (10) à la peau d'un patient au cours de l'administration de la formulation de médicament au patient.

12. Un procédé de fabrication d'un réseau de micro-aiguilles (12) comprenant :

(a) la formation d'un substrat sensiblement plan (14, 34) possédant un réseau d'ouvertures espacées (13, 46) dans celui-ci, et
(b) la formation d'une pluralité de micro-aiguilles (16, 36) en saillie à un angle à partir du plan dans lequel le substrat plan (14, 34) se situe, les micro-aiguilles (16, 36) possédant une extrémité en pointe définissant un point ou un sommet à l'extrémité de la micro-aiguille (16, 36), une partie base (15, 37) d'un seul tenant raccordée au substrat (14, 34), une partie extrémité en pointe (22, 42) distale de la partie base (15, 37) et une partie corps rectangulaire (17, 38) entre celles-ci, ladite partie extrémité en pointe (22, 42) étant biseautée à partir de la partie corps (17, 38) vers l'extrémité en pointe,

caractérisé en ce que

au moins une des micro-aiguilles (16, 36) possède au moins un canal allongé (24, 44) s'étendant sur 50% à 99% de la longueur de la au moins une micro-aiguille (16, 36), sensiblement à partir du substrat plan (14, 34) au travers de la partie base (15, 37) et au travers d'au moins une partie de la partie corps (17, 38),
où le canal (24, 44) : (i) est ouvert le long d'au moins une partie de la partie corps (17, 38) et en communication fluidique avec au moins une des ouvertures (13, 46) dans le substrat (14, 34), et (ii) forme une ouverture s'étendant au travers du substrat (14, 34), fournissant ainsi un conduit entre la partie extrémité en pointe (22, 42) de la micro-aiguille (16, 36) et la surface du substrat (14, 34) distale de la micro-aiguille (16, 36).

13. Le procédé selon la Revendication 12, qui comprend :

la fourniture d'un matériau de substrat sensiblement plan (14, 34),
la formation d'une pluralité de premières ouver-

tures (13, 46) dans le matériau de substrat (14, 34), où la surface intérieure d'au moins une des premières ouvertures (13, 46) définit une micro-aiguille (16, 36) possédant une pointe (22, 42), une base (15, 37) et une partie corps (17, 38) entre celles-ci,
la formation d'une pluralité de deuxièmes ouvertures dans le matériau de substrat, où au moins une des deuxièmes ouvertures définit un canal (24, 44) situé dans la partie corps de la micro-aiguille (16, 36), et
la flexion de ladite micro-aiguille (16, 36) près de sa base (15, 37) de sorte que la pointe (22, 42) fasse saillie hors du plan du matériau de substrat (14, 34), où la flexion de la micro-aiguille (16, 36) comprend l'application directe ou indirecte d'un élément parmi une force de compression, de la chaleur, ou une combinaison de ceux-ci, à la micro-aiguille (16, 36) et/ou au substrat (14, 34).

14. Un dispositif applicateur (50) adapté de façon à appliquer un réseau de micro-aiguilles (12, 62) selon l'une quelconque des Revendications 1 à 5 à la peau, le dispositif applicateur (50) comprenant :

un logement (51) possédant un côté application sensiblement plan (56) et un côté supérieur opposé (58),
un évidement (52) dans le logement (51) dans lequel un dispositif d'administration de médicament (60) peut être logé, le dispositif d'administration de médicament (60) comprenant le réseau de micro-aiguilles (12, 62) selon l'une quelconque des Revendications 1 à 5,
un bouton (54) sur le côté supérieur (58) du logement (51), ledit bouton (54) pouvant être enfoncé de façon à entraîner le dispositif d'administration de médicament (60) hors de l'évidement (52) avec les micro-aiguilles (16, 62) orientées sensiblement perpendiculairement au côté application plan (56), et
un rouleau (64) disposé partiellement dans une cavité (66) sur le côté application plan (56) du logement (51).

15. Le réseau de micro-aiguilles (12) selon la Revendication 1, où le au moins un canal allongé (24) est dimensionné de façon à fournir un effet de capillarité destiné à drainer le fluide dans la partie base (15) de ladite micro-aiguille (16) à partir de l'ouverture du substrat (13) au travers de la partie corps (17) de ladite micro-aiguille (16) et vers la partie extrémité en pointe (22) de ladite micro-aiguille (16).

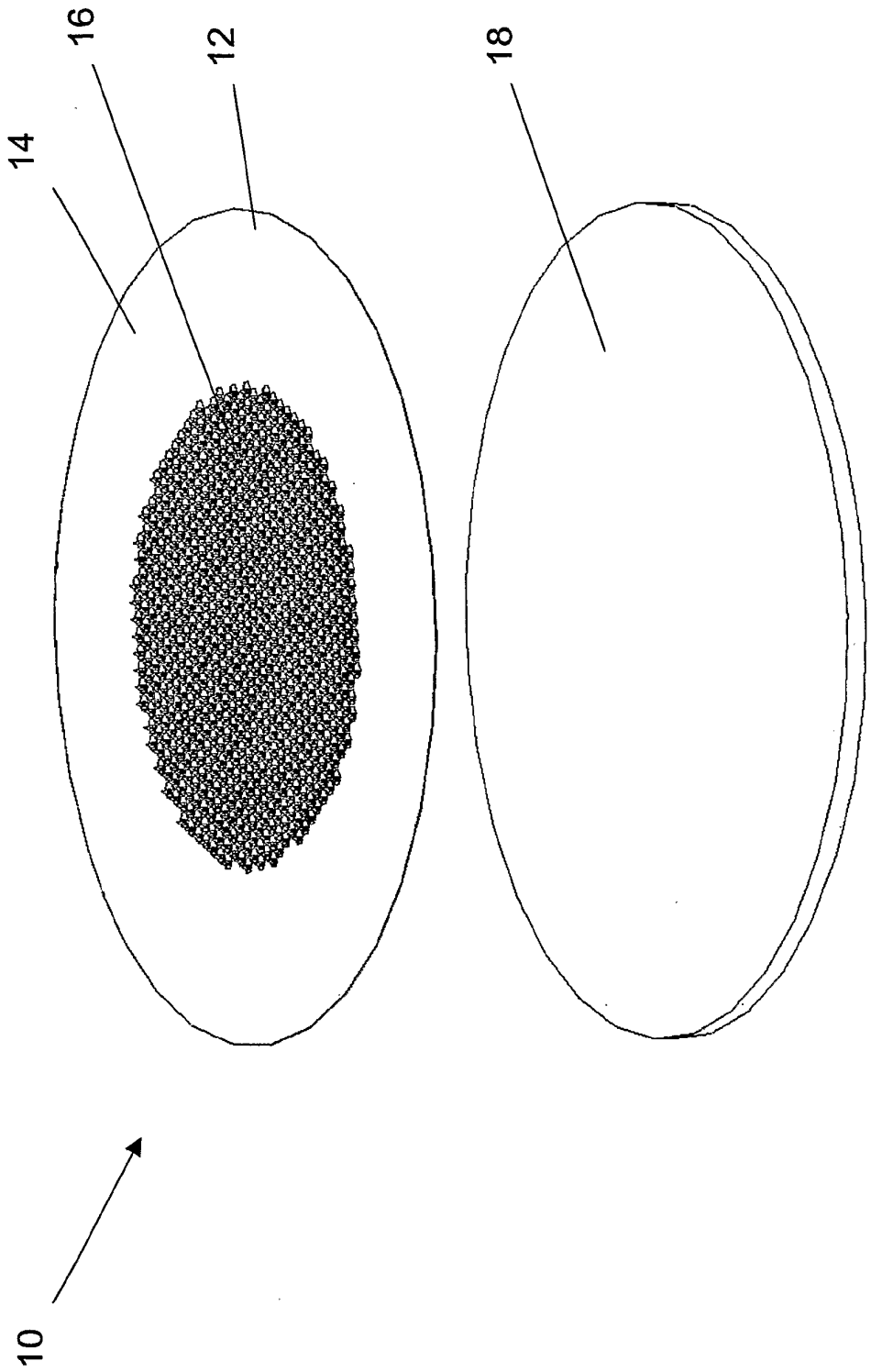

FIG. 1

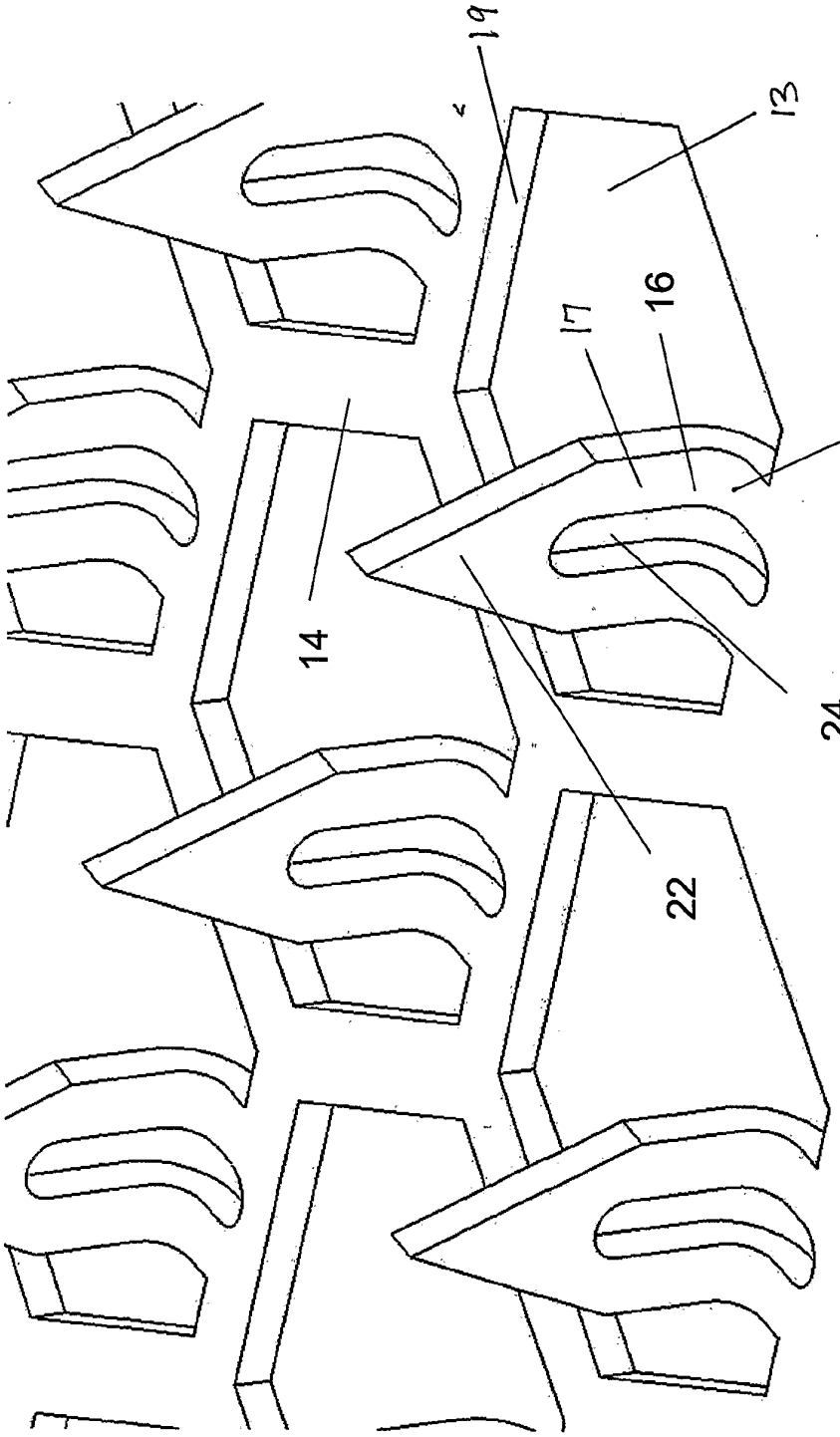

FIG. 2

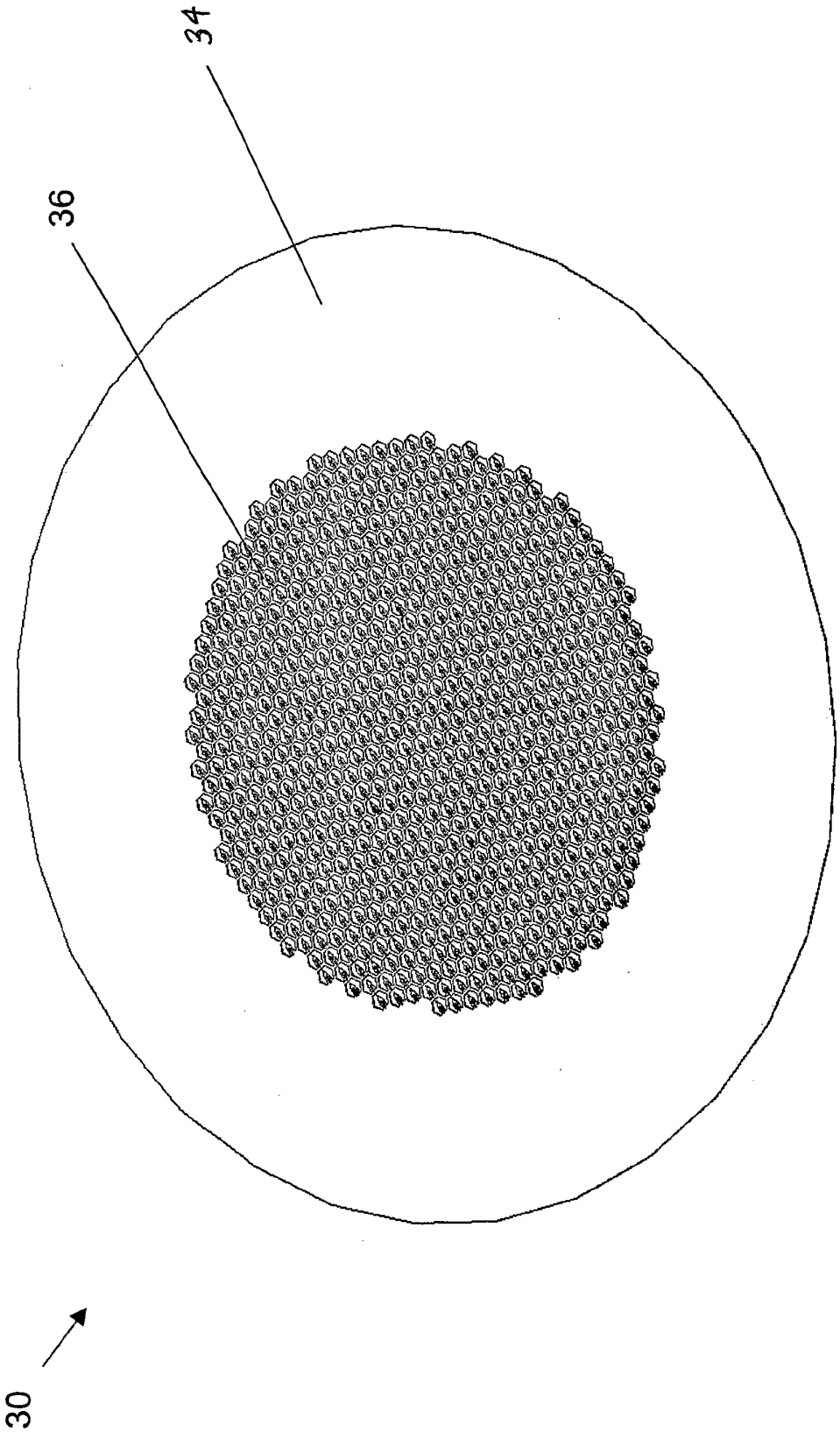

FIG. 3

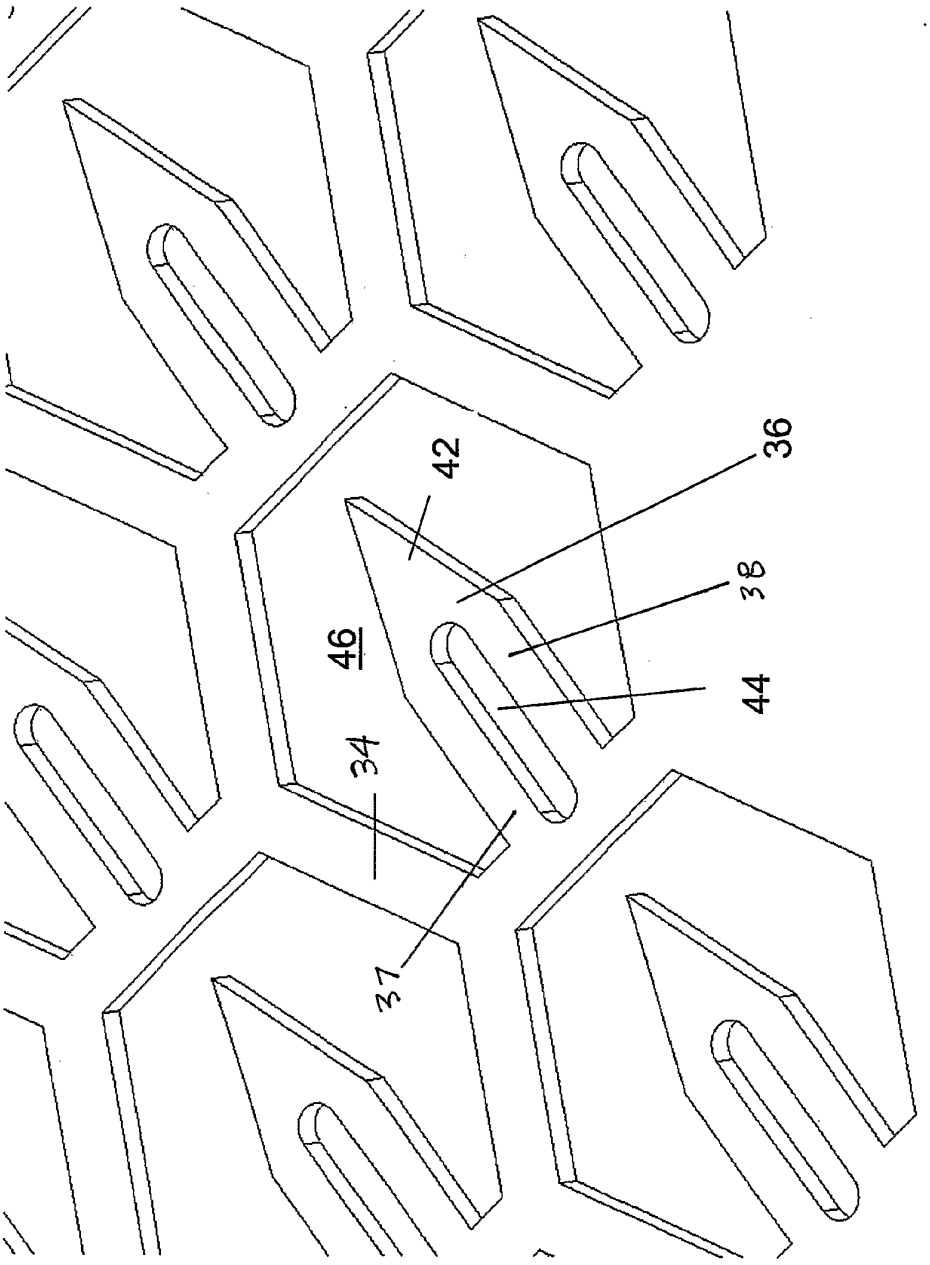

FIG. 4

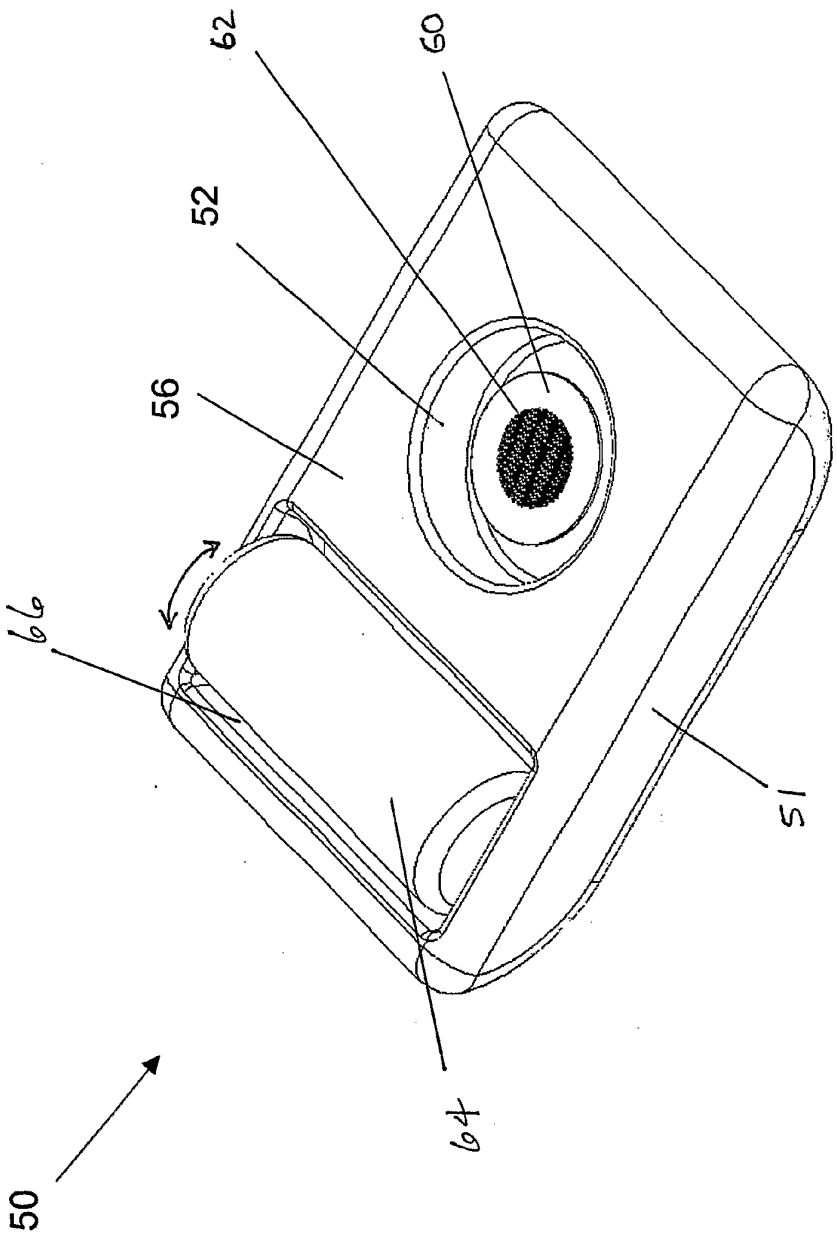

FIG. 5A

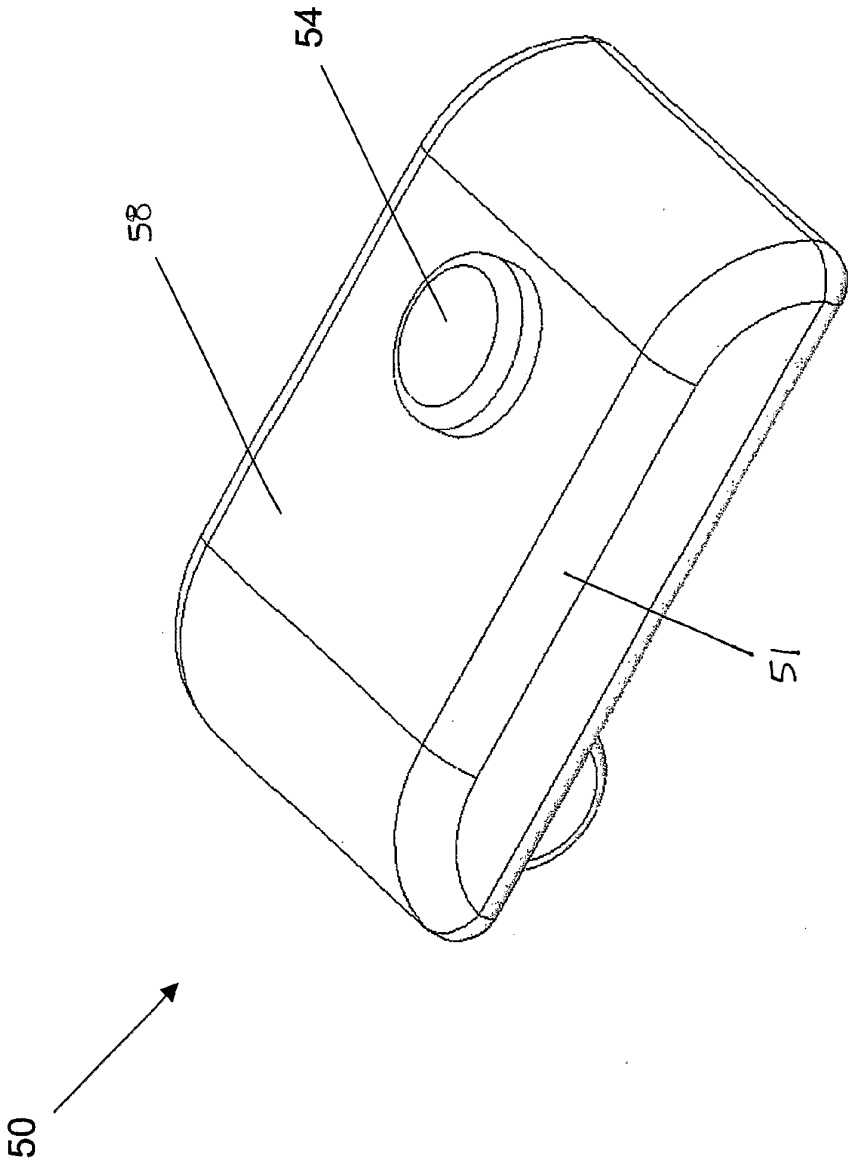

FIG. 5B

REFERENCES CITED IN THE DESCRIPTION

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