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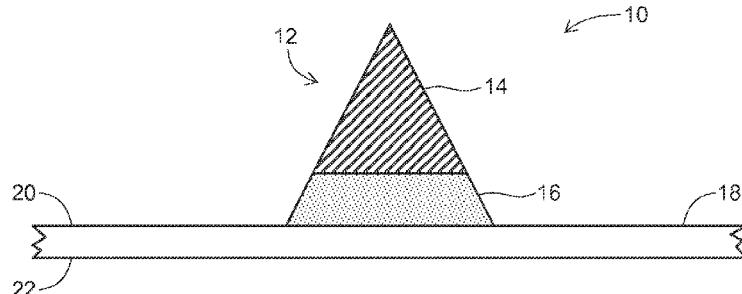
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**FIG. 2**

(57) Abstract: Microstructure arrays and methods for manufacturing microstructure arrays (10). The microstructure apparatus comprising: a backing (18) having a first surface (20) and a second surface (22) opposed thereto; a microstructure array comprising a plurality of microstructures (12) extending outwardly from the first surface of the backing; the microstructures comprising a biodegradable distal layer (14) and at least one proximal layer (16) positioned between the distal layer and the first surface of the backing; the distal layer comprised of at least one therapeutic agent and at least one polymer; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

## MICROARRAY FOR DELIVERY OF THERAPEUTIC AGENT AND METHODS OF USE

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of U.S. Provisional Application No. 61/745,513, filed December 21, 2012, which is incorporated herein by reference in its entirety.

### TECHNICAL FIELD

**[0002]** The disclosure relates generally to a method and delivery system for transdermally administering a therapeutic agent or drug or vaccine using an array of microstructures, and related features thereof.

### BACKGROUND

**[0003]** Arrays of microneedles were proposed as a way of administering drugs through the skin in the 1970s, for example in expired U.S. Pat. No. 3,964,482. Microneedle or microstructure arrays can facilitate the passage of drugs through or into human skin and other biological membranes in circumstances where ordinary transdermal administration is inadequate. Microstructure arrays can also be used to sample fluids found in the vicinity of a biological membrane such as interstitial fluid, which is then tested for the presence of biomarkers.

**[0004]** In recent years it has become more feasible to manufacture microstructure arrays in a way that makes their widespread use financially feasible. U.S. Pat. No. 6,451,240 discloses some methods of manufacturing microneedle arrays. If the arrays are sufficiently inexpensive, for example, they may be marketed as disposable devices. A disposable device may be preferable to a reusable one in order to avoid the question of the integrity of the device being compromised by previous use and to avoid the potential need of resterilizing the device after each use and maintaining it in controlled storage.

**[0005]** Despite much initial work on fabricating microneedle arrays in silicon or metals, there are significant advantages to polymeric arrays. U.S. Patent No. 6,451,240 discloses some methods of manufacturing polymeric microneedle arrays. Arrays made primarily of biodegradable polymers also have some advantages. U.S. Pat. No. 6,945,952 and U.S. Published Patent Applications Nos. 2002/0082543 and

2005/0197308 have some discussion of microneedle arrays made of biodegradable polymers. A detailed description of the fabrication of a microneedle array made of polyglycolic acid is found in Jung-Hwan Park et al., "Biodegradable polymer microneedles: Fabrication, mechanics, and transdermal drug delivery," *J. of Controlled Release*, 104:51-66 (2005).

**[0006]** A layered microstructure array has been described for hPTH delivery (U.S. Patent No. 2011/0276028) comprising a fast dissolving drug-in-tip distal layer and a backing layer formed of an insoluble biodegradable polymer.

**[0007]** Many drugs require sustained delivery for a prolonged period of time including hours, days, weeks, etc. Wearing a drug delivery device for the extended duration required for sustained or complete drug delivery from an array may be inconvenient and/or painful. A need exists for a device that is effective to provide delivery of a therapeutic agent that is sustained and/or for a prolonged period of time with minimal inconvenience and/or pain.

**[0008]** The foregoing examples of the related art and limitations related therewith are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

## BRIEF SUMMARY

**[0009]** The following aspects and embodiments thereof described and illustrated below are meant to be exemplary and illustrative, not limiting in scope.

**[0010]** In one aspect of the invention, an array of microstructures is provided comprising an approximately planar base and a plurality of microstructures. In an embodiment, at least a portion of the microstructures are comprised of one or more layers arranged roughly parallel to the plane of the base. In one embodiment, at least a portion of the microstructures is configured to detach, separate, or break from the base.

**[0011]** In a further aspect of the invention, an array of microprotrusions is formed by (a) dispensing a selected formulation atop a mold with a plurality of cavities corresponding to the negative of the microprotrusions, (b) transferring the formulation into the plurality of cavities, (c) drying the formulation into the cavities, and (d) de-molding the resulting array from the mold.

**[0012]** In one aspect microstructure apparatuses are contemplated. In an embodiment, the microstructure apparatus comprises a backing having a first surface

and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures extending outwardly from the first surface of the backing; the microstructures comprising a biodegradable distal layer and at least one proximal layer positioned between the distal layer and the first surface of the backing; the distal layer comprised of at least one therapeutic agent and at least one polymer; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0013]** In embodiments, the distal layer comprises at least one hydrophobic polymer. In further embodiments, the distal layer comprises at least one polymer comprises at least one hydrophobic polymer and about 0-99% of at least one hydrophilic polymer. In even further embodiments, the distal layer comprises at least one polymer that comprises at least one hydrophobic polymer and about 0-50% of a hydrophilic polymer. In additional embodiments, the distal layer comprises at least one polymer that comprises at least one hydrophobic polymer and about 0-20% of a hydrophilic polymer.

**[0014]** In further embodiments, at least one therapeutic agent is a small molecule drug at least partially soluble with the at least one polymer in a solvent or co-solvent. In embodiments, the distal layer comprises about 1-99% of the small molecule drug. In further embodiments, the distal layer comprises about 1-50% of the small molecule drug. In more embodiments, the distal layer comprises about 5-40% of the small molecule drug. In additional embodiments, the distal layer comprises about 10-30% of the small molecule drug.

**[0015]** In more embodiments, at least one therapeutic agent is dispersed in the distal layer. In embodiments, the distal layer comprises about 1-90% of the dispersed agent. In further embodiments, the distal layer comprises about 1-50% of the dispersed agent. In yet further embodiments, the distal layer comprises about 10-40% of the dispersed agent. In additional embodiments, the distal layer comprises about 20-30% of the dispersed agent.

**[0016]** In embodiments, the at least one polymer is in a glass state at room temperature. In further embodiments, the at least one polymer has a glass transition temperature (Tg) at or above about body temperature.

**[0017]** In embodiments, at least about 10% of the distal layer detaches readily upon insertion of the array into skin. In further embodiments, at least about 50% of the distal layer detaches readily upon insertion of the array into skin. In additional embodiments, at least about 70% of the distal layer detaches readily upon insertion of the array into skin. In yet more embodiments, at least about 90% of the distal layer detaches readily

upon insertion of the array into skin. In other embodiments, about 100% of the distal layer detaches readily upon insertion of the array into skin.

**[0018]** In embodiments, at least a portion of the microstructures have a first cross-dimensional diameter that is larger than a second cross-dimensional diameter. In other embodiments, at least a portion of the microstructures have a cross-dimensional shape selected from the group consisting of a diamond, a rectangle, and an oval. In further embodiments, at least a portion of the microstructures have an asymmetrical cross-dimensional shape.

**[0019]** In embodiments, a concentration of the at least one polymer in a polymer casting solution used to form the microstructures is lower than an entanglement concentration ( $C_E$ ) for the polymer. In additional embodiments, a concentration of the at least one polymer in a polymer casting solution used to form the microstructures is at a  $C_E$  for the polymer.

**[0020]** In embodiments, at least a portion of the proximal and/or distal layers has a funnel shape.

**[0021]** In further embodiments, at least a portion of the microstructures are affixed to the first surface of the backing.

**[0022]** In additional embodiments, at least a portion of the backing forms the proximal layer. In embodiments, the microstructure apparatus comprises a substrate having a first surface and a second surface opposed thereto, where the second surface of the backing is affixed to the first surface of the substrate.

**[0023]** In additional embodiments, the microstructure apparatus comprises a substrate having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed to the first surface of the substrate and extending outwardly therefrom; where the microstructures are comprised of a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the substrate; the distal layer comprised of at least one hydrophobic polymer and at least one therapeutic agent, and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0024]** In further embodiments, the microstructure apparatus comprises a backing having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom; the microstructures comprising of a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface

of the backing; the distal layer comprised of at least one polymer and about 1-90% of a therapeutic agent; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0025]** In other embodiments, the microstructure apparatus comprises a backing having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom; the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing; the distal layer is comprised of at least one polymer and a therapeutic agent, the at least one polymer having a glass transition temperature (Tg) at least above about body temperature; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0026]** In additional embodiments, the microstructure apparatus comprises a backing having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom; the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing; the distal layer being comprised of at least one polymer having a molecular weight between about 1-100K Da and a therapeutic agent; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0027]** In more embodiments, the microstructure apparatus comprises a backing having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom; the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing; the distal layer being comprised of at least one polymer and a therapeutic agent; and wherein at least about 10-100% of the distal layer detaches readily upon insertion of the array into skin.

**[0028]** In yet another embodiment, the microstructure apparatus comprises a substrate having a first surface and a second surface opposed thereto; a microstructure array comprising a plurality of microstructures affixed upon the first surface of the substrate and extending outwardly therefrom; the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and

the first surface of the substrate; the distal layer comprised of at least one polymer and a therapeutic agent, the distal layer having a first cross-dimensional diameter that is larger than a second cross-dimensional diameter; and wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

**[0029]** In another aspect, methods of making a microstructure apparatus are contemplated. In one embodiment, the method comprises dissolving or suspending a therapeutic agent in a solvent to form a therapeutic agent solution or suspension; dissolving at least one polymer in a solvent to form a polymer solution; mixing the therapeutic agent solution or suspension and the polymer solution or suspension to form a polymer matrix solution or suspension; dispensing the polymer matrix solution or suspension on a mold having an array of microstructure cavities; followed by pressurization; removing excess solution or suspension polymer matrix on the mold surface; and drying the matrix; and dispensing a basement or backing layer on the mold surface; and drying the basement or backing layer. In an embodiment, the method further comprises affixing the basement or backing layer to a substrate. In further embodiments, the method comprises using a nonwoven or porous film double coated with adhesive to affix the basement or backing layer to a substrate.

**[0030]** Additional embodiments of the present microstructures, arrays, methods, and the like, will be apparent from the following description, drawings, examples, and claims. As can be appreciated from the foregoing and following description, each and every feature described herein, and each and every combination of two or more of such features, is included within the scope of the present disclosure provided that the features included in such a combination are not mutually inconsistent. In addition, any feature or combination of features may be specifically excluded from any embodiment of the present invention. Additional aspects and advantages of the present invention are set forth in the following description and claims, particularly when considered in conjunction with the accompanying examples and drawings.

#### BRIEF DESCRIPTION OF DRAWINGS

**[0031]** FIGURE 1 is a microscopic image of one exemplary microstructure array.

**[0032]** FIGURE 2 is an illustration of an exemplary microstructure array showing a microstructure having at least a distal layer and a proximal layer on a substrate.

**[0033]** FIGURES 3A-3B are microscopic images of an exemplary microstructure array before (Fig. 3A) and after (Fig. 3B) application to skin for five minutes.

**[0034]** FIGURE 4 is a microscopic image of pig skin after application of a microstructure array for five minutes showing the microstructure tips implanted in the skin.

**[0035]** FIGURES 5A-5B are illustrations of an exemplary microstructure having a funnel shape. Fig. 5A is a front perspective view and Fig. 5B is a side view of the microstructure.

**[0036]** FIGURE 6 is a microscopic image of a microstructure array where the microstructures have a cylindrical funnel shape.

**[0037]** FIGURES 7A-7C are illustrations of exemplary shapes for microstructures of the arrays described herein.

**[0038]** Figures 8A-8B are illustrations of exemplary shapes for microstructures including a funnel shape. Fig. 8A depicts a microstructure having a pyramidal tip with a funnel shaped distal portion. Fig. 8B depicts a microstructure having a conical tip, a cylindrical shank and a conical funnel distal portion.

**[0039]** It will be appreciated that the thicknesses and shapes for the various microstructures have been exaggerated in the drawings to facilitate understanding of the device. The drawings are not necessarily "to scale."

#### DETAILED DESCRIPTION

**[0040]** Various aspects now will be described more fully hereinafter. Such aspects may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey its scope to those skilled in the art.

**[0041]** The practice of the present disclosure will employ, unless otherwise indicated, conventional methods of chemistry, biochemistry, and pharmacology, within the skill of the art. Such techniques are explained fully in the literature. See, e.g.; A.L. Lehninger, *Biochemistry* (Worth Publishers, Inc., current addition); Morrison and Boyd, *Organic Chemistry* (Allyn and Bacon, Inc., current addition); J. March, *Advanced Organic Chemistry* (McGraw Hill, current addition); Remington: *The Science and Practice of Pharmacy*, A. Gennaro, Ed., 20<sup>th</sup> Ed.; Goodman & Gilman *The Pharmacological Basis of Therapeutics*, J. Griffith Hardman, L. L. Limbird, A. Gilman, 10<sup>th</sup> Ed.

**[0042]** Where a range of values is provided, it is intended that each intervening

value between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the disclosure. For example, if a range of 1  $\mu\text{m}$  to 8  $\mu\text{m}$  is stated, it is intended that 2  $\mu\text{m}$ , 3  $\mu\text{m}$ , 4  $\mu\text{m}$ , 5  $\mu\text{m}$ , 6  $\mu\text{m}$ , and 7  $\mu\text{m}$  are also explicitly disclosed, as well as the range of values greater than or equal to 1  $\mu\text{m}$  and the range of values less than or equal to 8  $\mu\text{m}$ .

#### I. Definitions

**[0043]** As used in this specification, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a "polymer" includes a single polymer as well as two or more of the same or different polymers, reference to an "excipient" includes a single excipient as well as two or more of the same or different excipients, and the like.

**[0044]** In describing and claiming the present invention, the following terminology will be used in accordance with the definitions described below.

**[0045]** "Biodegradable" refers to natural or synthetic materials that degrade enzymatically, non-enzymatically or both to produce biocompatible and/or toxicologically safe by-products which may be eliminated by normal metabolic pathways.

**[0046]** As used herein, "body temperature" refers to normal body temperature, which is about 98.6° F  $\pm$  1-2° F for the core body temperature of a human. It will be appreciated that normal body temperature will vary slightly depending on the method used to measure and/or the time of day the measurement is made.

**[0047]** "Hydrophobic polymer" as used herein refers to polymers that are insoluble or poorly soluble in aqueous solvents. "Hydrophilic polymer" as used herein refers to polymers that are soluble or substantially soluble in aqueous solvents.

**[0048]** The terms "microprotrusion", "microprojection", "microstructure" or "microneedle" are used interchangeably herein to refer to elements adapted to penetrate or pierce at least a portion of the stratum corneum or other biological membranes. For example, illustrative microstructures may include, in addition to those provided herein, microblades as described in U.S. Patent No. 6,219,574, edged microneedles as described in U.S. Patent No. 6,652,478, and microprotrusions as described in U.S. Patent Publication No. U.S. 2008/0269685.

**[0049]** "Optional" or "optionally" means that the subsequently described circumstance may or may not occur, so that the description includes instances where

the circumstance occurs and instances where it does not.

**[0050]** “Substantially” or “essentially” means nearly totally or completely, for instance, 90-95% or greater of some given quantity.

**[0051]** “Transdermal” refers to the delivery of an agent into and/or through the skin for local and/or systemic therapy. The same inventive principles apply to administration through other biological membranes such as those which line the interior of the mouth, gastro-intestinal tract, blood-brain barrier, or other body tissues or organs or biological membranes which are exposed or accessible during surgery or during procedures such as laparoscopy or endoscopy.

**[0052]** A material that is “water-soluble” may be defined as soluble or substantially soluble in aqueous solvents, such that the material dissolves into, within or below the skin or other membrane which is substantially aqueous in nature.

## II. Microstructure Arrays

**[0053]** General features of microstructure arrays suitable for use in the instant arrays and methods are described in detail in U.S. Patent Publication No. 2008/0269685, U.S. Patent Publication No. 2011/0006458, and U.S. Patent Publication No. 2011/0276028, the entire contents of which are explicitly incorporated herein by reference.

**[0054]** Fig. 1 is an image showing an exemplary microstructure array. The microstructures in this array have a basement or proximal layer adjacent the substrate and a distal layer adjacent the proximal layer. Preferably, the distal layer includes at least one therapeutic agent. Preferably, at least a portion of the microstructure separates, detaches, is severed, fractures, shatters or breaks from the array after the microstructure array is applied to skin to remain in the skin after the substrate and any remaining microstructure is removed from the skin.

**[0055]** Fig. 2 illustrates an exemplary microstructure array 10 showing a microstructure 12 with a distal layer 14 and a proximal layer 16. In this embodiment, the microstructure is typically characterized as comprising at least one drug-in-tip (DIT) layer 14 and at least one proximal layer 16. It will be appreciated that any number of intermediate layers may be included between the distal layer 14 and the proximal layer 16. The microstructures 12 are typically positioned on a base, substrate or backing layer 18 having a first surface 20 and a second surface 22 to form the array 10. The microstructures may be attached to the substrate by any suitable means. In one, non-limiting embodiment, the microstructures are attached to the substrate using an

adhesive. Suitable adhesives include, but are not limited to, acrylic adhesives, acrylate adhesives, pressure sensitive adhesives, double-sided adhesive tape, double sided adhesive coated nonwoven or porous film, and UV curable adhesives. One exemplary double-sided tape is the #1513 double-coated medical tape available from 3M. One exemplary, but non-limiting, UV curable adhesive is the 1187-M UV light-curable adhesive available from Dymax. It will be appreciated that any medical device adhesive known in the art would be suitable. In another embodiment, at least a portion of the microstructures are integral with the substrate. It will be appreciated that the substrate or backing layer may include all or a portion of the proximal layer. In the embodiment where the substrate or backing layer comprises all of the proximal layer, the microstructure may comprise an additional layer between the substrate/backing layer and the distal layer or the distal layer may adjoin the portion of the substrate/backing layer that forms the proximal portion of the microstructure. As seen in Fig. 2, the microstructures typically extend upwardly at an angle from the substrate. In a preferred embodiment, the microstructures extend substantially perpendicular to the substrate.

**[0056]** The substrate and/or backing layer 18 is typically formed of one or more biocompatible and/or non-biodegradable materials. The substrate and/or backing layer may be formed of any suitable material that provides the necessary support for the microstructures. Preferably, the substrate and/or backing layer is formed of a synthetic or natural material that is biocompatible at least on the surface that may contact the patient's skin 20. Suitable materials include, but are not limited to, metals, silicon and/or polymers. Suitable metals include, but are not limited to titanium, tantalum, alloys such as stainless steel and cobalt-chromium alloys, or combinations thereof. In an embodiment, the substrate and/or backing layer comprises one or more polymer. In an embodiment, the substrate and/or backing layer comprises one or more water insoluble polymers. Suitable polymers include, but are not limited to, polyethylene terephthalate and polyether ether ketone, polycarbonate, polyethylene, or other film forming polymers. Further suitable polymers are described in U.S. Patent No. 7,785,301, which is incorporated herein in its entirety. The substrate and/or backing layer may be rigid, substantially rigid or may be at least partially flexible to conform to the surface of the patient's skin. In any case, the substrate and/or backing layer should be sufficiently strong and/or rigid to assist in or allow for the microstructures to at least partially penetrate the patient's skin. The substrate and/or backing layer is typically

substantially planar, but may be contoured.

**[0057]** In reference to the microstructures themselves, in general, at least a portion of the microstructures have a height above the base or structure that is sufficient to pierce at least a portion of the epidermis. In embodiments, the microstructures have a height sufficient to pierce all or a portion of the stratum corneum. Typically, the microstructures have a height that penetrates into the epidermis where the density of nerve receptors are low. In embodiments, at least a portion of the microstructures have a height of at least about 50  $\mu\text{m}$  or at least about 100  $\mu\text{m}$ , or at least about 150  $\mu\text{m}$ , or at least about 200  $\mu\text{m}$ , or at least about 250  $\mu\text{m}$ , or at least about 300  $\mu\text{m}$ . In general, the microstructures have a height of no more than about 1 mm, no more than about 500  $\mu\text{m}$ , no more than about 300  $\mu\text{m}$ , no more than about 200  $\mu\text{m}$ , or no more than about 150  $\mu\text{m}$ . In embodiments, the microstructures have a height of between about 50  $\mu\text{m}$  – 1 mm. It will be appreciated that the microstructures within an array may have different heights. The microstructures may have an aspect ratio (height to diameter at base) of at least 10:1, preferably at least about 5:1, more preferably at least about 3:1, or at least about 2:1, or at least about 1:1. As the depth of the epidermis and/or dermis layers may be different depending on the area of the body, it will be appreciated that the height of the microstructures may be adjusted depending on the administration site.

**[0058]** One illustrative shape for the microstructures is a cone with a polygonal bottom, for example, being hexagonal or rhombus-shaped. Additional microstructure shapes include those provided, for example, in U.S. Patent Publication No. 2004/0087992. In embodiments, at least a portion of the microstructure shape may be substantially cylindrical, cone-shaped, funnel-shaped, or pyramidal. In further embodiments, at least a portion of the microstructures has an asymmetrical cross-dimensional shape. Suitable asymmetric shapes include, but are not limited to, rectangular, square, oval, elliptical, circular, rhombus, triangular, polygonal, star-shaped, etc. In some embodiments, the distal layer has a cross-dimension in one direction that is smaller than the cross-dimension in the other direction. Exemplary cross-dimensional shapes with this configuration include, but are not limited to, rectangular, rhombus shaped, ellipse, and oval. In non-limiting embodiments, the base of the microstructure distal layer has a cross-dimensional distance that is less than about 100  $\mu\text{m}$ . In other embodiments, the base of the distal layer has a cross-dimensional distance that is less than about 70  $\mu\text{m}$ . In yet other embodiments, the base of the distal layer has a cross-dimensional diameter that is less than about 50  $\mu\text{m}$ .

In further embodiments, the base of the distal layer has a cross-dimensional diameter that is less than about 50-100  $\mu\text{m}$ , less than about 50-70  $\mu\text{m}$ , or less than about 70-100  $\mu\text{m}$ . It will be appreciated that the cross-dimensional shape may be varied along the length of the microstructure. The distal tip has a diameter < 1 micron, or < 5 microns, or < 10 microns. It will further be appreciated that different portions and/or layers of a microstructure may have different cross-dimensional shapes. At least a portion of the microstructures may include one or more blade or piercing elements along its length and/or at the distal tip.

**[0059]** Microstructure shape can be understood in terms of a tip, a shank and a funnel. The angle at the tip is the apex angle – included angle by the planes or cone – and can have values from about 5 degree to about 60 degrees. The straight or substantially straight shank may or may not be present in a particular microstructure design. At the base of the shank or tip, towards the distal end, the included angle has a discontinuity or a point of inflection. The included angle jumps to take on a value greater than the apex angle for a shank-less tip and to greater than 0 degrees for microstructures with a shank. Portions of the microstructure beyond this point of inflection may be referred to as a "funnel". Figures 8A and 8B show examples of cross sectional elevation of the microstructures delineating different regions including the tip 24, shank 26, inflection point or edge 28 and the funnel 30. In Fig. 8B, the diameter of the microstructure is growing faster than linear fashion with respect to the distance from the distal end. Where microstructures are thicker towards the base, a portion of the microstructure adjacent to the base, which may be referred to herein as a "proximal portion" "backing portion", "basement" or "foundation" or as an "upper portion" may be designed not to penetrate the skin.

**[0060]** As described in Example 4, the proximal funnel shape allows for relatively larger volumes to be dispensed in the microstructure mold for a given total length of the microstructure. The proximal funnel shape provides a larger volume (to fill) without requiring a proportional increase in microstructure height, which results in a longer drug containing portion in the microstructure. Thus, the proximal funnel shape allows for a larger solid volume for the distal portion of the microstructure with a single fill of the mold. Other shapes may require several fill and dry cycles to achieve the same amount of solid distal portion as one fill and dry cycle for the funnel shaped microstructures.

**[0061]** In one exemplary embodiment, at least a portion of the microstructures have a cylindrical funnel shape as shown in the array of Fig. 6. As seen in the image,

microstructures with this shape have a cylindrical shank and a funnel at the proximal end. In this embodiment, the distal tips of the microstructures typically, but not always, have a sharp, pointed or conical distal end to ease and/or facilitate penetration. The microstructures further have a funnel shape at the proximal end and a cylindrical shank between the distal and proximal ends.

**[0062]** The funnel shape offers several advantages including a reduction in pinning (liquid formulation adhering or sticking to the mold sides) during manufacturing.

**[0063]** The funnel portion may also be used to limit the depth of penetration. Since the funnel has a several times higher volume per unit height than the tip or shank, it also requires several times higher energy to penetrate per unit depth than the tip or shank. Hence for a given energy, the microstructure would typically penetrate no more than the length of the tip and shank. The funnel thus effectively acts as the design element in the microstructure that limits the depth of penetration thereby ensuring tolerable sensation. Generally, the number of microstructures in the array is preferably at least about 50, at least about 100, at least about 500, at least about 1000, at least about 1400, at least about 1600, or at least about 2000. For example, the number of microstructures in the array may range from about 1000 to about 4000, or from about 2000 to about 4000, or from about 2000 to about 3500, or from about 2200 to about 3200. The area density of microstructures, given their small size, may not be particularly high, but for example the number of microstructures per  $\text{cm}^2$  may be at least about 50, at least about 250, at least about 500, at least about 750, at least about 1000, at least about 2000, or at least about 3000.

**[0064]** While the array itself may possess any of a number of shapes, the array is generally sized to possess a diameter of from about 5 millimeters to about 25 millimeters, or from about 7 to about 20 millimeters, or from about 8 to about 16 millimeters. Exemplary diameters include 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, and 25 millimeters.

**[0065]** In a preferred embodiment, at least the distal layer of at least a portion of the microstructures is formed of a biodegradable, bioerodible, bioabsorbable and/or biocompatible polymer matrix. Biocompatible, biodegradable, bioabsorbable and/or bioerodible polymers for use in the instant microprojection arrays include, but are not limited to, poly(lactic acid) (PLA), poly(glycolic acid) (PGA), poly(lactic acid-co-glycolic acid)s (PLGAs), polyanhydrides, polyorthoesters, polyetheresters, polycaprolactones (PCL), polyesteramides, poly(butyric acid), poly(valeric acid), polyvinylpyrrolidone

(PVP), polyvinyl alcohol (PVA), polyethylene glycol (PEG), block copolymers of PEG-PLA, PEG-PLA-PEG, PLA-PEG-PLA, PEG-PLGA, PEG-PLGA-PEG, PLGA-PEG-PLGA, PEG-PCL, PEG-PCL-PEG, PCL-PEG-PCL, copolymers of ethylene glycol-propylene glycol-ethylene glycol (PEG-PPG-PEG, trade name of Pluronic® or Poloxamer®), dextran, hetastarch, tetrastarch, pentastarch, hydroxyethyl starches, cellulose, hydroxypropyl cellulose (HPC), sodium carboxymethyl cellulose (Na CMC), thermosensitive HPMC (hydroxypropyl methyl cellulose), polyphosphazene, hydroxyethyl cellulose (HEC), other polysaccharides, polyalcohols, gelatin, alginate, chitosan, hyaluronic acid and its derivatives, collagen and its derivatives, polyurethanes, and copolymers and blends of these polymers. A preferred hydroxyethyl starch has a degree of substitution of in the range of 0-0.9.

**[0066]** The biodegradability or dissolvability of the microprojection array may be facilitated by the inclusion of sugars. Exemplary sugars include dextrose, fructose, galactose, maltose, maltulose, iso-maltulose, mannose, lactose, lactulose, sucrose, and trehalose. Sugar alcohols, for example lactitol, maltitol, sorbitol, and mannitol, may also be employed. Cyclodextrins can also be used advantageously in microneedle arrays, for example  $\alpha$ ,  $\beta$ , and  $\gamma$  cyclodextrins, for example hydroxypropyl- $\beta$ -cyclodextrin and methyl- $\beta$ -cyclodextrin. Sugars and sugar alcohols may also be helpful in stabilization of peptides and proteins and in modifying the mechanical properties of the microprojections by exhibiting a plasticizing-like effect.

**[0067]** The polymers used may possess a variety and range of molecular weights. The polymers may, for example, have molecular weights of at least about 1K Da, at least about 5K Da, at least about 10K Da, at least about 20K Da, at least about 30K Da, at least about 50K Da, or at least about 100K Da. Where the microstructure is meant to be biodegradable, it may be desired to have biodegradable portion(s) comprise one or more polymers having a lower molecular weight. The strength-molecular weight relation in polymers is an inverse relation so polymers with lower molecular weights have a lower strength and will tend to be more biodegradable. Further polymers with a lower molecular weight will be more likely to break due to the lower strength. In one embodiment, at least the distal layer comprises at least one polymer having a lower molecular weight. In an embodiment, at least the distal layer comprises at least one polymer having a molecular weight less than about 100K Da. In another embodiment, at least the distal layer comprises at least one polymer having a molecular weight less than about 20K Da. In other embodiments, at least the distal layer comprises at least

one polymer having a molecular weight less than about 1K Da, less than about 5K Da, less than about 10K Da, less than about 15K Da or less than about 20K Da. In one embodiment, at least the distal layer comprises at least one polymer having a molecular weight of between about 1K-100K Da or between about 1K-20K Da. In other embodiments, the distal layer comprises at least one polymer having a molecular weight of between about 1K-100K Da, between about 1000-5000 Da, between about 1000-10,000 Da, between about 1000-15,000 Da, between about 5000-10,000 Da, between about 5000-15,000 Da, between about 5000-20,000 Da, between about 10,000-15,000 Da, between about 10,000-20,000 Da, and between about 15,000-20,000 Da. It will be appreciated that the distal layer may comprise one or more polymers having a lower molecular weight while the proximal layer and/or the substrate may comprise polymers having a higher molecular weight. It will be appreciated that the polymers for the distal and/or proximal portions may be selected based at least partly on the molecular weight of the polymers to facilitate separation or detachment of at least a portion of the microstructures.

**[0068]** In other embodiments, at least the distal layer comprises at least one hydrophobic polymer. In one embodiment, the distal layer is formed of a polymer matrix comprising one or more hydrophobic polymers, with or without hydrophilic polymers. Hydrophilic polymers tend to take up water to swell and weaken the strength of the distal layer, thus make it easier to detach. Hydrophobic polymers will be less prone to take up any water and would therefore remain brittle, if initially brittle. These brittle polymers are easier to break. In one embodiment, the polymer matrix comprises 1-100% hydrophobic polymer(s) and 0-99% hydrophilic polymer(s). In other embodiments, the polymer matrix comprises 50-100% hydrophobic polymer(s) and 0-50% of hydrophilic polymer(s). In yet another embodiment, the polymer matrix comprises 80-100% hydrophobic polymer(s) and 0-20% hydrophilic polymer(s). It will be appreciated that the hydrophobic and/or hydrophilic polymer portions of the matrix may comprise one or more polymers. Suitable hydrophobic and/or hydrophilic polymers are known in the art. Exemplary hydrophobic polymers include, but are not limited to, PLA,  $\alpha$ -hydroxy acids such as PLGA, polycaprolactones, and polyanhydrides. It will be appreciated that the hydrophobic and/or hydrophilic polymers may be selected to achieve a desired degradation rate. Further, the polymers may be co-polymerized to achieve a desired degradation rate. For co-polymers, it will further be appreciated that the ratio of the monomers may be adjusted to achieve a desired

hydrophobicity/hydrophilicity and/or degradation rate. For example, lactide rich PLGA copolymers are more hydrophobic than glycolide rich PLGA copolymers. Additionally, the ratio of hydrophobic:hydrophilic polymer in the matrix may be selected to achieve the desired degradation rate. It will be appreciated that the choice of polymer and/or ratio may be used to achieve a desired brittleness to facilitate separation or detachment of the microstructures.

**[0069]** Certain semi-crystalline as well as amorphous polymers exhibit a glass transition temperature (Tg). The Tg of a polymer is the temperature where the polymer transitions from a hard, glass-like state that is relatively brittle to rubber-like state. Polymers that are in the glass state are easier to break. Thus, it may be desirable to select polymers for portions of the microstructures that are below the Tg during use. In one embodiment, at least a portion of the microstructures is formed of at least one polymer that is in a glass state at room temperature. In another embodiment, at least the proximal layer and/or distal layer of the microstructures is formed of a polymer matrix that is in a glass state at room temperature (typically between about 16° C-30° C, preferably between about 20° C -25° C). In other embodiments, at least the proximal layer and/or the distal layer of the microstructures is formed of a polymer matrix that is in a glass state at body temperature, typically core body temperature (about 98.6° F ± 1°). This results in the proximal layer and/or the distal layer being relatively brittle during use and thus more prone to detach or break from the array. Thus, the detachment area may be controlled by forming the layer for detachment of a polymer matrix that is in a glass state at a desired temperature. In non-limiting embodiments, at least a portion of the microstructures are formed of at least one polymer having a Tg at or above room temperature. In embodiments, the at least one polymer has a Tg at or above about 20° C. In further embodiments, the at least one polymer has a Tg at or above about 20°-25° C. In other embodiments, at least a portion of the microstructures is formed of at least one polymer having a Tg at or above about normal body temperature. In one embodiment, at least a portion of the microstructures is formed of at least one polymer having a Tg at or above about 37° C ± 2° C. In embodiments, the at least one polymer has a Tg at or above about 35° C - 38° C. In further embodiments, at least a portion of the microstructures is formed of at least one polymer having a Tg at least about 5°-10° above body temperature. In embodiments, at least a portion of the at least one polymer has a Tg at least about 5° C, at least about 10° C, or at least about 15° C above about 35° C. In other

embodiments, at least a portion of the microstructures comprise a polymer matrix having one or more of the above Tg. Methods for determining the Tg of a polymer are well known in the art and include, but are not limited to, differential scanning calorimetry (DSC) and thermomechanical analysis (TMA).

**[0070]** Preferably, at least a portion of the distal layer comprises a polymer matrix and at least one therapeutic agent, active agent, or drug (collectively "agent" hereafter). The agent to be administered can be one or more of any of therapeutic agents, active agents or drugs known in the art, and include the broad classes of compounds such as, by way of illustration and not limitation: analeptic agents; analgesic agents; antiarthritic agents; anticancer agents, including antineoplastic drugs; anticholinergics; anticonvulsants; antidepressants; antidiabetic agents; antidiarrheals; antihelminthics; antihistamines; antihyperlipidemic agents; antihypertensive agents; anti-infective agents such as antibiotics, antifungal agents, antiviral agents and bacteriostatic and bactericidal compounds; antiinflammatory agents; antimigraine preparations; antinauseants; antiparkinsonism drugs; antipruritics; antipsychotics; antipyretics; antispasmodics; antitubercular agents; antiulcer agents; anxiolytics; appetite suppressants; attention deficit disorder and attention deficit hyperactivity disorder drugs; cardiovascular preparations including calcium channel blockers, antianginal agents, central nervous system agents, beta-blockers and antiarrhythmic agents; caustic agents; central nervous system stimulants; cough and cold preparations, including decongestants; cytokines; diuretics; genetic materials; herbal remedies; hormonolytics; hypnotics; hypoglycemic agents; immunosuppressive agents; keratolytic agents; leukotriene inhibitors; mitotic inhibitors; muscle relaxants; narcotic antagonists; nicotine; nutritional agents, such as vitamins, essential amino acids and fatty acids; ophthalmic drugs such as antiglaucoma agents; pain relieving agents such as anesthetic agents; parasympatholytics; peptide drugs; proteolytic enzymes; psychostimulants; respiratory drugs, including antiasthmatic agents; sedatives; steroids, including progestogens, estrogens, corticosteroids, androgens and anabolic agents; smoking cessation agents; sympathomimetics; tissue-healing enhancing agents; tranquilizers; vasodilators including general coronary, peripheral and cerebral; vescicants; and combinations thereof. In some embodiments, the agent is a protein or a peptide. In other embodiments, the agent is a vaccine.

**[0071]** Examples of peptides and proteins which may be used with the microstructure arrays include, but are not limited to, parathyroid hormone (PTH),

oxytocin, vasopressin, adrenocorticotropic hormone (ACTH), epidermal growth factor (EGF), prolactin, luteinizing hormone, follicle stimulating hormone, luliberin or luteinizing hormone releasing hormone (LHRH), insulin, somatostatin, glucagon, interferon, gastrin, tetragastrin, pentagastrin, urogastrone, secretin, calcitonin, enkephalins, endorphins, kyotorphin, taftsin, thymopoietin, thymosin, thymostimulin, thymic humoral factor, serum thymic factor, tumor necrosis factor, colony stimulating factors, motilin, bombesin, dinorphin, neuropeptides, cerulein, bradykinin, urokinase, kallikrein, substance P analogues and antagonists, angiotensin II, nerve growth factor, blood coagulation factors VII and IX, lysozyme chloride, renin, bradykinin, tyrocidin, gramicidines, growth hormones, melanocyte stimulating hormone, thyroid hormone releasing hormone, thyroid stimulating hormone, pancreozymin, cholecystokinin, human placental lactogen, human chorionic gonadotropin, protein synthesis stimulating peptide, gastric inhibitory peptide, vasoactive intestinal peptide, platelet derived growth factor, growth hormone releasing factor, bone morphogenic protein, and synthetic analogues and modifications and pharmacologically active fragments thereof. Peptidyl drugs also include synthetic analogs of LHRH, e.g., buserelin, deslorelin, fertirelin, goserelin, histrelin, leuprolide (leuprorelin), lutrelin, nafarelin, tryptorelin, and pharmacologically active salts thereof. Administration of oligonucleotides is also contemplated, and include DNA and RNA, other naturally occurring oligonucleotides, unnatural oligonucleotides, and any combinations and/or fragments thereof. Therapeutic antibodies include Orthoclone OKT3 (muromonab CD3), ReoPro (abciximab), Rituxan (rituximab), Zenapax (daclizumab), Remicade (infliximab), Simulect (basiliximab), Synagis (palivizumab), Herceptin (trastuzumab), Mylotarg (gemtuzumab ozogamicin), CroFab, DigiFab, Campath (alemtuzumab), and Zevalin (ibritumomab tiuxetan).

**[0072]** In other embodiments, at least a portion of the distal layer comprises an agent suitable for use as a prophylactic and/or therapeutic vaccine. Examples of vaccines include, but are not limited to, vaccines to varicella, diphtheria, pertussis, hepatitis (A and/or B), Human Papillomavirus, influenza, measles, mumps, rubella, whooping cough, polio, tetanus, meningitis, shingles, etc.

**[0073]** In another embodiment, at least a portion of the distal layer comprises an agent suitable for veterinary uses. Such uses include, but are not limited to, therapeutic and diagnostic veterinary uses.

**[0074]** It will be appreciated that addition of a drug in the polymer matrix may affect the Tg of the polymer(s) and/or matrix. The amount of drug in the matrix may be

selected to achieve a desired Tg and/or resulting brittleness/elasticity for the matrix. The agent may act as a plasticizer when added to the matrix resulting in a decrease of the matrix Tg and weaken the strength of microstructures. Further, the amount of agent loaded in the matrix may affect the Tg and/or the brittleness/elasticity of the polymer matrix.

**[0075]** In one embodiment, the agent is a small molecule drug. In non-limiting embodiments, the polymer matrix comprises at least about 1-99% of one or more small molecule drugs that are at least partially soluble with the at least one polymer in a solvent or co-solvent. In other embodiments, drug loading is at least about 5-50% of the drug, at least about 5-40% of the drug or at least about 10-30% of the drug in the matrix. Agents that are not soluble with the at least one polymer in a solvent or co-solvent may be added in particle form and suspended or dispersed in the matrix. This formulation will work at least for large molecular drugs such as proteins and peptides. For a suspension or dispersion, the drug load in the matrix is generally, but not limited to, at least about 1-99%, at least about 1-90%, at least about 5-50%, preferably at least about 10-40% or at least about 20-30%.

**[0076]** It will be appreciated that the microstructures may comprise one or more agents in each layer. It will further be appreciated that at least a portion of the microstructures may include a coating that may contain one or more agents.

**[0077]** In other embodiments, the at least one polymer is included in the matrix at a concentration that is lower than or close to the entanglement concentration ( $C_E$ ) for the polymer. The entanglement concentration is the concentration of the polymer in the matrix where polymer chains interwind and become entangled. The entangled polymer chains decrease the ability of the polymers to move within the matrix, thus, decreasing the ability of a portion of the microstructure to detach or break. The  $C_E$  is dependent upon molecular weight as the longer chains overlap and then entangle at lower concentrations. Conversely, polymers with a lower molecular weight have a higher  $C_E$ . In an embodiment, a concentration of at least one polymer in a polymer casting solution used to prepare the microstructures is at or below the  $C_E$  for that polymer. The  $C_E$  can be determined by e.g. viscosity measurement of polymer solution. By double logarithm plot of viscosity against polymer concentration, the transition point from one slope to another slope is estimated as entanglement concentration.

**[0078]** As further seen in Fig. 2, the microstructure includes one or more proximal layers 16. The proximal layer is preferably attached to or affixed to or integral with the

first surface of the substrate and the distal layer. It will be appreciated that where the microstructure includes one or more intermediate layers as discussed below, the proximal layer is attached to, affixed to, or integral with the first surface of the substrate and the adjoining intermediate layer. The proximal layer is typically biocompatible. The proximal layer may comprise one or more biodegradable and/or non-biodegradable polymers. Suitable biodegradable polymers are described with reference to the distal layer. Suitable non-biodegradable polymers are known in the art and include, but are not limited to, amphiphilic polyurethanes, polyether polyurethane (PEU), polyetheretherketone (PEEK), and polyamide-imide (PAI). In another embodiment, the proximal layer is an adhesive layer. One suitable adhesive is the Dymax® 1187-M UV medical device adhesive. It will be appreciated that any biocompatible adhesive is suitable for use with, in and/or as the proximal layer. This layer may also be a nonwoven or porous film double coated with pressure sensitive adhesive.

**[0079]** It will be appreciated that one or more layers may be included between the proximal 16 and distal 14 layers. These intermediate layers may comprise a biodegradable or non-biodegradable matrix. The intermediate layers may be formulated to promote detachment of the distal layer(s). Biodegradable intermediate layers may contain one or more agents that are the same as or different than the agent in the distal layer. In one embodiment, the intermediate layers comprise an agent that is different than the agent in the distal layer. In another embodiment, the intermediate layers comprise an adjuvant or other agent that modifies or modulates the action of the agent in the distal layer. In one non-limiting example, the distal layer may comprise a vaccine while the intermediate layer comprises an adjuvant for the vaccine. In a further embodiment, the intermediate layers comprise the same agent as in the distal layer. In this embodiment, the agent may be present at a different dose (higher or lower) than present in the distal layer. Further, the intermediate layer may degrade at a faster or slower rate than the distal layer. For example, the distal layer may degrade rapidly (e.g. minutes to hours) providing an initial dose of the agent while the intermediate layer degrades more slowly (e.g. hours to days, weeks, or months) providing sustained release of the agent. An intermediate layer may also be used to control separation or detachment of the microstructures. For example, an intermediate layer may be formulated to promote detachment to ensure the entire distal layer is deployed into the patient's skin.

**[0080]** Preferably, at least a portion of the microstructure detaches or breaks off

after the microstructure is inserted into tissue and remains in the skin until degraded or removed by normal processes. Preferably, at least a portion of the distal layer detaches from the microstructure after it is inserted into skin. The distal layer may detach at a point within the distal layer or the distal layer may detach at the intersection or joint of the distal layer and the proximal layer. In other embodiments, the microstructure detaches at or near an intermediate layer positioned between the distal layer and the proximal layer. The detachment point is not critical as long as enough agent is contained within the detached portion to be effective for treatment. In one embodiment, at least about 10% of the distal layer detaches from the microstructure. In further embodiments, at least about 25%, at least about 50%, at least about 70%, at least about 75%, at least about 80%, at least about 90%, at least about 95%, at least about 99%, or at least about 100% of the distal layer detaches from the microstructure. In other embodiments, at least about 10-100% of the distal layer detaches from the microstructure. In additional embodiments, at least about 15-100%, at least about 25-100, at least about 30-100%, at least about 40-100%, at least about 50-100%, at least about 60-100%, at least about 70-100%, at least about 75-100%, at least about 80-100%, at least about 90-100%, at least about 95-100%, or at least about 99-100% of the distal layer detaches from the microstructure. In one embodiment, the distal tip detaches below the surface of the skin. This ensures that the entire detached tip degrades into the skin thereby releasing all, substantially all, or most of the agent in the matrix into the skin. Having the distal tip detach below the skin surface may also allow skin to close over the top of the embedded tip, which promotes healing of the insertion area and prevents the microstructure from extending out from the skin, which may be irritating to the patient.

**[0081]** At least a portion of the microstructures detach readily upon insertion of the array into skin or shortly thereafter. In a non-limiting embodiment, the microstructures detach within about 10 seconds to about 10 or 15 minutes after insertion. In embodiments, the microstructures detach within about 1-10 minutes, about 2-10 minutes, about 3-10 minutes, about 4-10 minutes, about 5-10 minutes, about 6-10 minutes, about 7-10 minutes, about 8-10 minutes, about 9-10 minutes, about 30 seconds to about 6 minutes, about 1-6 minutes, about 2-6 minutes, about 3-6 minutes, about 4-6 minutes, about 5-6 minutes, about 30 seconds to about 5 minutes, about 1-5 minutes, about 2-5 minutes, about 3-5 minutes, about 4-5 minutes, about 30 seconds to about 4 minutes, about 1-4 minutes, about 2-4 minutes, about 3-4 minutes, about 30

seconds to about 3 minutes, about 1-3 minutes, about 2-3 minutes, about 30 seconds to about 2 minutes, or about 1-2 minutes. In other embodiments, the microstructures detach within at least about or less than about 10 seconds, about 30 seconds, about 1 minute, about 90 seconds, about 2 minutes, about 3 minutes, about 4 minutes, about 5 minutes, about 6 minutes, about 7 minutes, about 8 minutes, about 9 minutes, about 10 minutes, or about 15 minutes.

**[0082]** In non-limiting embodiments, detachment of the microstructure occurs at a time before or faster than all or a portion of the distal tip degrades. In this embodiment, the microstructures are inserted into the skin and at least a portion of the microstructures detach from the array. The detached microstructure portions degrade or continue to degrade within the skin. In embodiments, detachment of the microstructure occurs at a time before or faster than a majority of the distal tip degrades. In embodiments, the microstructure detaches at least about 10 seconds to about 10 minutes before the distal tip degrades. In embodiments, the microstructures detach about 30 seconds to about 10 minutes, about 1-10 minutes, about 2-10 minutes, about 3-10 minutes, about 4-10 minutes, about 5-10 minutes, about 6-10 minutes, about 7-10 minutes, about 8-10 minutes, about 9-10 minutes, about 30 seconds to about 6 minutes, about 1-6 minutes, about 2-6 minutes, about 3-6 minutes, about 4-6 minutes, about 5-6 minutes, about 30 seconds to about 5 minutes, about 1-5 minutes, about 2-5 minutes, about 3-5 minutes, about 4-5 minutes, about 30 seconds to about 4 minutes, about 1-4 minutes, about 2-4 minutes, about 3-4 minutes, about 30 seconds to about 3 minutes, about 1-3 minutes, about 2-3 minutes, about 30 seconds to about 2 minutes, or about 1-2 minutes before the distal tip degrades. In other embodiments, the microstructures detach at least about 10 seconds, about 30 seconds, about 1 minute, about 90 seconds, about 2 minutes, about 3 minutes, about 4 minutes, about 5 minutes, about 6 minutes, about 7 minutes, about 8 minutes, about 9 minutes, about 10 minutes, or about 15 minutes before the distal tip degrades, or a portion or a majority thereof.

**[0083]** In embodiments at least about 10-100% of at least a portion of the microstructures readily detach. In specific non-limiting embodiments, at least about 10-99%, about 10-95%, about 10-90%, about 10-85%, about 10-80%, about 10-75%, about 10-70%, about 10-65%, about 10-60%, about 10-50%, about 10-40%, about 10-30%, about 30-99%, about 30-95%, about 30-90%, about 30-85%, about 30-80%, about 30-75%, about 30-70%, about 30-65%, about 30-60%, about 30-50%, about 30-

40%, about 40-99%, about 40-95%, about 40-90%, about 40-85%, about 40-80%, about 40-75%, about 40-70%, about 40-65%, about 40-60%, about 40-50%, about 50-99%, about 50-95%, about 50-90%, about 50-85%, about 50-80%, about 50-75%, about 50-70%, about 50-65%, about 50-60%, about 60-99%, about 60-95%, about 60-90%, about 60-85%, about 60-80%, about 60-75%, about 60-70%, about 60-65%, about 65-99%, about 65-95%, about 65-90%, about 65-85%, about 65-80%, about 65-75%, about 65-70%, about 70-99%, about 70-95%, about 70-90%, about 70-85%, about 70-80%, about 70-75%, about 85-99%, about 85-95%, about 85-90%, about 90-99%, about 90-95%, or about 95-99%. In other embodiments, at least about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, about 65%, about 70%, about 75%, about 80%, about 85%, about 90%, about 95%, about 99%, or about 100% of at least a portion of the microstructures detach.

**[0084]** The microstructures may be fabricated such that all or a portion of the microstructures break off or dissolve off of the proximal layer, substrate or backing, or intermediate layer after insertion into skin. In an embodiment, the microstructure may be formed of a homogeneous material in which the material is more readily degradable at lower pH's as described in U.S. Patent Application No. 2009/0155330. In other embodiments, at least the distal tip may include a bioadhesive material or polymer that promotes adhesion to the interior skin adjacent the inserted microstructure. Thus, the bioadhesive facilitates detachment of the distal layer. In other embodiments, the microstructure may be etched, notched or scored to promote detachment as well as to promote detachment at a particular area of the microstructure.

**[0085]** The microstructures may further be shaped or formulated to promote detachment of all or a portion of the microstructures after insertion. The microstructure shape and content may be designed to promote and/or control detachment of at least a portion of the microstructure. For example, the microstructures may be formulated to soften or dissolve at certain points as described in U.S. Patent Publication No. 2009/0043279. Further, polymer(s) may be chosen for inclusion in one or more layers to promote detachment of that or other layers. For example, hydrophobic polymers, polymers having a high Tg, and/or polymers with a low molecular weight may be chosen to promote detachment. The composition of the layer may, alone or in addition to the polymer choices, be adjusted or manipulated to promote detachment of all or a portion of the microstructures. For example, the percentage of drug in the polymer matrix and/or the use of polymers at or near the entanglement concentration in the

matrix may promote detachment. Further, the microstructure shape may be designed or manipulated to promote detachment. Examples include having a shape with an asymmetrical cross-sectional diameter. It will be appreciated that the microstructures may be formulated with one or more, or all of the features as discussed above including adjusting the percentage of drug in the polymer layer, including polymers with a high Tg, using polymers with a lower molecular weight, including polymers in the matrix at or below the entanglement concentration, using hydrophobic polymers, and/or designing the shape of the microstructures.

**[0086]** All or a portion of the microstructures may include an indicator to provide visual verification of insertion and detachment of the microstructures in the skin as described in U.S. Patent Publication No. 2012/0150023. The indicator is preferably biocompatible as it will typically be delivered into the skin as the microstructure degrades.

### III Methods of Making Microstructure Arrays

**[0087]** Before describing the methods of manufacture in detail, it is to be understood that the methods are not limited to specific solvents, materials, or device structures, as such may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

**[0088]** Examples of forming various microstructure arrays having different configurations are provided in Examples 1 and 4. In one exemplary method, an array is prepared by (a) filling a mold with cavities corresponding to the negative of the microstructures with a casting solution comprising a biocompatible material such as a biocompatible polymer and a solvent, (b) removing the solvent, and (c) de-molding the resulting array from the mold. The solvent may be removed by any suitable means including, but not limited, to drying the mold filled with the casting solution in an oven. The casting solution preferably contains an active agent or ingredient. In one or more embodiments, the microstructures themselves comprise the active ingredient mixed, or dispersed in a polymer matrix, as opposed to having the active ingredient present as a coating on a microstructure or microneedle made of a different, biocompatible material such as a metal. Typically, excess formulation is scraped or wiped from the mold surface prior to drying. Where the microstructures are not integral with a substrate or backing layer, the microstructures are affixed to the substrate or backing layer with an adhesive prior to de-molding.

#### IV. Methods of Use

**[0089]** The methods, kits, microstructure arrays and related devices described herein may be used for treating any condition. It will be appreciated that the microstructure arrays may be used with any appropriate applicator including the applicator described in U.S. Publication No. 2011/0276027 and U.S. Provisional Applications (Attorney Docket No. 091500-0132 and 091500-0133), both filed on March 15, 2013, which are each incorporated herein in their entirety.

#### V. Examples

**[0090]** The following examples are illustrative in nature and are in no way intended to be limiting. Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.) but some errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, temperature is in °C. and pressure is at or near atmospheric.

##### EXAMPLE 1

###### CASTING TWO-LAYER ARRAYS

**[0091]** Clonidine was dissolved in an acetonitrile (ACN)/DMSO (7/3, v/v) mixture to a concentration of 35% (w/w) to form a drug solution.

**[0092]** Poly(D,L-lactide-co-glycolide) (PLGA, L/G 75/25) (available from Durect Corporation (PN B6007-1P), IV 0.55-0.75) and PLGA (L/G 75/25) from SurModics (1A, IV 0.1) was dissolved in ACN to a concentration of 40% to form a polymer solution.

**[0093]** The liquid drug formulation was prepared by mixing the drug solution with the polymer solution.

**[0094]** About 75 µL of liquid drug formulation was dispensed on a silicone mold, covered with 22 mm x 30 mm glass cover slip to spread the formulation on the mold, and then pressurized at 50 psi for 1 minute.

**[0095]** The formulation was wiped and the mold dried in an oven at 32 °C for about half an hour.

**[0096]** UV adhesive was dispensed on the drug formulation in the mold, covered with a 5 mL polyethylene terephthalate (PET) or polycarbonate (PC) film to spread the adhesive and cured using a UV Fusion system. The UV curing dose was 1.6 J/cm<sup>2</sup>. After curing, the microstructure (drug in tip distal layer and UV adhesive proximal layer on PET) was die cut with an 11 or 16 mm punch.

**[0097]** The resulting microstructures were inspected under microscope.

## EXAMPLE 2

### ADMINISTRATION OF A MICROSTRUCTURE ARRAY

**[0098]** A microstructure array comprising a therapeutic agent is prepared in accord with Example 1. The microstructure array is applied to skin and a force suitable to insert at least a portion of the microstructures into skin is applied to the second surface of the substrate. The microstructure array is removed from skin after 5 minutes.

**[0099]** The distal portion of the microstructures detaches from the microstructure array during removal of the array and remain implanted in skin. Fig. 3A shows an exemplary microstructure array before application to skin and Fig. 3B shows the array after application. As seen in Fig. 3B, the distal portions of the microstructures are detached or broken off from the proximal portions of the microstructures. Fig. 4 shows pig skin after application and removal of an exemplary microstructure array. The white dots within the stain are the microstructure distal ends implanted in the skin.

## EXAMPLE 3

### CASTING FUNNEL SHAPED MICROSTRUCTURE

**[0100]** A liquid drug solution prepared as described in Example 1 is dispensed onto a mold surface having funnel shaped cavities. The filled mold is pressurized to fill the cavities. The mold surface is wiped to remove excess liquid drug solution from the mold. After wiping, the mold with the drug solution is dried. During the drying, a solid dried matrix is formed in the distal microstructure cavities. This dried matrix fills a portion of the distal microstructures depending on the solid content in the liquid drug solution. To load higher doses of drug, the mold cavities will be filled with liquid drug solution as much as possible to achieve the maximum dried solid matrix containing drug. A larger funnel volume results in greater solid matrix after drying, particularly in cylindrical shaped microstructures.

1. A microstructure apparatus comprising:
  - a backing having a first surface and a second surface opposed thereto;
  - a microstructure array comprising a plurality of microstructures extending outwardly from the first surface of the backing;

the microstructures comprising a biodegradable distal layer and at least one proximal layer positioned between the distal layer and the first surface of the backing;

the distal layer comprised of at least one therapeutic agent and at least one polymer; and

wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

2. The microstructure apparatus of embodiment 1, wherein the distal layer comprises at least one hydrophobic polymer.
3. The microstructure apparatus of single or combined embodiments 1 or 2, wherein the distal layer comprises at least one polymer comprises at least one hydrophobic polymer and about 0-99% of at least one hydrophilic polymer.
4. The microstructure apparatus of the single or combined embodiments 1-3, where the distal layer comprises at least one polymer comprises at least one hydrophobic polymer and about 0-50% of a hydrophilic polymer.
5. The microstructure apparatus of the single or combined embodiments 1-4, where the distal layer comprises at least one polymer comprises at least one hydrophobic polymer and about 0-20% of a hydrophilic polymer.
6. The microstructure apparatus of the single or combined embodiments 1-5, where at least one therapeutic agent is a small molecule drug at least partially soluble with the at least one polymer in a solvent or co-solvent.
7. The microstructure apparatus of the single or combined embodiments 1-6, wherein the distal layer comprises about 1-99% of the small molecule drug.
8. The microstructure apparatus of the single or combined embodiments 1-7, wherein the distal layer comprises about 1-50% of the small molecule drug.
9. The microstructure apparatus of the single or combined embodiments 1-8, wherein the distal layer comprises about 5-40% of the small molecule drug.
10. The microstructure apparatus of the single or combined embodiments 1-9, wherein the distal layer comprises about 10-30% of the small molecule drug.
11. The microstructure apparatus of the single or combined embodiments 1-10, where at least one therapeutic agent is dispersed in the distal layer.
12. The microstructure apparatus of the single or combined embodiments 1-11, wherein the distal layer comprises about 1-90% of the dispersed agent.
13. The microstructure apparatus of the single or combined embodiments 1-12, wherein the distal layer comprises about 1-50% of the dispersed agent.

14. The microstructure apparatus of the single or combined embodiments 1-13, wherein the distal layer comprises about 10-40% of the dispersed agent.
15. The microstructure apparatus of the single or combined embodiments 1-14, wherein the distal layer comprises about 20-30% of the dispersed agent.
16. The microstructure apparatus of the single or combined embodiments 1-15, wherein the at least one polymer is in a glass state at room temperature.
17. The microstructure apparatus of the single or combined embodiments 1-16, wherein the at least one polymer has a glass transition temperature (Tg) above about body temperature.
18. The microstructure apparatus of the single or combined embodiments 1-17, where at least about 10% of the distal layer detaches readily upon insertion of the array into skin.
19. The microstructure apparatus of the single or combined embodiments 1-18, where at least about 50% of the distal layer detaches readily upon insertion of the array into skin.
20. The microstructure apparatus of the single or combined embodiments 1-19, where at least about 70% of the distal layer detaches readily upon insertion of the array into skin.
21. The microstructure apparatus of the single or combined embodiments 1-20, where at least about 90% of the distal layer detaches readily upon insertion of the array into skin.
22. The microstructure apparatus of the single or combined embodiments 1-21, where about 100% of the distal layer detaches readily upon insertion of the array into skin.
23. The microstructure apparatus of the single or combined embodiments 1-22, where at least a portion of the microstructures have a first cross-dimensional diameter that is larger than a second cross-dimensional diameter.
24. The microstructure apparatus of the single or combined embodiments 1-23, where at least a portion of the microstructures have a cross-dimensional shape selected from the group consisting of a diamond, a rectangle, and an oval.
25. The microstructure apparatus of the single or combined embodiments 1-24, where at least a portion of the microstructures have an asymmetrical cross-dimensional shape.
26. The microstructure apparatus of the single or combined embodiments 1-25,

wherein a concentration of the at least one polymer in a polymer casting solution used to form the microstructures is lower than an entanglement concentration ( $C_E$ ) for the polymer.

27. The microstructure apparatus of the single or combined embodiments 1-26, wherein a concentration of the at least one polymer in a polymer casting solution used to form the microstructures is at a  $C_E$  for the polymer.

28. The microstructure apparatus of the single or combined embodiments 1-27, wherein at least a portion of the proximal and/or distal layers has a funnel shape.

29. The microstructure apparatus of the single or combined embodiments 1-28, wherein the microstructures are affixed to the first surface of the backing.

30. The microstructure apparatus of the single or combined embodiments 1-29, wherein at least a portion of the backing forms the proximal layer.

31. The microstructure apparatus of the single or combined embodiments 1-30, further comprising a substrate having a first surface and a second surface opposed thereto, where the second surface of the backing is affixed to the first surface of the substrate.

32. A microstructure apparatus comprising:

    a substrate having a first surface and a second surface opposed thereto;

    a microstructure array comprising a plurality of microstructures affixed to the first surface of the substrate and extending outwardly therefrom;

    the microstructures comprising of a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the substrate;

    the distal layer comprised of at least one hydrophobic polymer and at least one therapeutic agent, and

    wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

33. A microstructure apparatus comprising:

    a backing having a first surface and a second surface opposed thereto;

    a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom;

    the microstructures comprising of a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing;

    the distal layer comprised of at least one polymer and about 1-90% of a therapeutic agent; and

wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

34. A microstructure apparatus comprising:

a backing having a first surface and a second surface opposed thereto;

a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom;

the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing;

the distal layer comprised of at least one polymer and a therapeutic agent, the at least one polymer having a glass transition temperature (Tg) at least above about body temperature; and

wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

35. A microstructure apparatus comprising:

a backing having a first surface and a second surface opposed thereto;

a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom;

the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing;

the distal layer comprised of at least one polymer having a molecular weight between about 1-100K Da and a therapeutic agent; and

wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

36. A microstructure apparatus comprising:

a backing having a first surface and a second surface opposed thereto;

a microstructure array comprising a plurality of microstructures affixed upon the first surface of the backing and extending outwardly therefrom;

the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the backing;

the distal layer comprised of at least one polymer and a therapeutic agent; and

wherein at least about 10-100% of the distal layer detaches readily upon insertion of the array into skin.

37. A microstructure apparatus comprising:

a substrate having a first surface and a second surface opposed thereto;

a microstructure array comprising a plurality of microstructures affixed upon the first surface of the substrate and extending outwardly therefrom;

the microstructures comprising a biodegradable distal layer and a proximal layer positioned between the distal layer and the first surface of the substrate;

the distal layer comprised of at least one polymer and a therapeutic agent, the distal layer having a first cross-dimensional diameter that is larger than a second cross-dimensional diameter; and

wherein at least a portion of the distal layer detaches readily upon insertion of the array into skin.

38. The embodiments of the microstructure apparatuses 32-37 in combination with the single or combined embodiments 2-31.

39. A method of making a microstructure apparatus comprising:

dissolving or suspending a therapeutic agent in a solvent to form a therapeutic agent solution or suspension;

dissolving at least one polymer in a solvent to form a polymer solution;

mixing the therapeutic agent solution or suspension and the polymer solution or suspension to form a polymer matrix solution or suspension;

dispensing the polymer matrix solution or suspension on a mold having an array of microstructure cavities; followed by pressurization;

removing excess solution or suspension polymer matrix on the mold surface; and drying the matrix; and

dispensing a basement or backing layer on the mold surface; and

drying the basement or backing layer.

40. The method of embodiment 39, further comprising:

affixing the basement or backing layer to a substrate.

41. The method of the single or combined embodiments 39-40 further comprising:

using a nonwoven or porous film double coated with adhesive to affix the basement or backing layer to a substrate.

**[0101]** While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true

spirit and scope.

**[0102]** All patents, patent applications, and publications mentioned herein are hereby incorporated by reference in their entireties. However, where a patent, patent application, or publication containing express definitions is incorporated by reference, those express definitions should be understood to apply to the incorporated patent, patent application, or publication in which they are found, and not necessarily to the text of this application, in particular the claims of this application, in which instance, the definitions provided herein are meant to supersede.

WHAT IS CLAIMED IS:

1. A microstructure apparatus comprising:
  - a backing having a first surface and a second surface opposed thereto;
  - a microstructure array comprising a plurality of microstructures extending outwardly from the first surface of the backing;
  - the microstructures comprising a biodegradable distal layer and at least one proximal layer positioned between the distal layer and the first surface of the backing;
  - the distal layer comprised of at least one therapeutic agent and at least one polymer (i) wherein the at least one polymer is selected from (a) a hydrophobic polymer, where the at least one polymer is comprised of about 50-100% of the hydrophobic polymer, or (b) a polymer having a glass transition temperature (Tg) at or above about body temperature; or (ii) wherein the at least one polymer is at a concentration in a polymer casting solution used to form the distal layer of the microstructures that is at or below its entanglement concentration ( $C_E$ ) for the polymer; and wherein selection of the polymer is such that at least a portion of the distal layer detaches from the microstructures upon insertion of the array into skin.
2. The microstructure apparatus of claim 1, wherein the at least one polymer of the distal layer comprises at least one hydrophobic polymer and about 0-99% of at least one hydrophilic polymer; or
  - wherein the at least one polymer of the distal layer comprises at least one hydrophobic polymer and about 0-50% of a hydrophilic polymer; or
  - wherein the at least one polymer of the distal layer comprises at least one hydrophobic polymer and about 0-20% of a hydrophilic polymer.
3. The microstructure apparatus of any previous claim, wherein the at least one therapeutic agent is a small molecule drug at least partially soluble with the at least one polymer in a solvent or co-solvent.
4. The microstructure apparatus of claim 3, wherein the distal layer comprises about 1-99% of the small molecule drug; or

wherein the distal layer comprises about 1-50% of the small molecule drug; or  
wherein the distal layer comprises about 5-40% of the small molecule drug; or

wherein the distal layer comprises about 10-30% of the small molecule drug.

5. The microstructure apparatus of any previous claim, where the at least one therapeutic agent is dispersed in the distal layer.

6. The microstructure apparatus of claim 5, wherein the distal layer comprises about 1-90% of the dispersed agent; or

wherein the distal layer comprises about 1-50% of the dispersed agent; or

wherein the distal layer comprises about 10-40% of the dispersed agent; or

wherein the distal layer comprises about 20-30% of the dispersed agent.

7. The microstructure apparatus of any previous claim, wherein the at least one polymer has a glass transition temperature (Tg) above about body temperature.

8. The microstructure apparatus of any previous claim, where at least about 10% of the distal layer detaches readily upon insertion of the array into skin; or

wherein at least about 50% of the distal layer detaches readily upon insertion of the array into skin; or

wherein at least about 70% of the distal layer detaches readily upon insertion of the array into skin; or

wherein at least about 90% of the distal layer detaches readily upon insertion of the array into skin; or

wherein about 100% of the distal layer detaches readily upon insertion of the array into skin.

9. The microstructure apparatus of any previous claim, where at least a portion of the microstructures have a first cross-dimensional diameter that is larger than a second cross-dimensional diameter; or

where at least a portion of the microstructures have a cross-dimensional shape selected from the group consisting of a diamond, a rectangle, and an oval; or

where at least a portion of the microstructures have an asymmetrical cross-dimensional shape.

10. The microstructure apparatus of any previous claim, wherein a concentration of the at least one polymer in a polymer casting solution used to form the microstructures is at a C<sub>E</sub> for the polymer.

11. The microstructure apparatus of any previous claim, wherein at least a portion of the proximal and/or distal layers has a funnel shape.

12. The microstructure apparatus of any previous claim, wherein the microstructures are affixed to the first surface of the backing.

13. The microstructure apparatus of any previous claim, wherein at least a portion of the backing forms the proximal layer.

14. The microstructure apparatus of any previous claim, further comprising a substrate having a first surface and a second surface opposed thereto, where the second surface of the backing is affixed to the first surface of the substrate.

15. The microstructure apparatus of any previous claim, wherein the distal layer is comprised of the at least one polymer and about 1-90% of the at least one therapeutic agent.

16. The microstructure apparatus of any previous claim, wherein at least one of the at least one polymer have a molecular weight between about 1-100K Da.

17. The microstructure apparatus of claim 9, wherein the distal layer having a first cross-dimensional diameter that is larger than a second cross-dimensional diameter.

18. A method of making a microstructure apparatus comprising:  
dissolving or suspending a therapeutic agent in a solvent to form a therapeutic agent solution or suspension;  
dissolving at least one polymer in a solvent to form a polymer solution, wherein the polymer is (i) selected from (a) a hydrophobic polymer and (b) a polymer with a

glass transition temperature at or above about body temperature; or (ii) at a concentration in a polymer casting solution used to form the distal layer of the microstructures that is at or below its entanglement concentration ( $C_E$ );

mixing the therapeutic agent solution or suspension and the polymer solution or suspension to form a polymer matrix solution or suspension;

dispensing the polymer matrix solution or suspension on a mold having an array of microstructure cavities; followed by pressurization;

removing excess solution or suspension polymer matrix on the mold surface; and drying the matrix; and

dispensing a basement or backing layer on the mold surface; and

drying the basement or backing layer;

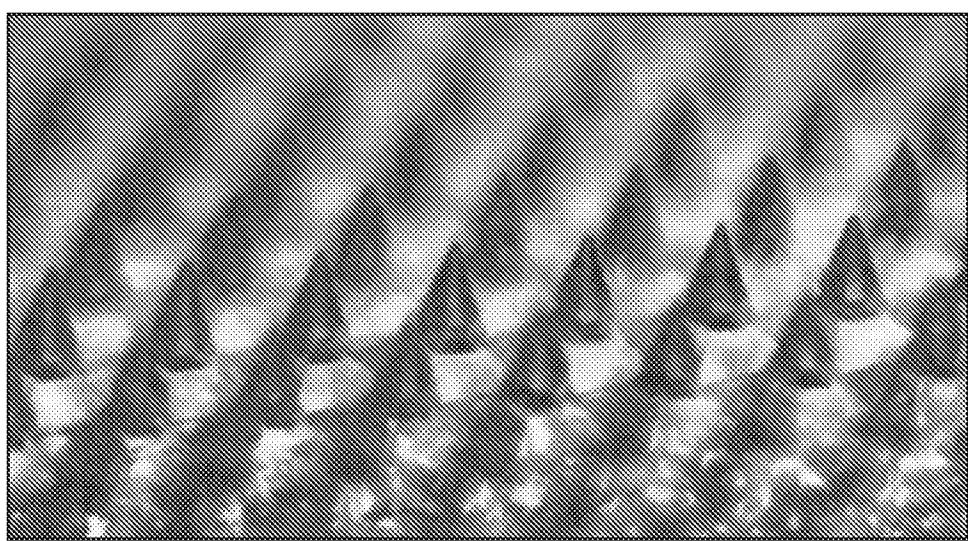
wherein selection of the polymer is such that at least a portion of the distal layer detaches from the microstructures upon insertion of the microstructure apparatus.

19. The method of claim 18, further comprising:

affixing the basement or backing layer to a substrate.

20. The method of claim 19, further comprising:

using a nonwoven or porous film double coated with adhesive to affix the basement or backing layer to a substrate.



**FIG. 1**

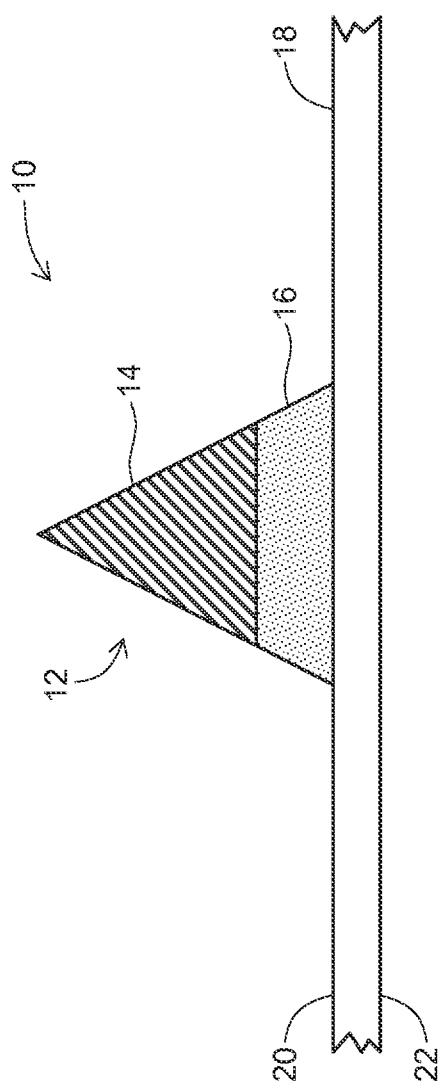
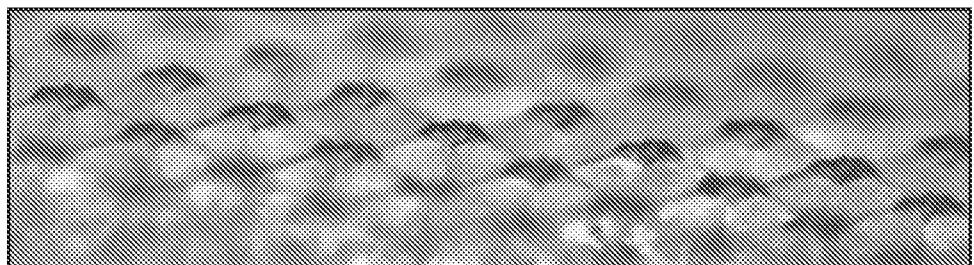


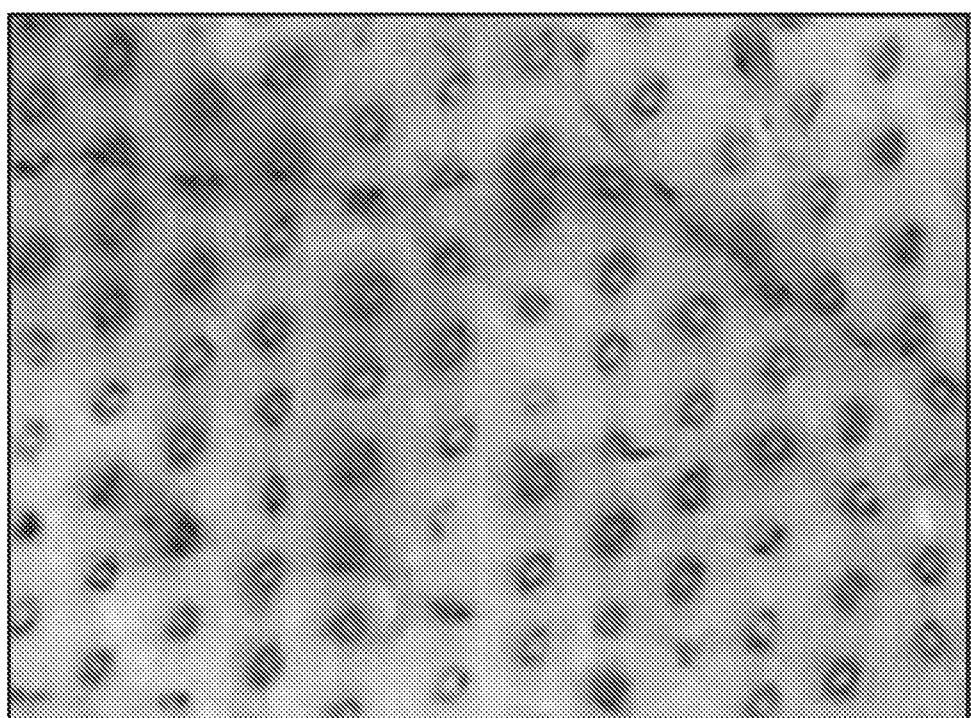
FIG. 2



**FIG. 3A**



**FIG. 3B**



**FIG. 4**

FIG. 5B

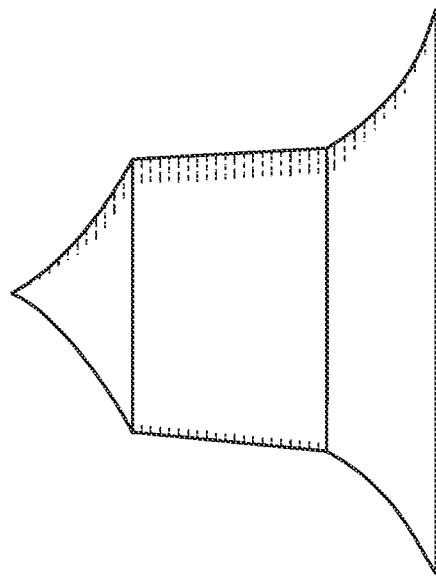
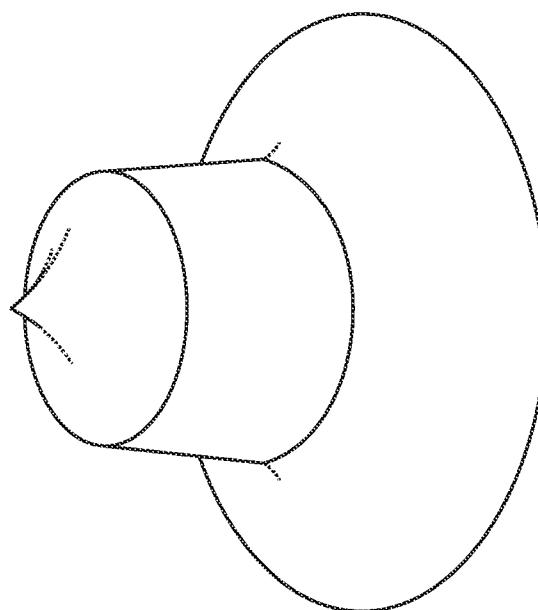


FIG. 5A



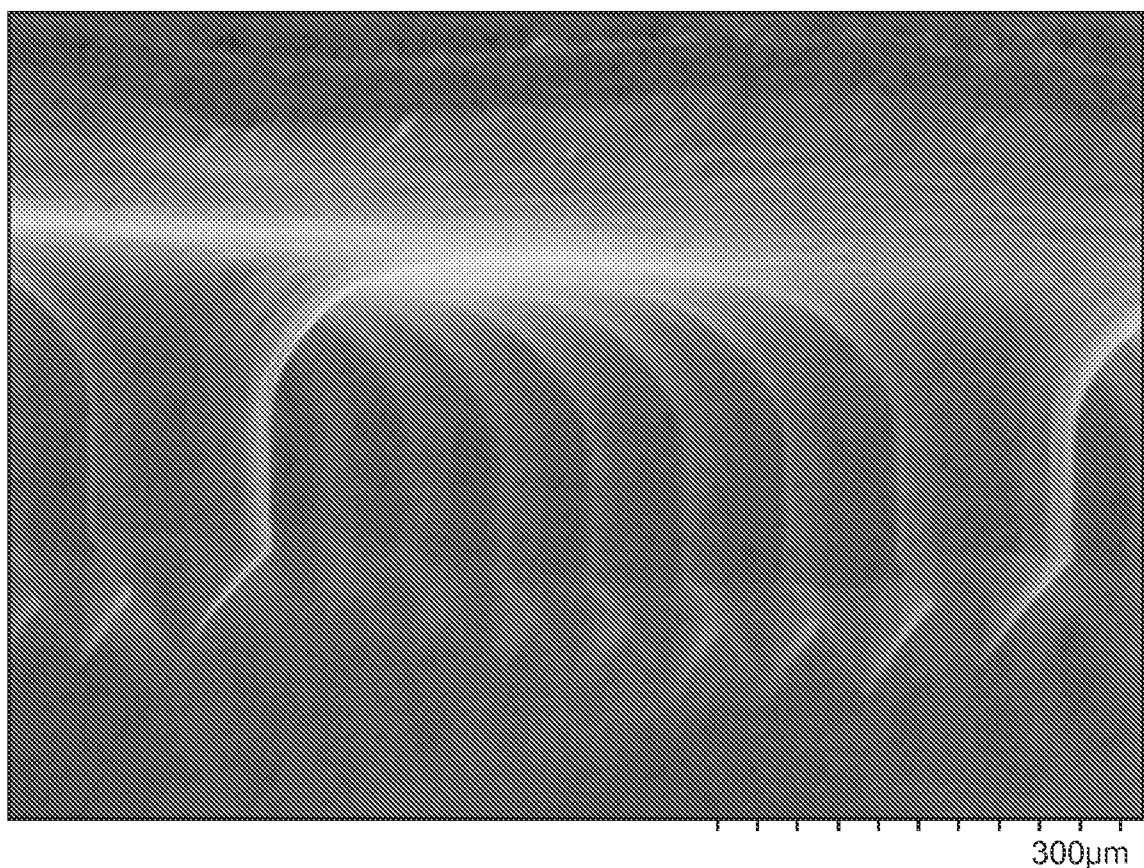


Fig. 6

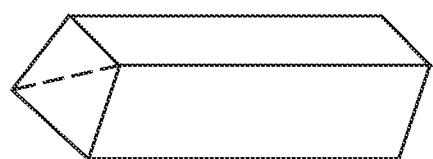


FIG. 7C

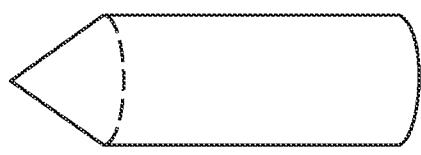


FIG. 7B

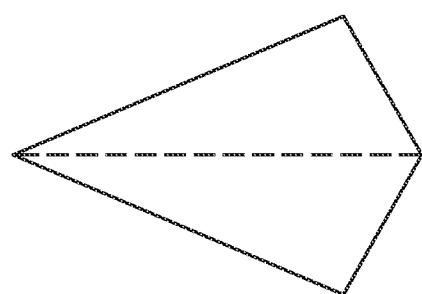
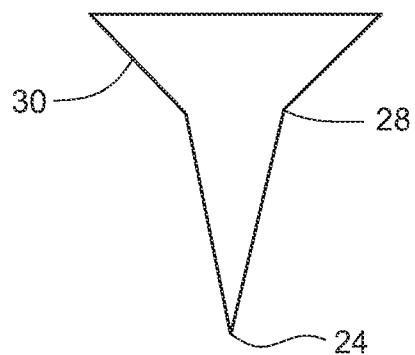
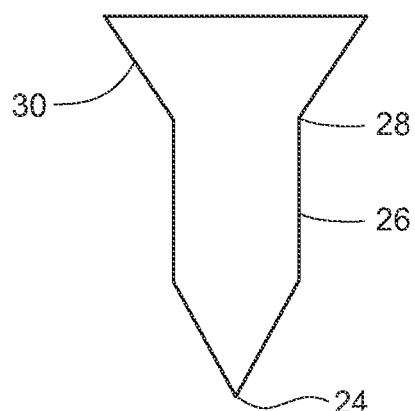


FIG. 7A



**FIG. 8A**



**FIG. 8B**