

METHOD AND APPARATUS FOR FRACTIONAL PHOTO THERAPY OF SKIN

FIELD OF THE INVENTION

5 The present invention relates generally to methods and apparatus for providing medical or surgical treatment using optical energy, and in particular, to a method and apparatus for providing fractional treatment of skin using lasers.

BACKGROUND OF THE INVENTION

10 Optical energy, particularly laser energy, is commonly used as a versatile tool in medicine to achieve desired outcomes in the tissue that is treated. For example, lasers have been used to treat common dermatological problems such as hypervascular lesions, pigmented lesions, acne scars, rosacea, etc. Additionally, lasers are also used in aesthetic surgery for achieving better cosmetic appearance by resurfacing the skin and remodeling the different
15 layers of skin to improve the appearance of wrinkled or aged skin. Generally, skin resurfacing is understood to be the process by which the top layers of the skin are completely removed by using chemicals, mechanical abrasion or lasers to reveal the underlying more youthful looking skin and stimulate the generation and growth of new skin. In laser skin remodeling, laser energy penetrates into the deeper layers of the skin and is aimed at stimulating the generation
20 of new extra-cellular matrix materials, such as collagen, that provide the youthful appearance to skin. In traditional CO₂ resurfacing, the skin may be completely ablated to a layer below the papillary dermis and there may be heat diffusion induced coagulation to several hundred micrometers below the original skin surface.

FPT 071003

Generally, the desired effects on the skin are accomplished by laser-induced heating of the tissue. The induced heat results in thermal coagulation, cell necrosis, hemostasis, welding and gross alteration of the extra-cellular matrix for specific temperature and heating time combinations. While using lasers for either skin resurfacing or remodeling, one of the critical objectives has been to accomplish uniform treatment across the desired treatment area of the chosen skin site. Generally, particular care is exercised, either by the physician alone or by combining the physician's judgment with intelligence that is built into the dermatological system, to leave no tissue untreated in the targeted region of the skin. Whether one uses a broadly radiating pulsed beam of light or a focused laser that produces a small spot size, the goal has been to expose the entire treatment area to the laser energy, heat the entire volume of tissue in the treatment area and bring about the desired change. It has been widely reported that such broad area treatment results in undesirable side effects such as pain, erythema, swelling, etc.

Lasers such as CO₂ and Erbium usually cause a superficial thermal treatment to a well-controlled depth. In contrast, yellow pulsed dye lasers designed for selective photothermolysis of microvascular lesions cause selective thermal treatment of microvessels. (See generally, *Cutaneous Laser Surgery*, edited by MP Goldman and RE Fitzpatrick and published by Mosby, 1999). Depending on the kind of laser used (CO₂, Erbium, etc.), the mode of usage (continuous wave or pulsed), the pulse width, energy density and power, different effects can be accomplished. When a CO₂ laser is used in typical continuous wave (CW) mode at modest powers for vaporization, surface ablation is accomplished. Although the CO₂ laser penetrates only 20 µm deep, the tissue bed remaining after continuous wave CO₂ laser vaporization is typically coagulated to a depth of about 1mm, desiccated and charred. In

contrast, shorter (<1 millisecond) pulses of higher energy densities (>5 J/cm²) pulses of CO₂ laser radiation remove tissue with greater efficiency, less thermal damage (about 50-100 μm residual denaturation) and no charring. **FIG. 1** illustrates the prior art treatment of laser skin resurfacing, where the target tissue is the epidermis. Laser skin resurfacing using prior art systems completely ablates the targeted epidermis.

Another approach to treat microscopic, pigmented tissue targets is to take advantage of the selectively absorbed pulse of radiation. Selective photothermolysis is accomplished by site-specific, thermally mediated injury of microscopic, pigmented tissue, where the selective absorption is due to the laser absorption characteristics of the pigmented tissue.

In all these cases, whether it is skin resurfacing or selective photothermolysis of anatomical structures or defects that are located deeper in the skin, a burn or an acute wound is created by the laser. For acute wounds, the skin heals by three distinct 'response to injury' waves. The initial inflammatory phase has a duration lasting minutes to days and seamlessly transitions into the cell proliferative phase, lasting 1 to 14 days. This cell proliferative phase is slowly replaced by the dermal maturation phase that lasts from weeks to months (Clark, R. Mechanisms of cutaneous wound repair. In: Fitzpatrick TB, ed. Dermatology in General Medicine, 5th Ed., New York, NY. McGraw-Hill. 1999. pp. 327-41). This concept is illustrated in **FIG. 2**. In general, a direct correlation exists between the size of the injury and the time required for complete repair. However, the inflammatory phase is a function of cellular necrosis, particularly epidermal (i.e., keratinocyte) necrosis and a direct correlation exists between the cellular necrosis and the inflammatory phase (Clark, 1999). Increased cellular necrosis, particularly epidermal necrosis, prolongs the inflammatory phase. Prolonging and/or accentuating the inflammatory phase are undesirable from a clinical

perspective (increased pain and extended wound repair) and may retard subsequent phases of wound repair. The cause(s) of this prolonged inflammatory phase are not well understood but laser injuries are associated with both early and high levels of dermal wound repair (e.g., angiogenesis, fibroblast proliferation and matrix metalloproteinase (MMP) expression) but
5 delayed epidermal resurfacing (Schaffer et al., Comparisons of Wound Healing Among Excisional, Laser Created and Standard Thermal Burn in Porcine Wounds of Equal Depth, Wound Rep. Reg. v5 (1) pp. 51-61 1997).

Unfortunately, most of the skin resurfacing efforts and selective photothermolysis treatments result in prolonged, exaggerated inflammatory phase leading to undesirable
10 consequences such as delayed wound repair. The prolonged inflammatory phase also leads to the pain experienced by most patients undergoing skin resurfacing procedures. The undesirable extended inflammatory response phase can be attributed to the bulk heating of the skin with little or no healthy tissue, particularly keratinocytes, left behind in the area where the skin was exposed to the laser energy. Particularly, when uniform treatment is desired, and
15 hence, the entire target tissue volume is exposed to laser energy without sparing any tissue within the target volume, pain, swelling, fluid loss, prolonged reepithelialization and other side effects of dermatological laser treatments are commonly experienced by patients.

Many systems have been devised to minimize epidermal necrosis. One such approach to minimize epidermal necrosis is by cooling the epidermal surface using plastic bags filled
20 with ice placed on the skin surface for a short while (about five minutes), compressed freon gas used during irradiation, or chilled water spread directly on the area being irradiated. Some of these methods are described in A. J. Welch et al., "Evaluation of Cooling Techniques for

the Protection of the Epidermis During ND-YAG Laser Irradiation of the Skin,” Neodymium-YAG Laser in Medicine, (Stephen N. Joffe ed. 1983).

Other devices and approaches have been proposed to treat dermal tissue regions without damaging the epidermal regions. One approach to minimize bulk heating of the skin is described in U.S. Pat. No. 6,120,497. In this approach, to treat skin wrinkles, the dermal region is targeted for eliciting a healing response to produce unwrinkled skin, while simultaneously cooling the epidermal region above the targeted dermal region. In another example, U.S. Pat. No. 5,814,040 describes cooling an epidermal tissue region while performing selective photothermolysis of selected buried chromophores in biological tissues using a laser. This cooling procedure is known as dynamic cooling. In this procedure, spraying with a cryogen to establish a predetermined dynamic temperature profile cools an epidermal tissue region. The epidermal and underlying dermal tissue regions are subsequently irradiated to thermally treat the dermal tissue region while leaving the epidermal tissue region substantially undamaged. **FIG. 3** illustrates the effect of using a prior art system using surface cooling for minimizing epidermal damage.

Muccini et al. (Muccini et al., “Laser Treatment of Solar Elastosis with Epithelial Preservation,” Lasers Surg. Med. 23:121-127, 1998) report a different approach to spare the epithelium during laser procedures. They describe a laser system that delivers laser energy over a relatively large area with the laser light focused in the dermis. In this system, air is used as the coolant to maintain minimal temperature at the skin surface. Additionally, the optical device that focuses the laser light also acts as thermal conductor on the surface to help minimize surface temperature and air is flowed over the optical device also to keep it cool.

However, all these systems pose practical limitations in terms of having the additional complexity of a system that also has cooling means. Hence, there is a need for an improvement in the art for a system and method to treat the dermal region and avoid the complexities associated with cooling. More importantly, all of these systems are global in nature, i.e., they expose the entire skin surface within the treatment region to laser irradiation (bulk heating) and cooling. These global treatments lead to an increase in clinical side effects and to an increase in healing time as described above. Hence, there is a need for an improvement in the art for a system and method to treat the dermal and epidermal regions that reduce the side effects associated with global resurfacing. This reduction in side effects will allow physicians to increase the treatment intensity such that skin treatments can be provided more effectively.

When lasers act on the skin to cut, vaporize, or coagulate tissue there are several 'zones' of tissue damage that surround the spot where the impact of the laser energy is the highest, i.e., the treatment zone where the tissue volume is necrosed. Usually, the temperature in this zone is greater than 75°C and tissue, whether it is made up primarily of keratinocytes and their derivatives or collagen, is necrosed. Immediately adjacent to the area of necrosis is a thin thermal coagulation zone of tissue clumping, where denatured proteins have formed a wall that contains necrotic cells, matrix, and cellular debris. Surrounding this zone is a larger zone of thermally-altered tissue in which proteins and cells have been heated to supra-physiologic temperatures over a short time, but they still remain viable. In this zone, the volume of the tissue is exposed to temperature typically in the of 37°C to 45°C range. The dimensions of these zones depends on laser parameters (wavelength, pulse duration, energy density, etc.), thermal relaxation of the tissue components, and ambient temperature. These zones are

illustrated in **FIG. 4**. Recent data indicate that the latter zone, the '*heat shock zone*' (HSZ), has special significance for subsequent biologic effects (Capon A. and Mordon S. Can thermal lasers promote wound healing? Am. J. Clin. Dermatol. 4(1):1-12. 2003). For illustrative purposes, the demarcation between the different zones is shown as an abrupt change.

5 However, one skilled in the art would understand that the change from one zone to another is not abrupt, but gradual.

Heat shock triggers multiple signaling pathways that induce both cell survival and programmed cell death pathways. The final outcome as to whether a cell lives or dies is believed to depend on the 'acquired stress tolerance' of the surrounding tissue. Mild heat
10 shock followed by a period of recovery makes cells more resistant to subsequent severe heat shock and multiple other stresses. This is achieved via the activation of cell survival pathways (i.e., extracellular signal-regulated kinase, ERK, and akt kinase) and the inhibition of apoptotic pathways (i.e., Jun terminal kinase, Fas, caspase-8 and others) via heat shock protein (i.e., HSP72) mediated signaling events (Gagai VL and Sherman MY Interplay between
15 molecular chaperones and signaling pathways in survival of heat shock. J. Appl. Physiol. 92:1743-48. 2002).

However, with conventional skin resurfacing and selective photothermolysis, the laser exposed tissue is dominated by the necrotic treatment zone instead of the viable, heat shock zone. In fact, the treatment is designed to cover the target tissue completely with overlapping
20 necrotic zones so that no target tissue is left unexposed to laser energy. To promote the cell survival pathways and inhibit the apoptotic pathways, it is desirable to have the viable tissue be more prevalent in the laser exposed tissue compared to the necrotic zone. Hence, there is

an unmet need for a planned laser treatment that promotes the existence of viable tissue in the target tissue volume compared to the necrotic treatment zone.

If the HSZ surrounding necrotic treatment zone is appropriately spaced and/or epidermal injury is limited, the viable tissue bordering thermal coagulation zones will be subjected to less inflammation from the products of cell death, tilting the balance in favor of cell survival and against apoptosis. These areas will be better able to mount reepithelialization, fibro-proliferative and subsequent remodeling phases of wound repair. One important reason for this effect is that HSZ and bordering spared tissue contain subpopulations of stem cells responsible for repopulating the epidermis (Watt F, "The Stem Cell Compartment in Human Interfollicular Epidermis", J Derm. Sci., 28, 173-180, 2002). In humans, these stem cells reside in two locations: 1) in focal clusters of the basal keratinocyte layer, in contact with basement membrane components and, 2) in the follicular bulge area of the pilosebaceous unit. The basal keratinocyte layer of the epidermis contains a low population of these stem cells interspersed with large numbers of transit-amplifying (TA) cells that are directly derived from stem cells. Interfollicular epidermal stem cells tend to cluster at the bases of rete ridges in acral areas and at the tips of dermal papillae in non-acral skin (Watt, 2002). The follicular stem cell compartment has been shown to possess the ability to repopulate the interfollicular epidermal surfaces when required under certain conditions. Such conditions include severe burns, large split-thickness epidermal injuries and cosmetic surgical procedures (e.g., ablative laser resurfacing, chemical peel, dermabrasion, keratotomy, etc.) that denude the epidermal layer, leaving no epidermal stem cell populations. This is illustrated in **FIG. 5**. In fact, it is well known that CO₂ resurfacing results in prolonged

reepithelialization when compared to steel scalpel or electrosurgical scalpel incisions even though laser wounds exhibit accelerated dermal healing (Schaffer, 1997).

Reepithelization to repair such defects is delayed under these circumstances, because resurfacing must occur from remaining follicular stem cell populations within the de-epidermized wound and from epithelial stem cells at the margins of the defect. If the wound is full thickness, extending down to the level of the pilosebaceous unit, then resurfacing is delayed even further because epidermal healing occurs only from the margins.

The speed of epidermal reepithelization is directly proportional to the number and density of TA and stem cells. In the case of the follicular stem cell population, the average density of the bulge area compartment is dependent on the number of pilosebaceous units per unit of skin surface area. For the densest hair bearing skin (scalp) the number of adult human hair ranges between 100 and 500 per cm^2 ; whereas surfaces such as the face have less than half that density. On the face, at least a two or three orders of magnitude greater density of epidermal stem cells exists versus follicular bulge stem cells based on the density of epidermal stem cell clusters that reside in the basal cell layer immediately above each dermal papillae in non-acral skin, where they are spaced every 10-100 μm .

If the entire volume of the target tissue is not treated but only a fraction of the tissue is treated promoting the existence of viable tissue and HSZs, with multiple treatments, macroscopic areas of tissue regeneration will occur at the maximum rate within the surrounding micro-HSZs and spared epidermal surfaces, creating a fractional 'wound repair field'. Such fractional wound repair fields are fundamentally different from previous techniques because the areas of epidermal tissue that are spared between treatment zones contain both epidermal stem cells and TA cell populations. Thus, reepithelization of treatment

zones proceeds rapidly with little or none of the side effects (i.e., pain, persistent erythema, edema, fluid drainage, etc.) observed after traditional resurfacing procedures. For example, if the spacing between fractional beam treatment zones creates an average density of 500/cm² there are ample epidermal stem cells that remain for interfollicular resurfacing of both the treatment zone itself and of the surrounding HSZs, if necessary. In addition, after fractional laser treatment the follicular bulge stem cell population remains intact, if needed. This concept is illustrated in **FIG. 6**.

Chronic UV irradiation appears to trigger dysfunctional wound repair pathways in the skin that involve gradual replacement of normal epidermal and dermal structures with characteristic atrophy and accumulation of elastotic dermal matrix components (Kligman, “Prevention and Repair of Photoaging: Sunscreens and Retinoids”, *Cutis*. 1989 May;43(5):458-65). Currently, reversal of photo-aging is attempted by imparting cutaneous injury that induces new dermal collagen formation. Such cutaneous injury could be accomplished using mechanical (e.g., dermabrasion), chemical (e.g., retinoids and acid peels), or laser surgical procedures. The expectation is that these cutaneous injuries will promote the normal fibro-proliferative responses of the upper reticular and papillary dermal compartments, and therefore yield rejuvenated skin. For example, U.S. Pat. No. 6,120,497 describes thermally injuring collagen in the targeted dermal region to activate fibroblasts. The fibroblasts in turn deposit increased amounts of extracellular matrix constituents.

However, as discussed above, epidermal injury promotes the inflammatory phase, which inhibits the rejuvenative process. As can be easily imagined, dermabrasion, which is a mechanical surface ablation process, results in epidermal injury. Hence, while the currently used methods, which are mentioned above, for promoting normal fibro-proliferative response

of the dermal compartments can yield rejuvenated skin, due to the epidermal injury that occurs with these processes, the rejuvenative process is compromised.

Hence, the objective of nonablative photorejuvenation is to induce a thermal wound repair response in the papillary and upper reticular dermal compartments (approximately 100-400 μm below the surface of the skin) while sparing the epidermal compartment. To spare the epidermis, one typically uses low fluences (laser energy densities). Unfortunately, such low levels are generally inadequate to promote the kinds of stimulation that is required to cause the desired dermal effect, hence resulting in minimal efficacy. Thus, in most cases, minimal dermal matrix remodeling is achieved by these procedures and clinical responses (e.g., wrinkle reduction, retexturing, dyschromia reduction, and telangiectasia removal) are also minimal (Nelson et al., "What is Nonablative Photorejuvenation of Human Skin", *Seminars in Cutaneous Medicine and Surgery*, Vol. 21, No. 4 (Dec.), 238-250, 2002; Leffell D, "Clinical Efficacy of Devices of Nonablative Photorejuvenation", *Arch. Dermatol.* 138: 1503-1508, 2002). Therefore, there is an unmet need for sparing the epidermal compartment, but achieving enough stimulation of dermal matrix remodeling to be clinically effective.

We can expect that isolated, non-contiguous treatment zones creating necrotic tissue, surrounded by zones of viable tissue that are capable of promoting healing, which will induce multiple sites of tissue regeneration to produce 'micro-thermal wound repair fields'. We call this process fractional photo therapy, as only fractional volumes of the target tissue volume is thermally altered, as opposed to the conventional treatments where the entire target volume is thermally altered. Each field is typically composed of thousands of individual HSZs and surrounding spared tissue units that comprise "nodes" of wound repair. Each node can be expected to expand beyond its own volume to merge with neighboring nodes, replace photo-

aged tissue components (e.g., solar elastosis, microvascular ectasia, pigment incontinence, epidermal atrophy, and atypia), and produce complete coverage. Hence, there is a need for generating isolated, non-contiguous tissue volumes of treatment zones composed of necrotic tissue, surrounded by zones of viable tissue that is capable of promoting healing of the target tissue.

SUMMARY OF THE INVENTION

One aspect of the present invention is a method for achieving beneficial effects in a target tissue in skin comprising treating the target tissue using optical radiation to create one or more microscopic treatment zones such that the ratio of the sum of the treatment zones to the target tissue volume is less than one, and the treatment zones are created by a predetermined treatment pattern.

Another aspect of this invention is a method for achieving beneficial effects in skin tissue comprising treating the skin by exposing a targeted part of the skin tissue to optical radiation to create one or more microscopic treatment zones such that the volume of the target tissue that remains unaffected by the optical radiation is controlled.

In general, the present invention features a method for treating either existing dermatological disease conditions or for improving the appearance of skin, by intentionally generating a pattern of thermally altered tissue surrounded by unaltered tissue. This approach offers numerous advantages over existing approaches in terms of safety and efficacy. This invention minimizes the undesirable side effects of pain, erythema, swelling, fluid loss, prolonged reepithelialization, infection, and blistering generally associated with laser skin

resurfacing. Another aspect of this invention is to stimulate the skin's wound repair system, by sparing healthy tissue around the treated tissue, whereby the rejuvenative process is more robust.

Yet another distinguishing feature of this invention is to reduce or eliminate the side
5 effects of repeated laser treatment to skin by controlling the extent of tissue necrosis due to laser exposure of skin.

In one aspect of the invention, the microscopic treatment zones are created by using lasers with wavelengths in the range of 0.4 to 12.0 μm , directing the laser radiation to a targeted region in the skin, and creating microscopic treatment zones of necrotic tissue. These
10 microscopic treatment zones could be in the epidermal or dermal regions or originate in the epidermal region and continue into the dermal region of the skin. Preferably, they originate in the epidermal region. The individual microscopic zones could have the shape of a cylinder, sphere, or any other shape that could be generated by an appropriate combination of wavelength, pulse duration, pulse width, pulse intensity, contact tip temperature, contact tip
15 thermal conductivity, contact lotion, numerical aperture of the focusing elements, optical source brightness, and power. The microscopic treatment zones could be between 10 and 4,000 μm in the direction of the beam (depth) and between 10 and 1,000 μm in the direction perpendicular to the beam (diameter).

Another specific aspect of this invention is a method of creating the microscopic
20 treatment zones of necrosed tissue that allows viable tissue to be interspersed between the microscopic treatment zones thereby enabling the skin to mount a more robust repair response to rejuvenate the skin.

This invention also relates to an apparatus for treating common dermatological conditions by treating a target tissue volume in the skin with optical energy and creating one or more treatment zones such that the ratio of the sum of the treatment zones to the target tissue volume is less than one, and the treatment zones are created by a predetermined treatment pattern.

Another aspect of this invention relates to an apparatus that exposes a targeted part of the skin tissue to optical radiation to create one or more microscopic treatment zones such that the volume of the target tissue that remains unaltered by the optical radiation is controlled.

Yet another aspect of this invention is an apparatus that provides the predetermined treatment pattern comprising at least one laser source, a means for delivering the laser beam to a targeted tissue volume, and a hand piece that contacts the targeted tissue volume, and a controller that controls the delivery of laser energy such that the predetermined treatment pattern is accomplished.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, objects and advantages of the present invention are more readily understood from the following detailed description in conjunction with the accompanying drawings, where:

FIG. 1 is an illustration of skin exposed to laser radiation using a prior art system for skin resurfacing.

FIG. 2 is a schematic showing the inflammatory, cell proliferative, and dermal maturation phase of normal cutaneous wound healing.

FIG. 3 is an illustration of skin exposed to laser radiation using a prior art system for skin remodeling.

trichoepitheliomas, trichilemmomas, xanthelasma, apocrine hidrocystoma, verruca, adenoma
sebaceum, angiokeratomas, angiolymphoid hyperplasia, pearly penile papules, venous lakes,
rosacea, wrinkles, etc. While specific examples of dermatological conditions are mentioned
above, it is contemplated that embodiments of the present invention can be used to treat
5 virtually any type of dermatological condition.

FIGS. 6 through 9 illustrate some embodiments of this invention. In FIGS. 6 through 9,
target tissue 10 is the volume of tissue comprising thermally altered and unaltered tissue that
is being addressed by the therapy. In FIGS. 6 and 7 the intended treatment is resurfacing of
the skin so that the patient's skin looks younger and healthier. The objective is to remove
10 much of epidermis 11 and stimulate the rejuvenation process in the dermal region 12. As
shown in FIG. 4, the thermally altered volume of tissue 20, comprises the treatment zone 21
and the HSZ 22. The thermally unaltered tissue 23 surrounds the thermally altered volume of
tissue 20. The thermally altered volume of tissue 20 comprising the treatment zone 21 and the
heat shock zone 22 (HSZ) are illustrated in FIGS. 7 through 9 also. For illustrative purposes
15 the boundaries between the treatment zone 21 and the HSZ 22 are clearly marked. One skilled
in the art would understand that the treatment zone 21 is made up of tissue that has been
almost completely necrosed and the HSZ 22 is made of substantially viable tissue that has
been thermally altered. Treatment zone 21 is made up of tissue that has lost its inherent
biological activity and has typically experienced temperatures higher than 75°C. HSZ 22 is
20 the tissue volume surrounding treatment zone 21 that has typically been exposed to
temperatures above 37°C and up to 45°C. This thermally altered tissue is viable and capable
of mounting and assisting a robust tissue repair response.

FIGS. 6 and 7 illustrate the situation where the treatment zones 21 are predominantly in the epidermis. FIG. 6 illustrates the effect of the inventive treatment where a significant portion of the keratinocyte stem cell cluster 110 and the basal keratinocyte transient amplifying cells 111 are spared. Again, one skilled in the art would understand that the treatment zones 21 and the HSZs 22 do not abruptly end at the epidermis, but are substantially in the epidermis. It is likely that there will be a thermal spread into the epidermis 11. The extent of the thermal spread is generally a function of the power, pulse width, and wavelength of the laser beam, of the optical focal length and focus depth of the optical system, and of the thermal conductivity and temperature of the tip that could be placed in contact with the surface of the skin.

FIG. 8 illustrates a skin remodeling treatment where the target tissue 10 is the dermis 12. Thermally altered tissue 20 is primarily confined to the dermis 12. Again, it is to be understood that it is likely that a small thermal spread could occur in the epidermis 11.

FIG. 9 shows where the thermally altered tissue 20 spans the epidermis 11 and the dermis 12. This illustrates the situation where one desires to have skin resurfacing, partial removal of the epidermis 11, and collagen shrinkage in the dermis 12.

FIGS. 9A, 9B, 9C, 9D, 9E, 9F, and 9G illustrate different shapes the thermally altered tissue 20 can take. A thermally altered tissue volume 20 would be made up of treatment zone 21 and a HSZ 22. The shape of the treatment zone 21 will dictate to a large extent the shape of the HSZ 22, as HSZ 22 is generated in part by thermal diffusion of the heat energy deposited in the treatment zone 21. The shape of the treatment zone 21 can be controlled by the appropriate combination of the laser beam spot size, fluence (energy per unit area), pulse

duration, energy per pulse, laser wavelength, optical beam profile, system optics, lotion, contact tip temperature, and contact tip thermal conductivity.

For example, a circular laser beam of 1500 nm wavelength emitted from a single mode fiber, focused to a depth of 615 μm within the skin with a pulse energy of 12 mJ, an exposure
5 time of 12 ms, a peak power of 1 W, an optical magnification of approximately 6:1 (i.e., the image is 6 times smaller at the focal point in comparison with the object at the output of the fiber when focused in air instead of in skin) when focused in air instead of in skin, and a passively cooled glass plate in contact with the skin through an optically transparent index matching lotion will create a treatment zone **21** that is approximately cylindrical as shown in
10 FIG. **9D**. Cross sections of several such treatment regions are shown in FIGS. **9A, 9B, 9C, 9D, 9E, 9F, and 9G**. For this type of treatment, the resulting treatment zone will be approximately 100 to 300 μm in diameter (perpendicular to the direction of the incident beam) and approximately 150 to 900 μm deep in the direction of the beam. FIGS. **9A, 9B, 9C, 9D, 9E, 9F, and 9G** illustrate the shape and depth of the thermally treated zones that could be
15 created by various combinations of laser pulse duration, pulse energy, and focal depth. In these figures, the y axis shows the depth of penetration of the thermally altered zone from the surface of the skin, where 0 is the skin surface and -600 would indicate 600 μm into the skin (past the epidermal-dermal junction). The x axis shows the size of the altered tissue zone in the radial direction. FIGS. **9A, 9B, 9C, 9E, 9F, and 9G** show shapes of the treatment zone **21**
20 and the HSZ **22** that could be generated by using the same parameters as used for FIG. **9D**, but with changes in the pulse duration, pulse energy, and focus depth as described in Table 1. As can be seen by examining FIG. **9C**, treatment zones **21** can be created that are non-cylindrical.

TABLE 1:

	Pulse Duration (msec)	Pulse Energy (mJ)	Focus Depth Below The Surface Of The Skin (μm)
FIG. 9A	3	3	55
FIG. 9B	12	12	55
FIG. 9C	12	12	335
FIG. 9D	12	12	615
FIG. 9E	20	20	615
FIG. 9F	12	12	755
FIG. 9G	25	25	755

FIG. 10 shows one embodiment of the present invention, where the heat shock zones 22 overlap. The center of the target zones 21 are separated by pitch 24. If the pitch is less than the diameter of the HSZs 22 then the HSZs 22 overlap. These overlapping HSZs 22 can be positioned such that, overall, the target tissue 10 is left with no thermally unaltered tissue. One way the HSZs 22 can be made to overlap with each other is by adjusting where the laser beam lays down the spots. If two or more treatment zones 21 are designed to lie in close proximity to each other and if the spots are laid down in quick succession, then the net increase of temperature due to closely spaced treatment zones may be sufficient to increase the size of individual HSZs 22. In this type of treatment, it is important for the treatment zones that are contributing to the creation of the HSZs to be created in a time short enough to prevent thermal diffusion from removing thermal energy from the adjacent treatment regions that are contributing thermal energy to the creation of the spatially enhanced HSZ. Another

method would use a combination of thermal diffusion and overlap of thermal energy to create spatially enhanced HSZs. It should be noted that the thermal diffusion constant depends on the dimensions of the cell structures and heat dissipating blood flow. Consequently, the thermal diffusion constants are different in the avascular epidermis and highly vascularized dermis. An alternative way to overlap the HSZs **22** will be to make the HSZ **22** significantly larger than the treatment zone **21**. One approach to make the HSZ **22** larger than the treatment zone **21** is to generate the desired treatment zone **21** using high energy densities, such that high temperature regions are created. These high temperature zones would then spread the thermal energy over a larger volume that would result in a larger HSZ **22**.

One of the key aspects of this invention is skin laser treatment that intentionally leaves behind healthy, substantially unaltered tissue **23**, such that the substantially unaltered tissue **23** helps in skin remodeling. This aspect of the invention is depicted in FIG. **11**. This illustration depicts target tissue **10** made up of treatment zone **21**, HSZs **22**, and thermally unaltered tissue **23**. As described above, the shape and size of the treatment zone **21** and the consequent HSZ **22** can be controlled by choosing the appropriate laser parameters. The volume of the unaltered tissue and the spacing between zones of thermally affected tissue **21** and **22**, and thermally unaltered tissue **23** can also be controlled by choosing the appropriate treatment parameters. For example, the treatment parameters that are used to produce the treatment zone **21** in FIG. **9A** result in a treatment zone that has its largest diameter in the epidermis **11**, with a HSZ **22** that is approximately 200 μm in diameter. A different set of treatment parameters is used to produce the treatment zone **21** in FIG. **9D**. These parameters result in a treatment zone **21** that penetrates significantly deeper into the skin and has a significantly smaller radius within the top 100 μm of the skin. In addition, these parameters

result in a HSZ 22 that is significantly wider and deeper than the corresponding HSZ 22 of FIG. 9A.

One embodiment of the apparatus used for practicing this invention is shown in FIG. 12. Apparatus 100 comprises a control system 120, an optical system 220, and a delivery system 230 to deliver the desired pre-determined treatment pattern to the target tissue 10. The control system 120 is operably connected to the optical system 220 and the delivery system 230.

For certain applications, the optical system 220 desirably includes multiple laser light sources, which can be arranged in an array, such as a one-dimensional array or a two-dimensional array. FIG. 13 shows a block diagram of the control system 120. Control system 120 is

operably connected to the input/output 103, the optical source 104, the scanning element 105, the focusing element 106 and the sensing element 107. Input/Output 103 could be a touch screen element or other such means that are well known in the art. FIG. 14 shows an optical source with the laser light sources arranged in a one-dimensional array. A laser light source can provide one or more optical beams having particular optical parameters, such as optical fluence, power, timing, pulse duration, inter-pulse duration, wavelength(s), and so forth, to produce a desired dermatological effect in the target tissue 10. By way of example, a laser light source can provide an optical beam having a wavelength or range of wavelengths between approximately 400 nm and 12,000 nm, such as between approximately 600 nm and 4,000 nm. For purposes of non-ablative coagulation of a dermal layer 12 of the targeted portion 10, a laser light source can provide an optical beam having a wavelength of approximately 1,500 nm and an optical fluence incident on the outer surface of the skin between approximately 0.001 Joules/cm² and 100,000 Joules/cm², such as between approximately 1 Joules/cm² and 1000 Joules/cm². For certain applications, the pulse duration

of an optical beam can be approximately equal to or less than a thermal diffusion time constant, which is approximately proportional to the square of the size of a focal spot within the targeted portion **10**, associated with the desired treatment zone **22**. Pulse durations that are longer than the thermal diffusion time constant can be less efficient and cause the focal spot to undesirably grow or shrink by thermal diffusion. This is one approach for making HSZs **32** overlap, as shown in FIG. **10**.

Examples of laser light sources include, but are not limited to, diode lasers, diode-pumped solid state lasers, Er:YAG lasers, Nd:YAG lasers, argon-ion lasers, He-Ne lasers, carbon dioxide lasers, excimer lasers, erbium fiber lasers, ruby lasers, and so forth. For certain embodiments, a laser light source is desirably a diode laser, such as an infrared diode laser. However, it should be recognized that the selection of a particular type of laser light source in the optical system **220** is dependent on the types of dermatological conditions to be treated using the dermatological apparatus **100**. The optical source **221** could include one particular type of laser light source capable of providing one wavelength or wavelength range. Alternatively, the optical source **221** could include two or more different types of laser light sources to provide a variety of different wavelengths or wavelength ranges. Optical beams from different laser light sources can be directed to the targeted portion **10** on a one-by-one basis or at the same time. In addition, one skilled in the art would recognize that while laser is the preferred embodiment of the optical source described here, other optical sources such as a flashlamp could also be used.

Referring to FIG. **15**, the optical delivery system **320** also includes a focusing element **106** that is optically coupled to the optical source **104**. The focusing element **106** functions to direct optical energy from the optical source **104** to the targeted portion **10**. In the present

embodiment, the focusing element **106** directs optical energy to the targeted portion **10** by focusing the power of the optical energy to one or more treatment zones within the target tissue **10**. Desirably, multiple treatment zones are simultaneously or sequentially exposed to optical energy. Multiple treatment zones can be separated from one another so as to form
5 discrete treatment zones. Alternatively, or in conjunction, multiple treatment zones can intersect or overlap one another.

In the present embodiment, the focusing element **106** directs optical energy in a pattern, such as a discontinuous or microscopic pattern, so that one or more treatment zones are exposed to optical energy. Use of a pattern of optical energy provides greater efficacy of
10 treatment by allowing for control of the fraction of the target tissue **10** that is exposed to optical energy. Different patterns can provide a variety of different thermally altered zone **20** and a particular pattern can be selected based on the type of dermatological condition to be treated. For instance, in the case of a sensitive dermatological condition such as dermal melasma or deep pigmented lesions, the use of a pattern of optical energy permits an effective
15 level of treatment within multiple treatment zones. At the same time, by controlling the fraction of the targeted portion **10** that is exposed to optical energy, pain, immune system reaction, trauma, and other complications can be reduced. By having the treatment zones adjacent to healthy and substantially undamaged cells, healing of the targeted portion **10** is quicker, since the possibility of congestion or impairment of repair processes is reduced. Use
20 of a pattern of optical energy also can facilitate multiple treatments to produce a desired effect by allowing safer individual fractional treatments to be combined to produce a significant result. This is expected to be milder and to pose a lower risk to a patient. Furthermore, visible impressions of treatment can be reduced by using a pattern of treatment where an

individual treatment zone is on the same or smaller scale than the normal visible texture or constituents of the skin itself.

The foregoing describes a system and method for laser surgery wherein a focused optical signal such as a laser, LED, or an incoherent source of optical energy is advantageously
5 created to achieve microscopic treatment zones in the range of about 1,000 μm in diameter or less. Further, the foregoing describes a method and apparatus wherein a focused optical signal can be used to treat sub-epidermal regions without damaging epidermal regions. Additionally, the disclosed system and method describe the use of a lens with high numerical aperture. Persons of ordinary skill in the art may modify the particular embodiments described herein
10 without undue experimentation or without departing from the spirit or scope of the present invention. All such departures or deviations should be construed to be within the scope of the following claims.

What is claimed is:

1. A method for achieving beneficial effects in a target tissue in skin comprising treating the target tissue using optical radiation to create one or more microscopic treatment zones such that the ratio of the sum of the treatment zones to the target tissue volume is less than one, and the treatment zones are created by a predetermined treatment pattern.
2. A method of claim 1, where the treatment zones are surrounded by thermally altered heat shock zones comprising viable tissue.
3. A method of claim 1, where the treatment zones are separated by thermally unaltered tissue.
4. A method of claim 2, where the heat shock zones are separated by thermally unaltered tissue.
5. A method of claim 1, where the treatment zone extends from the skin surface up to 4 mm into the skin.
6. A method of claim 5, where the treatment zone extends from the skin surface to the epidermal-dermal junction.
7. A method of claim 1, where the treatment zone extends from the epidermal-dermal junction to up to 4 mm into the dermis.
8. A method of claim 1, where the treatment zone ranges in size from 10 μm to 1,000 μm .
9. A method of claim 8, where the treatment zone ranges in size from 25 μm to 750 μm .
10. A method of claim 9, where the treatment zone ranges in size from 50 μm to 500 μm .
11. A method of claim 2 where the extent of the viable heat shock zone is controlled by the predetermined treatment pattern.

12. A method of claim 1, where the predetermined treatment pattern of creating the treatment zones is accomplished by choosing one or more variables from the list comprising laser wavelength, chromophore present in the skin, laser energy density, pulse duration, thermal diffusion constants and the temporal and spatial distribution of the laser energy.
- 5 13. A method for achieving beneficial effects in skin tissue comprising treating the skin by exposing a targeted part of the skin tissue to optical radiation to create one or more microscopic treatment zones such that the volume of the target tissue that remains substantially unaffected by the optical radiation is controlled.
14. A method of claim 13 where the control is achieved by focusing the optical radiation to
10 desired depths in the skin.
15. A method of claim 13 where each microscopic treatment zone is thermally altered by the optical exposure.
16. A method of claim 15 where each microscopic treatment zone is surrounded by a heat shock zone comprising viable tissue.
- 15 17. A method of claim 15 where the microscopic treatment zone is a volume defined by a radius of 10 to 1,000 μm normal to the direction of the optical radiation and a depth of up to 5mm in the direction of the optical radiation.
18. A method of claim 13 comprising choosing a target region, using a hand piece to deliver laser energy to the target region, where the target region is treated by the movement of the
20 hand piece over the target region when the area of the target region is greater than the cross sectional area of the hand piece.
19. A system for providing dermatological treatment comprising:
a source of optical radiation;

a means for delivering the optical radiation to a target volume of skin;

a control system that is operably connected to the source of optical radiation and the means for delivering the optical radiation;

the control system programmed to control the delivery of optical radiation to the target volume in a pre-determined treatment pattern; and

the pre-determined treatment pattern comprising microscopic treatment zones such that the ratio of the sum of the treatment zones to the target tissue volume is less than one.

20. A system for providing dermatological treatment comprising:

a source of optical radiation;

a means for delivering the optical radiation to a target volume of skin;

a control system that is operably connected to the source of optical radiation and the means for delivering the optical radiation;

the control system programmed to control the delivery of optical radiation to the target volume to create one or more microscopic treatment zones such that the volume of the

target tissue that remains substantially unaffected by the optical radiation is controlled.

ABSTRACT

- A method and apparatus for providing fractional treatment of skin using lasers is disclosed. The method involves creating one or more microscopic zones of thermally altered tissue and intentionally leaving viable tissue to surround the microscopic zones.
- 5 The dermatological apparatus includes one or more light source, a controller and an energy delivery means to generate the microscopic zones. The controller is also capable of generating these zones in a predetermined pattern and the zones could be confined to the epidermis, dermis or span the length of the epidermis and the dermis.

FIG. 1

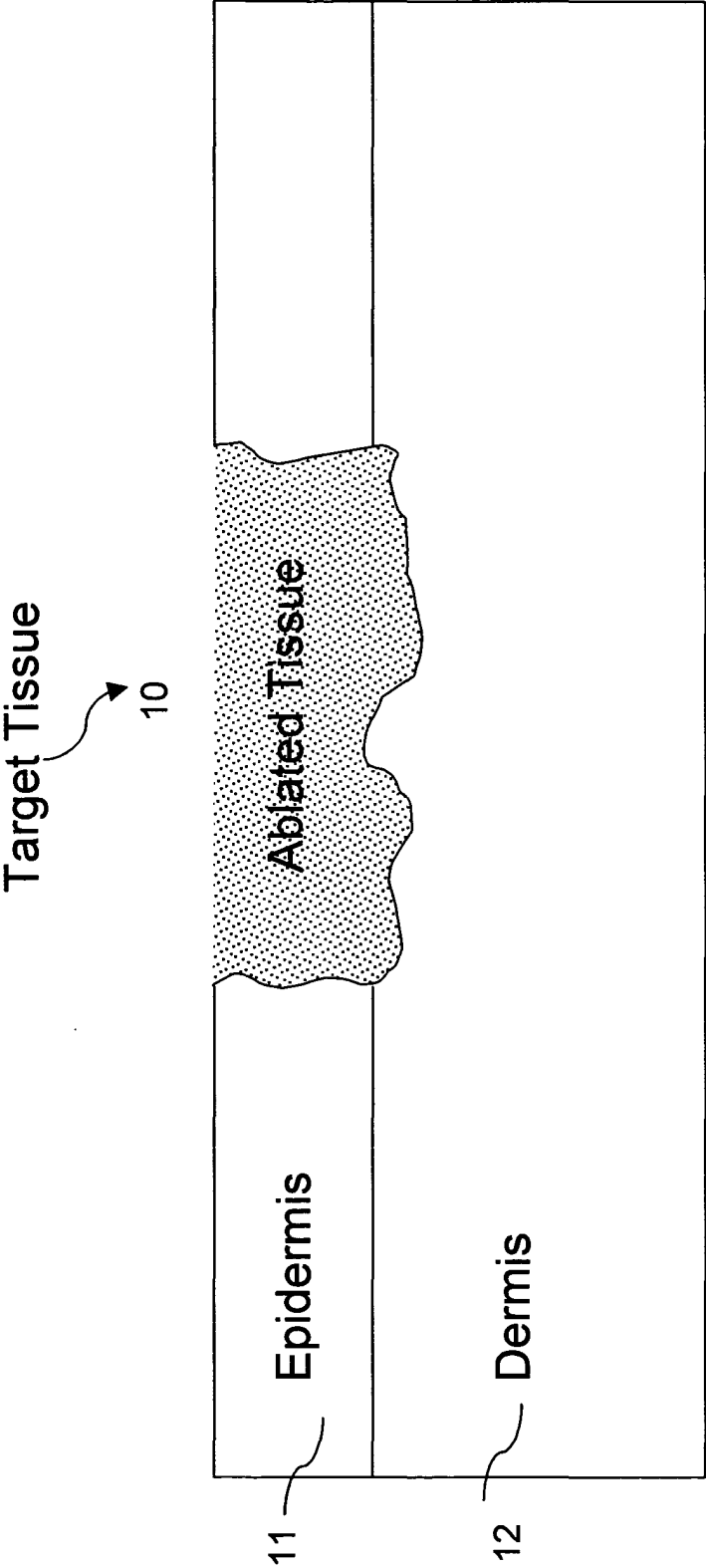


FIG. 2

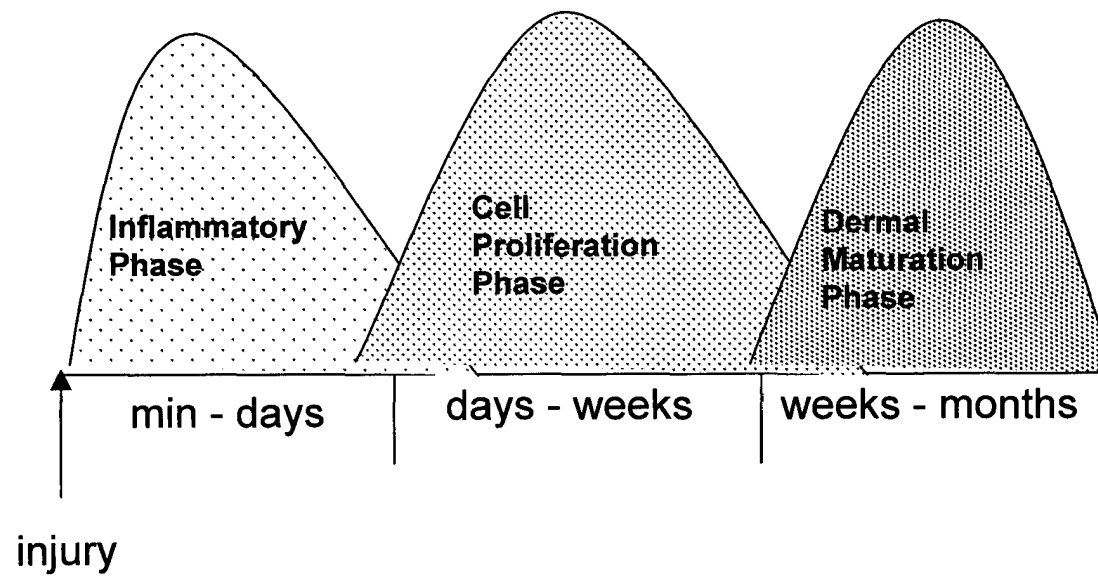


FIG. 3

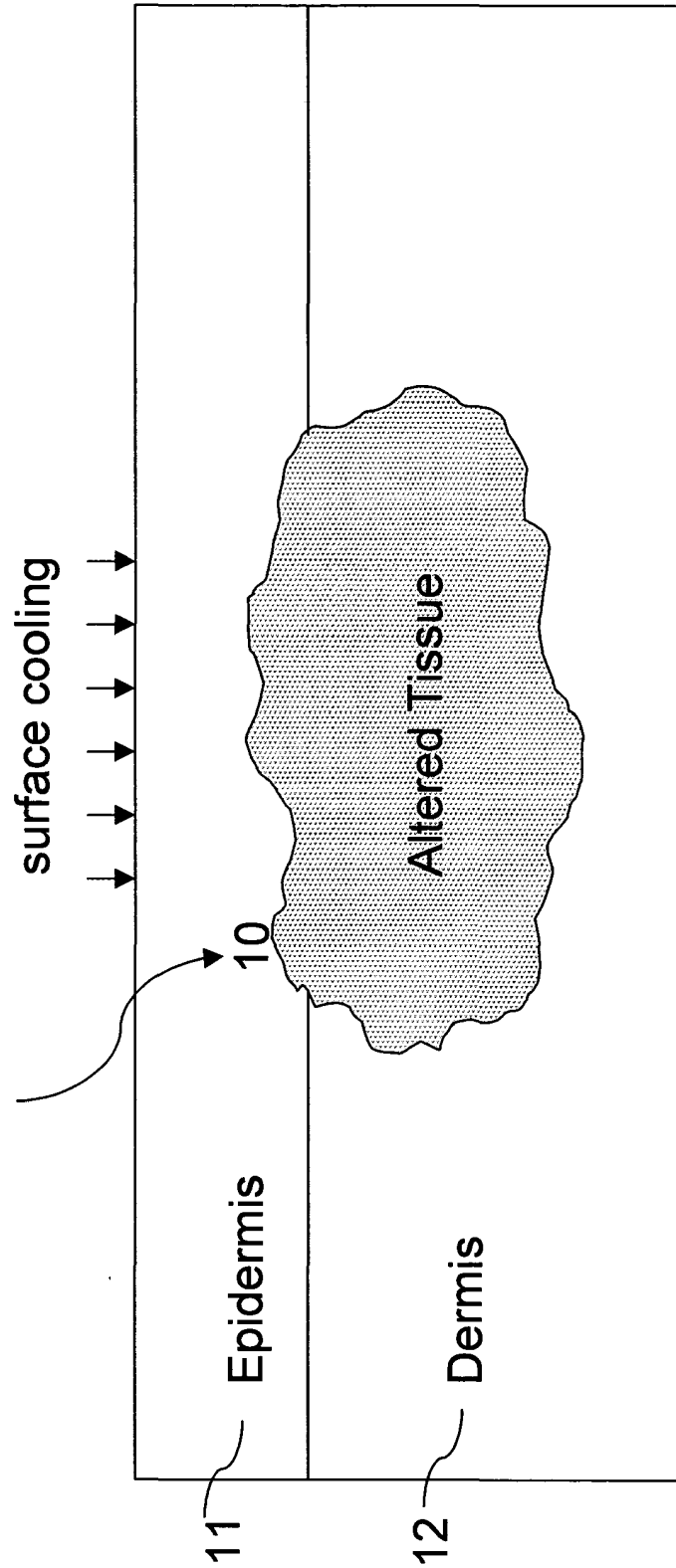


FIG. 4

Thermally Altered Tissue

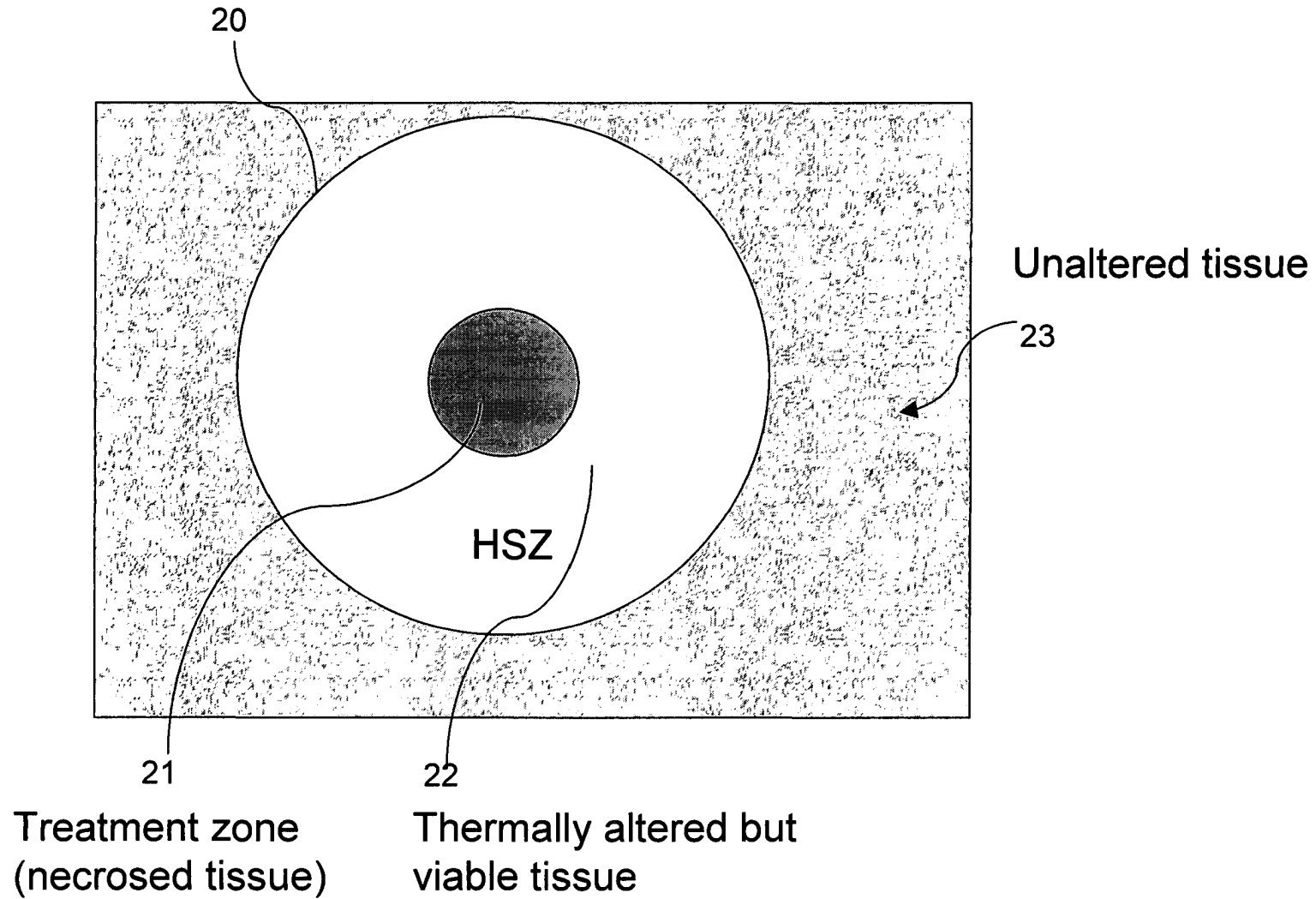


FIG. 5

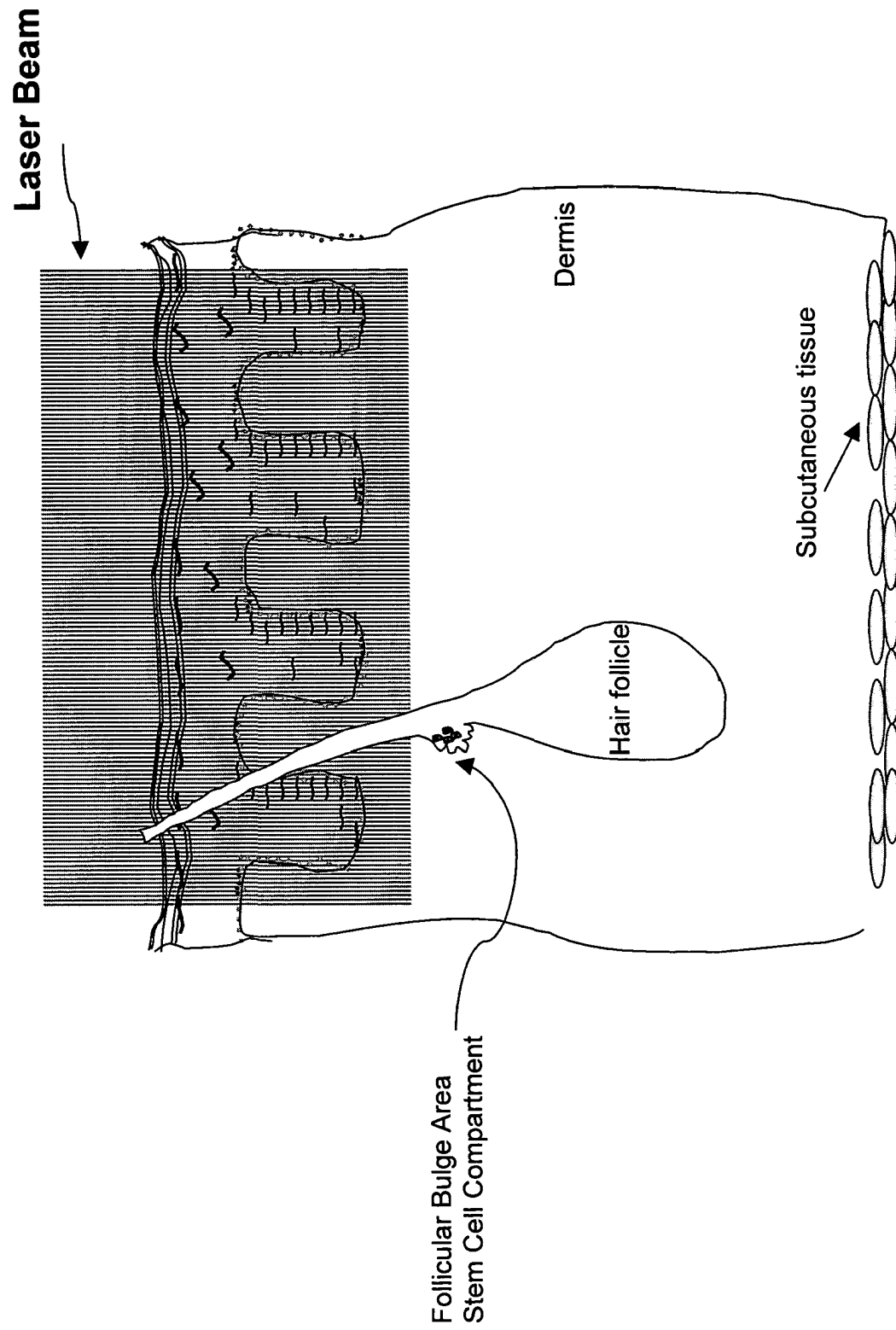


FIG. 6

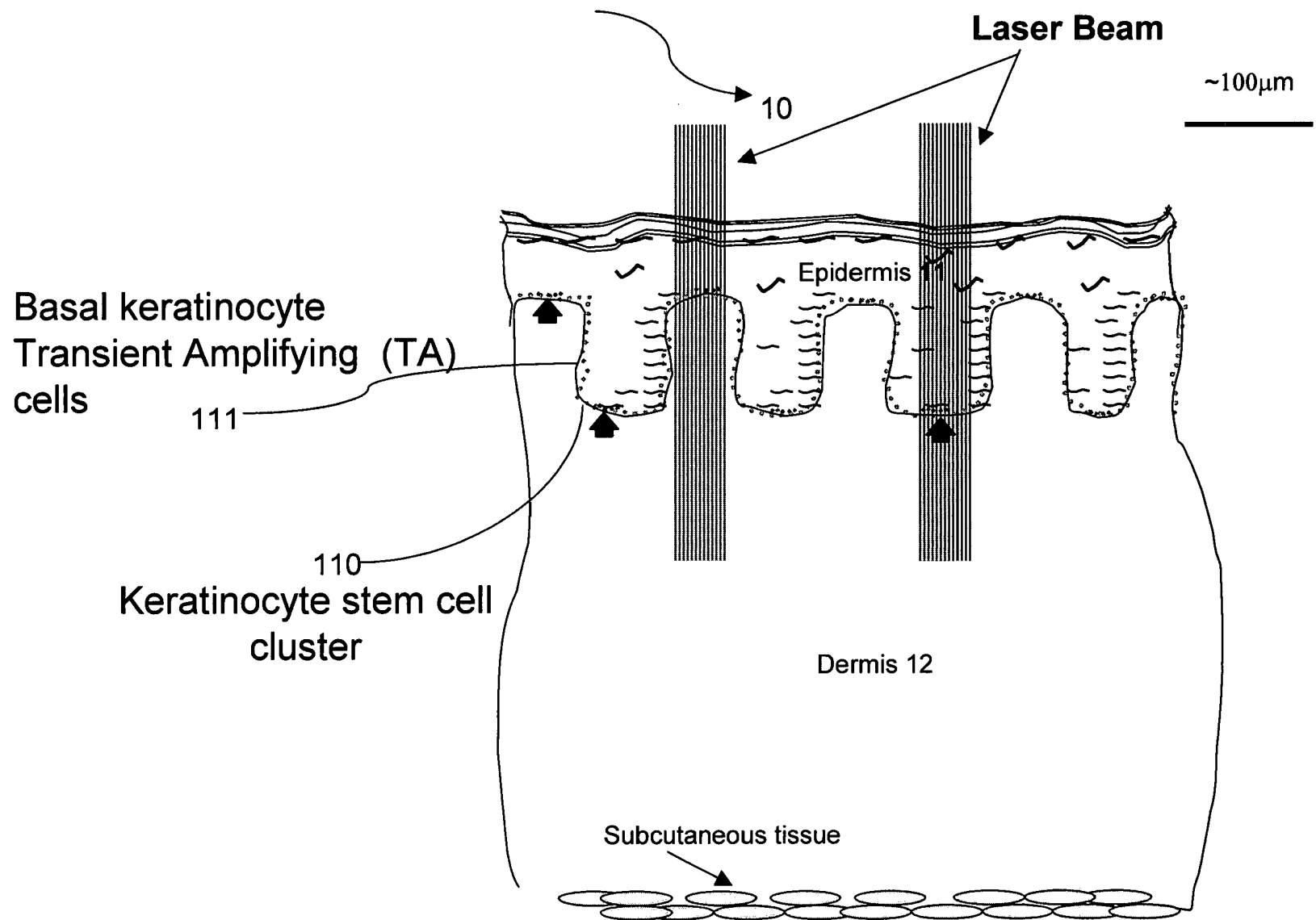


FIG. 7

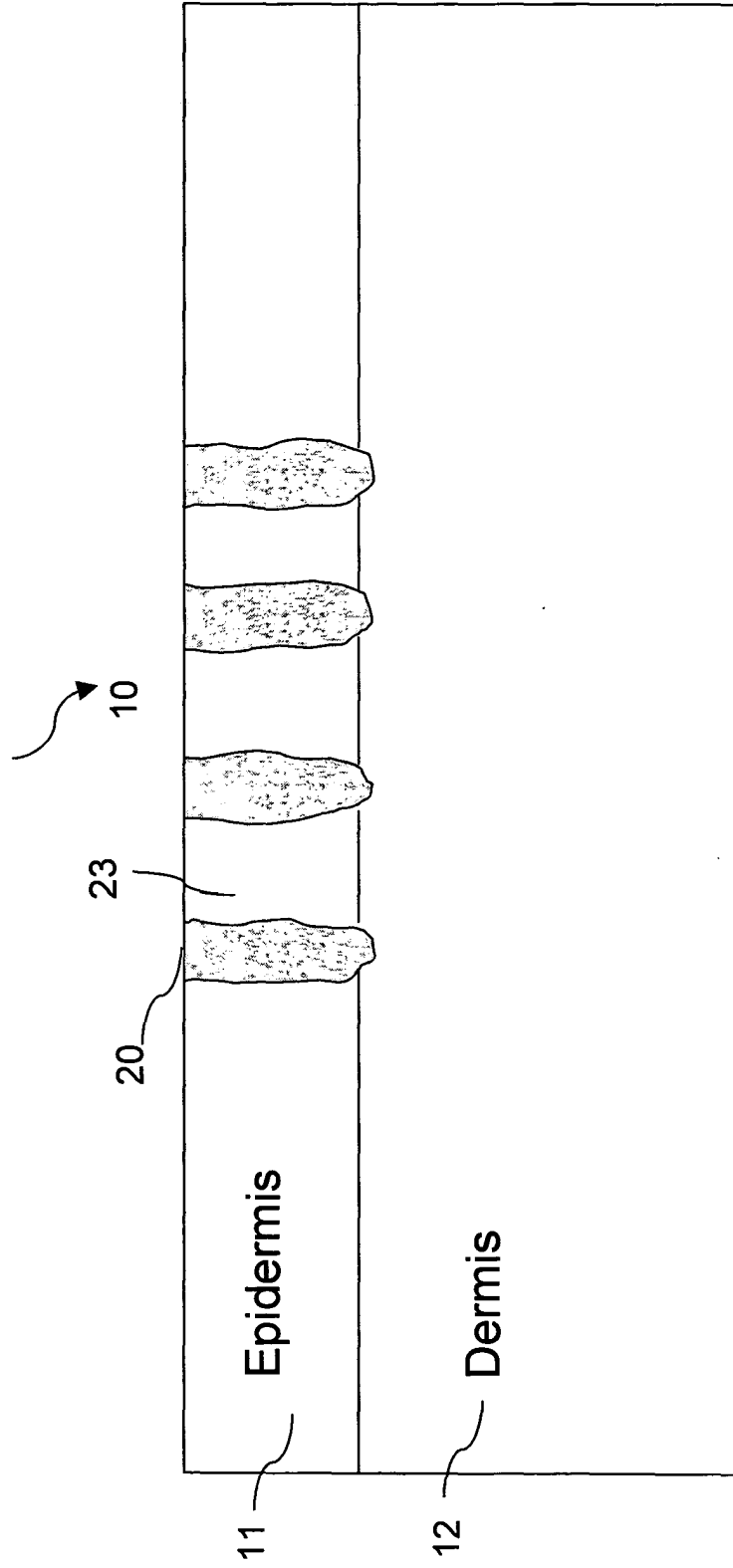


FIG. 8

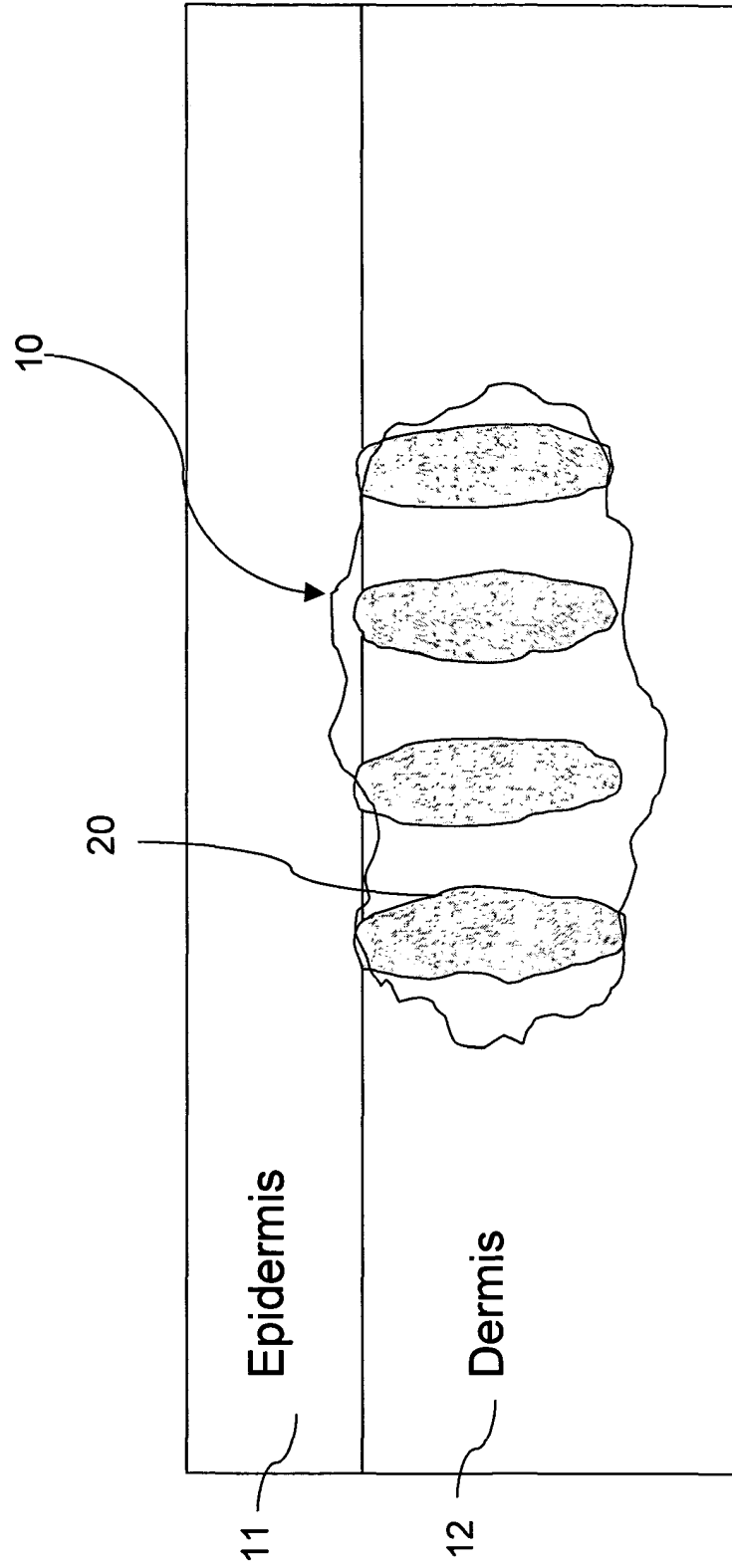


FIG. 9

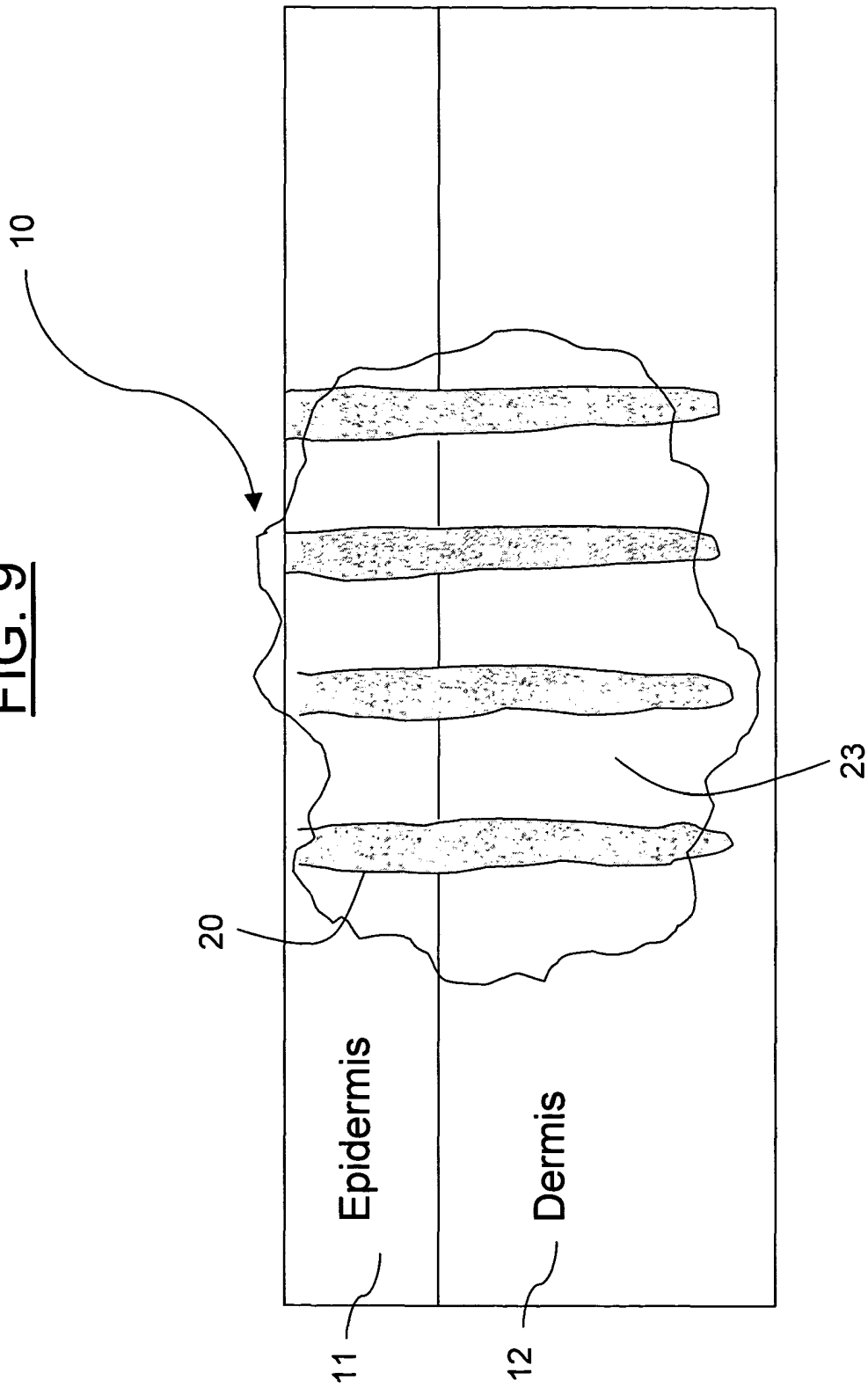


FIG. 9A

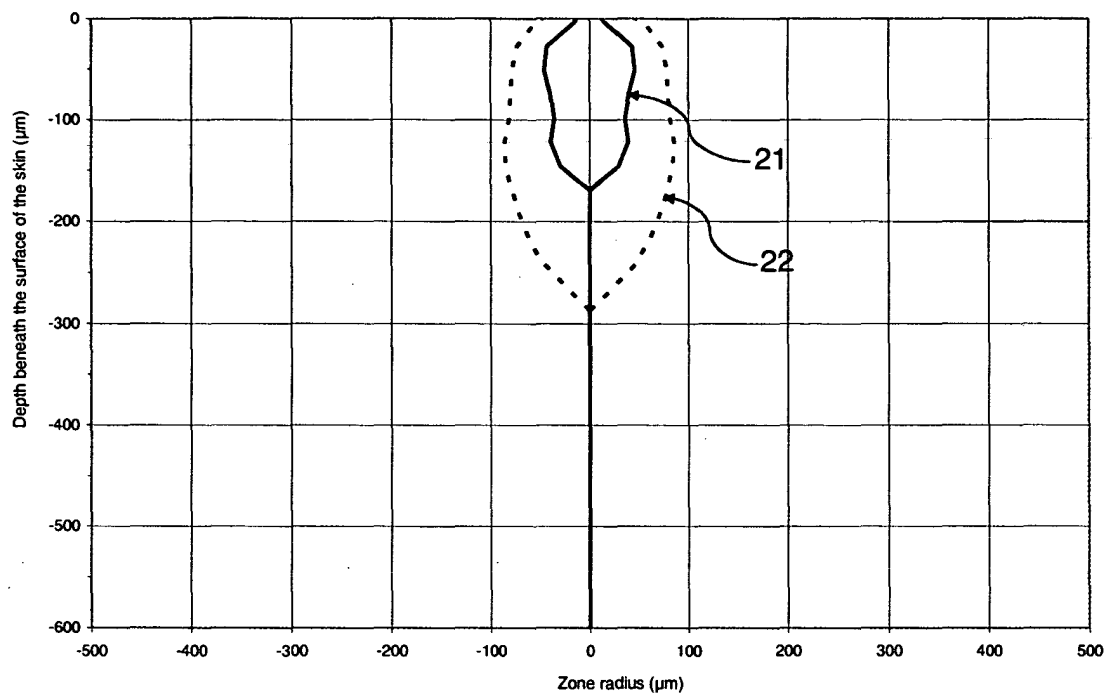


FIG. 9B

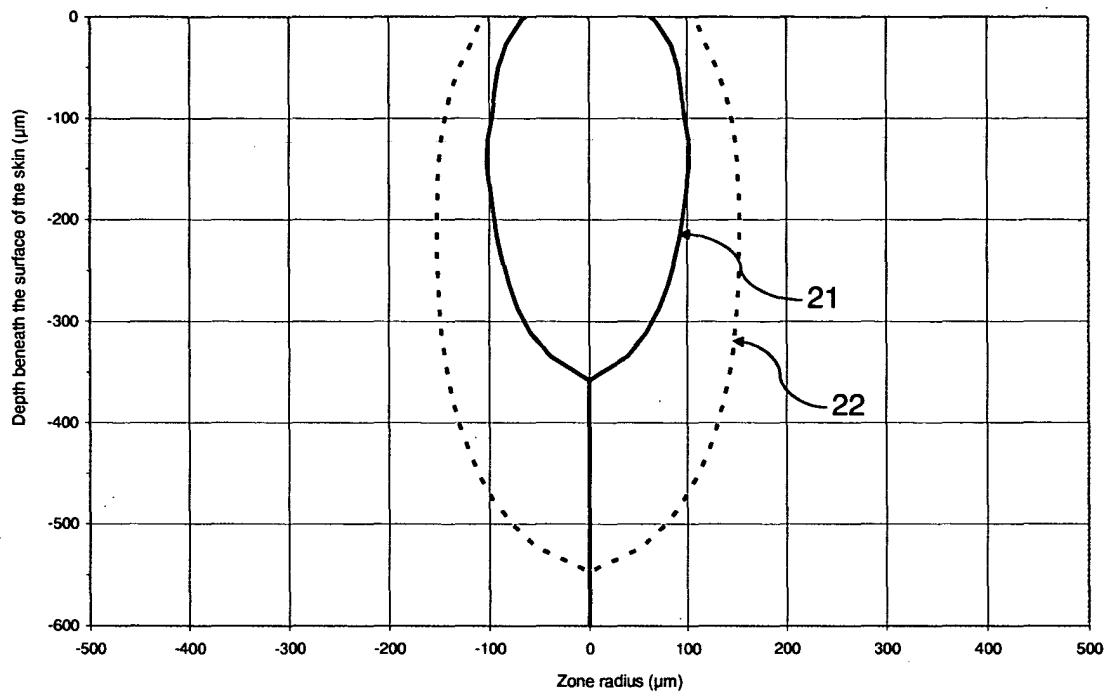


FIG. 9C

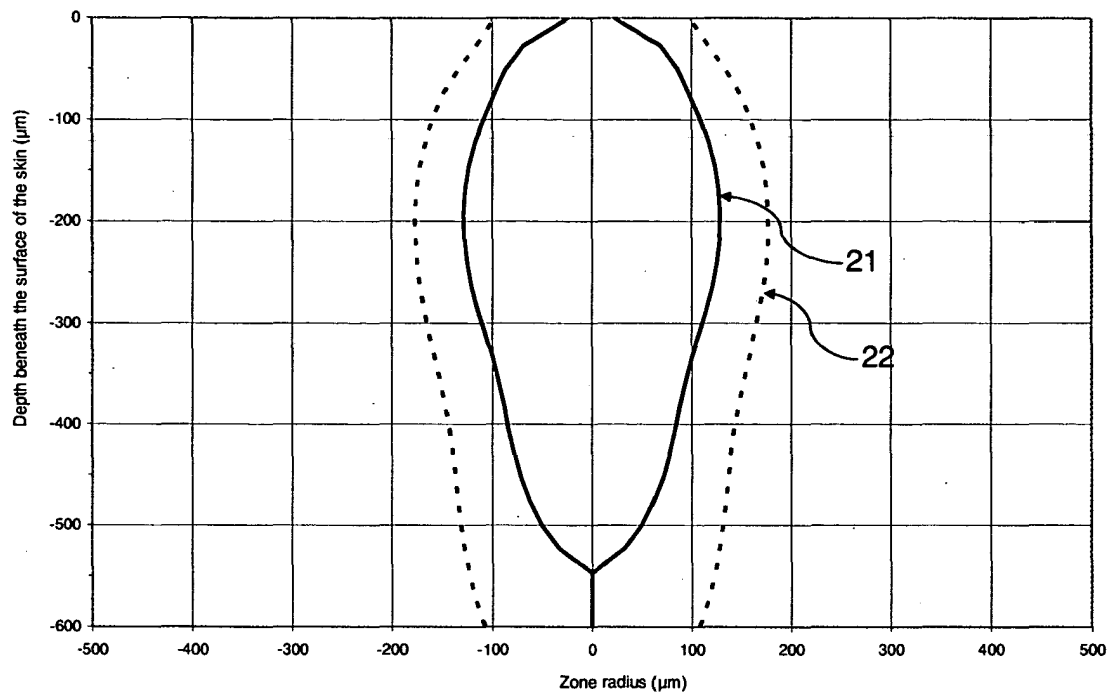


FIG. 9D

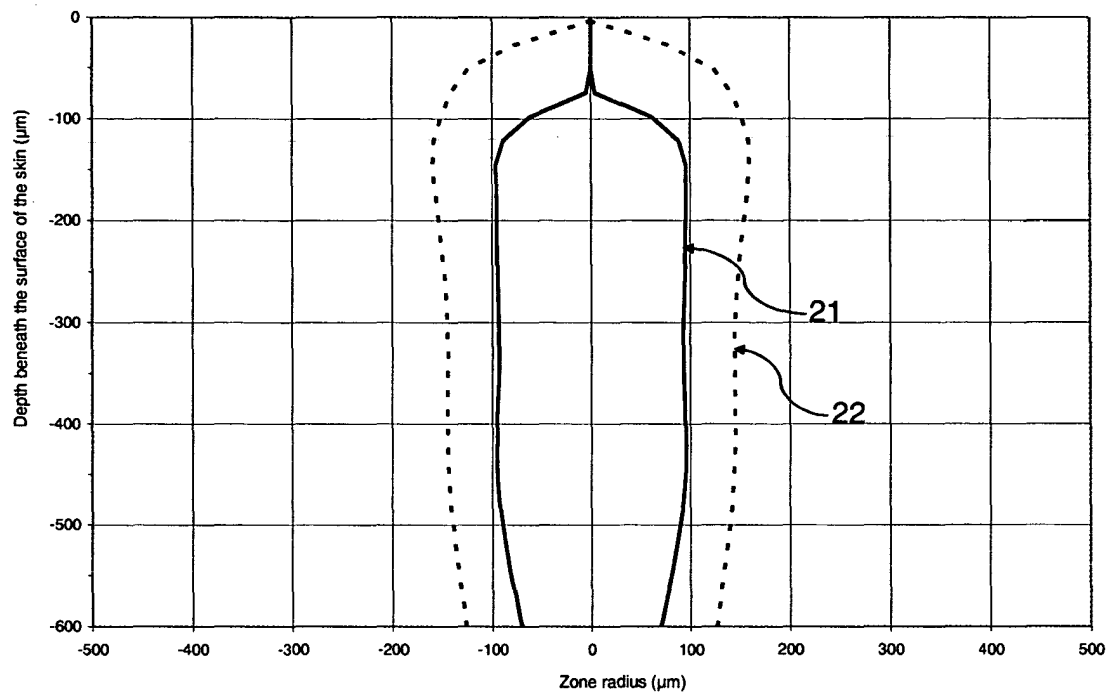


FIG. 9E

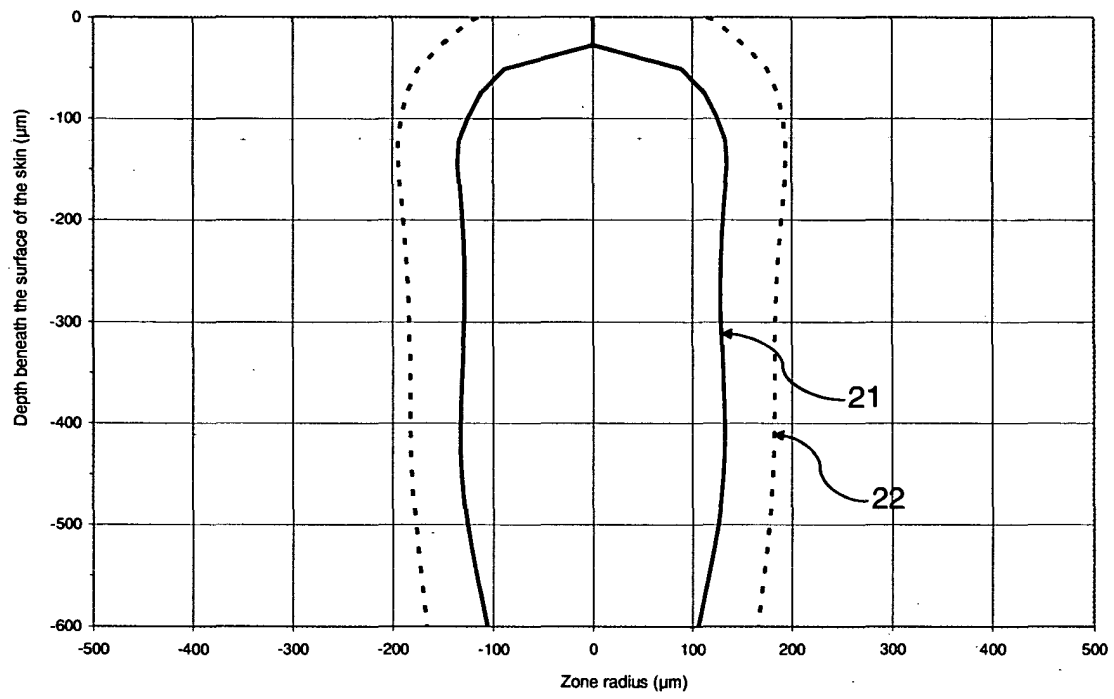


FIG. 9F

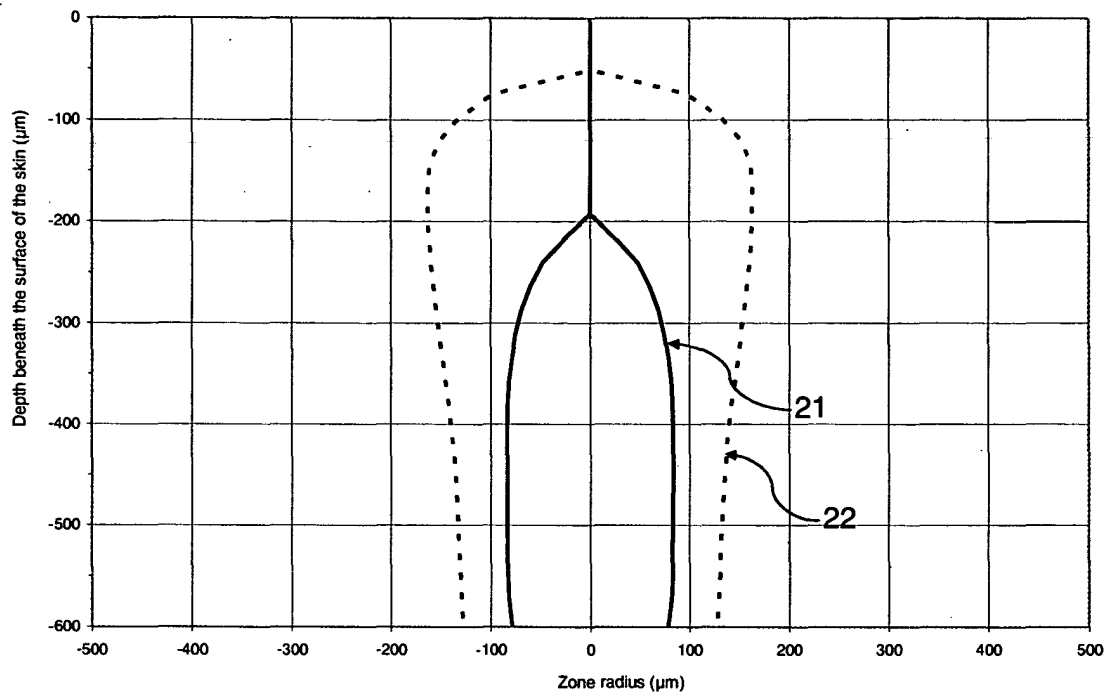


FIG. 9G

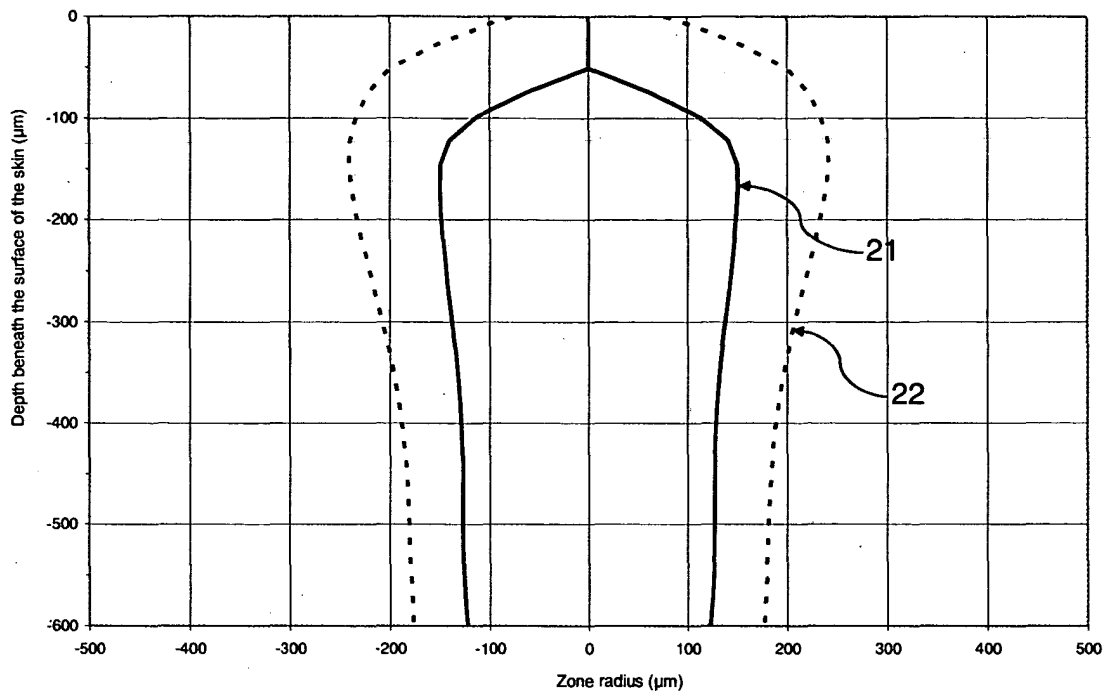


FIG. 10

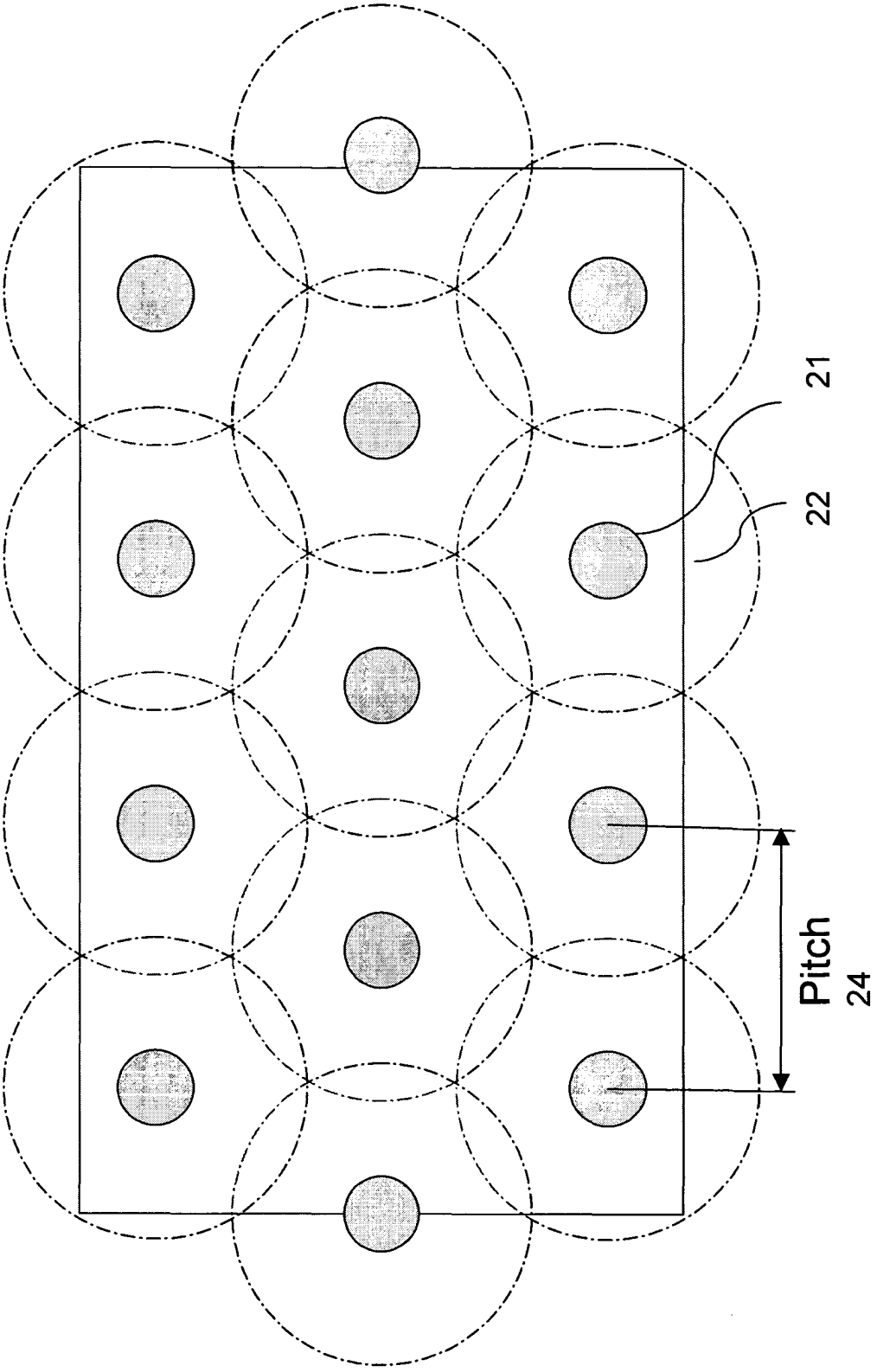


FIG. 11

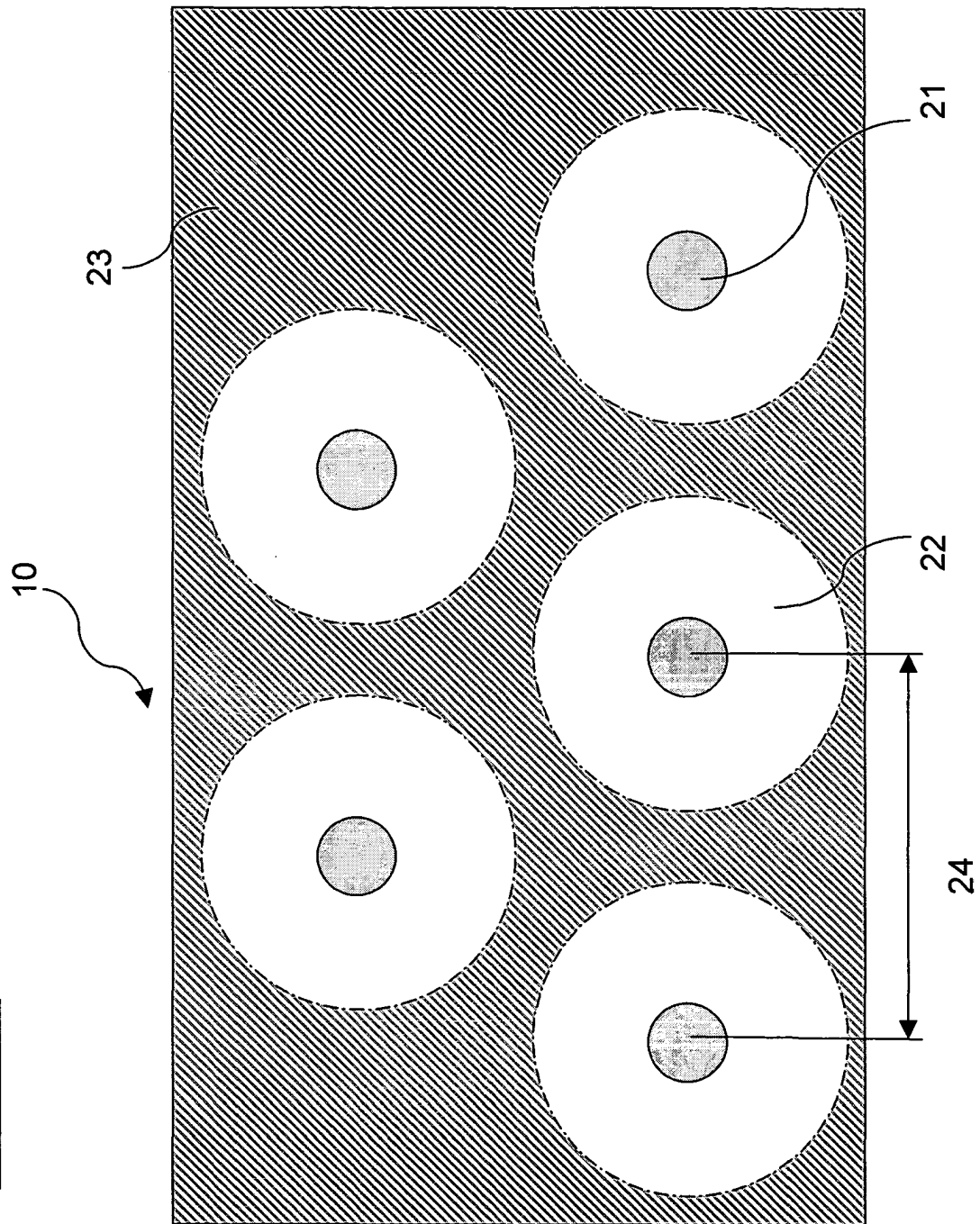


FIG. 12

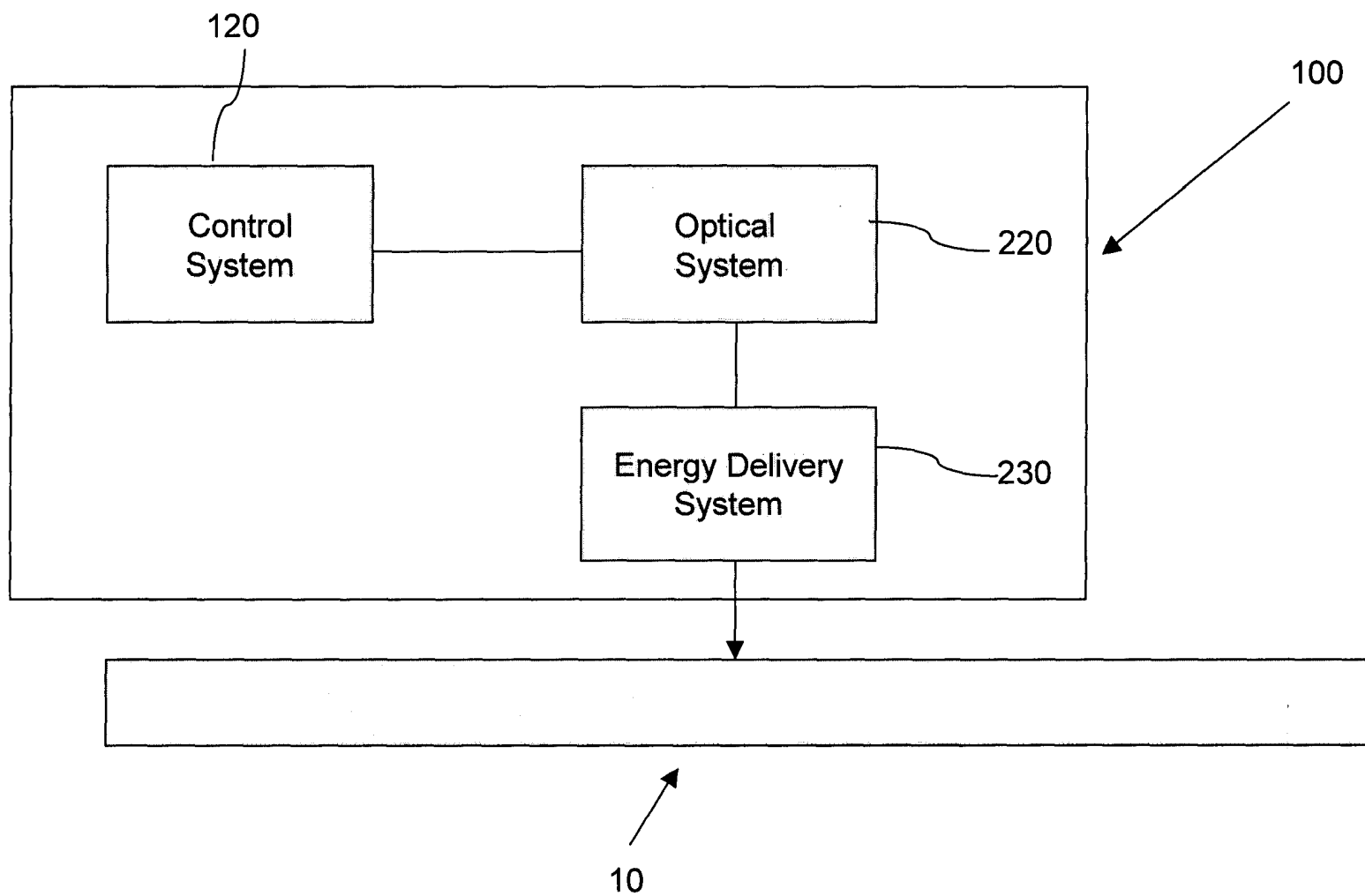


FIG. 13

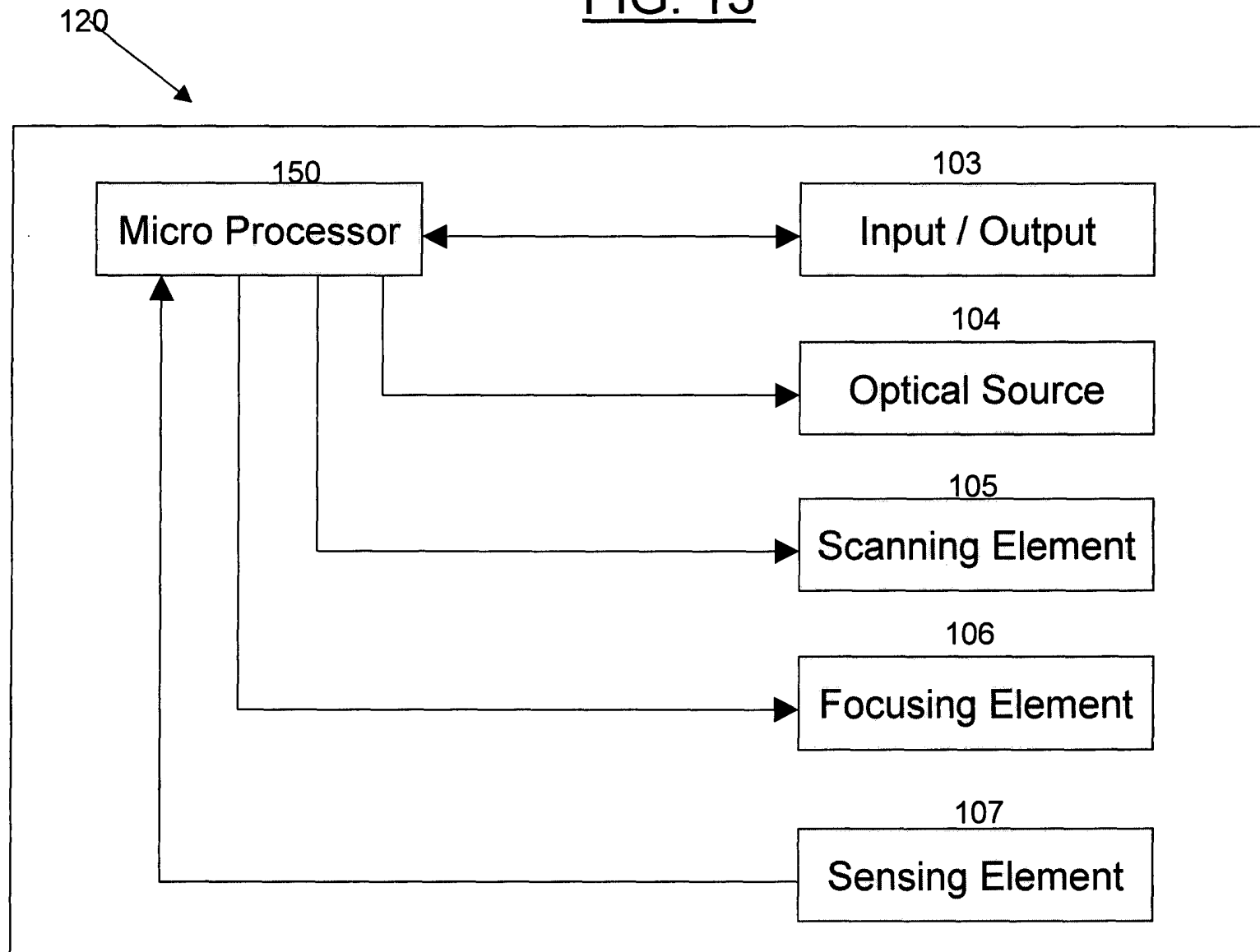


FIG. 14

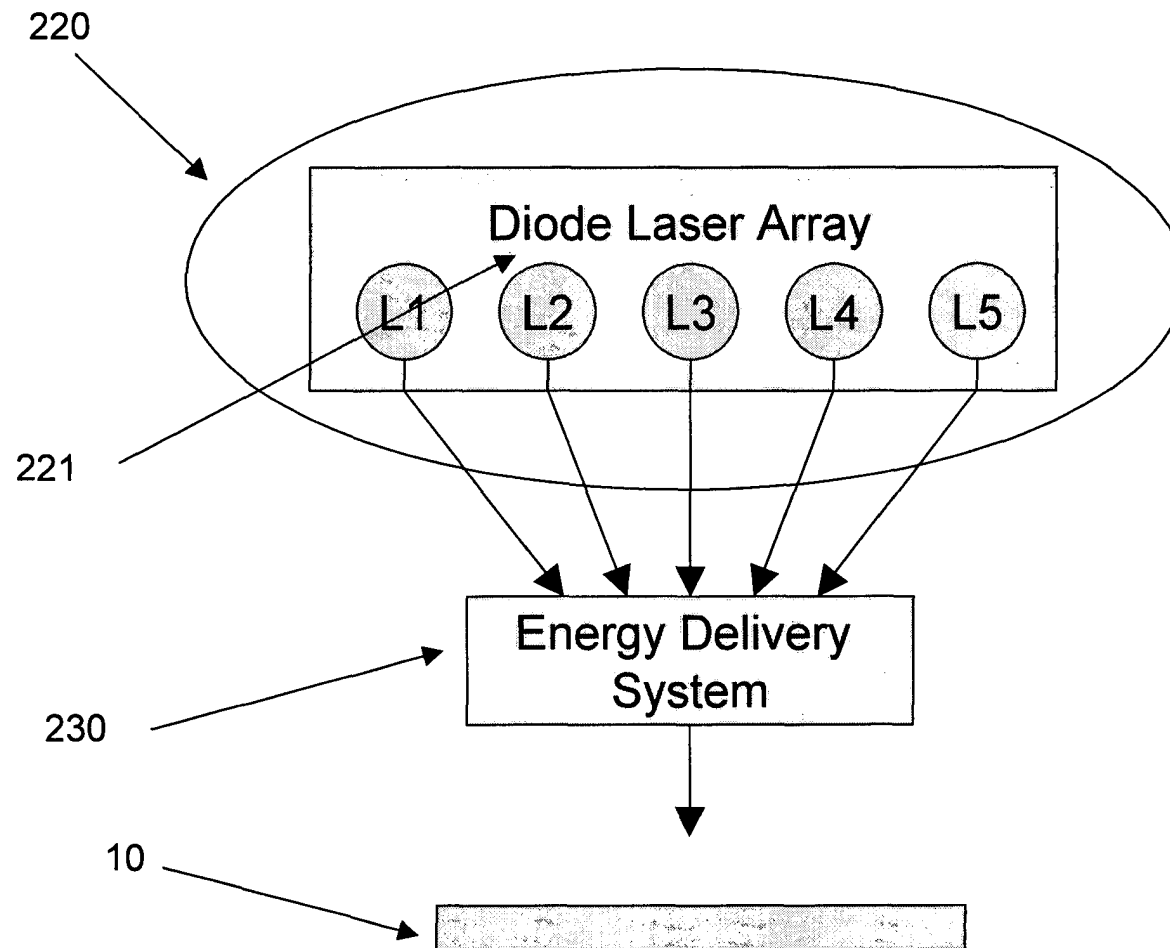


FIG. 15

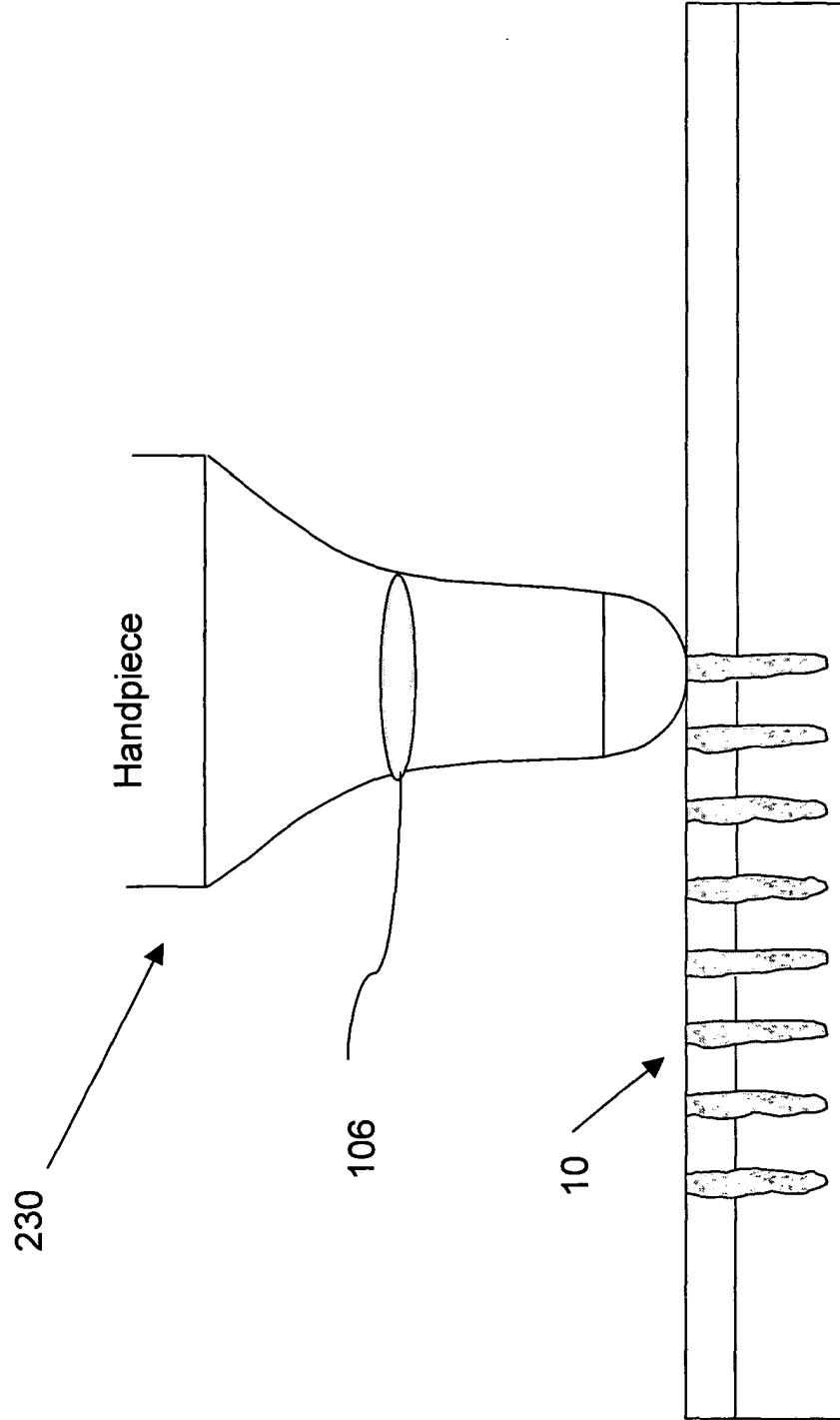


FIG. 16

