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(54) Title: SCANNER APPARATUS HAVING ELECTROMAGNETIC RADIATION DEVICES COUPLED TO MEMS ACUATORS

(57) Abstract: A disclosed scanner apparatus includes a member having spaced apart proximal and distal portions. An electromagnetic radiation device is configured to direct electromagnetic radiation therefrom and is moveably coupled to the distal portion of the member. The electromagnetic radiation device is configured to move in a first plane of movement to a first position to direct the electromagnetic radiation along a first path and configured to move in the plane of movement to a second position to direct the electromagnetic radiation along a second path. A MicroElectroMechanical Systems (MEMS) actuator is coupled to the electromagnetic radiation device, wherein the MEMS actuator is configured to move in a first direction to move the electromagnetic radiation device to the first position and configured to move in a second direction to move the electromagnetic radiation device to the second position. Other scanning and robotic structure devices are disclosed.

SCANNER APPARATUS HAVING ELECTROMAGNETIC RADIATION DEVICES COUPLED TO MEMS ACUATORS

CLAIM FOR PRIORITY

This application claims priority to U.S. Provisional Patent Application No. 60/233,262, filed on September 14, 2000, by Smith et al., entitled *Apparatus for Producing Forward-Looking Angular & Transverse Optical Scans*, the entire disclosure of which is hereby incorporated herein by reference in its entirety.

STATEMENT OF GOVERNMENT SUPPORT

This invention was made with U.S. Government support under grant number HL-58754 from the National Institute of Health. The U.S. Government has certain rights to this invention.

FIELD OF THE INVENTION

The present invention relates to scanner devices in general, and more particularly, to electromagnetic radiation scanner devices.

BACKGROUND OF THE INVENTION

It is known in some industrial, medical, and consumer applications to scan objects. For example, U.S. Patent No. 5,321,501 to Swanson et al. entitled *Method and Apparatus for Optical Imaging with Means for Controlling the Longitudinal Range of the Sample,* describes an assembly that scans angularly and transversely as shown in Figures 4A and 4B therein. As discussed in Swanson, the mechanism (107) that provides the scanning motion can be a piezoelectric crystal, a stepper motor, an electromagnetic actuator, or an electrostatic actuator. Some of these scanning mechanism may have control problems. For example, the oscillatory response of a piezoelectric crystal may suffer from hysteresis. Stepper motors can be large and consume significant power. Electromagnetic actuators may not be easily made in small sizes.

Scanners may also be utilized in biomedical areas. Some applications in the biomedical area include corneal resurfacing, optical imaging, and hair and tattoo removal. It is known to use galvanometers and other resonant scanners to steer optical beams in these types of biomedical applications. While galvanometers may offer a range of scan speeds and scan angles, galvanometers may require large magnetic bases and mirrors having relatively large masses to achieve desirable performance characteristics.

It is also known to fabricate scanners on silicon wafers using polysilicon as a substrate. It is also known to use electrostatic forces (amplified using comb drives), magnetic fields, thermal bending of bimorph cantilevers, and piezoelectric actuation to move mirrors in such scanners. These scanners can produce optical scan angles of about 7 to 180 degrees at frequencies from 40Hz to 34 kHz using voltages in a range from 20 volts to 171 volts.

SUMMARY OF THE INVENTION

Embodiments according to the present invention can provide scanner devices. Pursuant to these embodiments, a member can have spaced apart proximal and distal portions. An electromagnetic radiation device can be configured to direct electromagnetic radiation therefrom and can be moveably coupled to the distal portion of the member. The electromagnetic radiation device can be configured to move in a first plane of movement to a first position to direct the electromagnetic radiation along a first path and configured to move in the plane of movement to a second position to direct the electromagnetic radiation along a second path. A MicroElectroMechanical Systems (MEMS) actuator can be coupled to the electromagnetic radiation device, wherein the MEMS actuator can be configured to move in a first direction to move the electromagnetic radiation device to the first position and configured to move in a second direction to move the electromagnetic radiation device to the second position.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 to 4 are schematic diagrams that illustrate scanner devices according to embodiments of the present invention.

Figures 5a and 5c are schematic diagrams that illustrate integrated force array actuators in a relaxed state and in a contracted state respectively.

Figures 5b and 5d are perspective views that illustrate single cells of an integrated force array actuator in a relaxed state and in a contracted state respectively.

Figures 6a and 6b are schematic diagrams that illustrate electromagnetic radiation devices, frames, and integrated force array actuators according to embodiments of the present invention.

Figure 7 is a perspective view that illustrates electromagnetic radiation devices configured to pivot in two planes of movement according to embodiments of the present invention.

Figure 8 is a schematic diagram that illustrates optical barcode scanners according to embodiments of the present invention.

Figure 9 is a graph that illustrates optical angular displacement as a function of voltage according to embodiments of the present invention.

Figure 10 is a graph that illustrates optical angular displacement as a function of frequency according to embodiments of the present invention.

Figure 11A is an exemplary barcode scanned by an optical bar code scanner according to embodiments of the present invention.

Figure 11B is a graph of a signal produced by an optical bar code scanner scanning the barcode of Figure 11A according to embodiments of the present invention.

Figure 12 is a schematic diagram that illustrates optical scanner systems according to embodiments of the present invention.

Figure 13 is a schematic diagram that illustrates optical scanner systems according to embodiments of the present invention.

Figure 14 is a schematic diagram that illustrates confocal microscope systems according to embodiments of the present invention.

Figure 15 is a schematic diagram that illustrates optical coherence tomography systems according to embodiments of the present invention.

Figure 16 is a schematic diagram that illustrates hair/tattoo removal systems according to embodiments of the present invention.

Figure 17 is a schematic diagram that illustrates corneal resurfacing systems according to embodiments of the present invention.

Figure 18 is a schematic diagram that illustrates optical image projection systems according to embodiments of the present invention.

Figure 19 is a schematic diagram that illustrates two dimensional optical text scanners according to embodiments of the present invention.

Figure 20 is a schematic diagram that illustrates combined optical/2D ultrasound imaging system according to embodiments of the present invention.

Figure 21 is a schematic diagram that illustrates combined optical/ultrasound scanning catheters according to embodiments of the present invention.

Figure 22 is a schematic diagram that illustrates scanner devices according to embodiments of the present invention.

Figures 23 to 26 are cross-sectional views that illustrate electromagnetic radiation devices according to embodiments of the present invention.

Figures 27 to 30 are schematic diagrams that illustrate pivoting members according to embodiments of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS ACCORDING TO THE INVENTION

The invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. The invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, the embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

It will be understood that when an element such as a layer, region or substrate is described as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is described as being "directly on" another element, there are no intervening elements present. It will also be understood that when an element such as a member, frame, hinge, electromagnetic radiation device, or MicroElectroMechanical Systems (MEMS) actuator is described as being "coupled to" another element, it can be directly coupled to the other element or intervening elements may also be present.

As used herein, the term "electromagnetic radiation" can include radiation that can be used to transmit or direct information in a system, such as radiation in the visible, ultraviolet, infrared and/or other portions of the electromagnetic radiation spectrum. The power of the electromagnetic radiation can vary based on the application. For example, some embodiments according to the present invention use relatively high power lasers to generate the electromagnetic radiation.

As used herein the term "electromagnetic radiation device" can include any device which is capable of providing electromagnetic radiation therefrom, such as a reflector or mirror, or a device which generates electromagnetic radiation, such as a camera, or a device that allows electromagnetic radiation to pass therethrough, such as a lens or the like. Accordingly, it will be understood that the electromagnetic radiation devices described herein do not necessarily generate the electromagnetic radiation, but can instead reflect, focus, or otherwise direct the electromagnetic radiation along different paths to achieve a result, such as to direct information or therapy.

As used herein the term "hinge" is defined to mean a device that allows two elements, coupled thereto, to pivot in a plane of movement. For example, in some embodiments according to the present invention, the hinge can be a flexible material, an end of which may move in a direction in which an element coupled thereto is pivoted. The hinge can allow repeated pivoting of the elements over an extended duration.

Figure 1 is a schematic diagram that illustrates scanner devices according to embodiments of the present invention. A proximal portion of a member **110** is movably coupled to a first portion of an electromagnetic radiation device **100** by a hinge **125**. In some embodiments according to the present invention, the member **110** is made from a polyimide material. An integrated force array actuator (IFA) **105** is coupled to the electromagnetic radiation device **100** at a second portion thereof that is spaced apart from the first portion. The IFA **105** is configured to expand and contract, in directions **115a** and **115b** respectively, to pivot the electromagnetic radiation device **100** in a plane of movement **120** about the hinge **125**.

The IFA **105** can be used to pivot the electromagnetic radiation device **100** about the hinge **125** to direct electromagnetic radiation **117** incident thereon along different paths. For example, when the IFA **105** contracts in the direction **115b**, the electromagnetic radiation device **100** pivots in the plane of movement **120** to a first position **101a** to reflect the electromagnetic radiation **117** from a source **118** along a first path **106a**. When the IFA **105** expands in the second direction **115a**, the electromagnetic radiation device **100** pivots on the hinge **125** in the plane of movement **120** to a second position **101b** to reflect the electromagnetic radiation **117** along a second path **106b**. Accordingly, embodiments of scanner devices according to the present invention can be used to scan electromagnetic radiation in the plane of movement **120**.

In some embodiments according to the present invention, the IFA **105** is movably coupled to the electromagnetic radiation device **100** by a second hinge (not shown) so that the expansion and contraction of the IFA **105** can be translated into the plane of movement **120**. In some embodiments according to the present invention, the electromagnetic radiation **117** defines a different angle with the electromagnetic radiation device **100** than the one shown in Figure 1.

Figure 2 is a schematic diagram that illustrates scanner devices according to embodiments of the present invention. As shown in Figure 2, a distal end of an IFA **205** is coupled to a distal portion **211b** of a member **210** and a proximal end of the IFA **205** is coupled to an electromagnetic radiation device **200**. The electromagnetic radiation device **200** is moveably coupled to a proximal portion **211a** of the member **210** via a hinge **225**. The IFA **205** is configured to expand and contract in first and second directions **215a** and **215b** to pivot the electromagnetic radiation device **200** in a plane of movement **220** about the hinge **225** to direct electromagnetic radiation incident thereon along different paths.

Figure 3 is a schematic diagram that illustrates scanner devices according to embodiments of the present invention. As shown in Figure 3, an IFA **305** is connected to a proximal portion of a member **310** and to an electromagnetic device **300**. The IFA **305** is configured to expand and contract in first and second directions **315a, 315b** to pivot the electromagnetic radiation device **300** in a plane of movement **320** about a hinge **325** that moveably couples the electromagnetic radiation device **300** to the proximal portion of the member **310** to direct electromagnetic radiation along different paths. As shown in Figure 3, the points where the IFA **305** and the hinge **325** are coupled to the electromagnetic radiation device **300** are spaced apart from one another.

Figure 4 is a schematic diagram that illustrates embodiments of scanner devices according to the present invention. As shown in Figure 4, the points where an IFA **405** and a hinge **425** are coupled to an electromagnetic radiation device **400** can be spaced closer together in comparison to those shown in Figure 3. A member **410** is moveably coupled to the electromagnetic radiation device **400** by the hinge **425**. A distal end of the IFA **405** is coupled to a proximal portion of the member **400**. The IFA **405** is configured to expand and contract in directions **415a** and **415b** respectively to pivot the electromagnetic radiation device **400** in a plane of movement **420** about the hinge **425** to direct electromagnetic radiation along different paths.

In some embodiments according to the present invention, the IFAs are MEMS based actuators such as those disclosed in U.S. Patent No. 5,206,557 to Bobbio entitled *Microelectromechanical Transducer and Fabrication Method,* the disclosure of which is hereby incorporated herein by reference. As discussed in Bobbio, an IFA is a network of micron-scaled deformable capacitive cells that include capacitor electrodes. The capacitive cells can contract due to an electrostatic force produced by a differential voltage applied across the capacitor electrodes. The electrostatic force produced by a capacitive cell with polyamide electrodes and a dielectric of air is given as follows:

$$F = \frac{\varepsilon A V^2}{1.2L^2} \qquad (1)$$

where F is the electrostatic force produced, A is the surface area of the capacitor plate, V is the applied voltage, ε is the dielectric constant of air, and L is the capacitor electrode separation.

As shown in Figures 5A and 5B, when the capacitive cells are in a relaxed state, the spacing between the plates of the capacitive cells are at a first distance. As shown in Figures 5C and 5D, when a voltage is applied across the plates of the capacitive cells, the plates are deformed by the electrostatic force between the plates, thereby causing the IFA to contract along its length. Accordingly, when a voltage is applied to the IFA, the IFA contracts to reduce its length compared to when the IFA is in the relaxed state.

It will be understood that other types of MEMS actuators can be used. For example, in some embodiments according to the present invention, a Thermal Arched Beam (TAB) actuator is used to pivot the electromagnetic radiation device about the hinge. TABs are further described in U.S. Patent 5,909,078 entitled *Thermal Arched Beam Microelectromechanical Actuators* to Wood et al., the disclosure of which is hereby incorporated herein by reference.

Figure 6A is a perspective view that illustrates embodiments of an electromagnetic radiation device **600**. A member **610** is coupled to a frame having first and second opposing portions **630a-b**. The first opposing portion of the frame **630a** is moveably coupled to the electromagnetic radiation device **600** by a first hinge **625a**. The second opposing portion of the frame **630b** is moveably coupled to the electromagnetic radiation device **600** by a second hinge **625b**. The first and second hinges **625a-b** define an axis **629** therethrough. Although the frames are shown in depicted as rectangular square in the figures, it will be understood that other shapes, such as circular or elliptical, may be used for the frames.

An IFA **605** is coupled to a point on the electromagnetic radiation device **600** which is spaced apart from the axis **629** and is configured to expand and contract in directions **615a** and **615b** respectively to pivot the electromagnetic radiation device **600** in a plane of movement **620** about the axis **629**. Accordingly, the IFA **605** can be used to direct electromagnetic radiation therefrom along different paths. Figure 6B is a top view of the electromagnetic device **600** shown in Figure 6A.

In some embodiments according to the present invention, the hinges can be torsion type hinges having a rectangular shape that are configured to be subjected to a twisting torque applied by the expansion and contraction of the IFA coupled to the electromagnetic radiation device. In some embodiments according to the present invention, the hinges have dimensions of approximately 60 microns by 250 microns by about 3 microns thick. In some embodiments according to the present invention, the hinges are made of polyimide. The angular displacement of the hinges can be approximated by the following formulas:

$$\Theta(l) = \frac{Tl}{2(1-\mu)Dc}\left(\frac{\tanh(4\lambda)}{4\lambda}\right) \qquad (2)$$

$$\lambda = \frac{l}{c}\sqrt{1.5(1-\mu} \qquad (3)$$

$$D = \frac{Eh^3}{12(1-\mu^2)} \qquad (4)$$

in Equation (2) λ is an aspect ratio parameter that is provided by Equation (3) in which l is the length of the hinge which can be, for example, 250 microns, c is the hinge width which can be, for example, 60 microns, μ is Poisson's ratio for polyimide which is about .34, D is a local flexion stiffness that is described by Equation (4), where E is the elastic modulus of polyimide, which can be about 2600Mpa, and h is the hinge thickness which can be about 3 microns.

The angular displacement determined using Equation (2) can be used to determine a torsion constant that can be used to relate the applied moment to an angular displacement. The torsion constant, k, can be used to determine the resonant frequencies of the structure in air using the following equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{l}} \qquad (5)$$

Figure 7 is a perspective view that illustrates embodiments of an electromagnetic radiation **700** device in a Cardano type suspension according to the present invention. As shown in Figure 7, a first frame includes first and second opposing portions **730a, 730b** that are coupled to a member **710**. First and second hinges **725a, 725b** are coupled to the first and second opposing portions of the frame **730a, 730b** and define a first axis **727** therethrough. A second frame is located in an interior portion of the first frame and includes first and second opposing portions **740a, 740b**. A third hinge **745a** is coupled to the first opposing portion **740b** of the second frame and a fourth hinge **745b** is coupled to the second opposing portion**740a** of the second frame. The third and fourth hinges **745a-b** moveably couple the second frame to the electromagnetic radiation device **700** located in the interior region of the second frame. The third and fourth hinges **745a-b** define a second axis **747** therethrough about which the electromagnetic radiation device **700** pivots. The electromagnetic radiation device **700** also pivots about the first axis **727**. In particular, a first IFA **705a** is coupled to the second frame and is configured to expand and contract to pivot the second frame and the electromagnetic radiation device **700** about the first axis **727**. A second IFA **705b** is coupled to the electromagnetic radiation device **700** and is configured to pivot the electromagnetic radiation device **700** about the second axis **747**. Accordingly, the first and second IFAs **705a-b** pivot the electromagnetic radiation device **700** in two planes of movement, the first plane of movement being about the first axis **727**, and the second plane of movement being about the second axis **747**.

As discussed above, embodiments of electromagnetic radiation devices according to the present invention can direct electromagnetic radiation along different paths, generate electromagnetic radiation, focus the electromagnetic radiation, and the like. For example, in embodiments according to the present invention having electromagnetic radiation devices that reflect electromagnetic radiation, the electromagnetic radiation device can be a reflector or mirror. The reflector can be made a metal, such as gold.

For example, Figure 8 is a schematic diagram that illustrates scanning devices including reflectors according to embodiments of the present invention. In particular, the reflector can be used as part of an optical barcode scanner wherein a helium neon laser **850** projects laser light onto a reflector **800**. The reflector **800** is moveably coupled to a member **810** by at least one hinge which is not shown. The reflector **800** is configured to pivot about the at least one hinge in a plane of movement **820**. A distal end of an IFA **805** is coupled to a distal end of the member **810**. A proximal end of the IFA **805** is coupled to the reflector **800**. The IFA **805** is configured to contract and expand in directions **815a** and **815b** respectively to pivot the reflector **800** in the plane of movement **820** to scan the electromagnetic radiation across a barcode **840** which is reflected to a photo detector **845**. The photo detector **845** can determine the configuration of the barcode **840** based on the reflected energy therefrom.

In further embodiments according to the present invention, electromagnetic radiation can be used to scan a body to assist in the diagnosis of skin conditions, such as skin cancer. In other embodiments according to the present invention, electromagnetic radiation can be used to scan a body to provide body dimensions for the sizing of garments. In other embodiments according to the present invention, electromagnetic radiation can be used to direct light for light displays or light shows.

Figure 9 is an exemplary graph that illustrates optical angular displacement as a function of the voltage applied to an IFA according to the present invention. In particular, as the voltage increases, the angle over which the reflector is displaced increases. Figure 10 is an exemplary graph that illustrates angular displacement as a function of a frequency associated with the voltage applied to the IFA. In particular, Figure 10 shows that, according to some embodiments of the present invention, pronounced angular displacement can be achieved near a resonant frequency associated with the system. Figure 10 also shows that resonance can be achieved at about 60Hz while lesser displacements can be achieved at near a resonant frequency of about 30Hz.

Figure 11A is an exemplary barcode scanned by the optical barcode scanning system illustrated in Figure 8. Figure 11A is an exemplary graph that illustrates a response of the photo detector **845** based on the laser light scanned across the barcode in Figure 11A. As shown in Figure 11A, localized peaks of the voltage signal can be associated with lighter areas of the barcode where increased laser light is received by the photodetector **845**. Conversely, the localized minima of the voltage signal can be associated with the dark bands in the exemplary barcode of Figure 11A.

Figure 12 is a schematic diagram that illustrates optical scanning systems according to embodiments of the present invention. In particular, an electromagnetic radiation source **1250** directs electromagnetic radiation **1204** to a first reflector **1201** which reflects that electromagnetic radiation **1204** to a second reflector **1200** according to the present invention. The second reflector **1200** is coupled to an IFA **1205** that is configured to expand and contract to pivot the second reflector **1200** to reflect the electromagnetic radiation through a lens **1214** which focuses the electromagnetic radiation onto a sample **1216**.

Figure 13 is a schematic diagram that illustrates optical scanning systems according to embodiments of the present invention. In particular, an electromagnetic radiation source **1350** generates electromagnetic radiation **1304** which is reflected by a first reflector **1301** to a second reflector **1300**. The second reflector **1300** is coupled to an IFA **1305** which is configured to pivot the second reflector **1300** about a hinge (which is not shown) to reflect the electromagnetic radiation to a lens **1314**. The lens is coupled to a second IFA **1315** that is configured to move the lens **1314** towards and away from the second reflector **1300**. The lens **1314** moves to focus the electromagnetic radiation from the second reflector **1300** onto a sample **1316**.

Figure 14 is a schematic diagram of a confocal microscope system according to the present invention. According to Figure 14, the confocal microscope system can generate laser light which is reflected off a reflector **1400** to a tissue sample. As discussed above, the reflector **1400** is pivoted about hinges (not shown) by expansion and contraction of an IFA **1405** that is coupled to the reflector **1400**. A lens (not shown) can be positioned along the path of the electromagnetic radiation to focus the laser light. Accordingly, the confocal microscope system according to the present invention shown in Figure 14 can scan tissue to produce an image of a slice of the tissue.

Figure 15 is a schematic diagram that illustrates optical coherence tomography systems (OCT) according to embodiments of the present invention. An OCT system is analogous to ultrasound in that light incident on the tissue is reflected therefrom and can be used to create a tomographic image of the tissue. According to Figure 15, infrared light **1540** from an infrared light source **1530** is projected onto a reflector **1500** according to the present invention. The infrared light **1540** is scanned across the tissue by pivoting the reflector **1500** using an IFA **1505** as described above. The infrared light reflected from the tissue can be sampled to create a tomographic image.

Figure 16 is a schematic diagram that illustrates hair/tattoo removal systems according to embodiments of the present invention. According to Figure 16, an alexandrite laser **1650** projects light onto a reflector **1600** according to the present invention. The reflector **1600** is pivoted about a set of hinges (not shown) by the expanding and contracting an IFA **1605** that is coupled thereto to scan the hair or tattoo to be removed.

Figure 17 is a schematic diagram that illustrates corneal resurfacing systems according to embodiments of the present invention. According to Figure 17, an ultraviolet radiation source **1750** generates ultraviolet radiation which is reflected off a reflector **1700** onto a corneal surface of an eye **1701**. The reflector **1700** pivots about a hinge (not shown) when an IFA **1705** expands and contracts as discussed above. Scanning devices according to the present invention can therefore be used to scan ultraviolet radiation across a patient's eye to conduct laser eye surgery or the like. For example, the ultraviolet radiation can heat and reshape the cornea of the patient's eye to correct near and far sightedness.

Figure 18 is a schematic diagram that illustrates optical image systems according to embodiments of the present invention. According to Figure 18, image data is projected from an image source **1850** to a reflector **1800** which reflects the image data onto a retina of a subject's eye **1801**. The image is projected onto the retina by pivoting the reflector **1800** by expanding and contracting an IFA **1805** coupled thereto as discussed above.

Figure 19 is a schematic diagram that illustrates text scanners according to embodiments of the present invention. According to Figure 19, an electromagnetic radiation source **1900** can be pivoted to scan text on a page **1901**. For example, the scanning device of Figure 19 can be implemented in a text reading pen which a user drags across the text to be scanned. In particular, the electromagnetic radiation source **1900** is configured to pivot out of plane relative to a direction in which the pen is dragged across the text. In further embodiments according to the present invention, the electromagnetic radiation source **1900** can be mounted in a Cardano type suspension, such as that discussed in relation to Figure 7, so that the electromagnetic radiation source **1900** is configured to pivot in two dimensions to further reduce the time needed to scan text on the page **1901**.

Figure 20 is a schematic diagram that illustrates a combined optical/ultrasound scanner according to the present invention. According to Figure 20, an electromagnetic radiation source **2050** generates electromagnetic radiation **2021** which is reflected off a reflector **2000** onto a target **2001**. An ultrasound transducer is mounted on the reflector **2000** and produces ultrasonic energy which can be used to scan the target **2001**. When the reflector **2000** is pivoted by an IFA **2005**, the electromagnetic radiation and the ultrasound energy can both be directed to the target **2001** thereby producing both imaging and ultrasound data corresponding to the target **2001**.

Figure 21 is a schematic diagram that illustrates combined OCT/ultrasound scanners in a catheter **2160**. According to Figure 21, a scanning device **2100** according to embodiments of the present invention can be embedded in the catheter **2160** and configured to scan tissue in which the catheter is placed by pivoting in response to expansion and contraction of an IFA connected thereto as discussed above. The catheter **2160** also includes an ultrasound array **2170** which can be used to scan the tissue in which the catheter **2160** is inserted. In some embodiments according to the present invention, both the OCT scanner and the ultrasound transducer image in two or three dimensions. In further embodiments according to the present invention, the OCT scanner and the ultrasound transducer are angled towards each other in the catheter **2160** to scan the same area of tissue. For a two dimensional system, the OCT scanner can be implemented as described above in relation to the optical scanners. For a three dimension system, a cardano suspension, as discussed in reference to Figure 7, may be used to pivot the reflector in two dimensions.

Figure 22 is a schematic diagram that illustrates scanning devices according to embodiments of the present invention. In particular, an electromagnetic radiation device **2200** has an organic light emitting diode (LED) **2270** mounted thereon. The electromagnetic radiation device **2200** is moveably coupled to a member **2210** by a hinge (which is not shown). An IFA **2205** is configured to pivot the electromagnetic radiation device **2200** about the hinge in a plane of movement **2220** by contracting and expanding the IFA **2205**. The organic LED **2270** generates electromagnetic radiation which pivots as the electromagnetic radiation device **2200** pivots in the plane of movement **2220**.

The reflectors described herein can be fabricated to focus the electromagnetic radiation as well as reflect it. Figure 23 is a cross-sectional view that illustrates embodiments of focusing reflectors according to the present invention. In particular, a substrate **2300**, such as polyimide, has a reflective layer **2365**, such as a metal, formed thereon. An optically transparent layer **2370** is on the reflective layer **2365**. The optically transparent layer **2370** has a convex surface that is configured to face away from the reflective layer **2365**. Electromagnetic radiation **2375** passes through the optically transparent layer **2670** and reflects from the reflective layer **2365**. The convex shape of the optically transplant layer **2370** is configured to focus the electromagnetic radiation **2375** reflected therefrom. Moreover, the reflector **2300** can be pivoted as discussed above, to scan the electromagnetic radiation **2375** in a plane of movement to focus the electromagnetic radiation on a target.

Figure 24 is a cross-sectional view that illustrates focusing reflectors **2400** according to embodiments of the present invention. In particular, the reflector **2400** includes a substrate **2460**, such as a silicon, that is configured to have a concave shape. A reflective layer **2465** is on the concave shaped surface of the substrate **2460**. Electromagnetic radiation **2475** is reflected from the reflective layer **2465** and is focused by the concave shape of the reflective layer **2465**.

Figures 25A and 25B are cross-sectional views that illustrate focusing reflectors **2500** according to embodiments of the present invention including a flexible membrane **2585** that deflects to assume a concave shape. In particular, as shown in Figure 25A, a reflector **2500** includes a substrate layer **2560** that is a electrically coupled to a voltage source **2580**. The flexible membrane **2585** is spaced-apart from the substrate layer **2560** and has a reflective layer **2570** thereon that faces away from the substrate layer **2560**. The flexible membrane **2585** is electrically coupled to the voltage supply **2580**. In operation, when little or no voltage is provided by the voltage supply **2580**, the flexible membrane **2585** assumes a planer shape as shown.

According to Figure 25B, when the voltage supply **2580** generates an electrostatic force sufficient to deflect the flexible membrane **2585**, the flexible membrane **2585** deflects towards the substrate **2560** so that the flexible membrane **2585** assumes a concave shape that faces away from the substrate **2560**.

Electromagnetic radiation **2575** reflects from the reflective surface **2570** which is configured to focus electromagnetic radiation **2575** due to the concave shape of the reflective layer **2570**. Accordingly, a reflector **2500** according to the present invention can provide a planer shape reflective layer to reflect electromagnetic radiation as well as a concave shaped reflector to reflect and focus electromagnetic radiation depending on the voltage provided to the reflector **2500**.

In further embodiments according to the present invention, as shown in Figure 26, the electromagnetic radiation device can be a lens **2600** through which electromagnetic radiation is passed to focus the electromagnetic radiation on a target **2695**. Electromagnetic radiation **2675** is provided to a lens **2600**. The electromagnetic radiation **2675** passes through the lens **2600** which is configured to focus the electromagnetic radiation on a target **2695**. The lens **2600** can be mounted in an optical scanning system such as those described above, to pivot the lens **2600** using an IFA **2605** so that the electromagnetic radiation focused by the lens **2600** can scan the target. The lens **2600** is coupled to the electromagnetic radiation source **2675** and moves with the lens **2600** as the IFA pivots the lens **2600**. In some embodiments according to the present invention, the lens 2600 is a Fresnel lens of hologram that is fabricated in silicon or polymer using, for example, photolithography.

In further embodiments according to the present invention, the electromagnetic radiation devices described in the embodiments herein can be replaced by a second member that is moveably coupled to the first member and coupled together by an IFA. For example, Figure 27 is a schematic diagram that illustrates embodiments according to the present invention. In particular, a first member **2710** is moveably coupled to a second member **2700** by a hinge **2715**. One end of an IFA **2705** is coupled to a first side of the first member **2710** and a second end of the IFA **2705** is coupled to a first side of the second member **2700** as shown in Figure 27. The IFA **2705** is configured to expand and contract in directions **2715a** and **2715b** to pivot the second member **2700** about the hinge **2715**. The hinge **2715** can be a flexion type hinge to allow the second member **2700** to pivot about the hinge **2715** in a plane of movement **2720**. Accordingly, the first and second members **2710**, **2700** can function as an arm where the hinge **2015** functions as an elbow joint.

Furthermore, a third member **2730** can be moveably coupled to the first member **2710** by a second hinge **2735** that is configured to rotate in a plane of movement that is oriented out of the plane with respect to the plane of movement

2720. The second hinge **2735** provides the function of a wrist joint between the second and third members **2710, 2730**. The second hinge can be a torsion type hinge.

The rotation for the third member **2730** can be provided by a second IFA (not shown) that is coupled to the first and third members **2710, 2730**. One end of the second IFA is coupled the first member **2710** at a point thereof that is on a first side of the hinge. The other end of the second IFA is coupled to the third member **2730** at a point thereof that is on a second side of the hinge that is opposite the first side. For example, in some embodiments where the second hinge is a torsion hinge that is rectangular, the second IFA is coupled to the first member **2710** at a point thereon that is below the hinge. The other end of the second IFA is coupled to the third member **2730** at a point thereon that is above the hinge.

In still further embodiments according to the present invention, as shown in Figure 28A, a first member **2800** is moveably coupled to a second member **2810** by a first hinge **2815**. The first member **2800** is also moveably coupled to a third member **2850** by a second hinge **2816** that is adjacent to the first hinge **2815**. One end of a first IFA **2805** is coupled to a first side of the first member **2800** and the other end of the first IFA **2805** is coupled to a first side of the second member **2810**. One end of a second IFA **2806** is coupled to a second side of the first member **2800** that is opposite to the point where the first IFA **2805** is coupled. The other end of the second IFA **2806** is coupled to the third member **2850**.

The first and second IFAs **2805, 2806** are configured to expand and contract in the directions **2825a-b** to pivot the second and third members **2810, 2850** about the hinges **2815, 2816** in a plane of movement **2820**. The first and second IFAs **2805, 2806** are configured to expand and contract in cooperation with one another so that the second and third members **2810, 2850** can move in a flapping pattern.

Figure 28B is a top view that illustrates embodiments of robotic structures according to the present invention. As shown in Figures 28B, a first wing member **2870a** is moveably coupled to first and second connecting members **2875a-b** by first and second hinges **2871a-b** that define a first axis **2871a** therethrough about which the first wing member **2870a** pivots. A second wing member **2870a** is moveably coupled to the first and second connecting members **2875a-b** by third and fourth hinges **2871c-d** that define a second axis **2871b** therethrough about which the second wing member **2870b** pivots. The hinges can be torsion type hinges. Other types of hinges can be used.

An anchor **2880** is coupled to the first and second wing members **2870a-b** by first and second IFAs **2885a-b** respectively. The first and second IFAs **2885a-b** are coupled to the first and second wing members **2870a-b** at points thereon that are located between the anchor **2880** and the first and seconds axes **287a-b**. According to Figure 28B, the robotic structures illustrated therein can be fabricated, for example, on silicon using photolithography and configured for operation as shown in Figure 28C.

Figure 28C is a schematic diagram that illustrates embodiments of robotic structures according to the present invention. According to Figure 28C, the anchor **2880** is positioned beneath the first and second wing members **2870a-b** and the first and second connecting members **2875a-b**. The anchor **2880** is coupled to first and second connecting members **2875a-b** by a frame **2890**. The first and second IFAs **2885a-b** are configured to expand and contract to pivot the first and second wing members **2870a-b** in the planes of movement **2873a-b** respectively. Accordingly, the embodiments according to the present invention illustrated by Figures 28A-28C can provide robotic structures that may operate similar to a bird's or insect's wings.

Figure 28D is a schematic diagram that illustrates embodiments of robotic wing members according to the present invention. As shown in Figure 28D, a wing member **2893** is located in an interior region of a frame **2891** having first and second opposing portions **2899a-b**. The wing member **2893** is moveably coupled to the first and second opposing portions **2899a-b** of the frame **2891** by first and second hinges **2892a-b** respectively that define an axis **2895** that passes therethrough. An IFA **2896** is coupled to the wing member **2893** at a portion thereof that is spaced apart from the axis **2895**. The IFA is configured to expand and contract in the directions **2897a-b** respectively to pivot the wing member **2893** on the first and second hinges about the axis **2895**.

It will be understood that the embodiments of robotic structures according to the present invention illustrated in Figure 28D can be used as the wing members discussed above in reference to Figures 28B and 28C. Accordingly, embodiments of robotic structures according to the present invention can be configured to pivot in one plane of movement (for example, an up and down flapping motion) and simultaneously pivot in a second plane of movement such as the pivoting of the wing member **2893** about the axis **2895**.

Figure 29A is a top view that illustrates embodiments according to the present invention. In particular, Figure 29A shows a flexible substrate **2900** having a first length. An IFA **2905** is on the flexible substrate **2900** and has a first length L_R when the IFA **2905** is in a relaxed state. When the IFA **2905** contracts to a contracted state, the IFA causes the flexible substrate **2900** to arch as shown in Figure 29B wherein the length of the flexible substrate **2900** is reduced to L_C. A latch **2910**, or other such translation prevention member, is on a side of the flexible substrate **2900** and is configured to engage a surface **2930** when the IFA **2905** transitions from the contracted state to the relaxed state. For example, when the IFA **2905** is in the contracted state, the flexible substrate **2900** and the IFA **2905** arch as shown in Figure 29B. When the IFA **2905** transitions to the relaxed state, the flexible substrate **2900** and the IFA **2905** straighten causing the latch **2910** to engage the surface **2930** thereby causing the structure to advance along the surface **2930** in a direction **2915** when the IFA **2905** transitions from the contracted state to the relaxed state. In some embodiments according to the present invention, the latch **2910** can be a ratchet, a fish scale type arrangement commonly used on the underside of skis, mohair, or the like. Accordingly, the embodiments of robotic structures according to the present invention illustrated by Figures 29A and 29B can approximate a crawling movement.

Figure 30 is a plan view that illustrates embodiments according to the present invention. In particular, a first member **3000** is moveably coupled to a second member **3010** by a hinge **3005**. A first IFA **3015** is coupled to a first side of the first member **3000** and a first side of a second member **3010**. The IFA **3015** is configured to contract and expand in the directions **3025a-b** thereby causing the second member **3010** to pivot about the hinge **3005** in a plane of movement **3020**. A second IFA **3016** is coupled to the first and second members **3000, 3010** at points thereon which are opposite to the points where the first IFA **3015** is coupled to the first and second members **3000, 3010**. The first and second IFAs **3015, 3016** are configured to alternately expand and contract thereby causing the second member **3010** to pivot in a first direction in the plane of movement **3020** and then in a second direction opposite to the first direction in the plane of movement **3020**. Accordingly, the embodiments of robotic structures according to the present invention illustrated by Figure 30 can approximate a fishtail or swimming movement.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

WHAT IS CLAIMED:

1. A scanner apparatus comprising:

a member having spaced apart proximal and distal portions;

an electromagnetic radiation device, configured to direct electromagnetic radiation, moveably coupled to the distal portion of the member and configured to move in a first plane of movement to a first position to direct the electromagnetic radiation along a first path and configured to move in the plane of movement to a second position to direct the electromagnetic radiation along a second path; and

a MicroElectroMechanical Systems (MEMS) actuator coupled to the electromagnetic radiation device, wherein the MEMS actuator is configured to move in a first direction to move the electromagnetic radiation device to the first position and configured to move in a second direction to move the electromagnetic radiation device to the second position.

2. A scanner apparatus according to Claim 1 further comprising:

a hinge that moveably couples the electromagnetic radiation device to the distal portion of the member, wherein the electromagnetic radiation device pivots in the plane of movement about the hinge when the electromagnetic radiation device is moved by MEMS actuator.

3. A scanner apparatus according to Claim 2 wherein the hinge comprises one of a torsion hinge and a flexion hinge.

4. A scanner apparatus according to Claim 2 wherein the hinge comprises polyimide.

5. A scanner apparatus according to Claim 1:

wherein the MEMS actuator has proximal and distal portions; and

wherein the distal portion of the MEMS actuator is coupled to the member.

6. A scanner apparatus according to Claim 5 wherein the distal portion of the MEMS actuator is coupled to the proximal portion of the member.

7. A scanner apparatus according to Claim 1 further comprising:

a frame coupled to the distal portion of the member, the frame having first and second opposing portions;

a first hinge that moveably couples the electromagnetic radiation device to the first opposing portion of the frame; and

a second hinge that moveably couples the electromagnetic radiation device to the second opposing portion of the frame, wherein the first and second hinges define an axis therethrough about which the electromagnetic radiation device pivots in the plane of movement when the electromagnetic radiation device is moved by MEMS actuator.

8. A scanner apparatus according to Claim 1 wherein the MEMS actuator comprises a first MEMS actuator, the scanner apparatus further comprising:

a first frame coupled to the distal portion of the member, the first frame having two opposing portions that define an interior region of the first frame;

first and second hinges on the first and second opposing portions of the first frame respectively, wherein the first and second hinges define a first axis therethrough;

a second frame in the interior region of the first frame and coupled to the first MEMS actuator, the second frame defining an interior region of the second frame within which the electromagnetic radiation device is located, wherein the second frame has first and second opposing portions, wherein the second frame is movably coupled to the first frame by the first and second hinges to pivot about the first axis when moved by the first MEMS actuator;

third and fourth hinges that moveably couple the first and second opposing portions of the second frame to the electromagnetic radiation device, wherein the third and fourth hinges define a second axis therethrough that is substantially orthogonal to the first axis; and

a second MEMS actuator coupled to the electromagnetic radiation device, wherein the second MEMS actuator is configured to pivot the electromagnetic radiation device about the second axis when moved.

9. A scanner apparatus according to Claim 1 wherein the electromagnetic radiation device comprises a reflector, wherein the scanner apparatus further comprises:

an electromagnetic radiation source that projects electromagnetic radiation on the reflector, wherein the electromagnetic radiation source is selected from the list consisting of a laser light source, a confocal microscope system, an ultraviolet light source, an infrared light source, an image data source, and an Alexandrite laser.

10. A scanner apparatus according to Claim 1 wherein the electromagnetic radiation device comprises a reflector, wherein the scanner apparatus further comprises:

an electromagnetic radiation source that projects electromagnetic radiation on the reflector; and

an ultrasound source on the reflector that is configured to generate ultrasonic radiation.

11. A scanner apparatus according to Claim 10 wherein the reflector comprises gold.

12. A scanner apparatus according to Claim 1 wherein the electromagnetic radiation device comprises a focusing reflector that reflects electromagnetic radiation projected thereon to direct reflected electromagnetic radiation along a path, wherein the electromagnetic radiation is focused at a distance from the focusing reflector along the path.

13. A scanner apparatus according to Claim 12, the focusing reflector further comprising:

a substrate layer;

a reflective layer on the substrate layer;

an optically transparent layer, on the reflective layer, having a convex surface configured to face away from the reflective layer, wherein the electromagnetic radiation passes through the optically transparent layer to the reflective layer and reflects from the reflective layer through the optically transparent layer along the path.

14. A scanner apparatus according to Claim 12, the focusing reflector further comprising:

a substrate layer having a concave surface; and

a reflective layer on the concave surface, wherein the electromagnetic radiation reflects from the reflective layer along the path.

15. A scanner apparatus according to Claim 12, the focusing reflector further comprising:

a voltage supply that generates a voltage level;

a substrate layer electrically coupled to the voltage supply;

a flexible membrane layer spaced apart from the substrate layer and electrically coupled to the voltage supply, wherein the flexible membrane is configured to deflect towards the substrate layer to assume a concave shape in response to the voltage level;

a reflective layer on the flexible membrane layer that is configured to reflect the electromagnetic radiation along the path.

16. A scanner apparatus according to Claim 1 wherein the electromagnetic radiation device comprises a lens, wherein the scanner apparatus further comprises:

an electromagnetic radiation source that projects electromagnetic radiation through the lens along the path.

17. A scanner apparatus according to Claim 1 wherein the electromagnetic radiation device comprises one of an LED, a semiconductor laser, and an incandescent light that is configured to direct the electromagnetic radiation along the path.

18. A scanner apparatus according to Claim 1 wherein the MEMS actuator comprises an integrated force array actuator.

19. An apparatus comprising:

a first member having first and second spaced apart portions;

a second member having first and second spaced apart portions;

a hinge, configured to pivot in a plane of movement, that moveably couples the second portion of the first member to the first portion of the second member;

a MicroElectroMechanical Systems (MEMS) integrated force array actuator (IFA) having first and second ends, wherein the first end is coupled to the first member and the second end is coupled to the second member, wherein the IFA is configured to move in the plane of movement to pivot the second member in the plane of movement about the hinge.

20. An apparatus according to Claim 19 wherein the first end of the IFA is coupled to the second portion of the first member and the second end of the IFA is coupled to the second portion of the second member.

21. An apparatus according to Claim 19 wherein the hinge comprises a first hinge that pivots in a first plane of movement and the IFA comprises a first IFA that moves in the first plane of movement, the apparatus further comprising:

a third member having first and second spaced apart portions;

a second hinge, configured to pivot in a second plane of movement, that moveably couples the second portion of the first member to the first portion of the third member; and

a second IFA having first and second ends, wherein the first end is coupled to the first member and the second end is coupled to the third member, wherein the second IFA is configured to move to pivot the second member in the second plane of movement about the second hinge.

22. An apparatus according to Claim 21 wherein the first and second IFAs are configured to contract to pivot the second and third members in the first and second planes of movement synchronously.

23. An apparatus according to Claim 19 wherein the first and second members have respective first and second opposing sides, wherein the IFA comprises a first IFA coupled to the first side of the first member and the first side of the second member, the apparatus further comprising:

a second IFA having first and second ends, wherein the first end of the second IFA is coupled to the second side of the first member opposite the first IFA and the second end of the second IFA is coupled to the second side of the second member opposite the first IFA.

24. An apparatus according to Claim 23 wherein the first and second IFAs are configured to contact and expand to pivot the second member in the plane of movement alternately.

25. An apparatus according to Claim 24 wherein the apparatus comprises a swimming robotic structure.

26. An apparatus according to Claim 22 wherein the apparatus comprises a flying robotic structure.

27. An apparatus comprising:

a flexible substrate having a length and first and second sides;

an IFA on the flexible substrate, wherein the IFA has a first length along the length of the flexible substrate in a relaxed state and a second length along the length of the flexible substrate, that is less than the first length, in a contracted state, wherein the IFA is configured to arch the flexible substrate when in the contracted state and to straighten the flexible substrate when in the relaxed state; and

a latch on the first side of the flexible substrate that is configured to engage with a surface adjacent to the first side when the IFA moves from the contracted state to the relaxed state and to release from surface when the IFA moves from the relaxed state to the contracted state.

28. An apparatus according to Claim 27 wherein the apparatus comprises a crawling robotic structure.

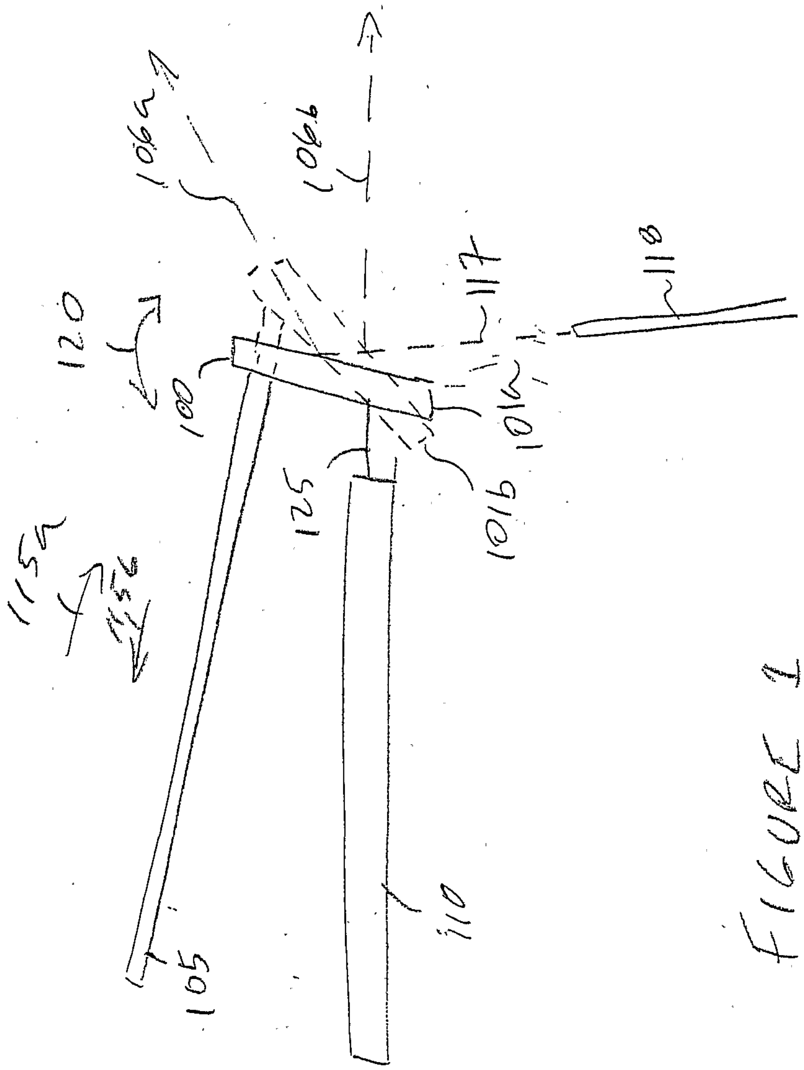

FIGURE 1

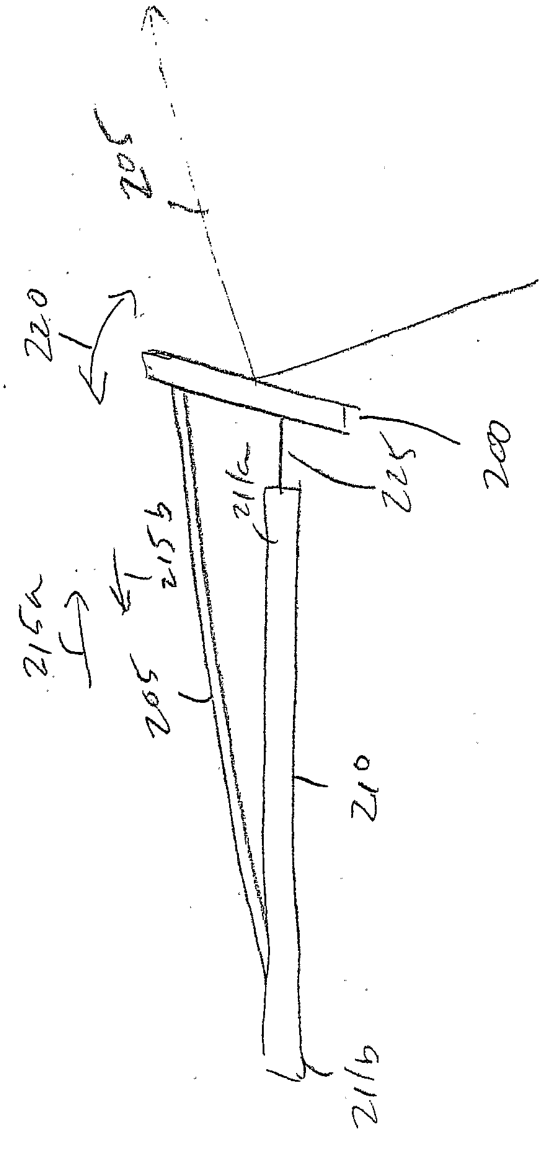

FIGURE 2

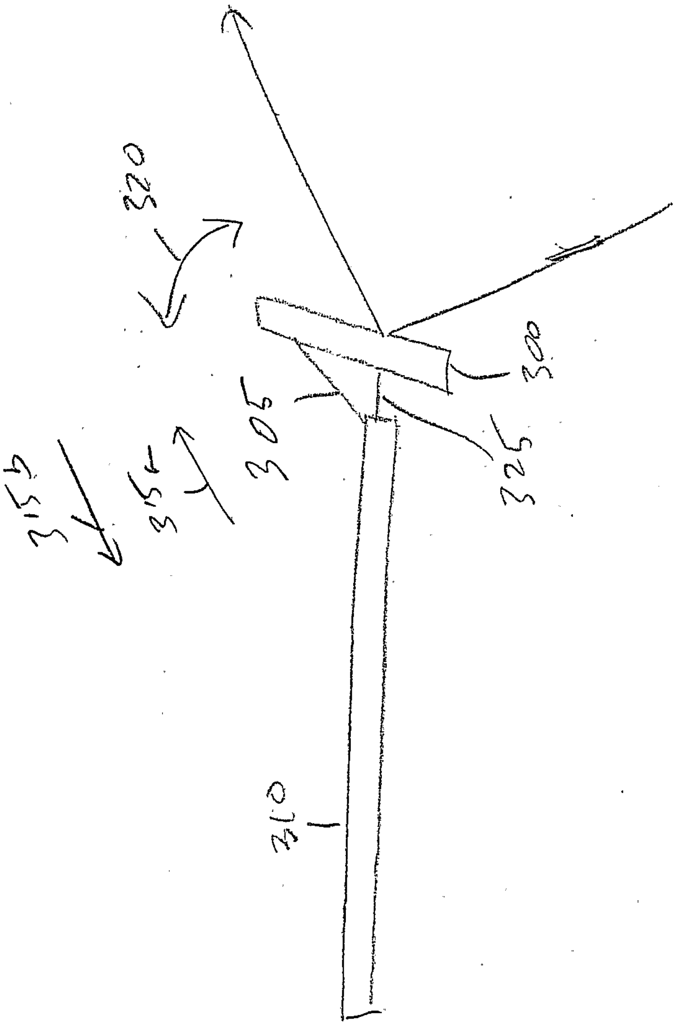

FIGURE 3

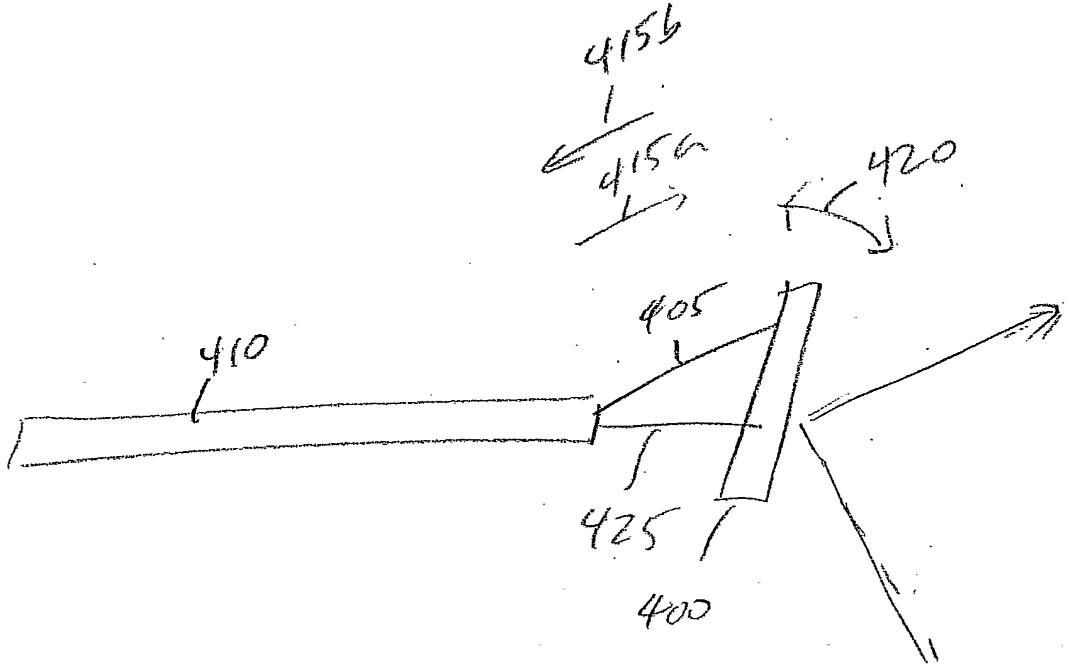

FIGURE 4

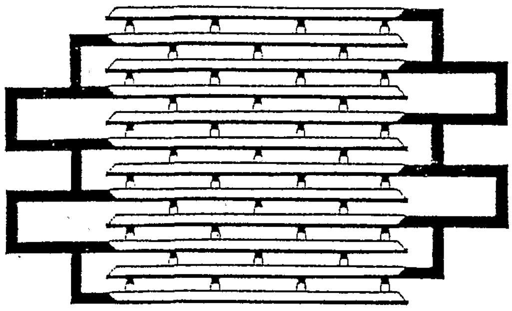

FIGURE 5A

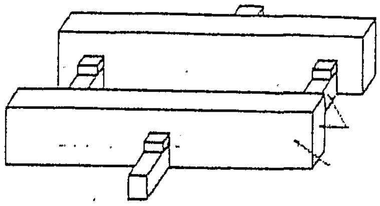

FIGURE 5B

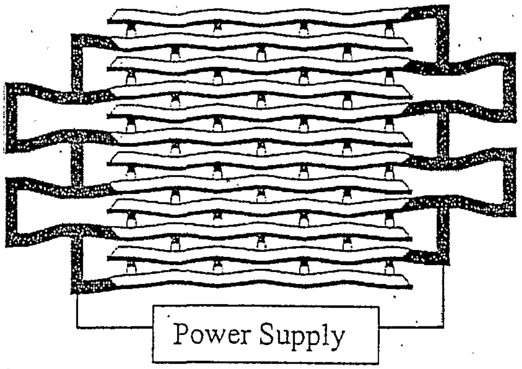

FIGURE 5C

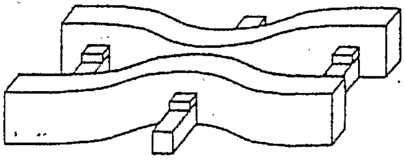

FIGURE 5D

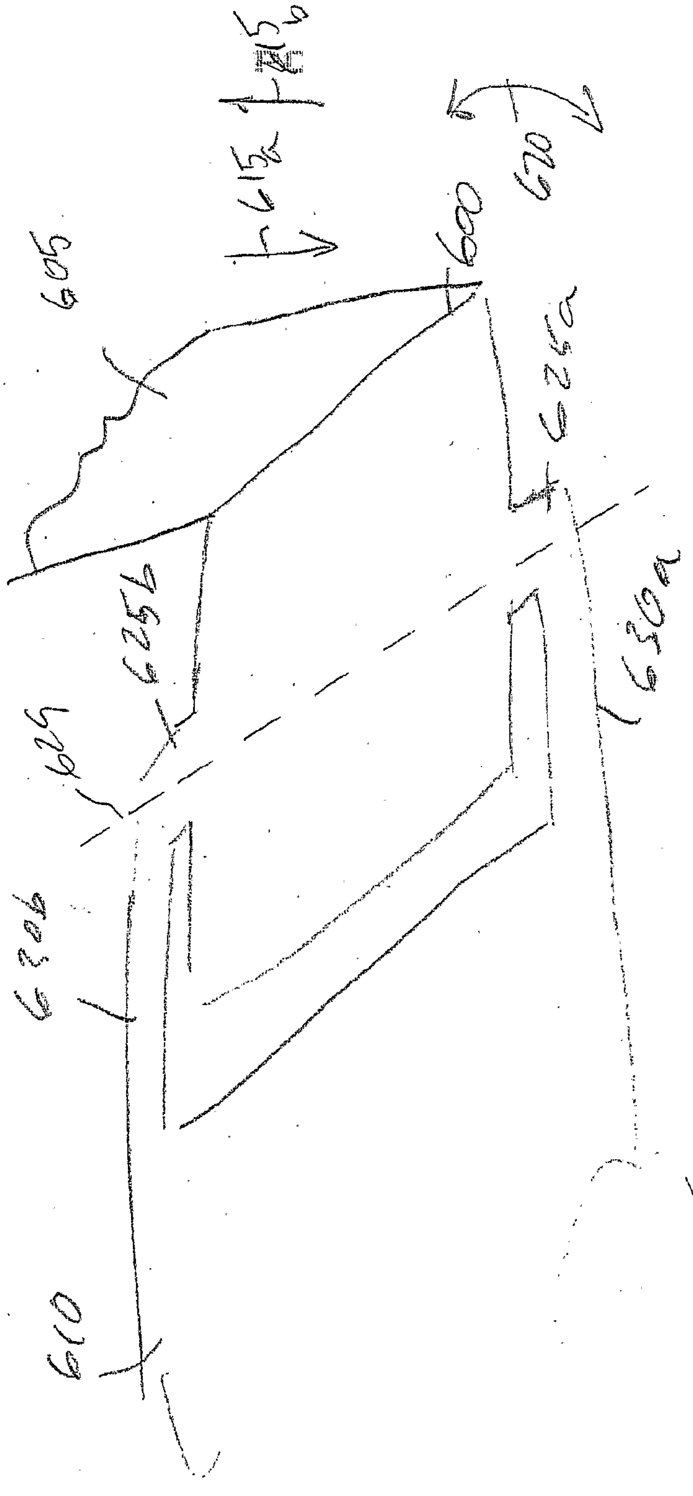

FIGURE 6A

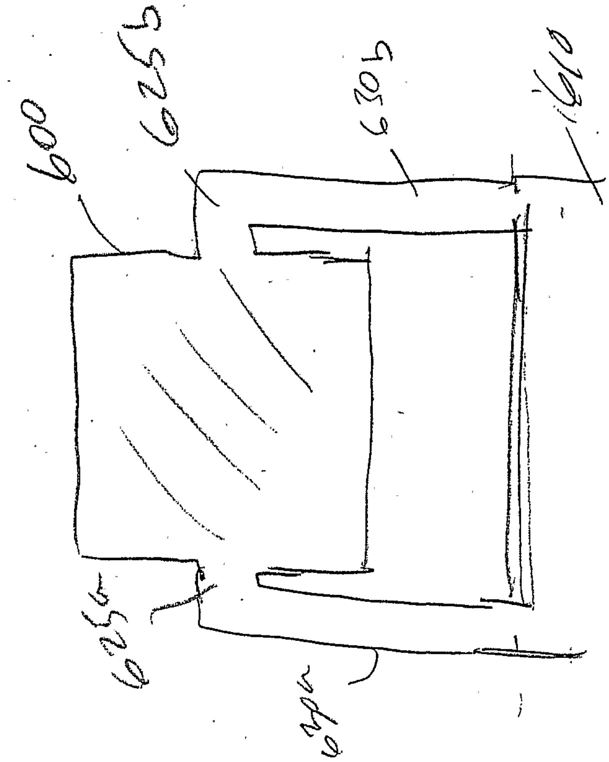

FIGURE 6B

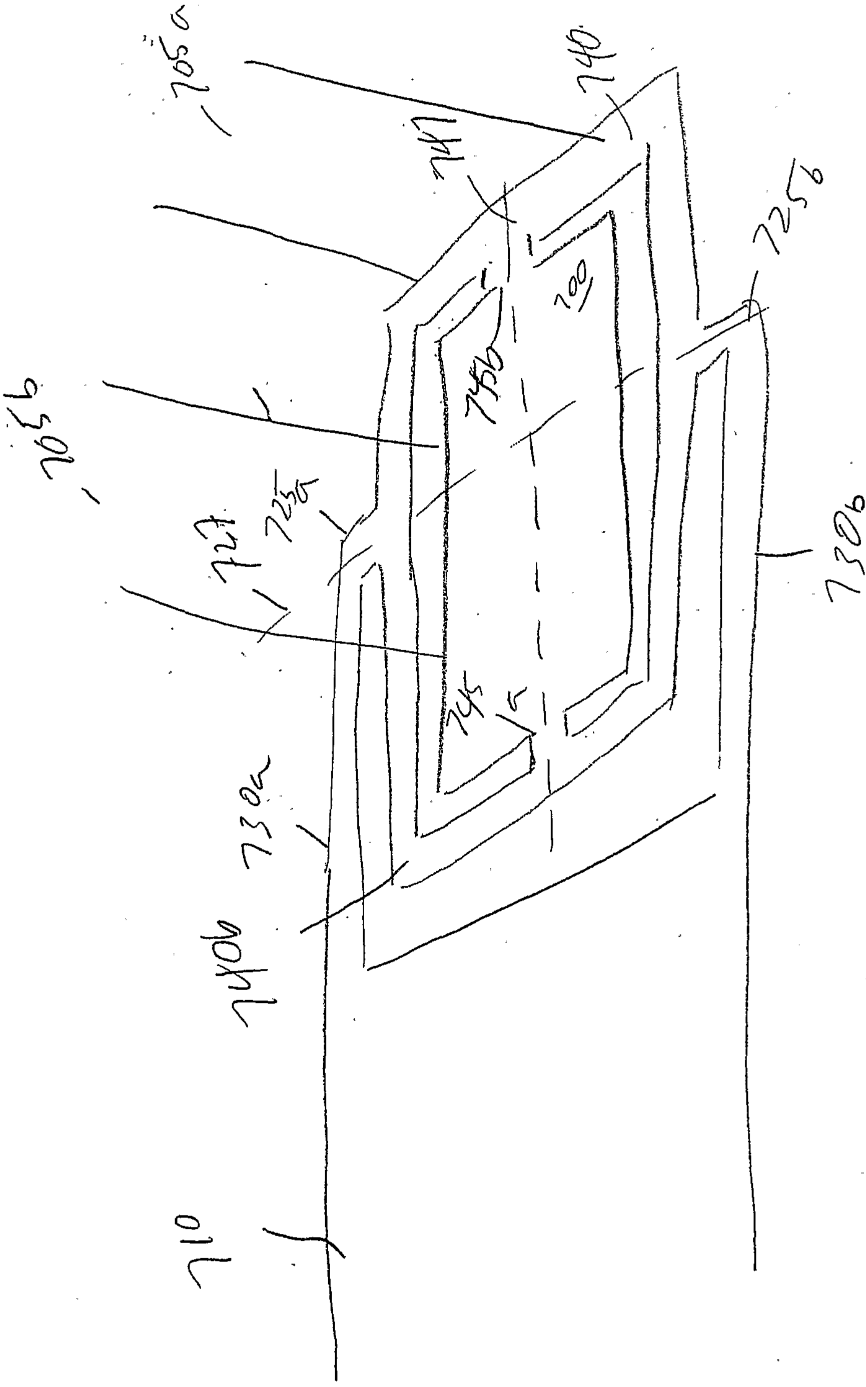
705a
747
740
725b
700
745b
705b
727
725a
745a
730a
740b
710
730b

FIGURE 7

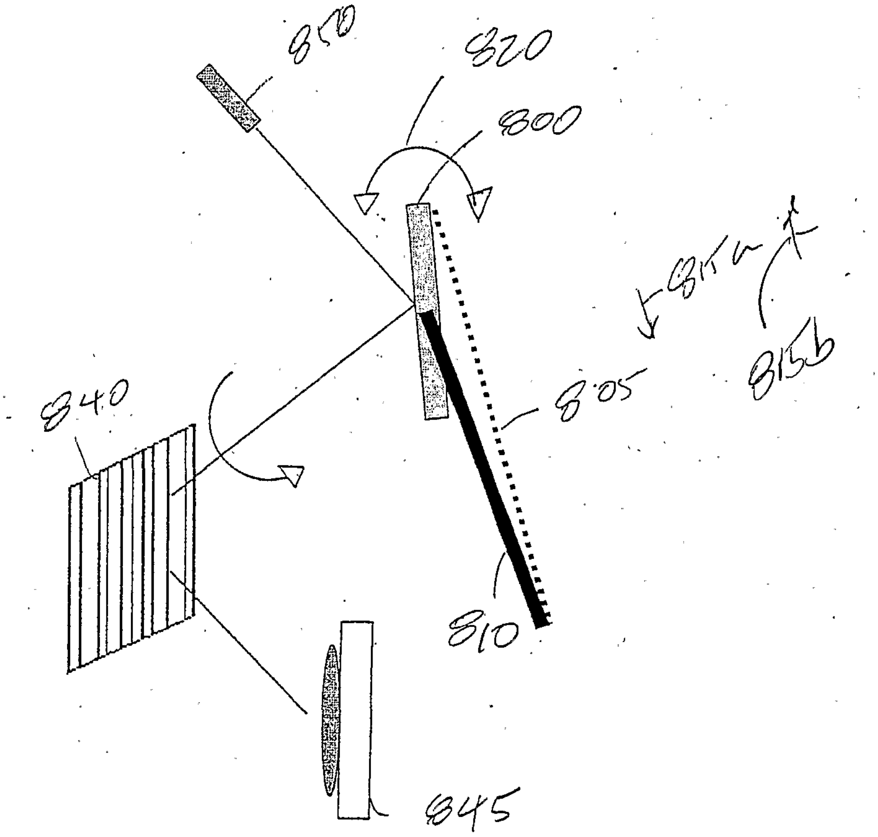

FIGURE 8.

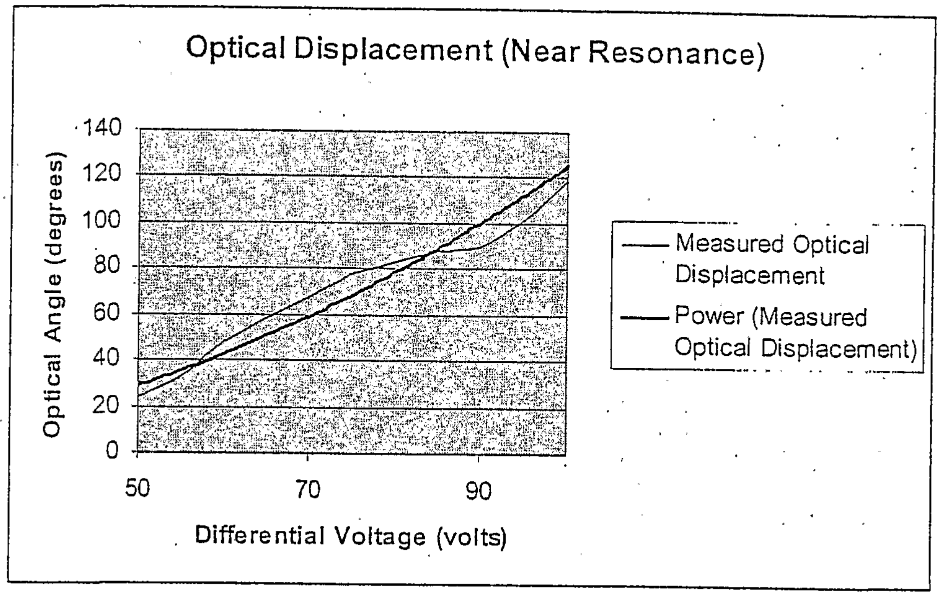
Optical Displacement (Near Resonance)
Optical Angle (degrees)
140
120
100
80
60
40
20
0
50
70
90
Differential Voltage (volts)
Measured Optical Displacement
Power (Measured Optical Displacement)

FIGURE 9

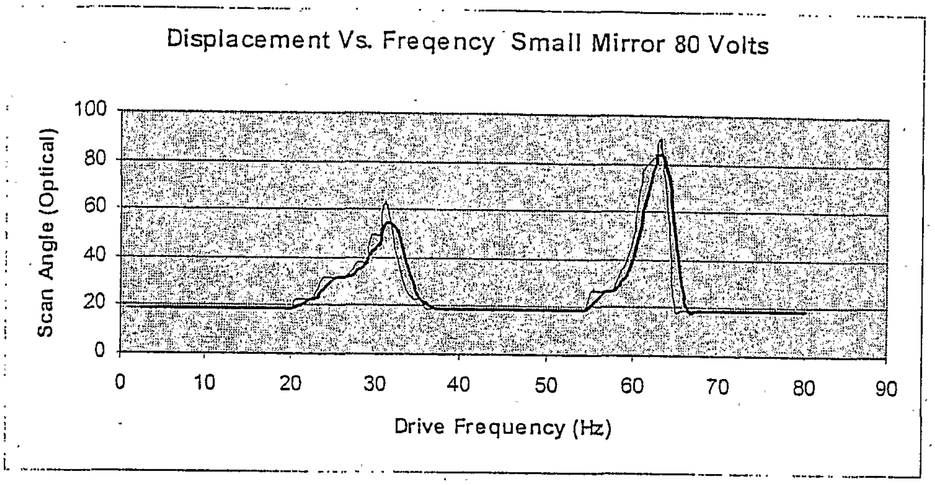
Displacement Vs. Freqency Small Mirror 80 Volts
Scan Angle (Optical)
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
Drive Frequency (Hz)

FIGURE 10

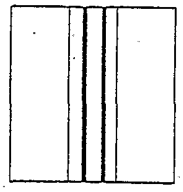

FIGURE 11A

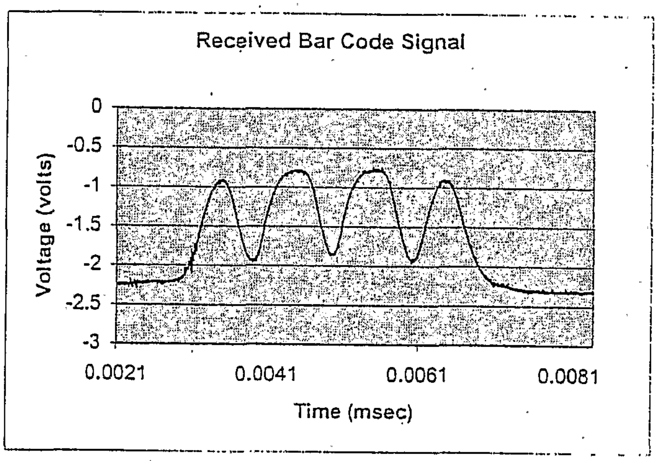

FIGURE 11B

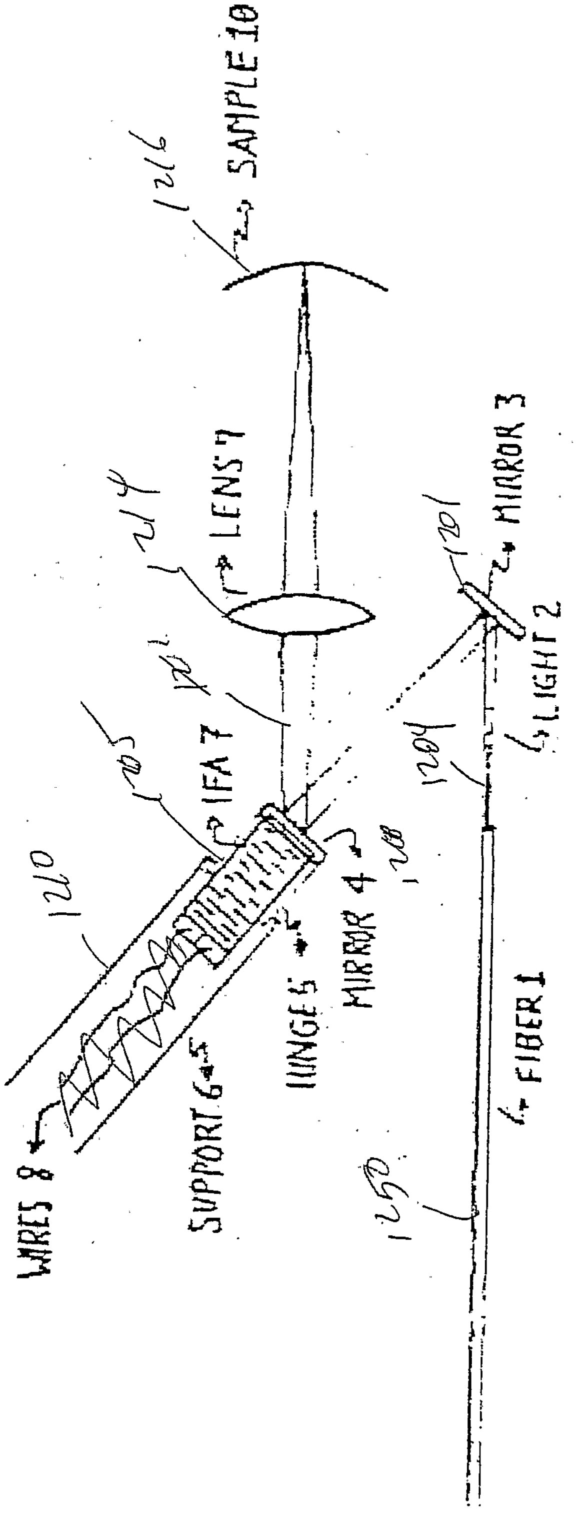
SAMPLE 10
1216
LENS 7
1214
1212
MIRROR 3
1202
LIGHT 2
1204
IFA 7
1206
1210
MIRROR 4
1208
HINGES 5
SUPPORT 6
WIRES 8
FIBER 1
1250

FIGURE 12

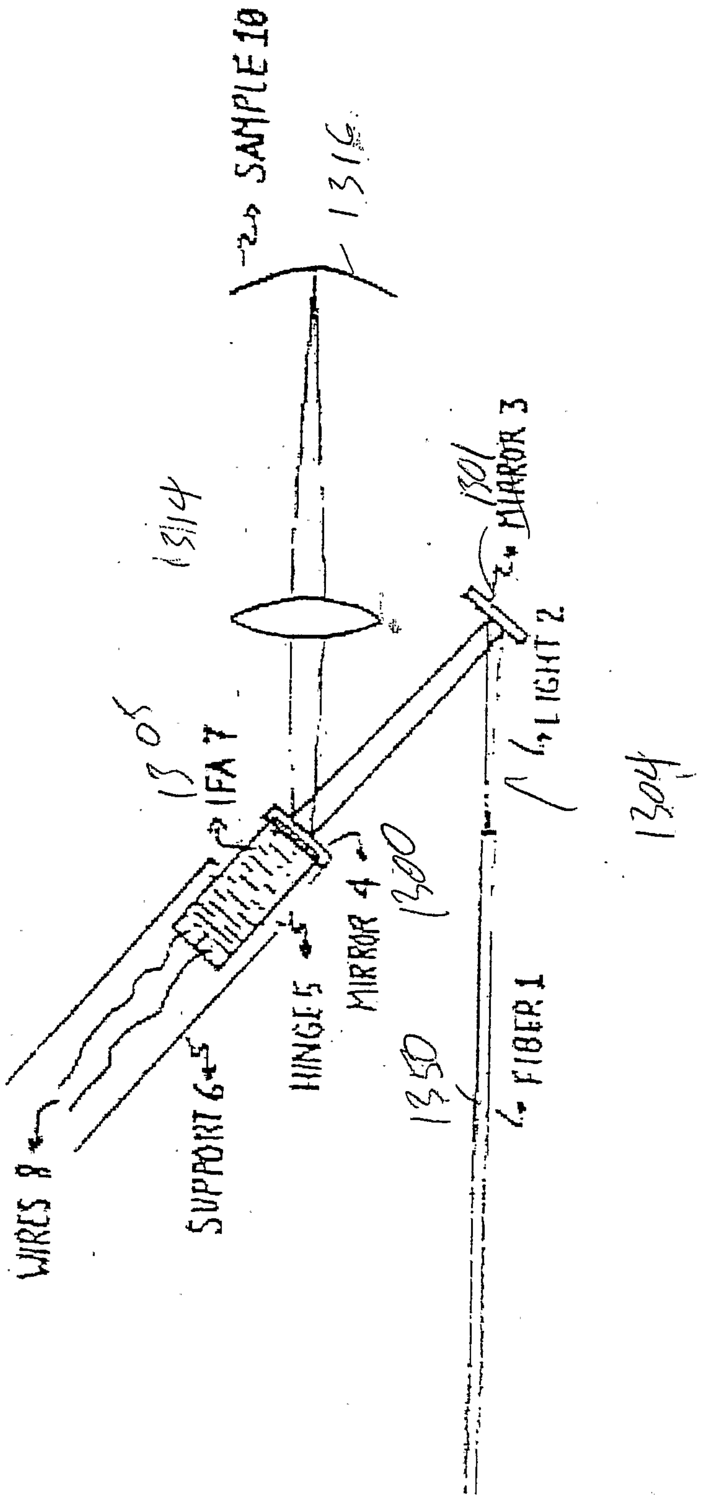
SAMPLE 10
1316
1314
MIRROR 3
1301
LIGHT 2
1304
IFA 7
1305
MIRROR 4
1300
HINGE 5
SUPPORT 6
WIRES 8
FIBER 1
1350

FIGURE 13

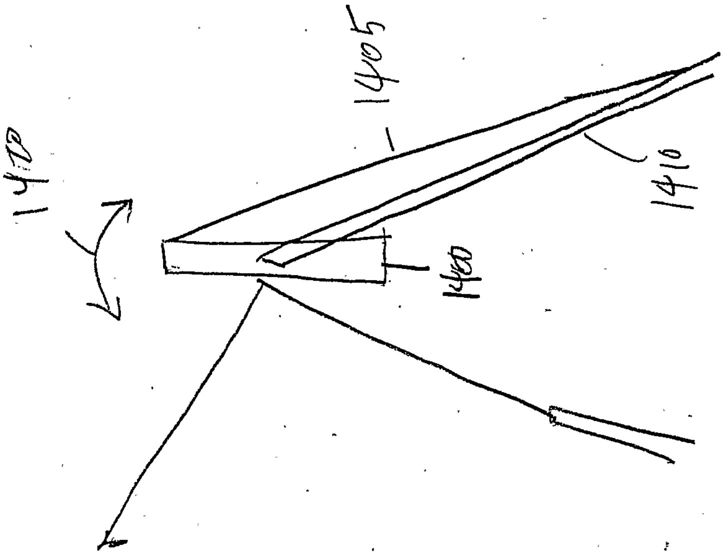

FIGURE 14

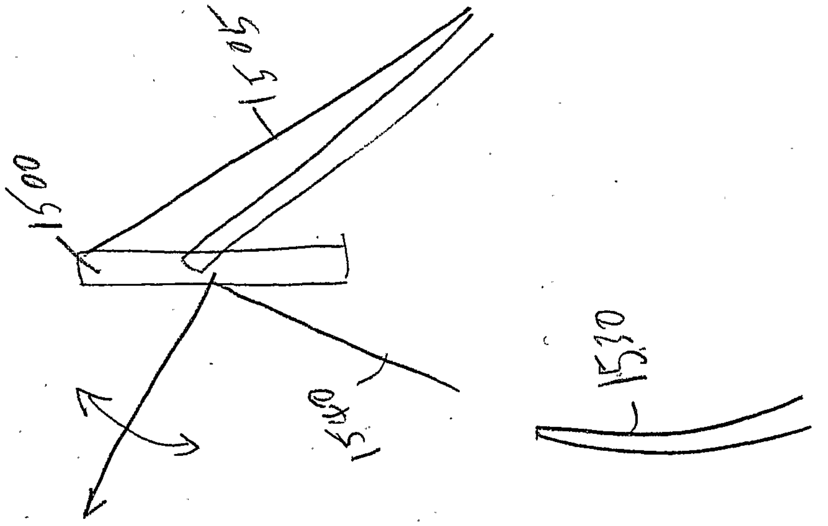

FIGURE 15

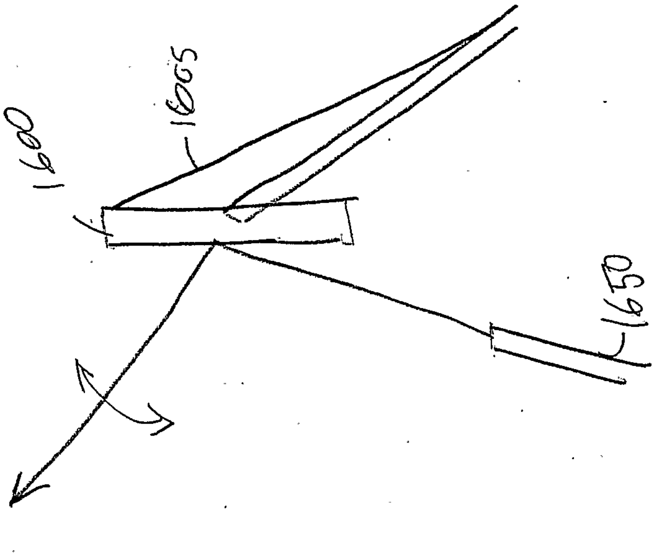

FIGURE 16

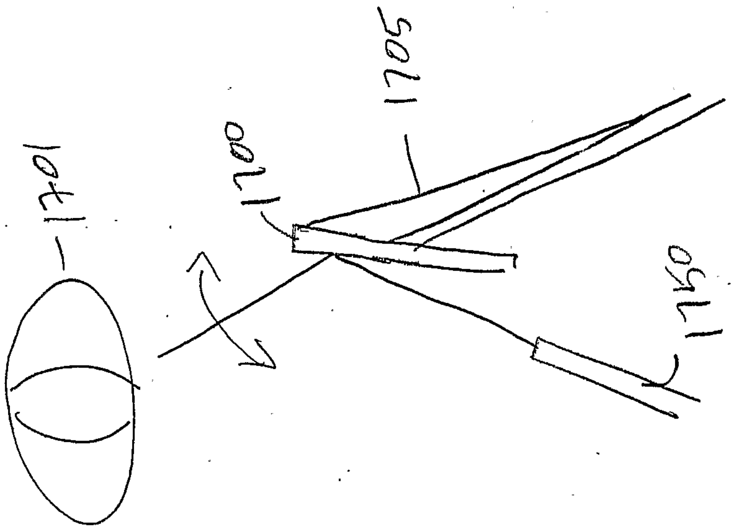

FIGURE 17

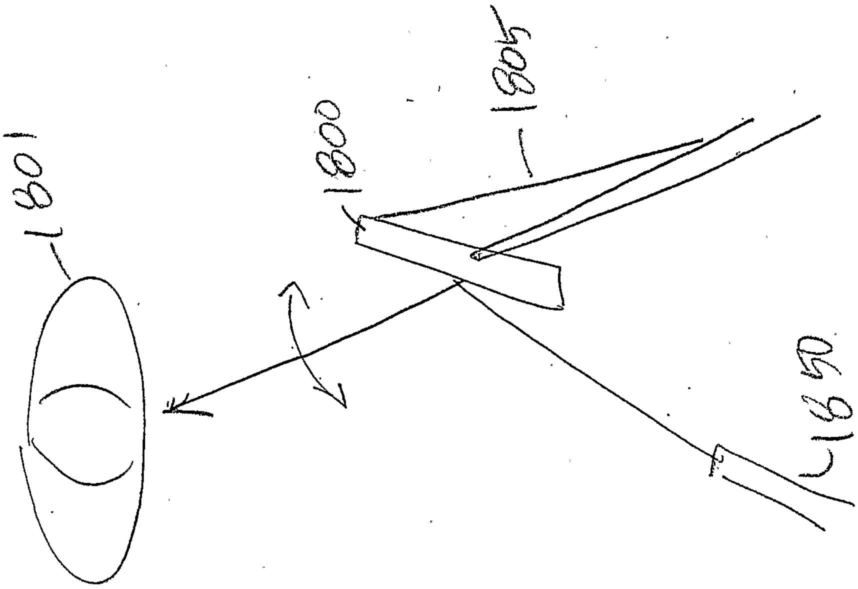

FIGURE 18

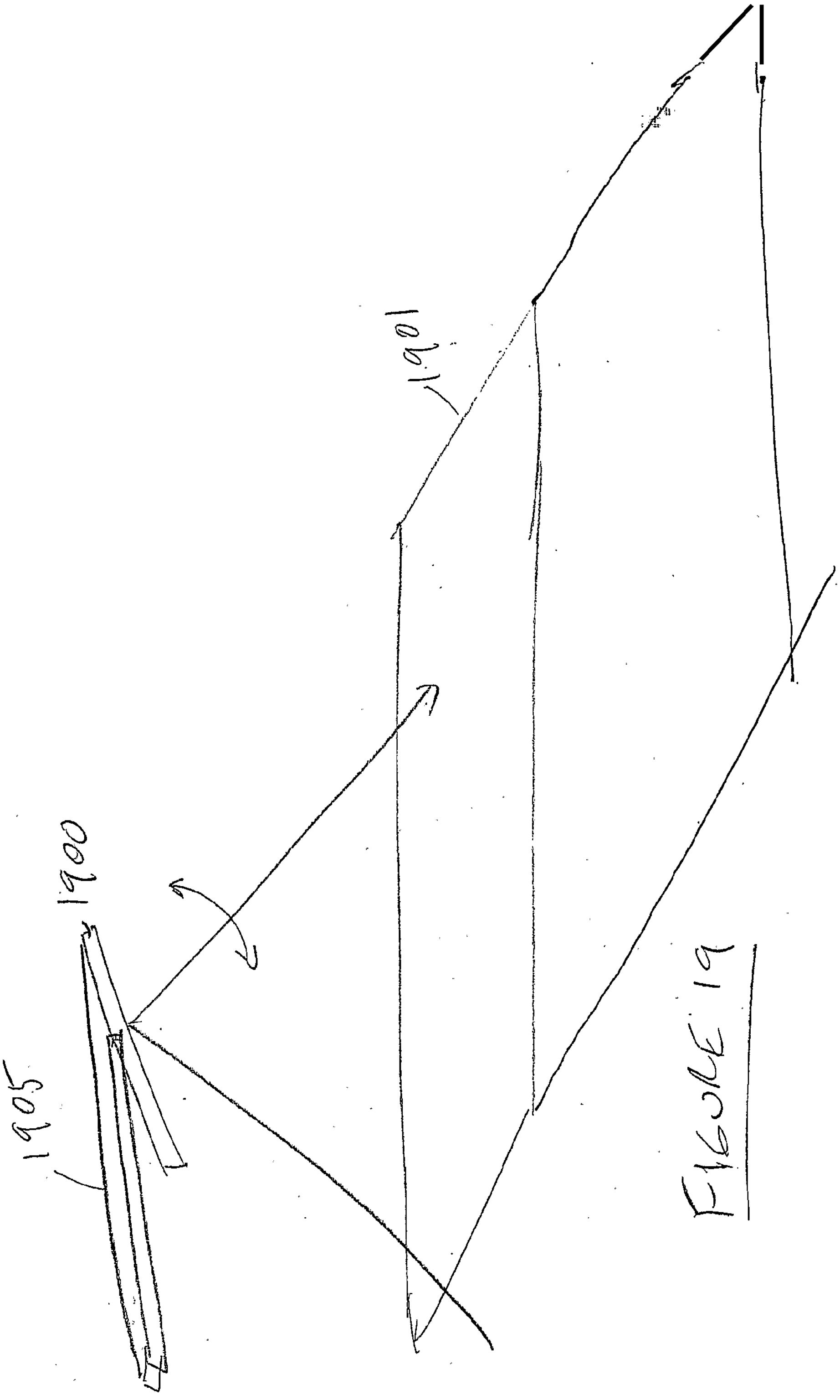

FIGURE 19

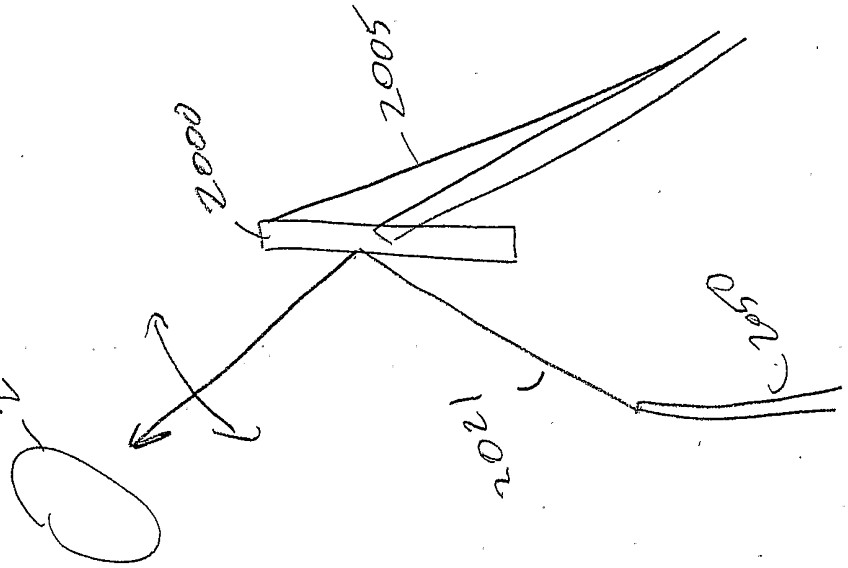

FIGURE 20

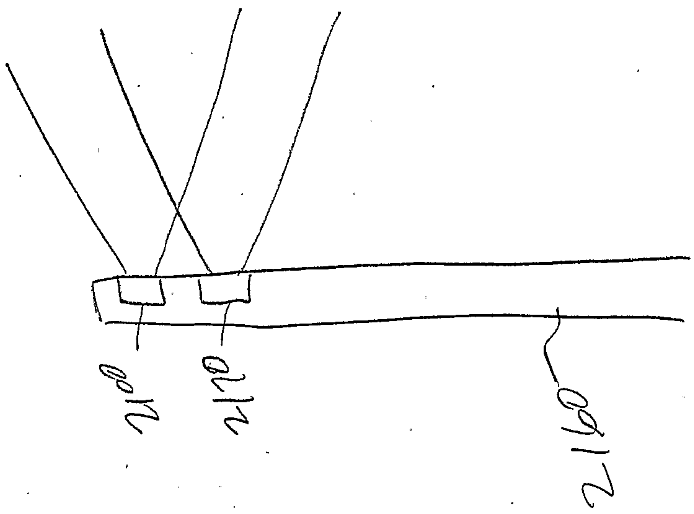

FIGURE 21

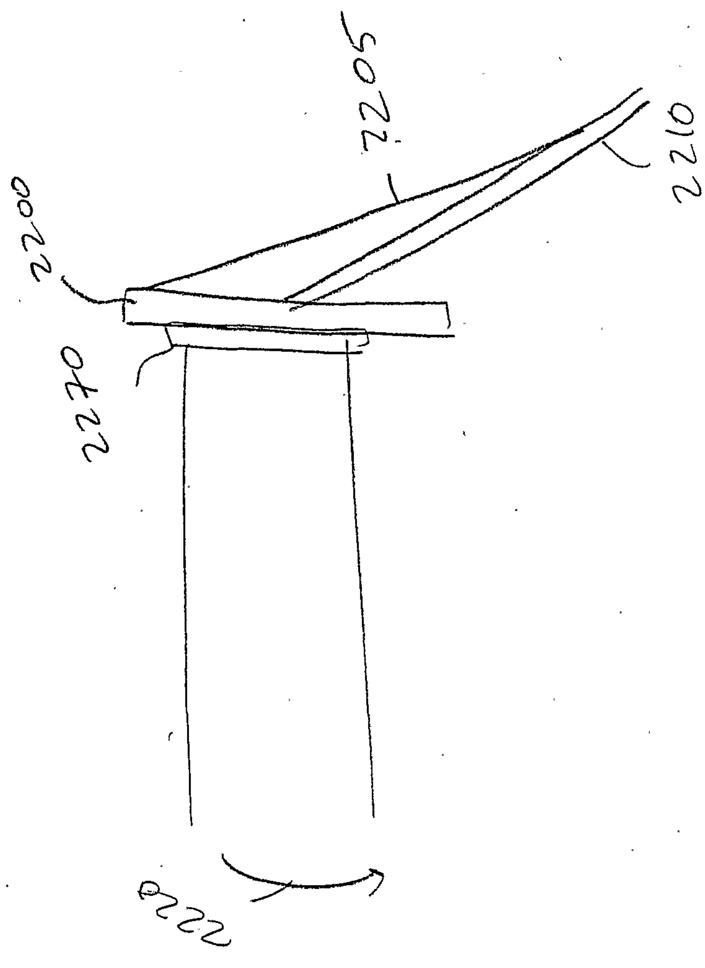

FIGURE 22

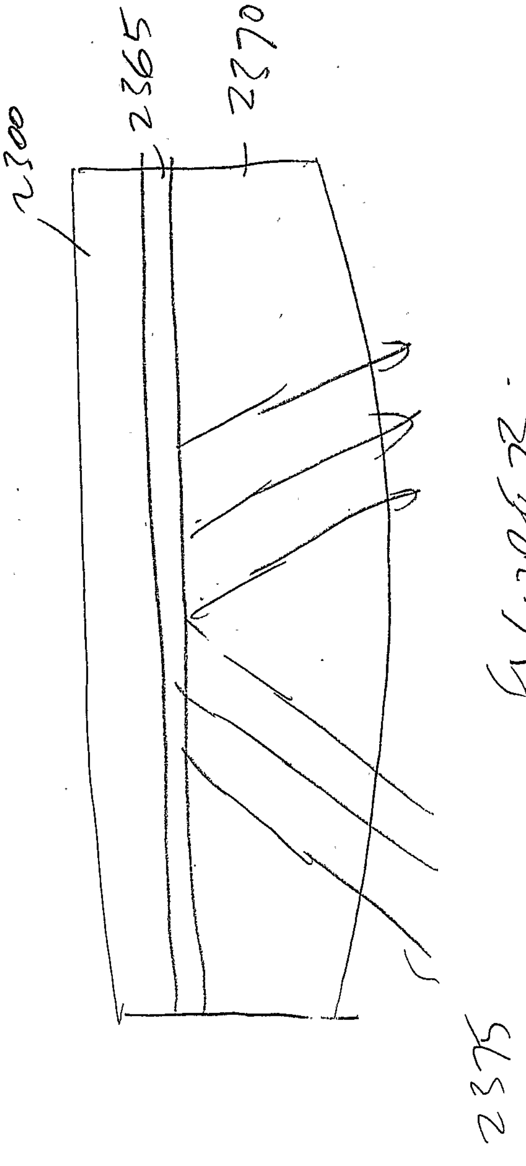

FIGURE 23

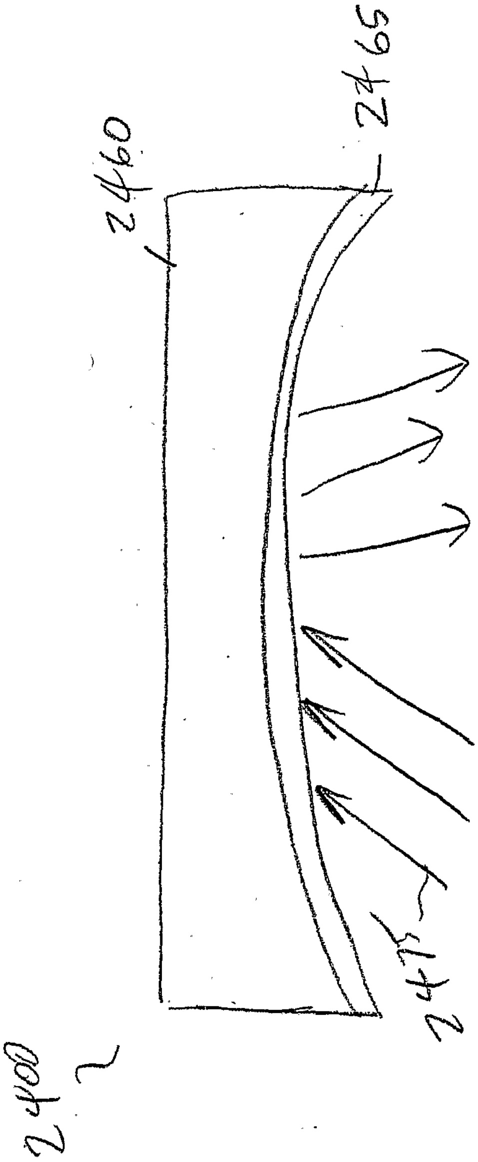

FIGURE 24

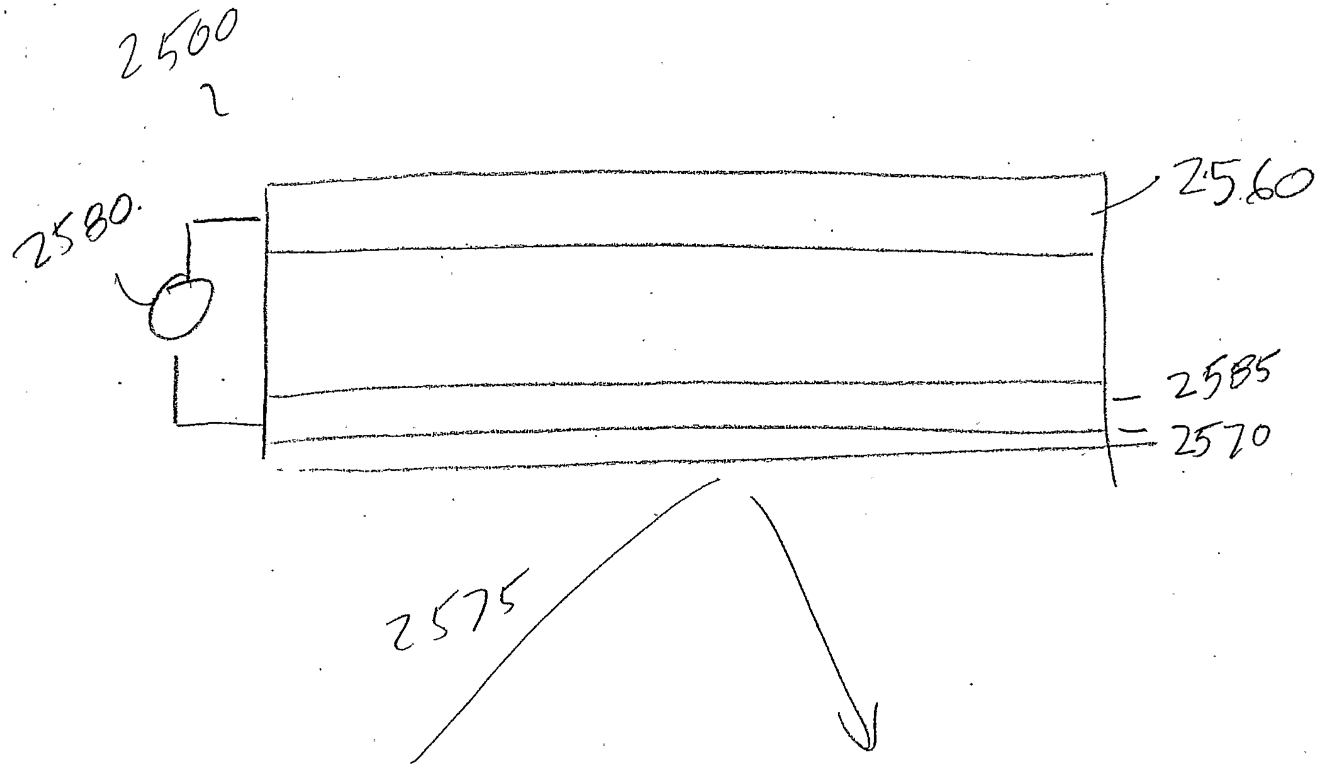

FIGURE 25A

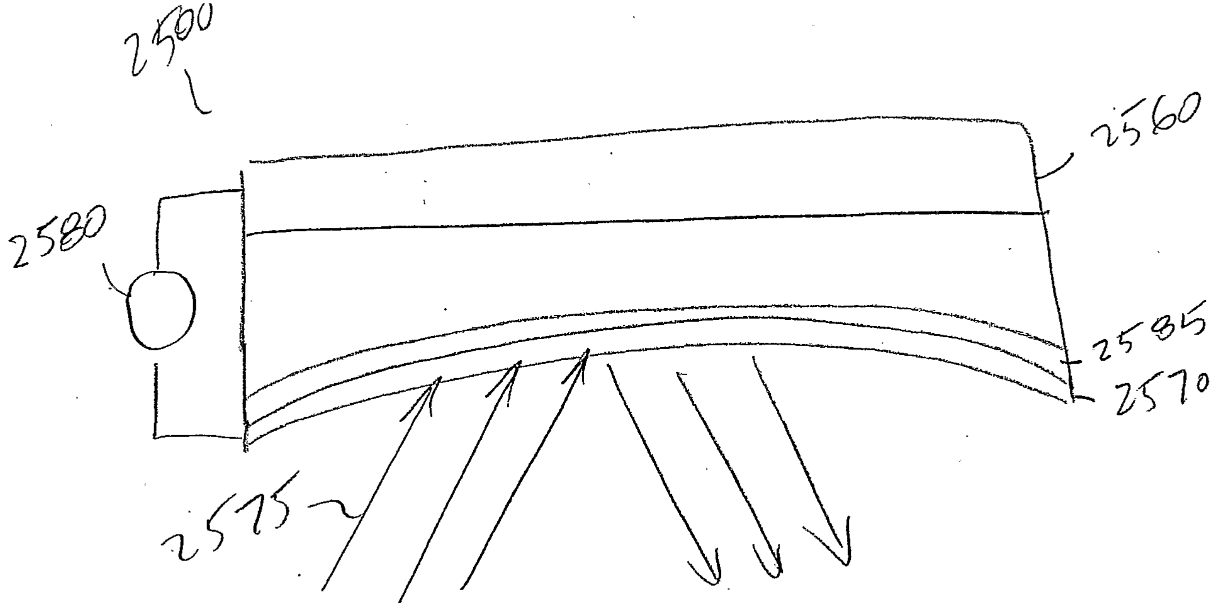

FIGURE 25B

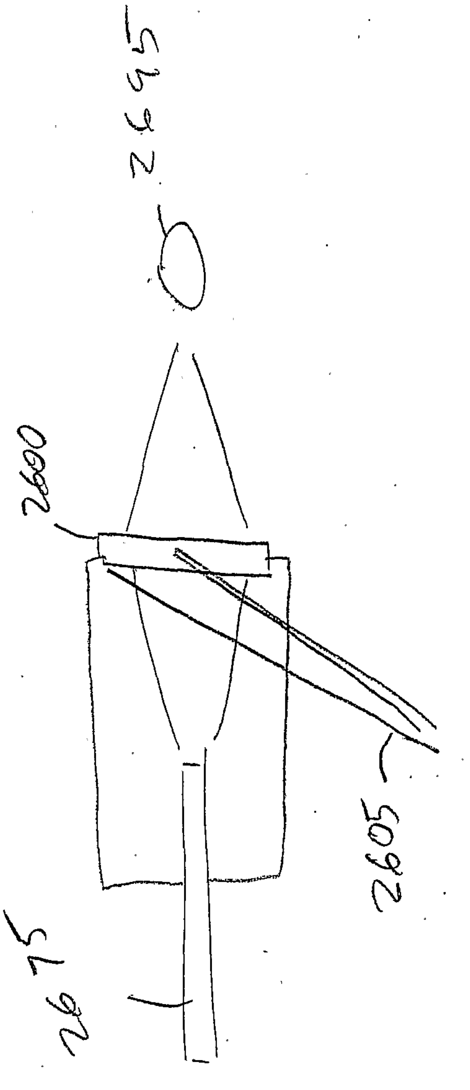

FIGURE 26

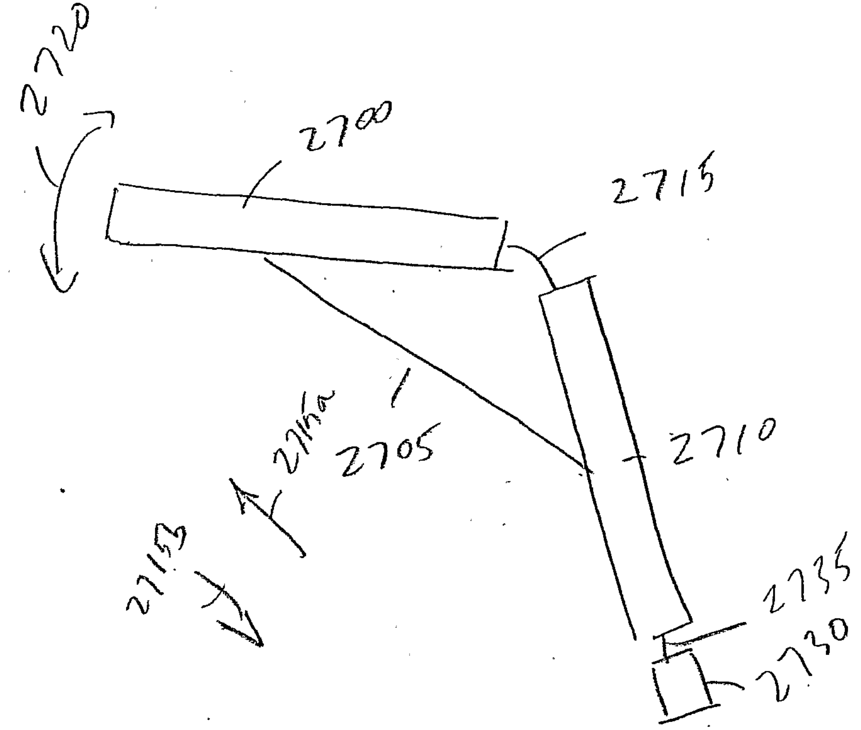

FIGURE 27

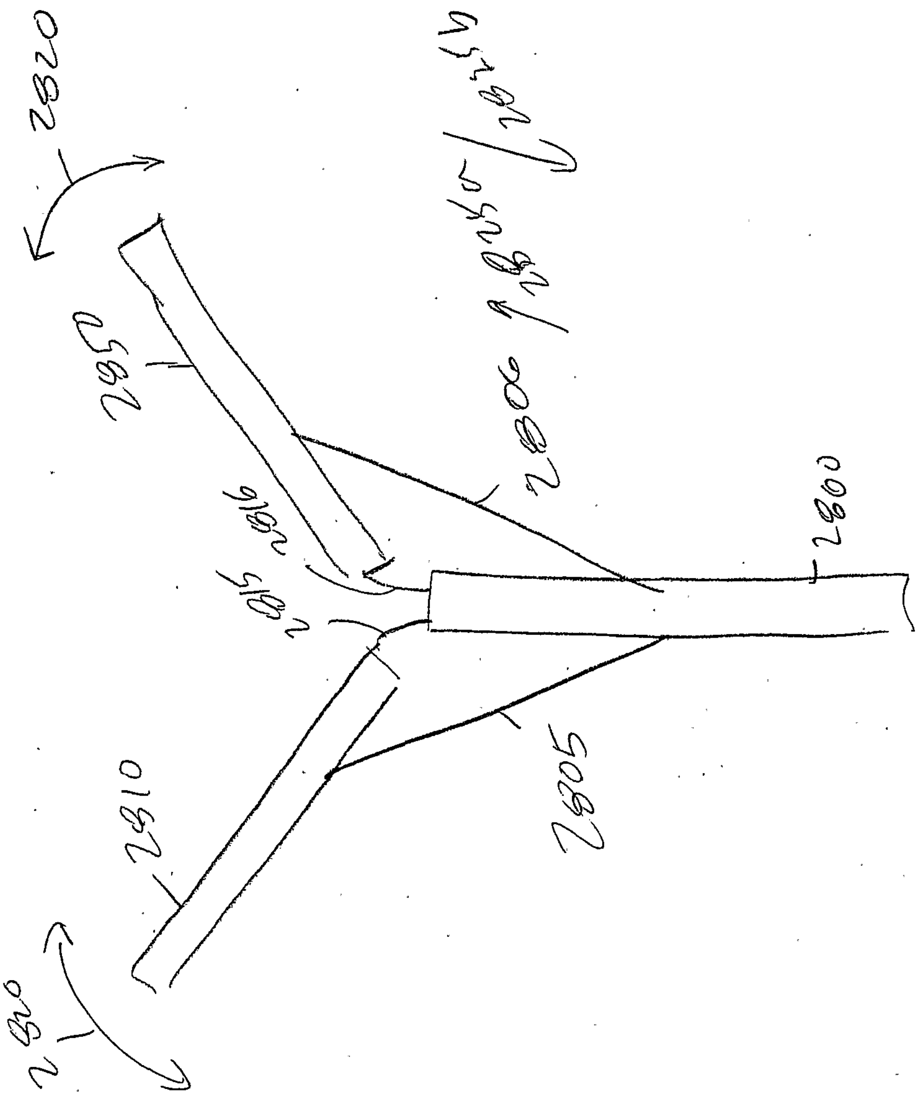

FIGURE 28A

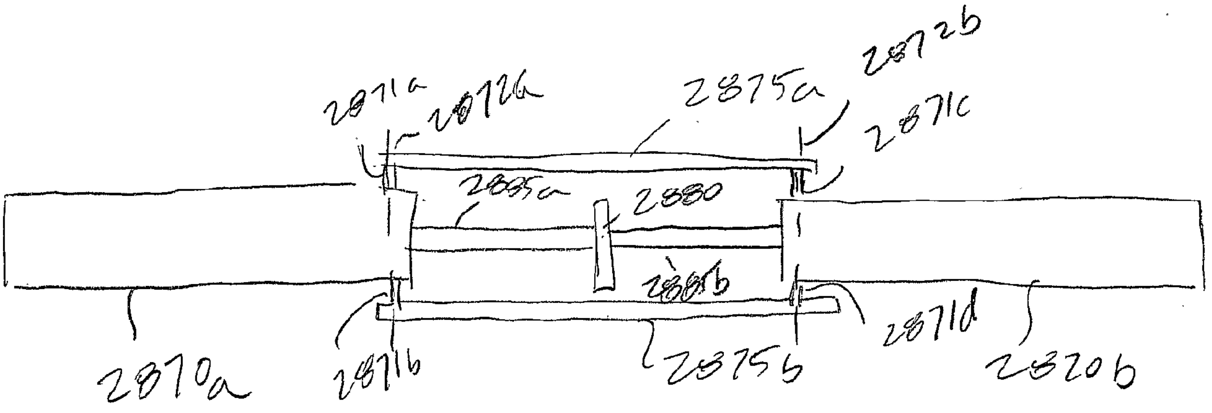

FIGURE 28 B

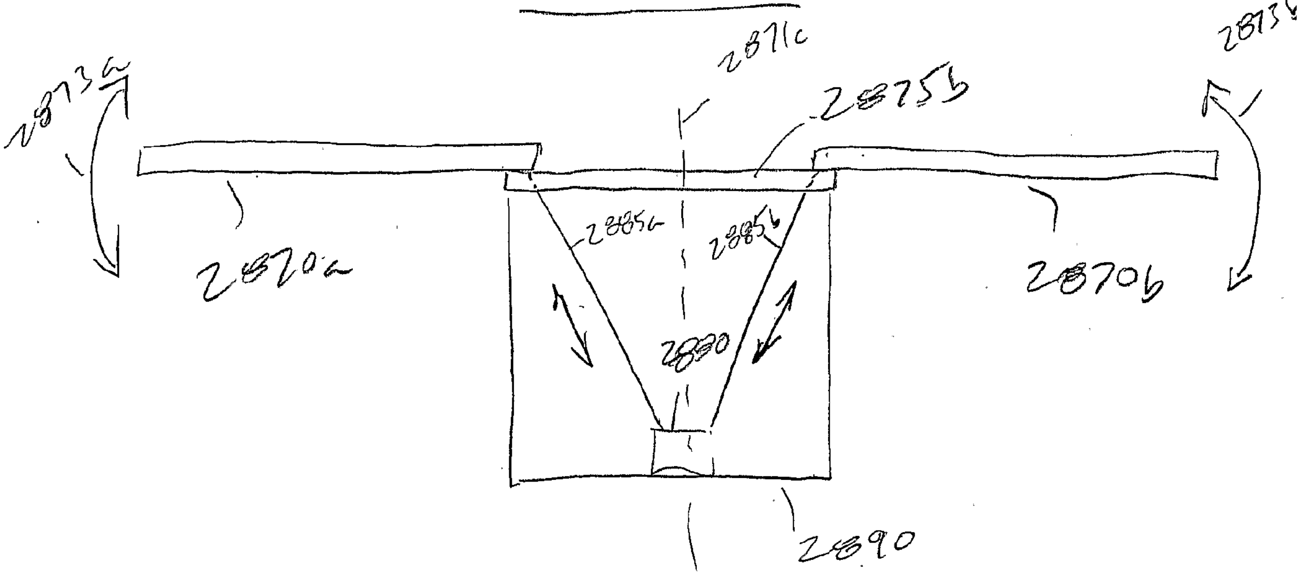

FIGURE 28C

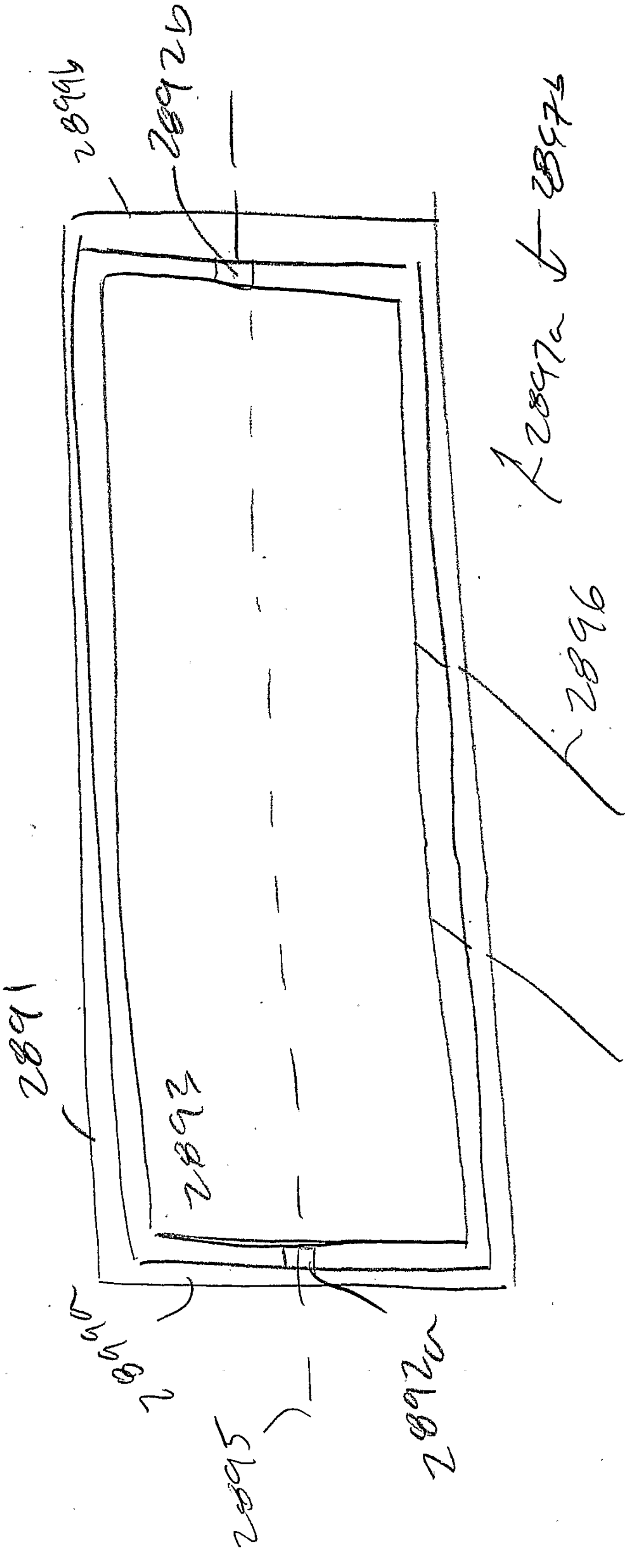

FIGURE 28D

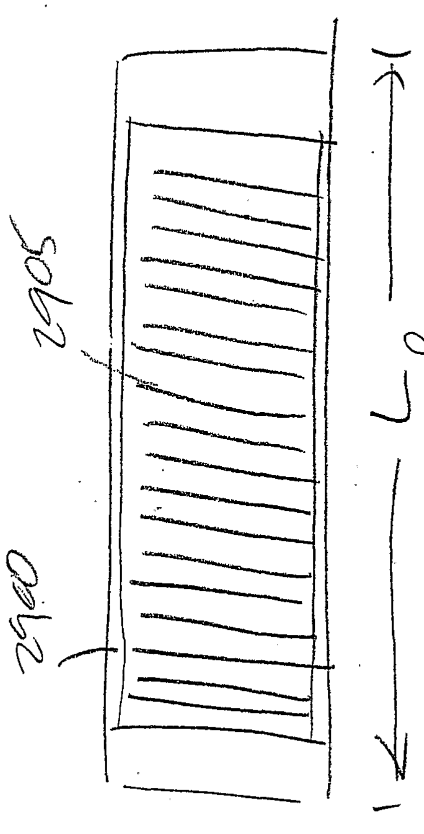

FIGURE 29A

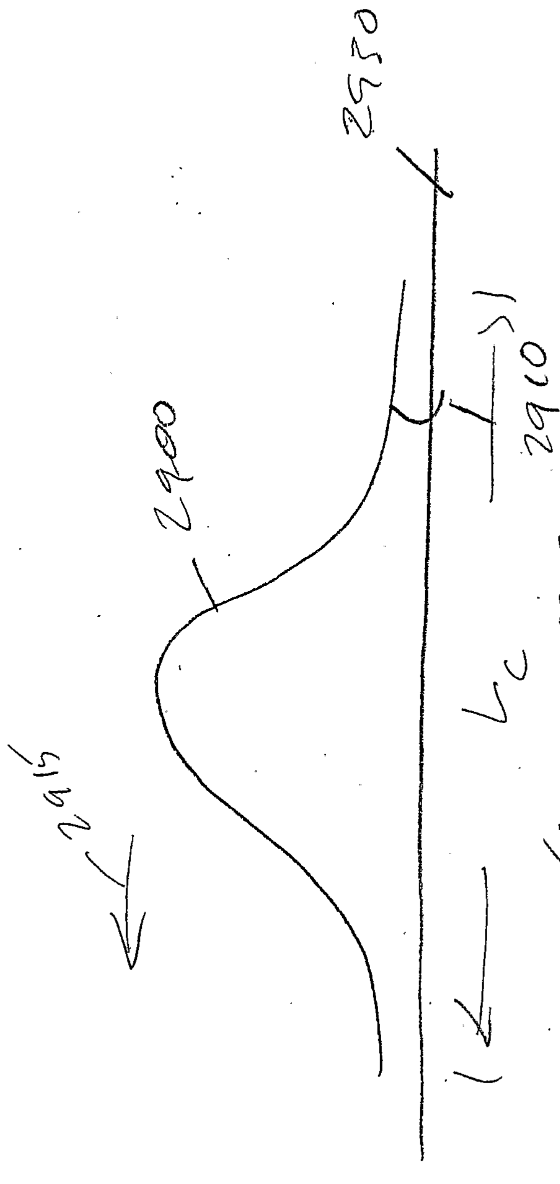

FIGURE 29B

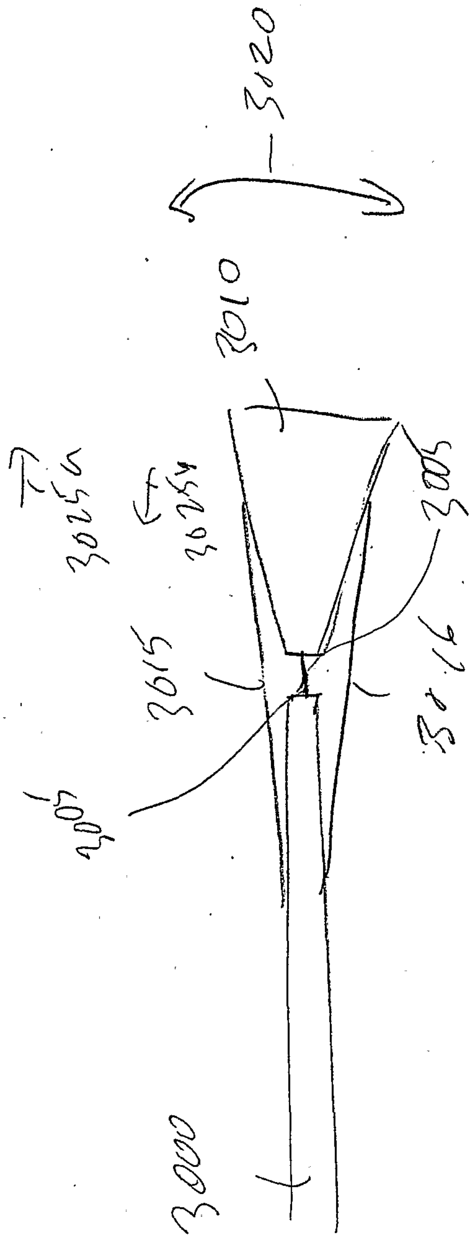

FIGURE 30