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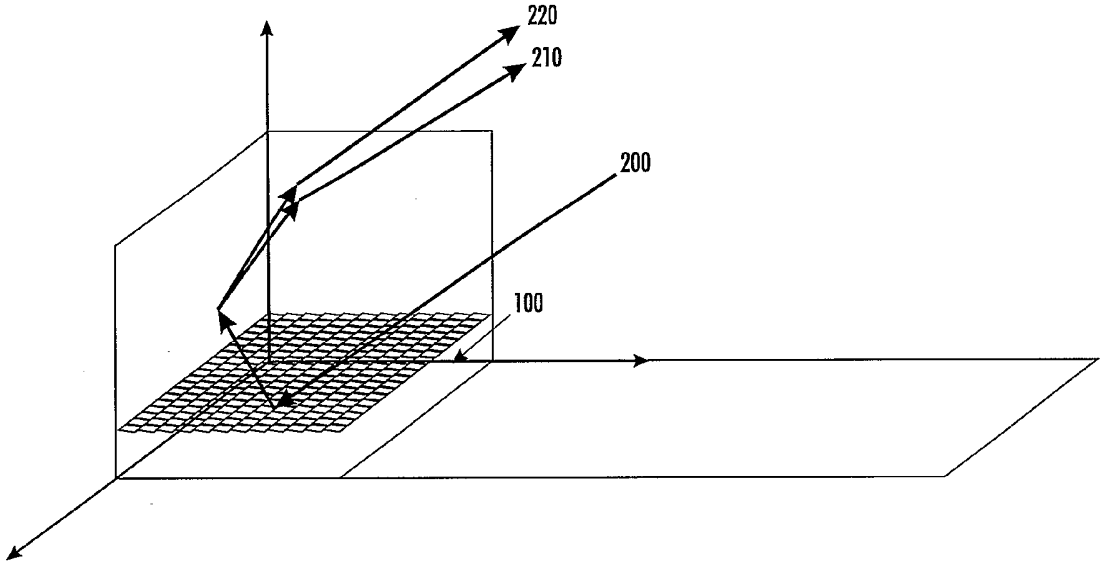

(57) **Abstract:** A deformable reflector includes a plurality of MEMS devices, each having an electrode membrane having a reflective surface thereon, a flat surface, and a pulldown electrode formed in the flat substrate. The electrode membrane has substantially a same flatness of the flat substrate when the electrode membrane comes into contact with the flat substrate across a majority of its surface area in response to a voltage being applied to the pulldown electrode. The electrode membrane has a two-dimensional curvature when no voltage is applied to the pulldown electrode.

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LIGHT MODULATING MIRROR DEVICE AND ARRAY OF MIRROR DEVICES

PRIORITY INFORMATION

This application claims priority to U.S. Patent Application Serial Number 11/000,427, filed on November 30, 2004, which is incorporated herein by reference in its entirety.

FIELD OF THE PRESENT INVENTION

[0001] The present invention is directed to light modulators using an array of deformable mirrors. More particularly, the present invention is an array of deformable mirrors wherein each deformable mirror is in a same plane so as to provide planar reflection of light when a voltage is applied to a pulldown electrode.

BACKGROUND OF THE PRESENT INVENTION

[0002] Light modulating mirror devices have been developed in which a mirror or reflector is can be positioned at various locations to either direct the impinging light to one location or to direct the impinging light to another location.

[0003] When a voltage is applied to one region housing the mirror, the mirror is moved so that the impinging light is directed to a first location. When the voltage is removed or applied to another region housing the mirror, the mirror is moved so that the impinging light is directed to a second location.

[0004] Such a device can be implemented in a variety of optical applications. For example, US Patent Number 5,061,049, issued on October 29, 1991, entitled "Spatial Light Modulator and Method," describes an spatial light modulator with a movable mirror.

[0005] Spatial light modulators are transducers that modulate incident light in a spatial pattern corresponding to an electrical or optical input. The incident light may be modulated in its phase, intensity, polarization, or direction, and the light modulation may achieved by a variety of materials exhibiting various electrooptic or magnetoopotic effects and by materials that modulate light by surface deformation.

[0006] An example of a prior art single pixel of an electrostatic (rigid) movable mirror device is illustrated by Figure 1. The pixel, generally denoted **20**, is basically a plate (flap) covering a shallow well and includes silicon substrate **22**, insulating spacer **24**, metal hinge layer **26**, metal plate layer **28**, plate **30** formed in layers **26-28**, and plasma etch access holes **32** in plate **30**. The portions **34** & **36** of hinge layer **26** that are not covered by plate layer **28** form torsion hinges (torsion rods) attaching beam **30** to the portion of layers **26-28** supported by spacer **24**. Electrodes **40**, **42**, **46**, and **41** run between spacer **24** and substrate **22** and are isolated from substrate **22** by silicon dioxide layer **44**.

[0007] The design of Figure 1 allows that the plate metal be as thick as desired and the hinge metal be as thin as desired without the problems of step coverage of the hinge metal over the plate metal and that the spacer surface under the beam metal is not exposed to processing side effects which would arise if the hinge were formed as a rectangular piece on the spacer prior to deposition of the plate metal.

[0008] Pixel **20** is operated by applying a voltage between metal layers **26-28** and electrodes **42** or **46** on substrate **22**: beam **30** and the electrodes form the two plates of an air gap capacitor and the opposite charges induced on the two plates by the applied voltage exert electrostatic force attracting beam **30** to substrate **22**, whereas electrodes **40** and **41** are held at the same voltage as beam **30**. This attractive force causes beam **30** to twist at hinges **34** and **36** and be deflected towards substrate **22**.

[0009] Figure 1 also indicates the reflection of light from deflected beam **30** as may occur during operation of a deformable mirror device. The deflection of beam **30** can be a highly non-linear function of the applied voltage because the restoring force generated by the twisting of hinge **34** is approximately a linear function of the deflection but the electrostatic force of attraction increases as a function of the reciprocal of the distance between the closest corner of beam 30 and substrate **22**.

[0010] Although electrostatic movable mirror devices have been used, the conventional electrostatic movable mirror devices fail to realize many desired characteristics. For example, the conventional electrostatic movable mirror devices have a relatively slow speed of actuation and use a relatively large amount of energy for actuation. Moreover, the conventional electrostatic movable mirror devices have a relatively high voltage of actuation, are complicated to build, and are not necessarily scalable to very small sizes. Lastly, the conventional electrostatic movable mirror devices have a relatively small extinction ratio.

[0011] Therefore, it is desirable to provide a mirror device that has a relatively higher speed of actuation, lower energy of actuation, lower voltage of actuation, simpler to build, easier to scale to very small sizes, and/or larger extinction ratio. Moreover, it is desirable to provide a deformable mirror device that has a relatively higher speed of actuation, lower energy of actuation, lower voltage of actuation, simpler to build, easier to scale to very small sizes, and/or larger extinction ratio.

SUMMARY OF THE PRESENT INVENTION

[0012] One aspect of the present invention is a retroreflector. The retroreflector includes a first non-deformable mirror to provide reflection of light back to a source thereof and a deformable mirror having a first state to provide reflection of light back to the source thereof and a second state to provide misdirection of light to prevent the reflection of light back to the source thereof.

[0013] Another aspect of the present invention is a passive interrogatable sensor. The passive interrogatable sensor includes a sensing device to sense predetermined conditions of a surrounding environment and generate signals representative of the sensed predetermined conditions; a controller to process the generated signals and to produce drive signals in response thereof; a first non-deformable mirror to provide reflection of light back to a source thereof; and a deformable mirror, operatively connected to the controller, being driven to either a first state or a second state in response to drive signals from said controller. The first state provides reflection of light back to the source thereof. The second state provides misdirection of light to prevent the reflection of light back to the source thereof.

[0014] A further aspect of the present invention is an optical identification system. The optical identification system includes a laser source, disposed remotely from an object to be interrogated, for transmitting an unmodulated beam toward the object to be interrogated; a controller, disposed with the object to be interrogated, to produce drive signals associated with identification information; a first non-deformable mirror, disposed with the object to be interrogated, to provide reflection of light back to the laser source; a deformable mirror, disposed with the object to be interrogated and operatively connected to the controller, being driven to either a first state or a second state in response to drive signals from said controller. The first state provides reflection of light back to the laser source. The second state provides misdirection of light to prevent the reflection of light back to the laser source. The deformable mirror modulates the light to be reflected back to the laser source so as to encode identification information as reflected modulated light. A detector, disposed with the laser source, decodes identification information from light received from the deformable mirror disposed with the object to be interrogated.

[0015] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a plurality of MEMS devices. Each MEMS device includes an electrode membrane having a reflective surface thereon, a flat substrate, and a pulldown electrode formed in the flat substrate. The electrode membrane has substantially a same flatness of the flat substrate when the electrode membrane comes into contact with the flat substrate across a majority of its surface area in response to a voltage being applied to the pulldown electrode. The electrode membrane has a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0016] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a substrate; a plurality of MEMS devices formed in the substrate, each MEMS device including an electrode membrane having a reflective surface thereon; and a pulldown electrode formed in the substrate. The electrode membrane has substantially a same flatness of the substrate when the electrode membrane comes into contact with the substrate across a majority of its surface area in response to a voltage being applied to the pulldown electrode. The electrode membrane has a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0017] A further aspect of the present invention is a deformable mirror. The deformable mirror includes a plurality of MEMS devices. Each MEMS device includes a flat substrate, a flexible membrane attached, at one end, to a surface of the flat substrate and having a reflective surface thereon, and a pulldown electrode formed in the flat substrate. The flexible membranes, each, have a plurality of dimples formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the substrate at the dimples when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0018] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a substrate; a plurality of MEMS devices formed in the substrate, each MEMS device including a flexible membrane, at one end, to a surface of the substrate and having a reflective surface thereon; and a pulldown electrode formed in the substrate. The flexible membranes, each, have a plurality of dimples formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the substrate at the dimples when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0019] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a plurality of MEMS devices. Each MEMS device includes a flat substrate, a flexible membrane attached, at one end and an opposite end, to a surface of the flat substrate and having a reflective surface thereon, and a pulldown electrode formed in the flat substrate. The flexible membranes, each, have a plurality of dimples formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the substrate at the dimples when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0020] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a substrate; a plurality of MEMS devices formed in the substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of the substrate and having a reflective surface thereon; and a pulldown electrode formed in the substrate. The flexible membranes, each, have a plurality of dimples formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the substrate at the dimples when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0021] A further aspect of the present invention is a deformable mirror. The deformable mirror includes a plurality of MEMS devices. Each MEMS device includes a flat substrate, a flexible membrane attached, at one end, to a surface of the flat substrate and having a reflective surface thereon, and a pulldown electrode formed in the flat substrate. The flat substrate has a plurality of posts formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the posts when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0022] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a substrate; a plurality of MEMS devices formed in the substrate, each MEMS device including a flexible membrane, at one end, to a surface of the substrate and having a reflective surface thereon; and a pulldown electrode formed in the substrate. The substrate has a plurality of posts formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the posts when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0023] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a plurality of MEMS devices. Each MEMS device includes a flat substrate, a flexible membrane attached, at one end and an opposite end, to a surface of the flat substrate and having a reflective surface thereon, and a pulldown electrode formed in the flat substrate. The flat substrate has a plurality of posts formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the posts when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

[0024] Another aspect of the present invention is a deformable mirror. The deformable mirror includes a substrate; a plurality of MEMS devices formed in the substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of the substrate and having a reflective surface thereon; and a pulldown electrode formed in the substrate. The substrate has a plurality of posts formed thereon. The flexible membranes, each, are configured such that when a voltage is applied to the pulldown electrode, the flexible membrane is disposed to provide a desired reflection of light. The flexible membranes, each, contact the posts when a voltage is applied to the pulldown electrode. The flexible membranes, each, have a two-dimensional curvature when no voltage is applied to the pulldown electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The present invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be construed as limiting the present invention, wherein:

[0026] Figure 1 illustrates a prior art deformable mirror device;

[0027] Figures 2 and 3 illustrate two possible examples of cantilever structures used in a deformable mirror device according to the concepts of the present invention;

[0028] Figure 4 illustrates a deformable mirror membrane anchored in the center to a flat substrate according to the concepts of the present invention;

[0029] Figure 5 illustrates the deformable mirror membrane of Figure 4 in a flattened state according to the concepts of the present invention;

[0030] Figure 6 illustrates a top view of the deformable mirror membrane of Figure 4 according to the concepts of the present invention;

[0031] Figure 7 illustrates a deformable mirror membrane anchored at opposite ends to a flat substrate according to the concepts of the present invention;

[0032] Figure 8 illustrates the deformable mirror membrane of Figure 7 in a flattened state according to the concepts of the present invention;

[0033] Figure 9 illustrates a top view of the deformable mirror membrane of Figure 7 according to the concepts of the present invention;

[0034] Figure 10 illustrates a deformable mirror membrane anchored in the center to a flat substrate with posts or dimples formed on the deformable mirror membrane according to the concepts of the present invention;

[0035] Figure 11 illustrates a top view of the deformable mirror membrane of Figure 10 according to the concepts of the present invention;

[0036] Figure 12 illustrates a deformable mirror membrane anchored in the center to a flat substrate with posts or dimples formed on the substrate according to the concepts of the present invention;

[0037] Figure 13 illustrates one example of a pulldown electrode design according to the concepts of the present invention;

[0038] Figure 14 illustrates another example of a pulldown electrode design according to the concepts of the present invention;

[0039] Figure 15 illustrates an array of deformable mirror devices according to the concepts of the present invention;

[0040] Figure 16 illustrates a modulated retroreflector using deformable mirror devices according to the concepts of the present invention;

[0041] Figures 17 and 18 show the possible operational states of a modulated retroreflector using deformable mirror devices according to the concepts of the present invention;

[0042] Figure 19 illustrates the effect of misalignment of one of the mirrors on the reflection intensity;

[0043] Figures 20 through 22 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0044] Figures 23 through 25 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0045] Figures 26 through 28 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0046] Figures 29 through 31 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0047] Figures 32 through 34 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0048] Figures 35 through 37 illustrate another example of a deformable mirror membrane according to the concepts of the present invention;

[0049] Figures 38 through 43 illustrate a fabrication process for the deformable mirror membranes according to the concepts of the present invention; and

[0050] Figures 44 and 45 show top views of a modulated retroreflector using deformable mirror devices according to the concepts of the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0051] The present invention will be described in connection with preferred embodiments; however, it will be understood that there is no intent to limit the present invention to the embodiments described herein. On the contrary, the intent is to cover all alternatives, modifications, and equivalents as may be included within the spirit and scope of the present invention, as defined by the appended claims.

[0052] For a general understanding of the present invention, reference is made to the drawings. In the drawings, like reference have been used throughout to designate identical or equivalent elements. It is also noted that the various drawings illustrating the present invention are not drawn to scale and that certain regions have been purposely drawn disproportionately so that the features and concepts of the present invention could be properly illustrated.

[0053] As noted above, the present invention relates to light modulators using deformable mirrors either individually or in arrays for applications such as special light modulators and modulated retroreflectors.

[0054] Modulated retroreflector devices can be divided into two types, modulated corner cube retroreflectors and Cats-Eye. The Cats-Eye type are a device which relies upon one or more lenses to focus the laser beam to a small spot, having a modulating reflector at this spot and sending the light back through the lens to the source. The position of the focal spot will depend on the direction of the incoming light beam, so that the Cats-Eye type requires a modulation area at least as large as the aperture of the lens in order to reflect back light coming from a wide variety of angles. In most cases the total mirror area for the Cats-Eye type is at least as large for the Cats-Eye type as for one of the modulated corner cube retroreflector mirrors.

[0055] Modulated retroreflector and reflective display devices can also be divided into several categories (liquid crystal light valve, electro-optic (multiple quantum well) light valve, electrostatic modulated mirror) depending on the modulation technique. The electrostatic mirror or reflector devices can again be divided into two categories, electrostatic (rigid) movable mirror or reflector and deformable mirror or reflector.

[0056] A modulated corner cube retro reflector includes an array of deformable mirrors or reflectors that fills the area of one of the three surfaces of a corner cube, the other two surfaces being non-deformable mirrors or reflectors. All the deformable mirrors or reflectors in the array can operate in unison, so that a laser beam entering the aperture of the modulated corner cube retroreflector will be reflected back on itself and returned to the source with little change in divergence when all the deformable mirrors or reflectors are flat.

[0057] When the deformable mirrors or reflectors are not so flat, a divergent beam is returned, so that when the deformable mirror or reflector array's flatness is modulated, the returned beam, when it is measured at the source, is modulated in its intensity. Such a modulated corner cube retroreflector can be used as a communication device consuming very low power at the modulated corner cube retroreflector site since is a "passive device" and is only reflecting the energy of the remote laser source.

[0058] In the case of a second application, the special light modulator, the deformable mirrors in the array are individually addressed and modulated such that each deformable mirror is a pixel and can be used to make a reflective display for television, computer monitors, and movie projectors. This type of display is a "passive display" because the light energy for the display comes from a separate light source.

[0059] Conventional deformable mirror or reflector devices have a mirror or reflector membrane electrode whose curvature is varied by applying an electrostatic voltage more or less perpendicular to the surface of the membrane. In some of these conventional cases, the membrane is stretched flat over an opening or across a gap. Moreover, in other conventional designs, the membrane is held all around the edges or held by two parallel edges. This later mode is sometime referred to as a fixed-fixed beam.

[0060] In the conventional device, through the application of an electrostatic field, the membrane is deformed or curved spoiling the flat mirror reflection, thereby causing the reflected light beam to converge or diverge. An example of such a conventional device is disclosed in US Patent Number 4,441,791.

[0061] As disclosed in US Patent Number 4,441,791, the flexing action stretches the membrane like a spring or a rubber band, increasing the stress. There is a limit to how far the membrane can be stretched in this case because it will eventually undergo plastic flow or a tensile failure. This type of conventional deformable mirror membrane can also be sensitive to temperature when the membrane has a temperature expansion coefficient different than the substrate, because the stress, and therefore the actuation voltage will vary with temperature.

[0062] In accordance with the concepts of the present invention, the deformable mirror or reflector is constructed using a free-standing membrane wherein the membrane is held only at one point or along one edge, referred to here as a cantilever. Figures 2 and 3 illustrate two types of cantilever designs according to the concepts of the present invention.

[0063] As illustrated in Figure 2, the deformable mirror or reflector **10** is held to the substrate at a single point. In the example of Figure 2, the single point is located at approximately the center of the deformable mirror or reflector **10**. Figure 2 uses shading to illustrate the degree of curvature or deformity of the deformable mirror or reflector **10**. Furthermore, Figure 2 illustrates the shape of the deformable mirror or reflector **11** when in a flattened state.

[0064] As illustrated in Figure 3, the deformable mirror or reflector **10** is held to the substrate along a single edge. In the example of Figure 3, the edge is located at approximately one end of the deformable mirror or reflector **10**. Figure 3 uses shading to illustrate the degree of curvature or deformity of the deformable mirror or reflector **10**. Furthermore, Figure 3 illustrates the shape of the deformable mirror or reflector **11** when in a flattened state.

[0065] In the deformable mirror or reflector, in accordance with the concepts of the present invention, the membrane will not be flattened by support structures. Moreover, the deformable mirror or reflector will respond to internal stresses in the membrane and take on a curved shape. If the membrane is lying generally in the x-y plane, the curvature will likely have a z component in both the x and y directions.

[0066] If the membrane is attached along one edge (Figure 3), it could be flat in the vicinity of that edge and curved further from the edge. It could also have some tensile or compressive stress along that attachment edge, which will affect the shape in the vicinity of that edge.

[0067] When an electric field is used to move this curved cantilever membrane, the membrane will have more of a bending action rather than a stretching action. Such a cantilevered membrane can be made to have much larger excursions without distortion or failure, than a fixed-fixed beam, for similar sized structures. Such a cantilevered membrane can be made to have a temperature stable shape and therefore have a more controlled threshold voltage for electrostatic actuation. It is noted that flattening an already formed curved free standing membrane, a cantilever, to a high degree of flatness is difficult when using only an electric field, unless it is brought in contact with a flat surface.

[0068] With respect to the concepts of the present invention, a high speed, very small apertured, deformable mirror or reflector is provided which can achieve a high degree of flatness when actuated and uses a low cost fabrication process. The deformable mirror or reflector of the present invention is made using an electrode membrane which has a built in stress that causes curvature in both the x and y directions in its natural state with no outside forces acting upon it.

[0069] The membrane, according to the concepts of the present invention, in its most general form, is in contact with a highly flat substrate at only one or a few points, or along one edge. The membrane, according to the concepts of the present invention, is designed so that when a voltage is applied to one or more electrodes in the substrate, the membrane comes into intimate contact with the substrate across a large part of its surface, or at a significant number of contact points. The membrane, according to the concepts of the present invention, upon application of the voltage, becomes nearly the same flatness as the substrate. When the voltage is dropped to zero, the mirror springs back to its original position.

[0070] The cantilever modulated mirror devices of the present invention have many advantages over other technologies. When compared to the fixed-fixed structures, the mirror excursions can be much larger leading to larger depth of modulation, and temperature changes have a much smaller effect on the device performance.

[0071] Compared to the rigid tilting plate mirror devices, patents 4,710,732 and 5,061,049, the cantilever design of the present invention is much faster, can be easily scaled to smaller sizes, is simpler to build because of fewer steps, does not require maintaining flat mirrors in the relaxed state or in all actuation states, operates using lower voltages, and requires less power. For modulated corner cube retroreflector applications, the requirement of needing less power translates into less energy per bit.

[0072] Compared to the liquid crystal on silicon devices used in reflective projection devices, cantilever modulated mirror devices of the present invention have a much higher brightness, much faster switching, wider temperature range of operation, and longer life.

[0073] Compared to electro-optic or multiple quantum well modulator absorption devices, the cantilever modulated mirror devices of the present invention requires much lower power or energy for switching and have a much larger extinction ratio.

[0074] Figure 4 shows a deformable mirror or reflector membrane **10** anchored in the center to a flat substrate **17**, whereas Figure 6 shows a top view of the deformable mirror or reflector membrane **10** anchored in the center to a flat substrate by substrate contact **16**. The deformable mirror or reflector membrane **10** consists of three layers, an oxide layer **12** at the bottom, an aluminum layer **13** in the middle, and another oxide layer **14** on top. In one embodiment, the deformable mirror or reflector membrane is twenty microns square (twenty microns along each edge), the oxide layers are twenty nanometers thick, and the aluminum layer is fifty nanometers thick.

[0075] The combined stresses, in the three layers (**12**, **13** & **14**), cause the deformable mirror or reflector membrane **10** to curve upward, as illustrated in Figure 4, after it is released from the substrate **17**. A voltage applied between the substrate contact **16** and outer pulldown electrodes **15** flattens the deformable mirror or reflector membrane **10** against the substrate **17**, as illustrated in Figure 5.

[0076] The deformable mirror or reflector membrane of the present invention can also take other shapes, for example, as illustrated in Figure 7. As illustrated in Figure 7, the deformable mirror or reflector membrane **10** is held at a corner and is concave down, whereas Figure 9 shows a top view of the deformable mirror or reflector membrane **10** anchored at a corner to a flat substrate, having a centered pulldown electrode **15**, by substrate contact **16**. The deformable mirror or reflector membrane **10** consists of three layers, an oxide layer **12** at the bottom, an aluminum layer **13** in the middle, and another oxide layer **14** on top. In one embodiment, the deformable mirror or reflector membrane is twenty square microns, the oxide layers are twenty nanometers thick, and the aluminum layer is fifty nanometers thick.

[0077] The combined stresses, in the three layers (**12**, **13** & **14**), cause the deformable mirror or reflector membrane **10** to curve upward in the center, as illustrated in Figure 7, after it is released from the substrate **17**. A voltage applied to the pulldown electrode **15** in the substrate **17** will again flatten the deformable mirror or reflector membrane **10** against the substrate **17**.

[0078] Figures 10 and 12 illustrate the deformable mirror or reflector membrane **10** can be flattened against the surface of the flat substrate **17** through strategically placed dimples or posts **18**, whereas Figure 11 illustrates a top view of the deformable mirror or reflector membrane **10** anchored in the center to a flat substrate by substrate contact **16** with surrounding dimples or posts **18**.

[0079] Figure 10 shows a deformable mirror or reflector membrane **10** anchored in the center to a flat substrate **17** with a plurality of dimples or posts **18** formed on the substrate **17**, surround the substrate contact **16**. The deformable mirror or reflector membrane 10 consists of three layers, an oxide layer **12** at the bottom, an aluminum layer **13** in the middle, and another oxide layer **14** on top. In one embodiment, the deformable mirror or reflector membrane is twenty square microns, the oxide layers are twenty nanometers thick, and the aluminum layer is fifty nanometers thick.

[0080] The combined stresses, in the three layers (**12, 13** & **14**), cause the deformable mirror or reflector membrane **10** to curve upward after it is released from the substrate **17**. A voltage applied between the substrate contact **16** and outer pulldown electrodes **15** flattens the deformable mirror or reflector membrane **10** against the plurality of dimples or posts **18** formed on the substrate **17**.

[0081] The size of the dimples or posts and the surfaces are important in determining the stiction, or stickiness, between the membrane and the substrate. Smaller posts and dimples and a rougher surface at the end of the post will generally have less stiction. One could have posts or dimples as small as 10 nm or perhaps smaller to provide low stiction.

[0082] Figure 12 shows a deformable mirror or reflector membrane **10** anchored in the center to a flat substrate **17** with a plurality of dimples or posts **18** formed on the deformable mirror or reflector membrane **10**, surrounding a center point of the deformable mirror or reflector membrane **10**. The deformable mirror or reflector membrane **10** consists of three layers, an oxide layer **12** at the bottom, an aluminum layer **13** in the middle, and another oxide layer **14** on top. In one embodiment, the deformable mirror or reflector membrane is twenty microns square, the oxide layers are twenty nanometers thick, and the aluminum layer is fifty nanometers thick.

[0083] The combined stresses, in the three layers (**12, 13** & **14**), cause the deformable mirror or reflector membrane **10** to curve upward after it is released from the substrate **17**. A voltage applied between the substrate contact **16** and outer pulldown electrodes **15** flattens the deformable mirror or reflector membrane **10** by bringing the plurality of dimples or posts **18** formed on the deformable mirror or reflector membrane **10** in contact with the substrate **17**.

[0084] If the dimples or posts **18** are sufficiently close together, the curvature of the deformable mirror or reflector membrane **10** between dimples or posts **18** when in contact with the substrate **17** becomes negligible for any given application. The dimples or posts **18** result in a gap between the deformable mirror or reflector membrane **10** and the flat substrate **17** over the large majority of the area which can result in easier fabrication and less likelihood for stiction.

[0085] The easier fabrications results from the use of a thicker release layer which is easier to remove.

[0086] The stiction can occur when the restoring force is low, which happens when the deformable mirror or reflector membrane has a relatively small curvature and low actuation voltage and where the van der Waals and other attractive forces can become quite large when the spacing is less than ten nanometers. Additional stiction forces can come from absorbed water vapor collection in narrow gaps.

[0087] The pulldown electrodes **15**, as illustrated in Figures 13 and 14, can have a small fraction of the area if the pulldown electrodes **15** are placed near the edges of the deformable mirror or reflector membrane **10** that is being flattened because as the deformable mirror or reflector membrane **10** flattens, the deformable mirror or reflector membrane **10** will contact the flat substrate first near the center. As the deformable mirror or reflector membrane **10** continues to flatten, the contact area moves outward while, due to the stress in the deformable mirror or reflector membrane 10, the areas already contacted remain in contact.

[0088] The voltage applied to the deformable mirror or reflector membrane 10 to flatten it can be quite small, of the order of 1 volt, using small curvatures (small stress differential). The advantage of using small pulldown electrodes **15** and small pulldown voltages is the very low energy required for the pulldown which is important for some communications applications to be described later.

[0089] One of the many applications for the deformable mirror or reflector membrane, as described above, is the use in large array devices. The array **100** in Figure 15 shows a plurality of cantilever or deformable mirror or reflector membrane devices **10** having a design where the individual deformable mirror or reflector membranes **10** are anchored along one edge. The individual deformable mirror or reflector membranes **10** in the array **100** could be connected so that all the individual deformable mirror or reflector membranes **10** are part of one electrode and all the pulldown electrodes are connected together to form one electrode. In this example, the array **100** becomes a simple two terminal device where all the individual deformable mirror or reflector membranes **10** in the array actuate in unison and could be made into a large area modulated mirror. The speed of modulation could be as fast as the individual deformable mirror or reflector membranes **10**.

[0090] This array is useful for the corner cube retroreflector application which will be discussed below. Alternatively, the individual deformable mirror or reflector membranes could be actuated individually through the use of an integrated circuit whose components are mostly beneath the mirrors. After fabrication of the circuit, a flat insulating surface would be created with feedthroughs for the electrodes and the mirrors would be fabricated on top. This type of device structure would be used for a display.

[0091] A schematic of a modulated corner cube retroreflector is shown in Figure 16. Each incoming ray of light or infrared radiation **200** coming through the usable aperture will reflect off of all three mirrors and will be returned to its source. When one of the mirrors loses its flatness or is oriented a few milli-degrees off perpendicular orientation relative to the other two mirrors, all the reflected rays will be slightly diverted from the return path to the source. With the mirror array described earlier, the return beam **210** & **220** will be modulated in its intensity as much as ten to one or more as the individual deformable mirror or reflector membranes in the deformable mirror or reflector membrane array **100** are alternately flattened or return to their curved state.

[0092] Figure 17 shows the results of a beam pattern with proper mirror alignment. In this example, a light source **300** produces a light beam which is directed towards an aligned corner cube retroreflector **350**. The light is properly reflected back and collected by the receiver **400**.

[0093] Figure 18, on the other hand, shows the effect of misaligned deformable mirror or reflector membranes in the modulated corner cube retroreflector. In this example, a light source **300** produces a light beam which is directed towards a misaligned corner cube retroreflector **375**. The light is misdirected from it proper reflected path such that the reflected light cannot be collected by the receiver **400**.

[0094] Figure 19 shows the effect of a misalignment of one of the mirrors on the reflection intensity. As the misalignment angle increases, the reflection intensity drops sharply.

[0095] Figures 20 to 37 show top views and sectional views of schematics of a number of examples of cantilever or deformable mirror or reflector membrane designs.

[0096] Figure 20 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with some slits **115** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a uniform upward curvature from the attached end **110** to the non-attached end, as illustrated in Figure 22.

[0097] The pulldown electrode **125** will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. In this example, the deformable mirror or reflector membrane **140** has dimples **135** and ridges **120** which become the contact points (as illustrated in Figure 21) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the dimples or posts **135** and ridges **120** may also be formed on the substrate.

[0098] The space between the posts **135** and ridges **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 21, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridges **120** are in contact with the substrate and the surface curvature between posts **135** and ridges **120** is negligible.

[0099] The posts **135** and ridges **120** are made small and narrow and there are holes **130** in the pulldown electrode **125** surrounding the contact area **135** to minimize the electric field in the contact area and to minimize stiction. When the posts **135** and ridges **120** are in the membrane they are also minimized to avoid light scattering.

[00100] Figure 23 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with a slot **1150** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a uniform concave curvature from the attached end **110** to the non-attached end with the center point being the furthest distance from the substrate, as illustrated in Figure 25.

[0100] The pulldown electrode **125**, located in the center of the deformable mirror or reflector membrane **140**, will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. In this example, the deformable mirror or reflector membrane **140** has posts **135** and a ridge **120** which become the contact points (as illustrated in Figure 24) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the posts **135** and ridge **120** may also be formed on the substrate.

[0101] The space between the posts **135** and ridge **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 24, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridge **120** are in contact with the substrate and the surface curvature between posts **135** and ridge **120** is negligible.

[0102] The posts **135** and ridge **120** are made small and narrow and there are holes **130** in the pulldown electrode **125** surrounding the contact area **135** to minimize electric field in the contact area and to minimize stiction. When the posts **135** and ridge **120** are in the membrane they are also minimized to avoid light scattering.

[0103] Figure 26 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with slits **1155** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a non-uniform curvature from the attached end **110** to the non-attached end, as illustrated in Figure 28. In this example, the curvature along the attachment edge **110** is made to be larger than the rest of the deformable mirror or reflector membrane **140** so that the edge furthest from the attachment edge **110** comes up higher when there is no voltage.

[0104] The pulldown electrode **125** will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. In this example, the deformable mirror or reflector membrane **140** has posts **135** and ridges **120** which become the contact points (as illustrated in Figure 27) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the posts **135** and ridges **120** may also be formed on the substrate.

[0105] The space between the posts **135** and ridges **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 27, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridges **120** are in contact with the substrate and the surface curvature between posts **135** and ridges **120** is negligible.

[0106] The posts **135** and ridges **120** are made small and narrow and there are holes **130** in the pull down electrode **125** surrounding the contact area **135**to minimize stiction. The posts **135** and ridges **120** are also minimized to avoid light scattering.

[0107] Figure 29 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with cutaways **1157** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a non-uniform curvature from the attached end **110** to the non-attached end, as illustrated in Figure 31. In this example, the curvature along the attachment edge **110** is made to be larger that the rest of the deformable mirror or reflector membrane **140** so that the edge furthest from the attachment edge **110** comes up higher when there is no voltage. The cutaways **1157** are placed along the attachment edge **110** to make the deformable mirror or reflector membrane **140** more flexible at the attachment edge **110**, thereby allowing the deformable mirror or reflector membrane **140** to be more easily flattened.

[0108] The pulldown electrode **125** will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. In this example, the deformable mirror or reflector membrane **140** has posts **135** and ridges **120** which become the contact points (as illustrated in Figure 30) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the posts **135** and ridges **120** may also be formed on the substrate.

[0109] The space between the posts **135** and ridges **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 30, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridges **120** are in contact with the substrate and the surface curvature between posts **135** and ridges **120** is negligible.

[0110] The posts **135** and ridges **120** are made small and narrow and there are holes **130** in the pulldown electrode **125** surrounding the contact area **135** to minimize stiction. The posts **135** and ridges **120** are also minimized to avoid light scattering.

[0111] Figure 32 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with cutaways **1157** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a non-uniform curvature from the attached end **110** to the non-attached end, as illustrated in Figure 34. In this example, the curvature along the attachment edge **110** is made to be larger that the rest of the deformable mirror or reflector membrane **140** so that the edge furthest from the attachment edge **110** comes up higher when there is no voltage. The cutaways **1157** are placed along the attachment edge **110** to make the deformable mirror or reflector membrane **140** more flexible at the attachment edge **110**, thereby allowing the deformable mirror or reflector membrane **140** to be more easily flattened.

[0112] The pulldown electrode **125** will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. The pulldown electrode **125**, as illustrated in Figure 32, is segmented and shaped so that the force for pull down is higher in the middle of the deformable mirror or reflector membrane **140** which helps in the actuation dynamics. By having the force higher in the middle, the deformable mirror or reflector membrane **140** will have a lesser tendency to pull down along one of the lateral edge before the other.

[0113] In this example, the deformable mirror or reflector membrane **140** has posts **135** and ridges **120** which become the contact points (as illustrated in Figure 33) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the posts **135** and ridges **120** may also be formed on the substrate.

[0114] The space between the posts **135** and ridges **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 33, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridges **120** are in contact with the substrate and the surface curvature between posts **135** and ridges **120** is negligible.

[0115] The posts **135** and ridges **120** are made small and narrow and there are holes **130** in the pulldown electrode **125** surrounding the contact area **135**to minimize stiction. The posts **135** and ridges **120** are also minimized to avoid light scattering.

[0116] Figure 35 shows a cantilever electrode or deformable mirror or reflector membrane **140** attached along one edge **110** with cutaways **1157** to relieve stress at the edge **110**. The deformable mirror or reflector membrane **140** has a uniform concave curvature from the attached end **110** to the non-attached end, as illustrated in Figure 37. In this example, the curvature along the attachment edge **110** is made to be larger that the rest of the deformable mirror or reflector membrane **140** so that the edge furthest from the attachment edge **110** comes up higher when there is no voltage. The cutaways **1157** are placed along the attachment edge **110** to make the deformable mirror or reflector membrane **140** more flexible at the attachment edge **110**, thereby allowing the deformable mirror or reflector membrane **140** to be more easily flattened. In this example, the attachment edge **110** is greatly reduced, thereby reducing the edge stress and curvature and helping make the deformable mirror or reflector membrane **140** easier to flatten.

[0117] The pulldown electrode **125** will pull down the deformable mirror or reflector membrane **140** when the voltage is applied between it and the deformable mirror or reflector membrane **140**. In this example, the deformable mirror or reflector membrane **140** has posts **135** and ridges **120** which become the contact points (as illustrated in Figure 36) when the deformable mirror or reflector membrane **140** is flattened on the substrate. It is noted that the posts **135** and ridges **120** may also be formed on the substrate.

[0118] The space between the posts **135** and ridges **120** and the deformable mirror or reflector membrane's stress is such that when, as illustrated in Figure 36, the deformable mirror or reflector membrane **140** is pulled down all posts **135** and ridges **120** are in contact with the substrate and the surface curvature between posts **135** and ridges **120** is negligible.

[0119] The posts **135** and ridge **120** are made small and narrow and there are holes **130** in the pulldown electrode **125** surrounding the contact area **135** to minimize electric field in the contact area and to minimize stiction. When the posts **135** and ridge **120** are in the membrane they are also minimized to avoid light scattering.

[0120] Figures 38 through 43 illustrate a fabrication process for the deformable mirror or reflector membranes, according to the concepts of the present invention. As illustrated in Figure 38, a metal pattern **200** is formed on a substrate **210**. Thereafter, as illustrated in Figure 39, an oxide layer **230** and a release layer **220** are formed. Thereafter, as illustrated in Figure 40, the deformable mirror or reflector membranes **240** are formed with an oxide layer, aluminum layer, and another oxide layer. As illustrated in Figure 41, vias **250** are etched. In Figure 42, a contact metal lift is formed, and in Figure 43, the deformable mirror or reflector membranes **140** are released.

[0121] As mentioned above, in communications systems, the power required for transmission of the signal, usually through radiated electromagnetic energy, is often the largest part of the energy required by the entire system. For many locations from which communication of data is required, especially when little power is available, a MEMS microshutter corner cube retroreflector can be extremely valuable since it provides the only possible mode for communication. The MEMS microshutter corner cube retroreflector does not radiate energy, rather it is actually a modulated reflector of electromagnetic energy, and it sends the energy directly back to the source of the energy. A MEMS microshutter corner cube retroreflector **3000**, as shown in Figure 44 is composed of an inside corner cube where one of the mirrors is actually an array of deformable mirror or reflector membranes **1140**, as described above. The deformable mirror or reflector membranes **1140** can be moved slightly, in unison, which results in a ten to one change in signal returned to the source. Using the deformable mirror or reflector membranes of the present invention, a MEMS microshutter corner cube retroreflector can achieve approximately 100 pJ/bit to 1 nJ/bit at ranges between one hundred meters to and several kilometers assuming a clear line of sight is available when using a laser as the source power. Since the individual deformable mirror or reflector membranes are very small, they can be moved at a rate of between 10^5 to 10^7 Hz.

[0122] Moreover, using the deformable mirror or reflector membranes of the present invention, a MEMS microshutter corner cube retroreflector requires more than an order of magnitude lower energy per bit than conventionally communication links for mega Hz range of data rate such that the energy is low enough to be used with low energy sensors with the capability to run without batteries by scavenging energy, for example ambient light energy (in Figure 44, solar cells **310** are used to generate the needed energy), from the local environment.

[0123] In Figure 45, an imager **3200** and a lens **330** are shown as a sensor to gather information that can be transmitted by the deformable mirror or reflector membranes **1140** of the MEMS microshutter corner cube retroreflector **3000**. An energy storage device 340 is also included to store the energy generated by the solar cells **310**.

[0124] While various examples and embodiments of the present invention have been shown and described, it will be appreciated by those skilled in the art that the spirit and scope of the present invention are not limited to the specific description and drawings herein, but extend to various modifications and changes.

What is claimed is:

1. A retroreflector, comprising:

a first non-deformable mirror to provide reflection of light back to a source thereof; and

a deformable mirror having a first state to provide reflection of light back to the source thereof and a second state to provide misdirection of light to prevent the reflection of light back to the source thereof.

2. The retroreflector as claimed in claim 1, wherein said deformable mirror comprises a plurality of MEMS devices, each having a reflective surface thereon, such that when said deformable mirror is in the first state, each reflective surface is in a first position to form a reflective surface that provides reflection of light back to the source thereof.

3. The retroreflector as claimed in claim 2, wherein when said deformable mirror is in the second state, each reflective surface is in a second position to form a reflective surface that misdirects light to prevent the reflection of light back to the source thereof.

4. The retroreflector as claimed in claim 3, wherein said reflective surfaces of said deformable mirror varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a serial pattern of light pulses representing encoded information.

5. The retroreflector as claimed in claim 1, further comprising:

a second non-deformable mirror to provide reflection of light back to a source thereof;

said first non-deformable mirror, said second non-deformable mirror, and said deformable mirror forming a modulated corner cube retroreflector.

6. The retroreflector as claimed in claim 2, wherein each MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to the source thereof, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to the source thereof; and

a plurality of dimples formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the dimples.

7. The retroreflector as claimed in claim 2, wherein each MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to the source thereof, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to the source thereof; and

a plurality of posts formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the posts.

8. The retroreflector as claimed in claim 1, wherein said deformable mirror comprises a plurality of MEMS devices, each having an electrode membrane having a reflective surface thereon;

said electrode membrane having substantially a same flatness of said flat substrate when said electrode membrane comes into contact with said flat substrate across a majority of its surface area in response to a voltage being applied to a pulldown electrode formed in said flat substrate;

said electrode membrane having a two-dimensional curvature when no voltage is applied to an electrode formed in said flat substrate.

9. The retroreflector as claimed in claim 8, wherein said electrode membrane being in contact with said flat substrate when no voltage is applied to said pulldown electrode formed in said flat substrate.

10. The retroreflector as claimed in claim 8, wherein said electrode membrane being in contact with said flat substrate along an edge of said electrode membrane when no voltage is applied to said pulldown electrode formed in said flat substrate.

11. The retroreflector as claimed in claim 8, wherein each electrode membrane is

individually addressable such that each electrode membrane has associated therewith an individual pulldown electrode so that each electrode membrane may have a state different from an adjacent electrode membrane.

12. The retroreflector as claimed in claim 8, wherein all the electrode membranes have a common pulldown electrode associated therewith so that all the electrode membranes are electrically ganged together.

13. The retroreflector as claimed in claim 8, wherein said pulldown electrode is located under a center of an associated electrode membrane.

14. The retroreflector as claimed in claim 8, wherein said edge of said electrode membrane, being in contact with said flat substrate, having slits therein to make said electrode membrane more flexible at said edge.

15. The retroreflector as claimed in claim 8, wherein said edge of said electrode membrane, being in contact with said flat substrate, having cutaway sections therein to make said electrode membrane more flexible at said edge.

16. The retroreflector as claimed in claim 8, wherein said pulldown electrode is segmented.

17. The retroreflector as claimed in claim 8, wherein said pulldown electrode is segmented to reduce capacitance and energy.

18. The retroreflector as claimed in claim 1, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when the individually addressable MEMS device is in a first state, the reflective surface thereof is in a first position to form a reflective surface that provides reflection of a portion of the light back to the source thereof.

19. The retroreflector as claimed in claim 18, wherein when the individually addressable MEMS device is in the second state to scatter a portion of the light to prevent the reflection of a portion of the light back to the source thereof.

20. The retroreflector as claimed in claim 19, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a

parallel pattern of light pulses representing encoded information.

21. The retroreflector as claimed in claim 1, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when all of the individually addressable MEMS devices are in a first state, the reflective surface thereof is in a first position to form a reflective surface, the reflective surfaces of all the individually addressable MEMS device being in the same plane so as to provide reflection of the light back to the source thereof.

22. The retroreflector as claimed in claim 21, wherein when all of the individually addressable MEMS devices are in the second state, the reflective surface thereof is in a second position so as to scatter the light to prevent the reflection of the light back to the source thereof.

23. The retroreflector as claimed in claim 22, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a serial pattern of light pulses representing encoded information.

24. The retroreflector as claimed in claim 1, further comprising:

a light absorbing material;

said deformable mirror, when in the second state, misdirecting light to said light absorbing material to prevent the reflection of light back to the source thereof.

25. A passive interrogatable sensor, comprising:

a sensing device to sense predetermined conditions of a surrounding environment and generate signals representative of the sensed predetermined conditions;

a controller to process the generated signals and to produce drive signals in response thereof;

a first non-deformable mirror to provide reflection of light back to a source thereof; and

a deformable mirror, operatively connected to said controller, being driven to either a first state or a second state in response to drive signals from said controller, said first state providing reflection of light back to the source thereof, said second state providing misdirection of light to prevent the reflection of light back to the source thereof.

26. The passive interrogatable sensor as claimed in claim 25, wherein said deformable mirror comprises a plurality of MEMS devices, each having a reflective surface thereon, such that when said deformable mirror is driven to said first state, each reflective surface is in a first position to form a reflective surface that provides reflection of light back to the source thereof.

27. The passive interrogatable sensor as claimed in claim 26, wherein when said deformable mirror is driven to said second state, each reflective surface is in a second position to misdirect light to prevent the reflection of light back to the source thereof.

28. The passive interrogatable sensor as claimed in claim 27, wherein said reflective surfaces of said deformable mirror varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a serial pattern of light pulses representing encoded information.

29. The passive interrogatable sensor as claimed in claim 25, further comprising:

a second non-deformable mirror to provide reflection of light back to a source thereof;

said first non-deformable mirror, said second non-deformable mirror, and said deformable mirror forming a modulated corner cube retroreflector.

30. The passive interrogatable sensor as claimed in claim 26, wherein each MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to the source thereof, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to the source thereof; and

a plurality of dimples formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the dimples.

31. The passive interrogatable sensor as claimed in claim 26, wherein each MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to the source thereof, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to the source thereof; and

a plurality of posts formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the posts.

32. The passive interrogatable sensor as claimed in claim 25, wherein said deformable mirror comprises a plurality of MEMS devices, each having an electrode membrane having a reflective surface thereon;

said electrode membrane having substantially a same flatness of said flat substrate when said electrode membrane comes into contact with said flat substrate across a majority of its surface area in response to a voltage being applied to a pulldown electrode formed in said flat substrate;

said electrode membrane having a two-dimensional curvature when no voltage is applied to an electrode formed in said flat substrate.

33. The passive interrogatable sensor as claimed in claim 32, wherein said electrode membrane being in contact with said flat substrate at two points when no voltage is applied to said pulldown electrode formed in said flat substrate.

34. The passive interrogatable sensor as claimed in claim 32, wherein said electrode membrane being in contact with said flat substrate along an edge of said electrode membrane when no voltage is applied to said pulldown electrode formed in said flat substrate.

35. The passive interrogatable sensor as claimed in claim 32, wherein each electrode membrane is individually addressable such that each electrode membrane has associated therewith an individual pulldown electrode so that each electrode membrane may have a state different from an adjacent electrode membrane.

36. The passive interrogatable sensor as claimed in claim 32, wherein all the electrode membranes have a common pulldown electrode associated therewith so that all the electrode membranes are electrically ganged together.

37. The passive interrogatable sensor as claimed in claim 32, wherein said pulldown electrode is located under a center of an associated electrode membrane.

38. The passive interrogatable sensor as claimed in claim 32, wherein said edge of said electrode membrane, being in contact with said flat substrate, having slits therein to make said electrode membrane more flexible at said edge.

39. The passive interrogatable sensor as claimed in claim 32, wherein said edge of said electrode membrane, being in contact with said flat substrate, having cutaway sections therein to make said electrode membrane more flexible at said edge.

40. The passive interrogatable sensor as claimed in claim 32, wherein said pulldown electrode is segmented.

41. The passive interrogatable sensor as claimed in claim 32, wherein said pulldown electrode is segmented so that a greater electrostatic force is realized at a center of an associated electrode membrane.

42. The passive interrogatable sensor as claimed in claim 25, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when the individually addressable MEMS device is in a first state, the reflective surface thereof is in a first position to form a reflective surface that provides reflection of a portion of the light back to the source thereof.

43. The passive interrogatable sensor as claimed in claim 42, wherein when the individually addressable MEMS device is in the second state, the reflective surface thereof is in a second position to scatter a portion of the light to prevent the reflection of a portion of the light back to the source thereof.

44. The passive interrogatable sensor as claimed in claim 43, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a parallel pattern of light pulses representing encoded information.

45. The passive interrogatable sensor as claimed in claim 25, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when all of the individually

addressable MEMS devices are in a first state, the reflective surface thereof is in a first position to form a reflective surface, the reflective surfaces of all the individually addressable MEMS device being in the same plane so as to provide reflection of the light back to the source thereof.

46. The passive interrogatable sensor as claimed in claim 45, wherein when all of the individually addressable MEMS devices are in the second state, the reflective surface thereof is in a second position so as to scatter the light to prevent the reflection of the light back to the source thereof.

47. The passive interrogatable sensor as claimed in claim 46, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a serial pattern of light pulses representing encoded information.

48. The passive interrogatable sensor as claimed in claim 25, further comprising:

a light absorbing material;

said deformable mirror, when in the second state, misdirecting light to said light absorbing material to prevent the reflection of light back to the source thereof.

49. An optical identification system, comprising:

a laser source, disposed remotely from an object to be interrogated, for transmitting an unmodulated beam toward the object to be interrogated;

a controller, disposed with the object to be interrogated, to produce drive signals associated with identification information;

a first non-deformable mirror, disposed with the object to be interrogated, to provide reflection of light back to said laser source;

a deformable mirror, disposed with the object to be interrogated and operatively connected to said controller, being driven to either a first state or a second state in response to drive signals from said controller, said first state providing reflection of light back to said laser source, said second state providing misdirection of light to prevent the reflection of light back to said laser source;

said deformable mirror modulating the light to be reflected back to the laser source so as to encode identification information as reflected modulated light; and

a detector, disposed with said laser source, to decode identification information from light received from said deformable mirror disposed with the object to be interrogated.

50. The optical identification system as claimed in claim 49, wherein said deformable mirror comprises a plurality of MEMS devices, each having a reflective surface thereon, such that when said deformable mirror is driven to the first state, each reflective surface is in a first position to form a reflective surface that provides reflection of light back to said laser source.

51. The optical identification system as claimed in claim 50, wherein when said deformable mirror is driven to the second state, each reflective surface is in a second position to misdirect light to prevent the reflection of light back to said laser source.

52. The optical identification system as claimed in claim 51, wherein said reflective surfaces of said deformable mirror varying between said first and second positions to modulate the light being reflected back to said laser source so as to create a serial pattern of light pulses representing encoded identification information.

53. The optical identification system as claimed in claim 49, further comprising:

a second non-deformable mirror to provide reflection of light back to said laser source;

said first non-deformable mirror, said second non-deformable mirror, and said deformable mirror forming a modulated corner cube retroreflector.

54. The optical identification system as claimed in claim 50, wherein each MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to said laser source, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to said laser source; and

a plurality of dimples formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the dimples.

55. The optical identification system as claimed in claim 50, wherein each

MEMS device comprises:

a substrate;

a flexible membrane attached at least one end to a surface of the substrate and having said reflective surface thereon, the flexible membrane being configured such that, in a first state, said flexible membrane is disposed to form a reflective surface that provides reflection of light back to said laser source, and, in a second state, said flexible membrane is disposed to form a reflective surface that scatters light to prevent the reflection of light back to said laser source; and

a plurality of posts formed on the flexible membrane such that when the flexible membrane is in the first state, the flexible membrane contacts the substrate at the posts.

56. The optical identification system as claimed in claim 51, wherein said deformable mirror comprises a plurality of MEMS devices, each having an electrode membrane having a reflective surface thereon;

said electrode membrane having substantially a same flatness of said flat substrate when said electrode membrane comes into contact with said flat substrate across a majority of its surface area in response to a voltage being applied to a pulldown electrode formed in said flat substrate;

said electrode membrane having a two-dimensional curvature when no voltage is applied to an electrode formed in said flat substrate.

57. The optical identification system as claimed in claim 56, wherein said electrode membrane being in contact with said flat substrate at two points when no voltage is applied to said pulldown electrode formed in said flat substrate.

58. The optical identification system as claimed in claim 56, wherein said electrode membrane being in contact with said flat substrate along an edge of said electrode membrane when no voltage is applied to said pulldown electrode formed in said flat substrate.

59. The optical identification system as claimed in claim 56, wherein each electrode membrane is individually addressable such that each electrode membrane has associated therewith an individual pulldown electrode so that each electrode membrane may have a state different from an adjacent electrode membrane.

60. The optical identification system as claimed in claim 56, wherein all the electrode membranes have a common pulldown electrode associated therewith so that all

the electrode membranes are electrically ganged together.

61. The optical identification system as claimed in claim 56, wherein said pulldown electrode is located under a center of an associated electrode membrane.

62. The optical identification system as claimed in claim 56, wherein said edge of said electrode membrane, being in contact with said flat substrate, having slits therein to make said electrode membrane more flexible at said edge.

63. The optical identification system as claimed in claim 56, wherein said edge of said electrode membrane, being in contact with said flat substrate, having cutaway sections therein to make said electrode membrane more flexible at said edge.

64. The optical identification system as claimed in claim 56, wherein said pulldown electrode is segmented.

65. The optical identification system as claimed in claim 56, wherein said pulldown electrode is segmented so that a greater electrostatic force is realized at a center of an associated electrode membrane.

66. The optical identification system as claimed in claim 49, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when the individually addressable MEMS device is in a first state, the reflective surface thereof is in a first position to form a reflective surface that provides reflection of a portion of the light back to said laser source.

67. The optical identification system as claimed in claim 66, wherein when the individually addressable MEMS device is in the second state, the reflective surface thereof is in a second position to scatter a portion of the light to prevent the reflection of a portion of the light back to said laser source.

68. The optical identification system as claimed in claim 67, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to said laser source so as to create a parallel pattern of light pulses representing encoded identification information.

69. The passive interrogatable sensor as claimed in claim 49, wherein said deformable mirror comprises a plurality of individually addressable MEMS devices, each having a reflective surface thereon, such that when all of the individually addressable MEMS devices are in a first state, the reflective surface thereof is in a first position to form a reflective surface, the reflective surfaces of all the individually addressable MEMS device being in the same plane so as to provide reflection of the light back to the source thereof.

70. The passive interrogatable sensor as claimed in claim 69, wherein when all of the individually addressable MEMS devices are in the second state, the reflective surface thereof is in a second position so as to scatter the light to prevent the reflection of the light back to the source thereof.

71. The passive interrogatable sensor as claimed in claim 70, wherein said individual reflective surfaces of said deformable mirror individually varying between said first and second positions to modulate the light being reflected back to the source thereof so as to create a serial pattern of light pulses representing encoded information.

72. The optical identification system as claimed in claim 49, further comprising:

a light absorbing material;

said deformable mirror, when in the second state, misdirecting light to said light absorbing material to prevent the reflection of light back to said laser source.

73. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

an electrode membrane having a reflective surface thereon,

a flat surface, and

a pulldown electrode formed in said flat substrate;

said electrode membrane having substantially a same flatness of said flat substrate when said electrode membrane comes into contact with said flat substrate across a majority of its surface area in response to a voltage being applied to said pulldown electrode;

said electrode membrane having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

74. The deformable mirror as claimed in claim 73, wherein each electrode

membrane is in a same plane so as to provide reflection of light when a voltage is applied to all of said pulldown electrodes.

75. The deformable mirror as claimed in claim 73, wherein each electrode membrane is individually addressable.

76. The deformable mirror as claimed in claim 73, wherein all pulldown electrodes are electrically ganged together.

77. The deformable mirror as claimed in claim 73, wherein said pulldown electrode is located under a center of an associated electrode membrane.

78. The deformable mirror as claimed in claim 73, wherein an edge of said electrode membrane is in contact with said flat substrate, said edge having slits therein to make said electrode membrane more flexible at said edge.

79. The deformable mirror as claimed in claim 73, wherein an edge of said electrode membrane is in contact with said flat substrate, said edge having cutaway sections therein to make said electrode membrane more flexible at said edge.

80. The deformable mirror as claimed in claim 73, wherein said pulldown electrode is segmented.

81. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including an electrode membrane having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said electrode membrane having substantially a same flatness of said substrate when said electrode membrane comes into contact with said substrate across a majority of its surface area in response to a voltage being applied to said pulldown electrode;

said electrode membrane having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

82. The deformable mirror as claimed in claim 81, wherein each electrode membranes is in a same plane so as to provide reflection of light when a voltage is applied to said pulldown electrode.

83. The deformable mirror as claimed in claim 81, wherein said pulldown electrode is located under a center of an associated electrode membrane.

84. The deformable mirror as claimed in claim 81, wherein an edge of said electrode membrane is in contact with said substrate, said edge having slits therein to make said electrode membrane more flexible at said edge.

85. The deformable mirror as claimed in claim 81, wherein an edge of said electrode membrane is in contact with said substrate, said edge having cutaway sections therein to make said electrode membrane more flexible at said edge.

86. The deformable mirror as claimed in claim 81, wherein said pulldown electrode is segmented.

87. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flexible membranes, each, having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

88. The deformable mirror as claimed in claim 87, wherein said dimples are less than 500 nanometers.

89. The deformable mirror as claimed in claim 87, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

90. The deformable mirror as claimed in claim 87, wherein each flexible

membrane is individually addressable.

91. The deformable mirror as claimed in claim 87, wherein all said pulldown electrodes are electrically ganged together.

92. The deformable mirror as claimed in claim 87, wherein said pulldown electrode is located under a center of an associated flexible membrane.

93. The deformable mirror as claimed in claim 87, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

94. The deformable mirror as claimed in claim 87, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

95. The deformable mirror as claimed in claim 87, wherein said pulldown electrode is segmented.

96. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flexible membranes, each, having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

97. The deformable mirror as claimed in claim 96, wherein said posts are less than 500 nanometers.

98. The deformable mirror as claimed in claim 96, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

99. The deformable mirror as claimed in claim 96, wherein each flexible membrane is individually addressable.

100. The deformable mirror as claimed in claim 96, wherein all said pulldown electrodes are electrically ganged together.

101. The deformable mirror as claimed in claim 96, wherein said pulldown electrode is located under a center of an associated flexible membrane.

102. The deformable mirror as claimed in claim 96, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

103. The deformable mirror as claimed in claim 96, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

104. The deformable mirror as claimed in claim 96, wherein said pulldown electrode is segmented.

105. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said flexible membranes, each, having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

106. The deformable mirror as claimed in claim 105, wherein said dimples are less than 500 nanometers.

107. The deformable mirror as claimed in claim 105, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

108. The deformable mirror as claimed in claim 105, wherein said pulldown electrode is located under a center of an associated flexible membrane.

109. The deformable mirror as claimed in claim 105, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

110. The deformable mirror as claimed in claim 105, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

111. The deformable mirror as claimed in claim 105, wherein said pulldown electrode is segmented.

112. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said flexible membranes, each, having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

113. The deformable mirror as claimed in claim 112, wherein said posts are less than 500 nanometers.

114. The deformable mirror as claimed in claim 112, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

115. The deformable mirror as claimed in claim 112, wherein said pulldown electrode is located under a center of an associated flexible membrane.

116. The deformable mirror as claimed in claim 112, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

117. The deformable mirror as claimed in claim 112, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

118. The deformable mirror as claimed in claim 112, wherein said pulldown electrode is segmented.

119. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end and an opposite end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flexible membranes, each, having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

120. The deformable mirror as claimed in claim 119, wherein said dimples are less than 500 nanometers.

121. The deformable mirror as claimed in claim 119, wherein said flexible

membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

122. The deformable mirror as claimed in claim 119, wherein each flexible membrane is individually addressable.

123. The deformable mirror as claimed in claim 119, wherein all said pulldown electrodes are electrically ganged together.

124. The deformable mirror as claimed in claim 119, wherein said pulldown electrode is located under a center of an associated flexible membrane.

125. The deformable mirror as claimed in claim 119, wherein said pulldown electrode is segmented.

126. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end and an opposite end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flexible membranes, each, having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

127. The deformable mirror as claimed in claim 126, wherein said posts are less than 500 nanometers.

128. The deformable mirror as claimed in claim 126, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

129. The deformable mirror as claimed in claim 126, wherein each flexible membrane is individually addressable.

130. The deformable mirror as claimed in claim 126, wherein all said pulldown electrodes are electrically ganged together.

131. The deformable mirror as claimed in claim 126, wherein said pulldown electrode is located under a center of an associated flexible membrane.

132. The deformable mirror as claimed in claim 126, wherein said pulldown electrode is segmented.

133. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said flexible membranes, each, having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

134. The deformable mirror as claimed in claim 133, wherein said dimples are less than 500 nanometers.

135. The deformable mirror as claimed in claim 133, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

136. The deformable mirror as claimed in claim 133, wherein said pulldown electrode is located under a center of an associated flexible membrane.

137. The deformable mirror as claimed in claim 133, wherein said pulldown

electrode is segmented.

138. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said flexible membranes, each, having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said substrate at said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

139. The deformable mirror as claimed in claim 138, wherein said posts are less than 500 nanometers.

140. The deformable mirror as claimed in claim 138, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

141. The deformable mirror as claimed in claim 138, wherein said pulldown electrode is located under a center of an associated flexible membrane.

142. The deformable mirror as claimed in claim 138, wherein said pulldown electrode is segmented.

143. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flat substrate having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

144. The deformable mirror as claimed in claim 143, wherein said posts are less than 500 nanometers.

145. The deformable mirror as claimed in claim 143, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

146. The deformable mirror as claimed in claim 143, wherein each flexible membrane is individually addressable.

147. The deformable mirror as claimed in claim 143, wherein all said pulldown electrodes are electrically ganged together.

148. The deformable mirror as claimed in claim 143, wherein said pulldown electrode is located under a center of an associated flexible membrane.

149. The deformable mirror as claimed in claim 143, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

150. The deformable mirror as claimed in claim 143, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

151. The deformable mirror as claimed in claim 143, wherein said pulldown electrode is segmented.

152. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

153. The deformable mirror as claimed in claim 152, wherein said posts are less than 500 nanometers.

154. The deformable mirror as claimed in claim 152, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

155. The deformable mirror as claimed in claim 152, wherein said pulldown electrode is located under a center of an associated flexible membrane.

156. The deformable mirror as claimed in claim 152, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

157. The deformable mirror as claimed in claim 152, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

158. The deformable mirror as claimed in claim 152, wherein said pulldown electrode is segmented.

159. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end and an opposite end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flat substrate having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

160. The deformable mirror as claimed in claim 159, wherein said posts are less than 500 nanometers.

161. The deformable mirror as claimed in claim 159, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

162. The deformable mirror as claimed in claim 159, wherein each flexible membrane is individually addressable.

163. The deformable mirror as claimed in claim 159, wherein all said pulldown electrodes are electrically ganged together.

164. The deformable mirror as claimed in claim 159, wherein said pulldown electrode is located under a center of an associated flexible membrane.

165. The deformable mirror as claimed in claim 159, wherein said pulldown electrode is segmented.

166. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of posts formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said posts when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

167. The deformable mirror as claimed in claim 166, wherein said posts are less than 500 nanometers.

168. The deformable mirror as claimed in claim 166, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

169. The deformable mirror as claimed in claim 166, wherein said pulldown electrode is located under a center of an associated flexible membrane.

170. The deformable mirror as claimed in claim 166, wherein said pulldown electrode is segmented.

171. A deformable mirror, comprising:

a substrate;

a flexible membrane in contact with a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of posts formed thereon;

said flexible membrane being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membrane contacting said posts when a voltage is applied to said pulldown electrode;

said flexible membrane having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

172. The deformable mirror as claimed in claim 171, wherein said posts are less than 500 nanometers.

173. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flat substrate having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

174. The deformable mirror as claimed in claim 173, wherein said dimples are less than 500 nanometers.

175. The deformable mirror as claimed in claim 173, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

176. The deformable mirror as claimed in claim 173, wherein each flexible membrane is individually addressable.

177. The deformable mirror as claimed in claim 173, wherein all said pulldown electrodes are electrically ganged together.

178. The deformable mirror as claimed in claim 173, wherein said pulldown electrode is located under a center of an associated flexible membrane.

179. The deformable mirror as claimed in claim 173, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

180. The deformable mirror as claimed in claim 173, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections

therein to make said flexible membrane more flexible at said edge.

181. The deformable mirror as claimed in claim 173, wherein said pulldown electrode is segmented.

182. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

183. The deformable mirror as claimed in claim 182, wherein said dimples are less than 500 nanometers.

184. The deformable mirror as claimed in claim 182, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

185. The deformable mirror as claimed in claim 182, wherein said pulldown electrode is located under a center of an associated flexible membrane.

186. The deformable mirror as claimed in claim 182, wherein an edge of said flexible membrane is in contact with said substrate, said edge having slits therein to make said flexible membrane more flexible at said edge.

187. The deformable mirror as claimed in claim 182, wherein an edge of said flexible membrane is in contact with said substrate, said edge having cutaway sections therein to make said flexible membrane more flexible at said edge.

188. The deformable mirror as claimed in claim 182, wherein said pulldown electrode is segmented.

189. A deformable mirror, comprising:

a plurality of MEMS devices;

each MEMS device including,

a flat substrate,

a flexible membrane attached, at one end and an opposite end, to a surface of said flat substrate and having a reflective surface thereon, and

a pulldown electrode formed in said flat substrate;

said flat substrate having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

190. The deformable mirror as claimed in claim 189, wherein said dimples are less than 500 nanometers.

191. The deformable mirror as claimed in claim 189, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to all of said pulldown electrodes.

192. The deformable mirror as claimed in claim 189, wherein each flexible membrane is individually addressable.

193. The deformable mirror as claimed in claim 189, wherein all said pulldown electrodes are electrically ganged together.

194. The deformable mirror as claimed in claim 189, wherein said pulldown electrode is located under a center of an associated flexible membrane.

195. The deformable mirror as claimed in claim 189, wherein said pulldown electrode is segmented.

196. A deformable mirror, comprising:

a substrate;

a plurality of MEMS devices formed in said substrate, each MEMS device including a flexible membrane, at one end and an opposite end, to a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of dimples formed thereon;

said flexible membranes, each, being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membranes, each, contacting said dimples when a voltage is applied to said pulldown electrode;

said flexible membranes, each, having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

197. The deformable mirror as claimed in claim 196, wherein said dimples are less than 500 nanometers.

198. The deformable mirror as claimed in claim 196, wherein said flexible membranes are in a same plane so as to provide the desired reflection of light when a voltage being applied to said pulldown electrode.

199. The deformable mirror as claimed in claim 196, wherein said pulldown electrode is located under a center of an associated flexible membrane.

200. The deformable mirror as claimed in claim 196, wherein said pulldown electrode is segmented.

201. A deformable mirror, comprising:

a substrate;

a flexible membrane in contact with a surface of said substrate and having a reflective surface thereon; and

a pulldown electrode formed in said substrate;

said substrate having a plurality of dimples formed thereon;

said flexible membrane being configured such that when a voltage is applied to said pulldown electrode, said flexible membrane is disposed to provide a desired reflection of light;

said flexible membrane contacting said dimples when a voltage is applied to said pulldown electrode;

said flexible membrane having a two-dimensional curvature when no voltage is applied to said pulldown electrode.

202. The deformable mirror as claimed in claim 201, wherein said dimples are less than 500 nanometers.

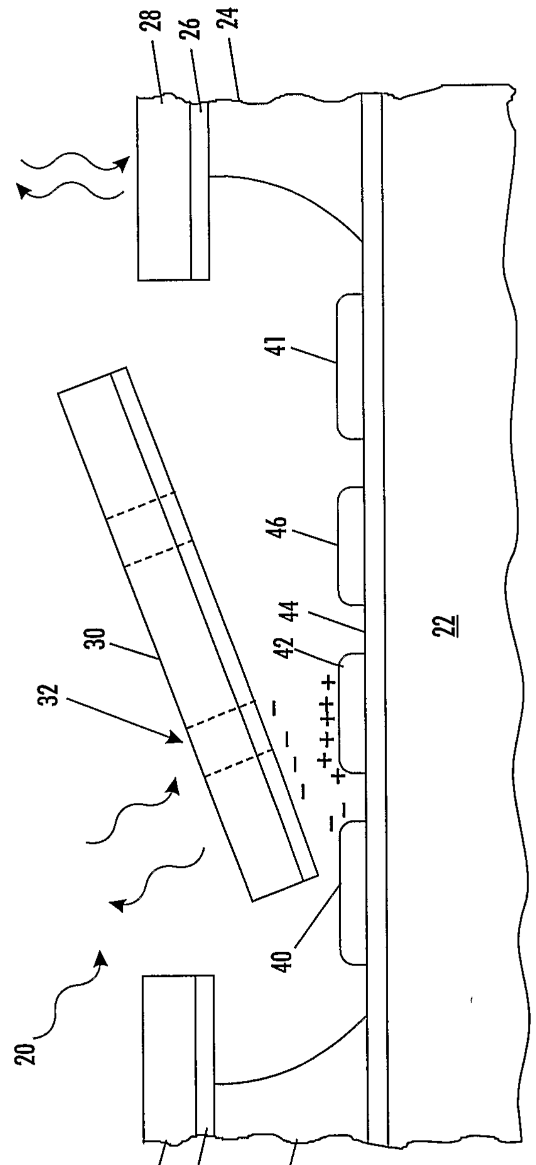

FIG. 1
PRIOR ART

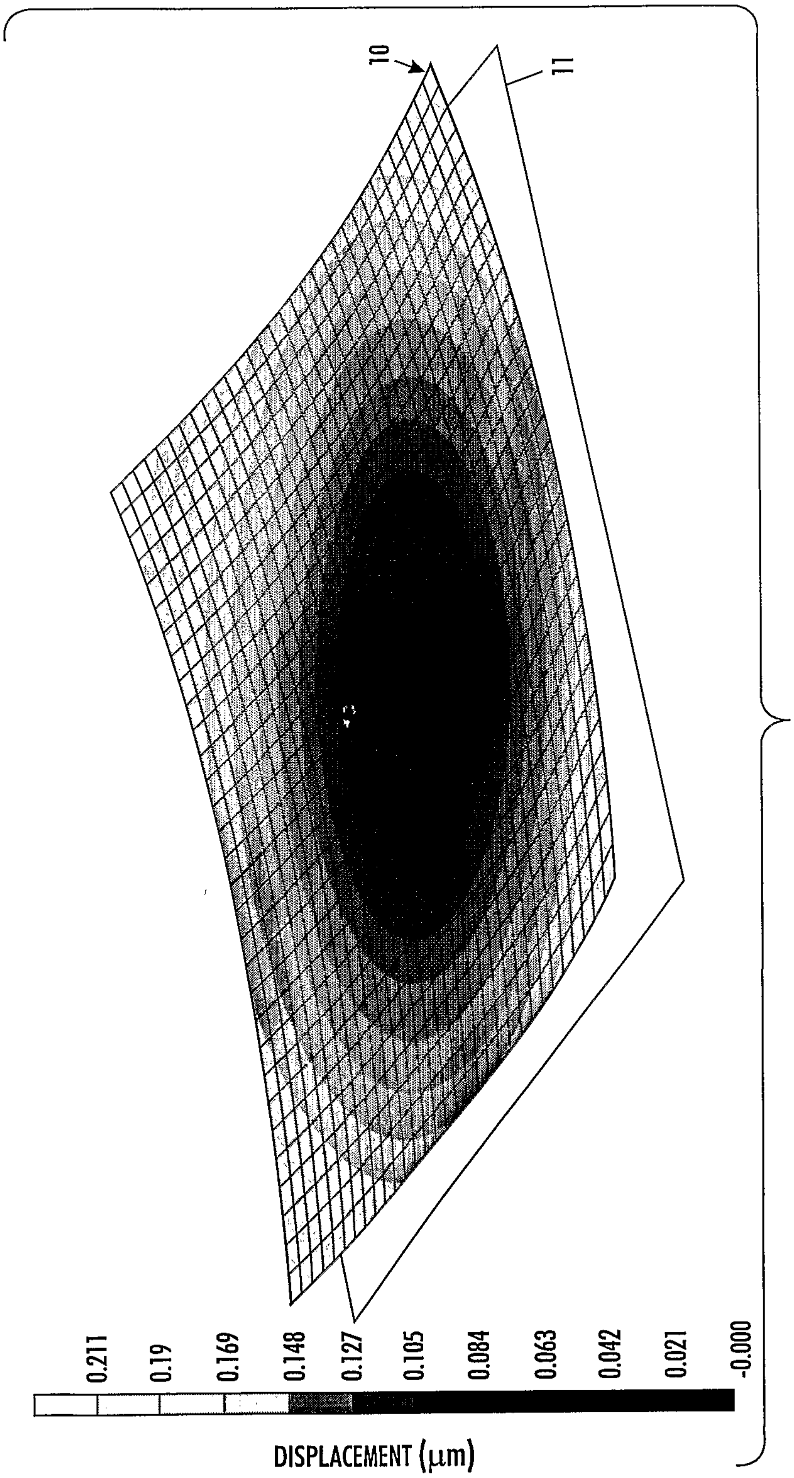
10
11
0.211
0.19
0.169
0.148
0.127
0.105
0.084
0.063
0.042
0.021
-0.000
DISPLACEMENT (μm)

FIG. 2

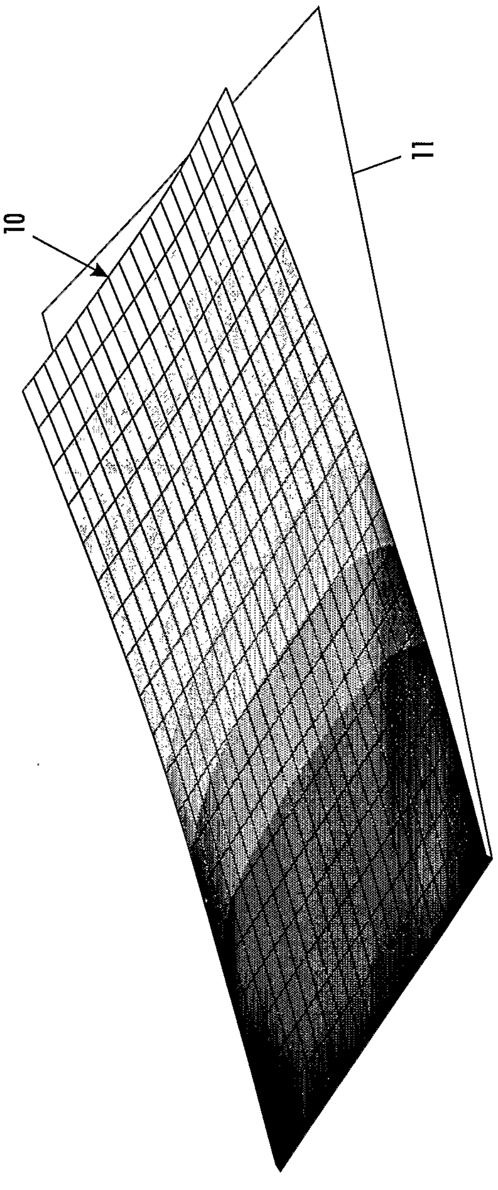

FIG. 3

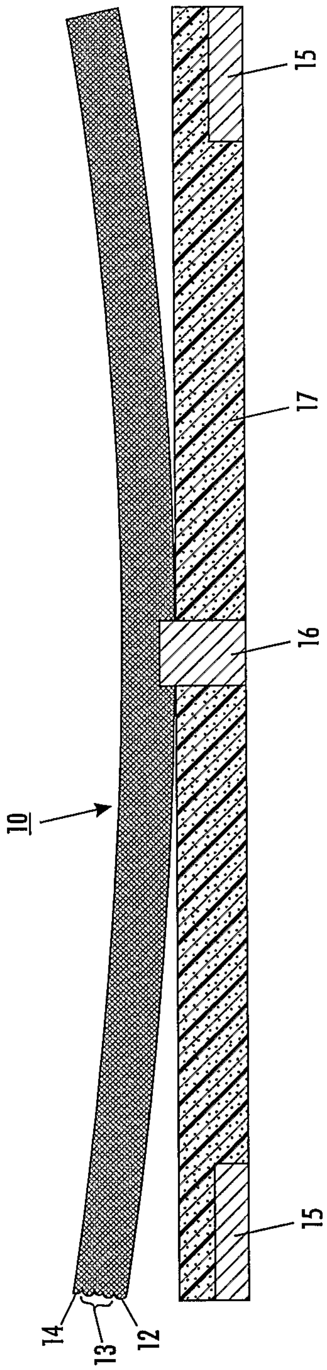

FIG. 4

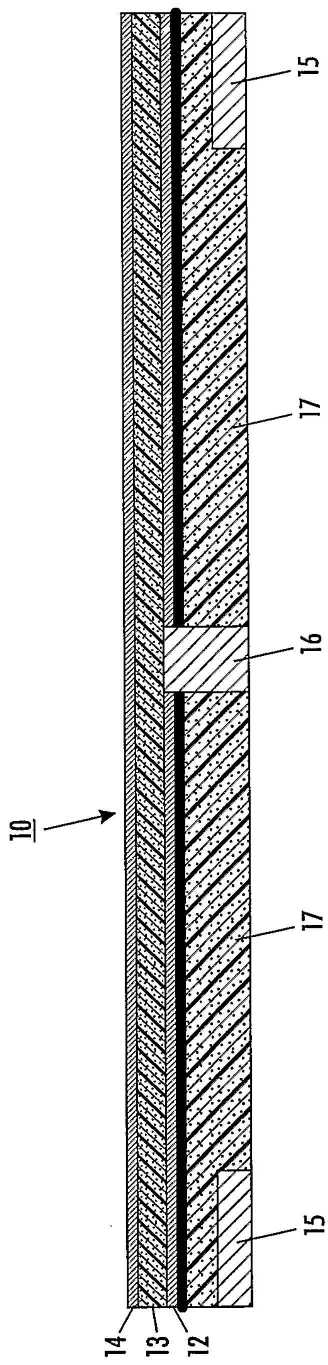

FIG. 5

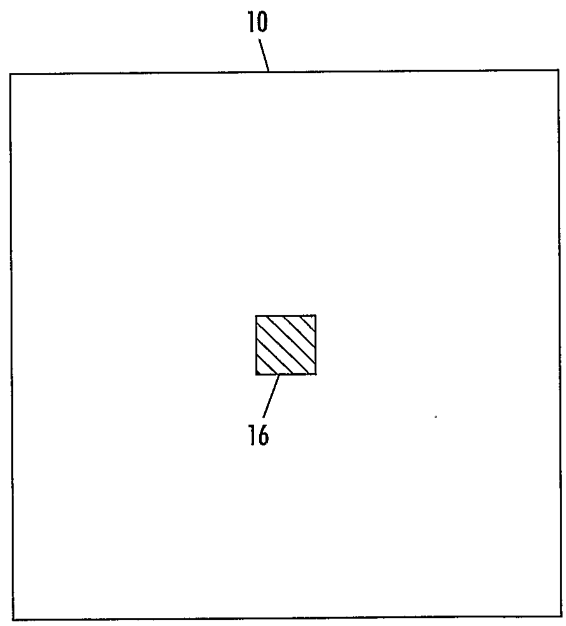

FIG. 6

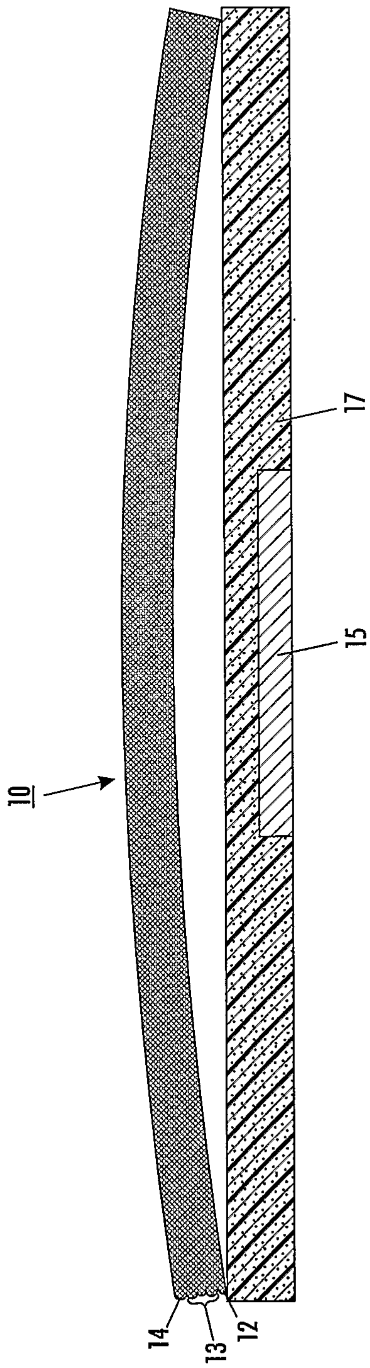

FIG. 7

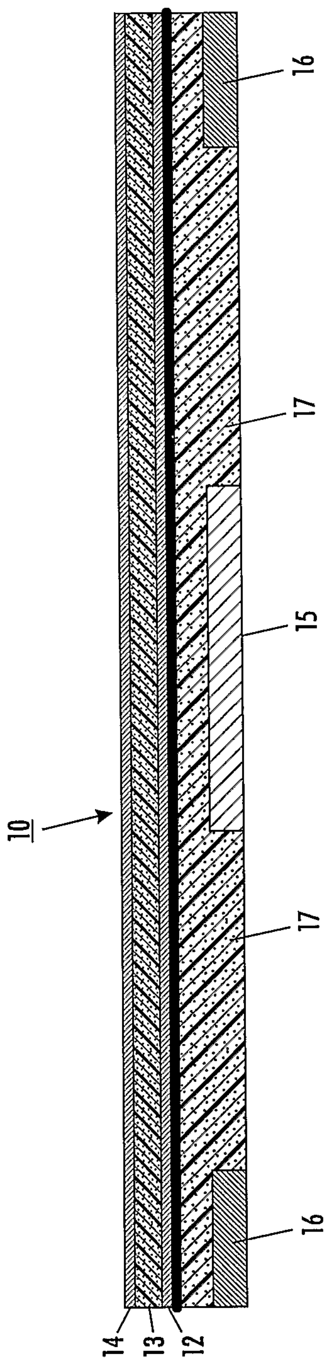

FIG. 8

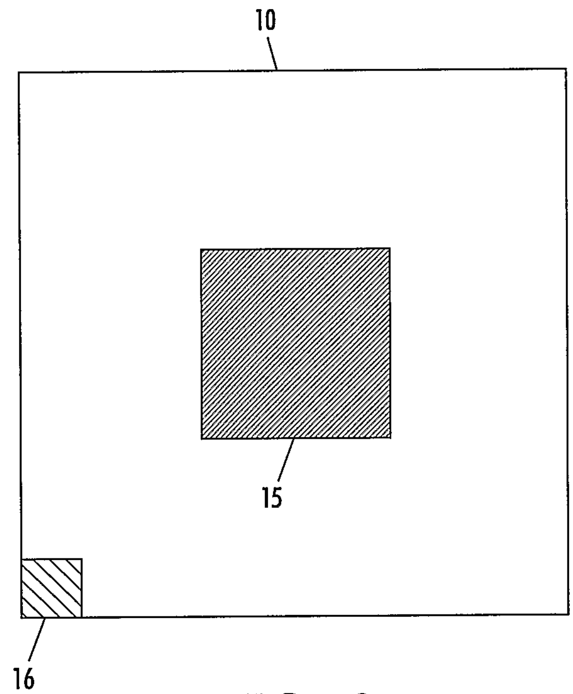

FIG. 9

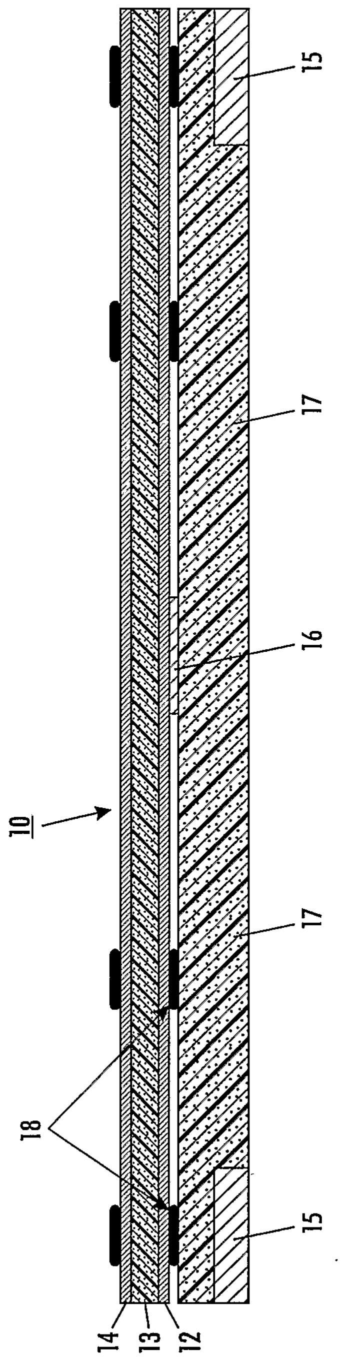

FIG. 10

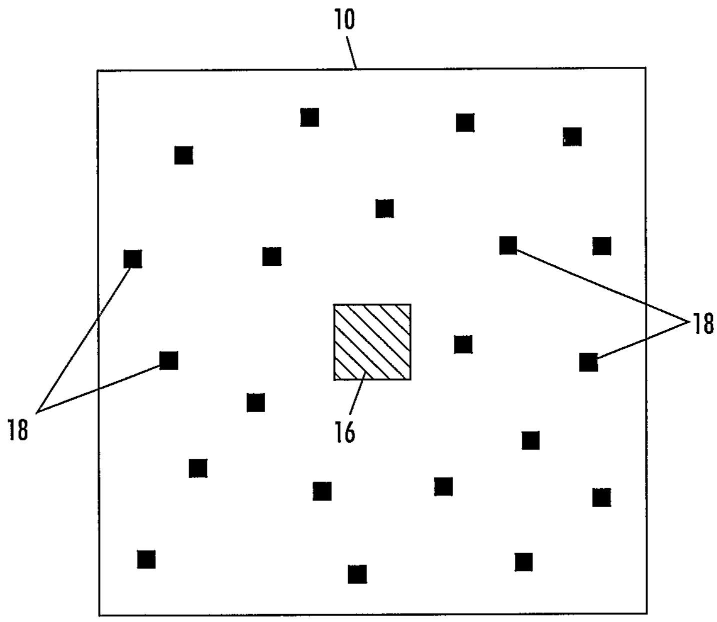

FIG. 11

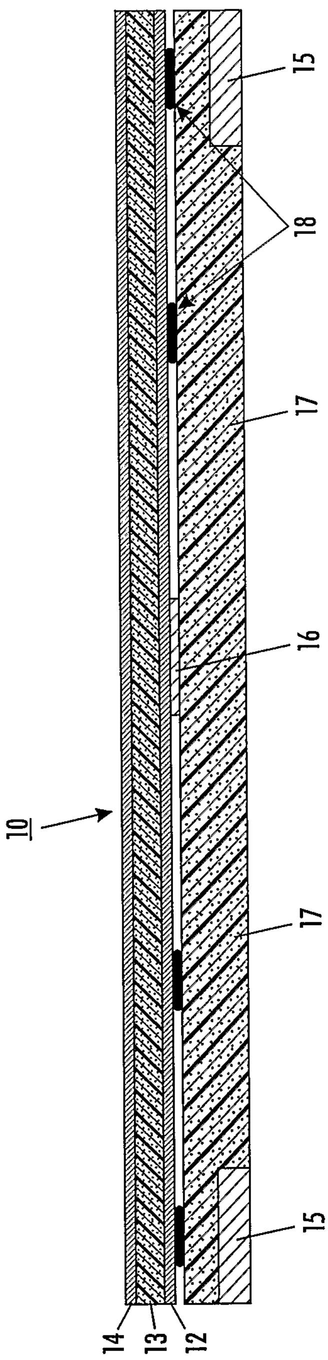

FIG. 12

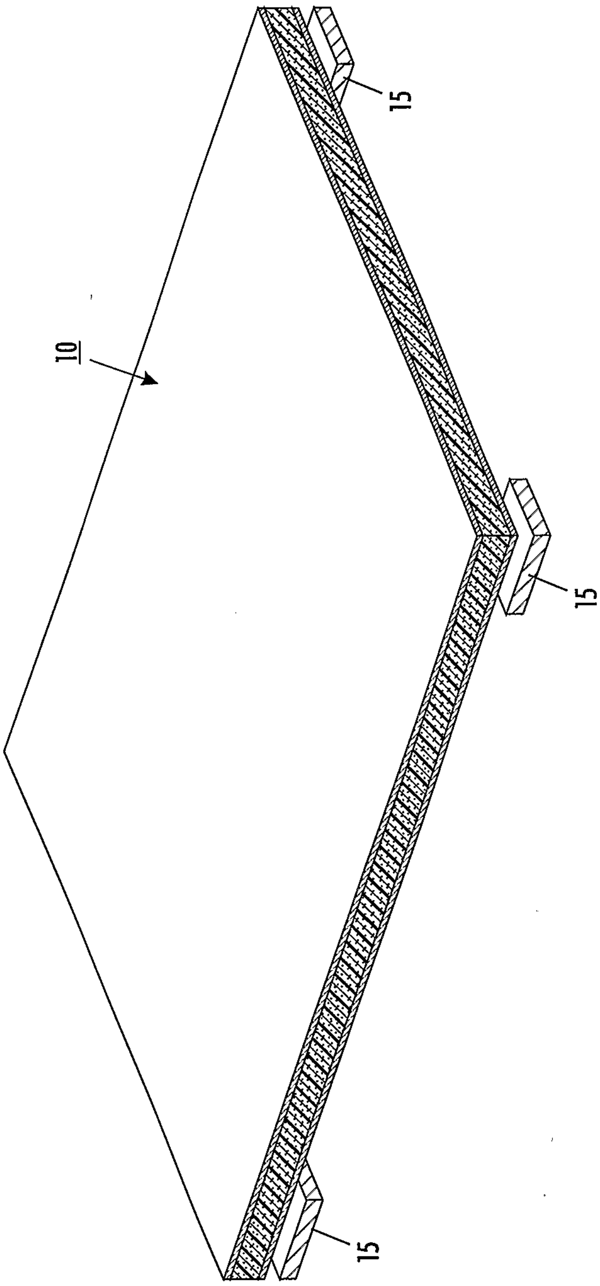

FIG. 13

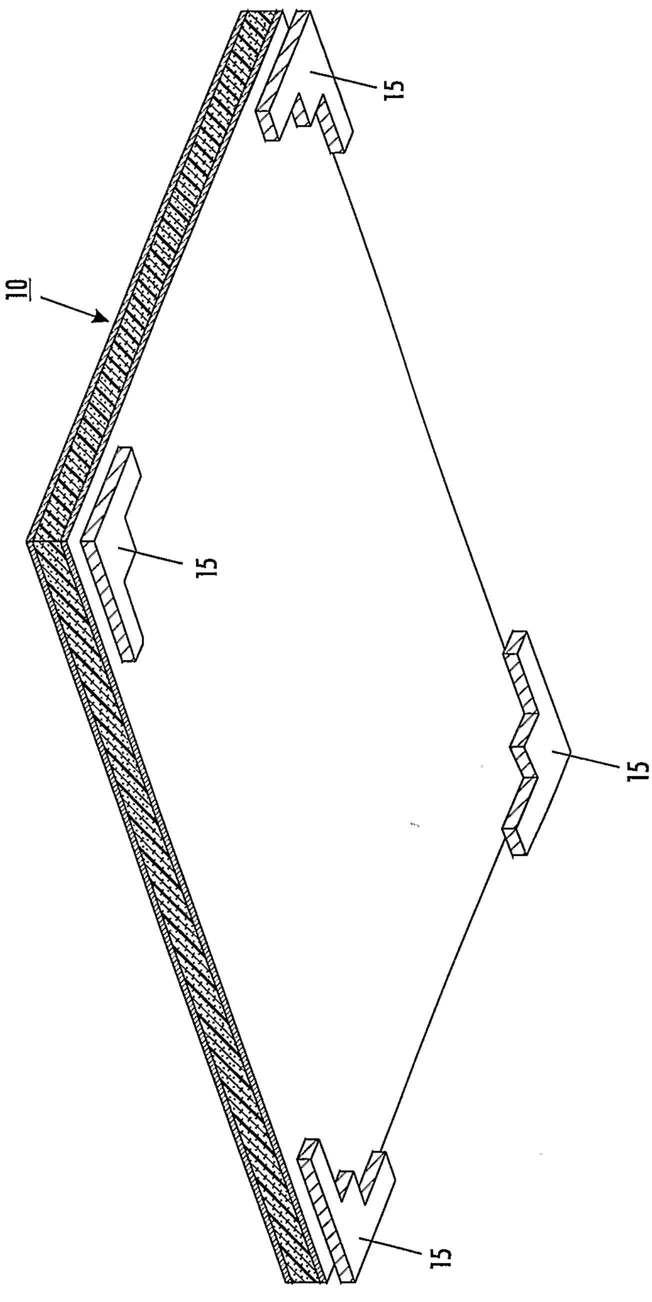

FIG. 14

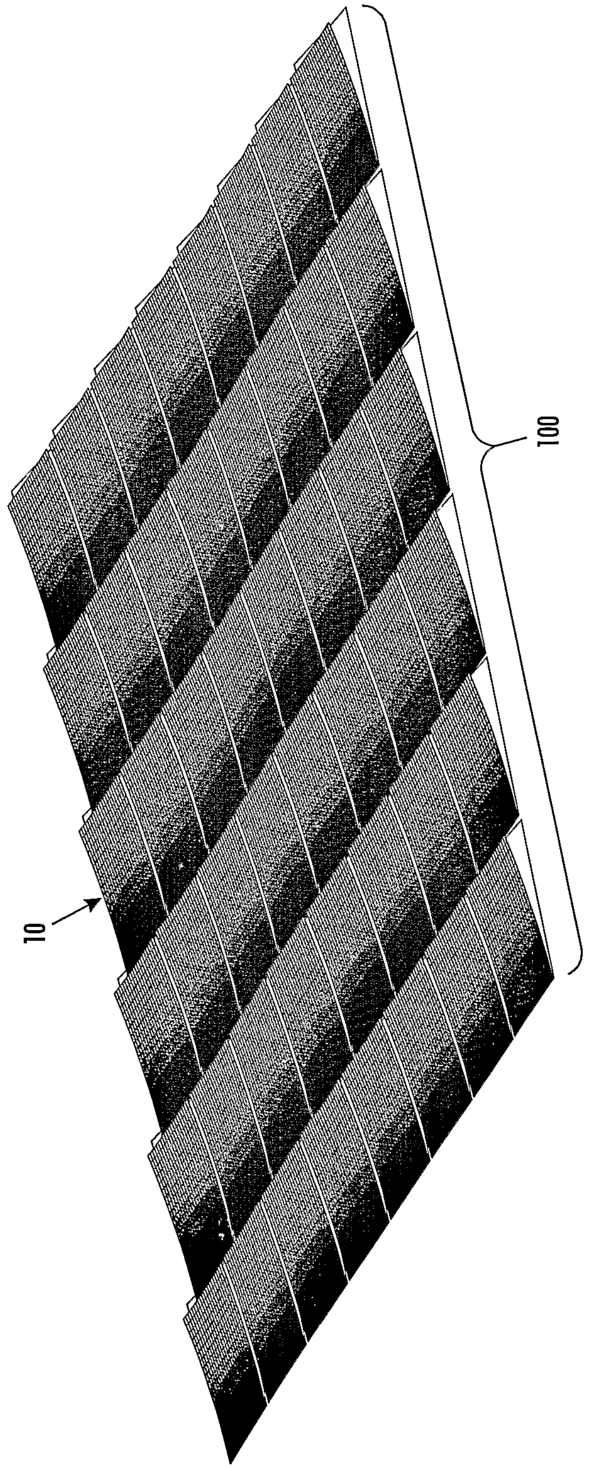

FIG. 15

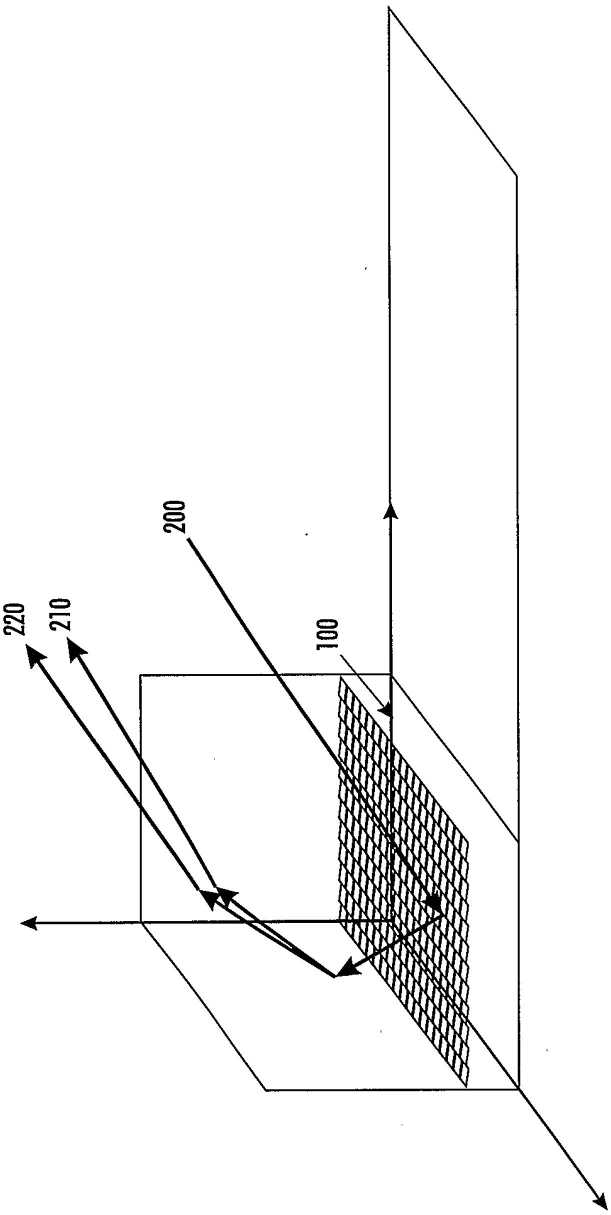

FIG. 16

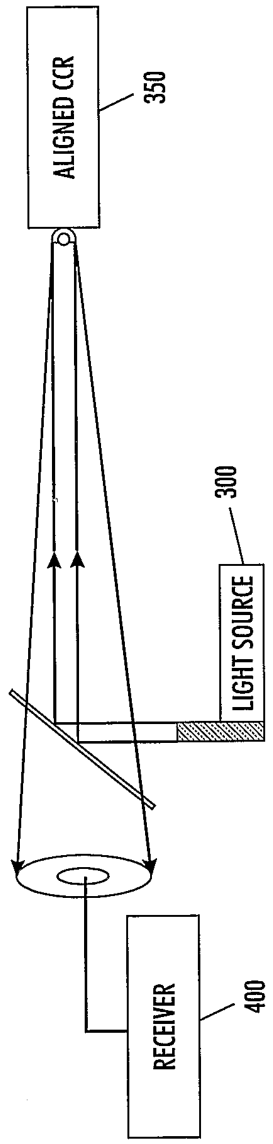

FIG. 17

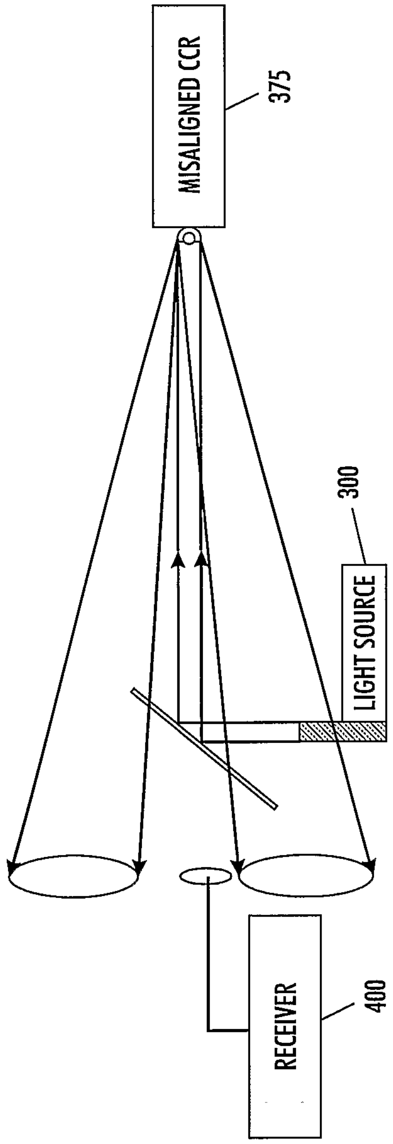

FIG. 18

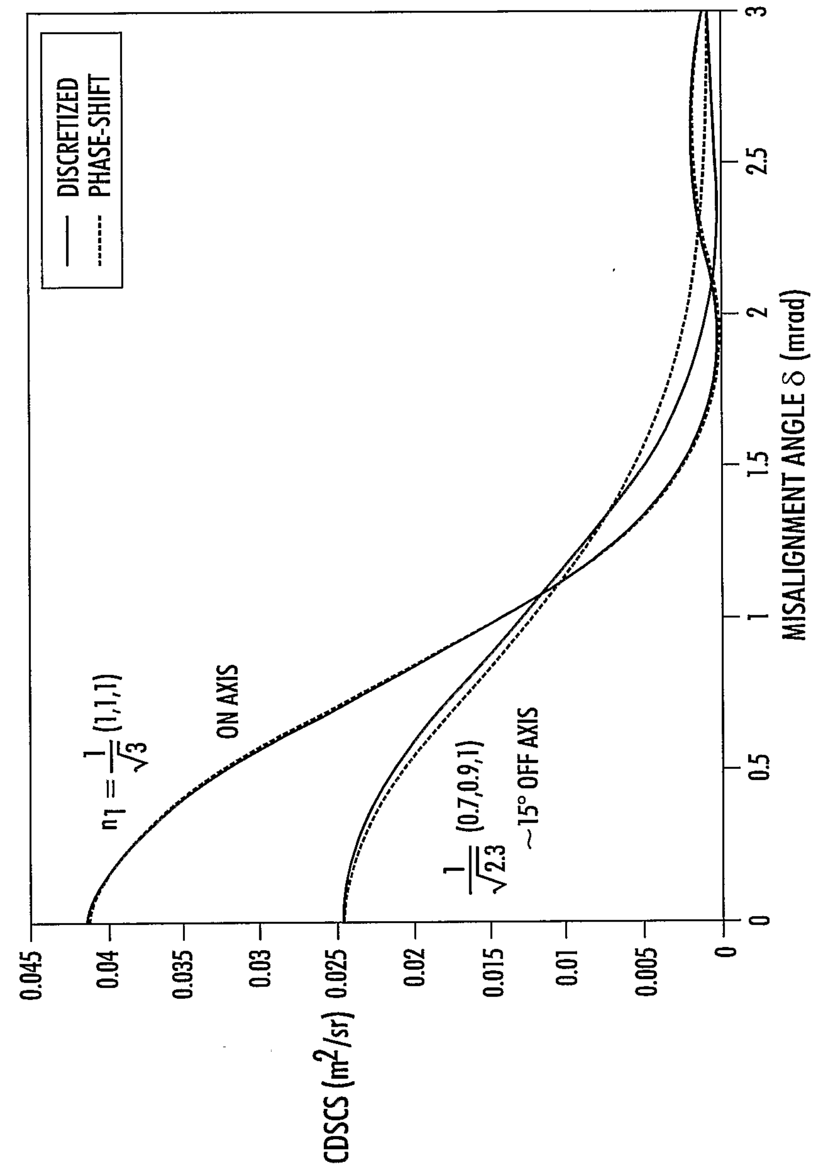
DISCRETIZED
PHASE-SHIFT
$n_1 = \frac{1}{\sqrt{3}}(1,1,1)$
ON AXIS
$\frac{1}{\sqrt{2.3}}(0.7,0.9,1)$
~15° OFF AXIS
CDSCS (m^2/sr)
MISALIGNMENT ANGLE δ (mrad)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
1.5
2
2.5
3

FIG. 19

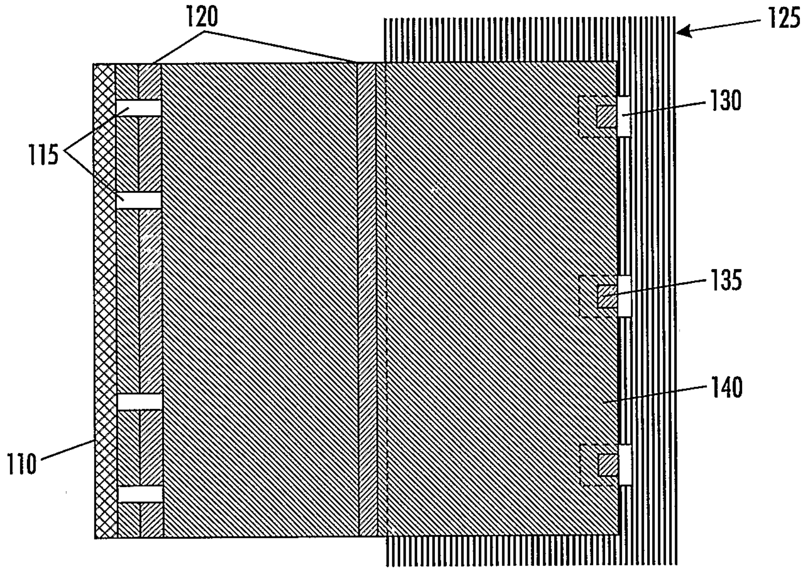

FIG. 20

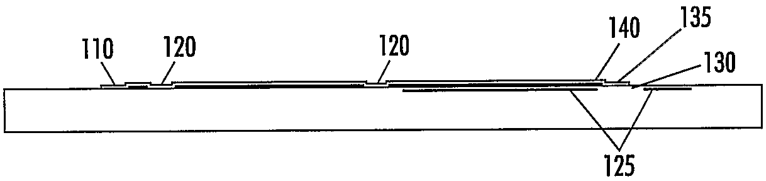

FIG. 21

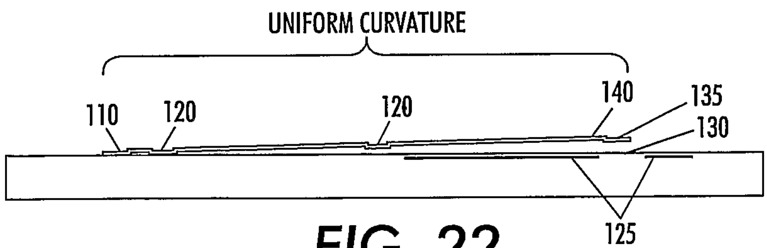

FIG. 22

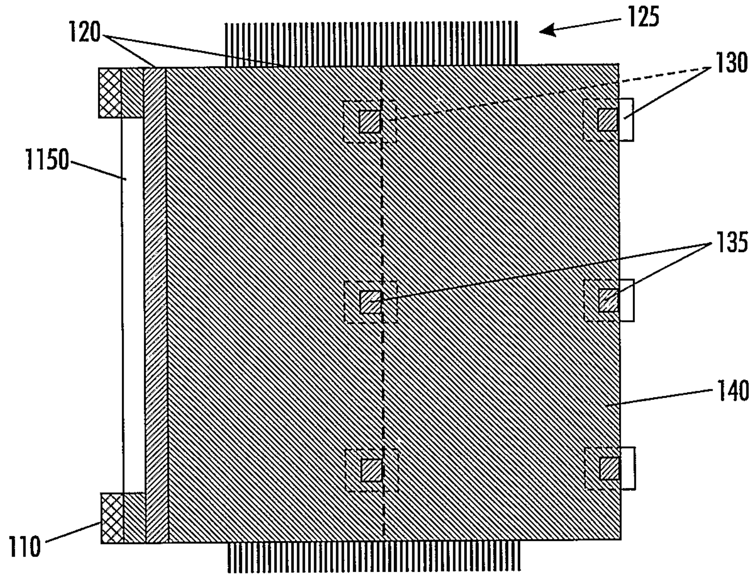

FIG. 23

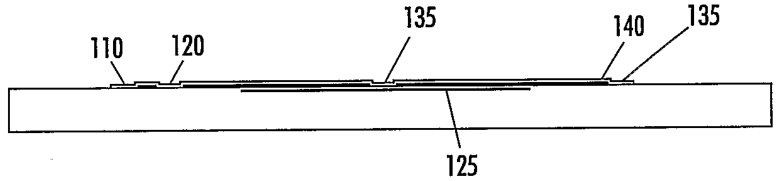

FIG. 24

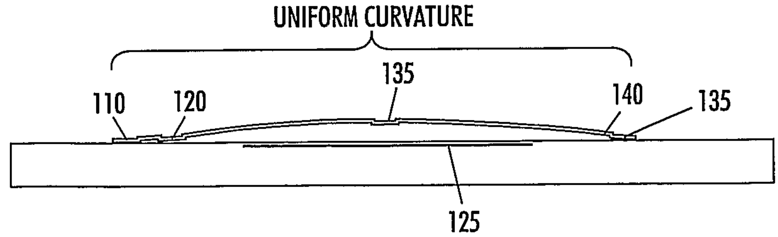

FIG. 25

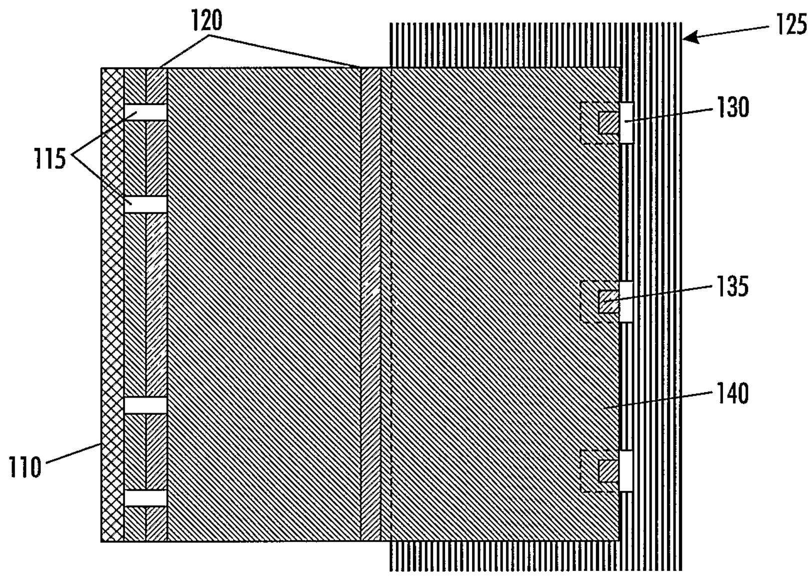

FIG. 26

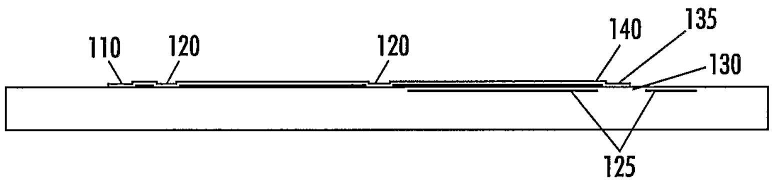

FIG. 27

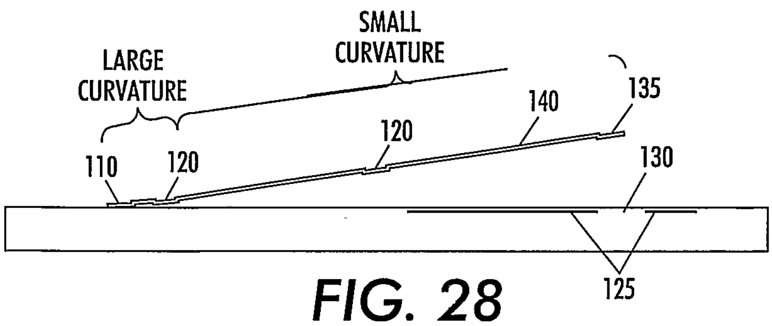

FIG. 28

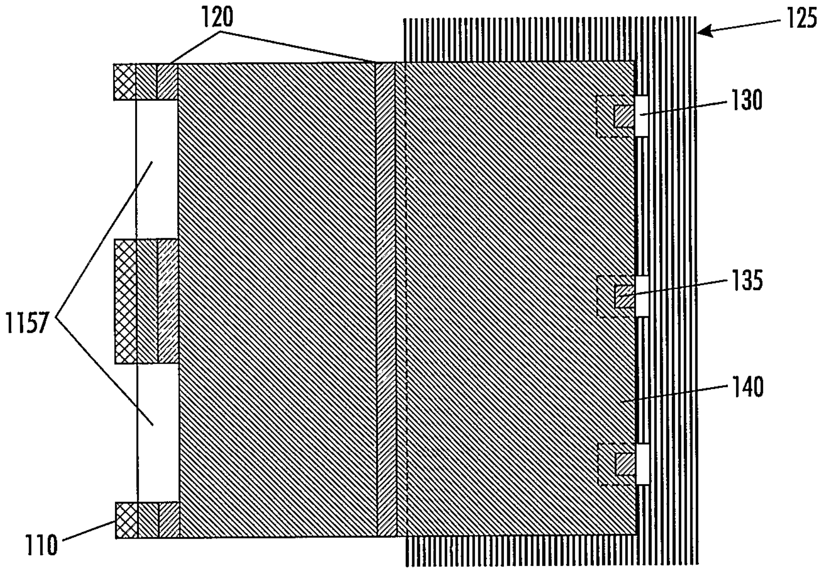

FIG. 29

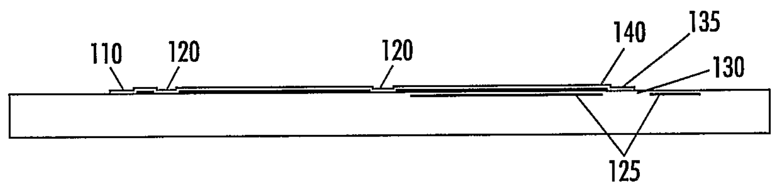

FIG. 30

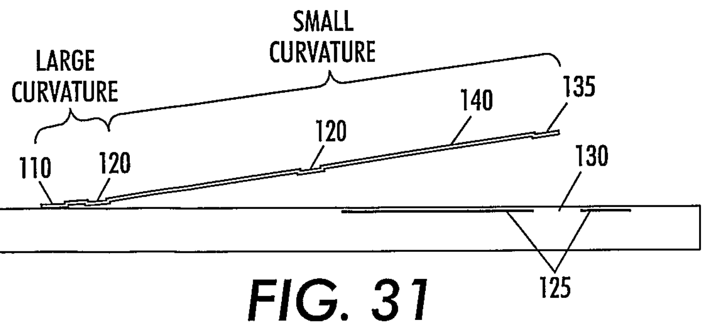

FIG. 31

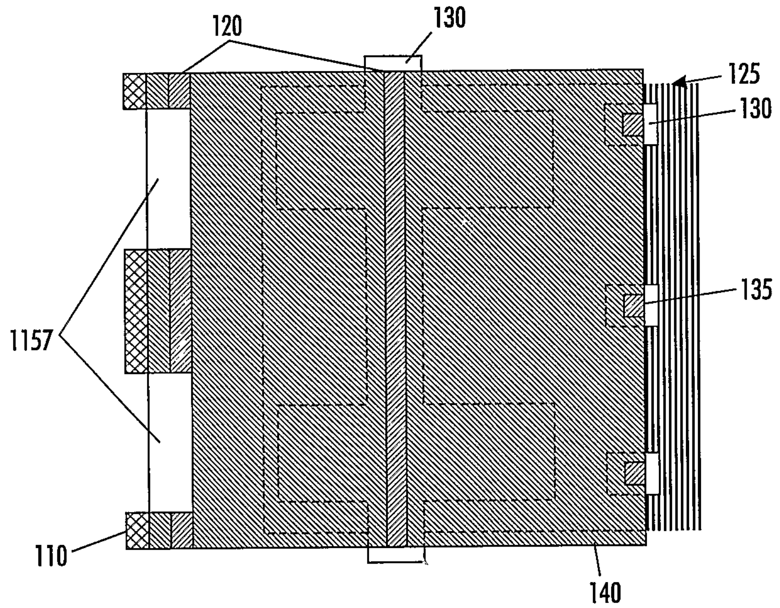

FIG. 32

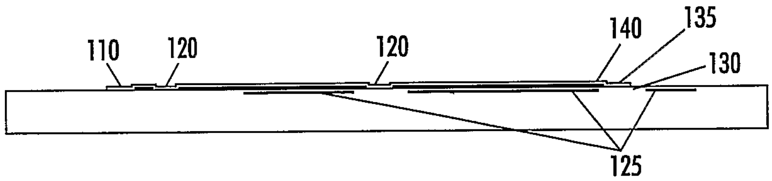

FIG. 33

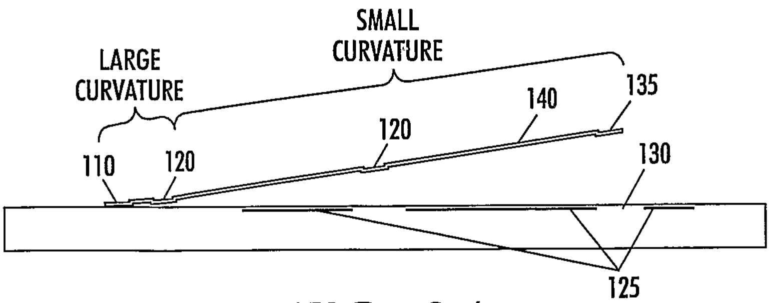

FIG. 34

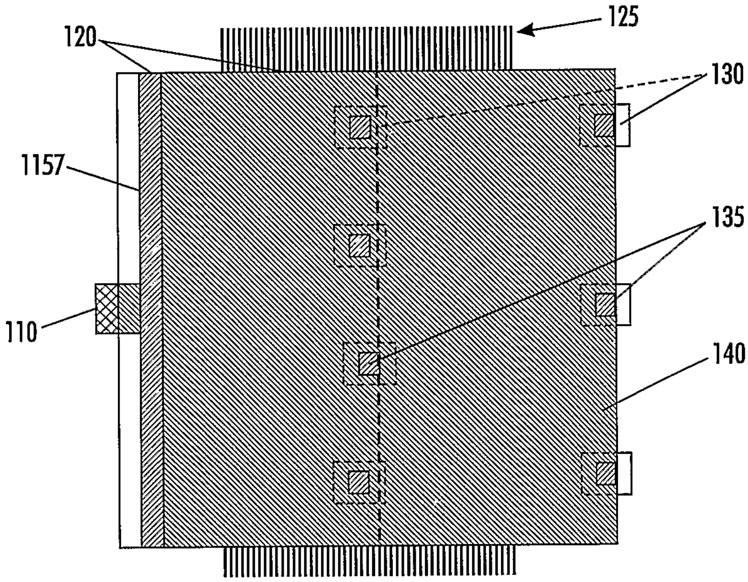

FIG. 35

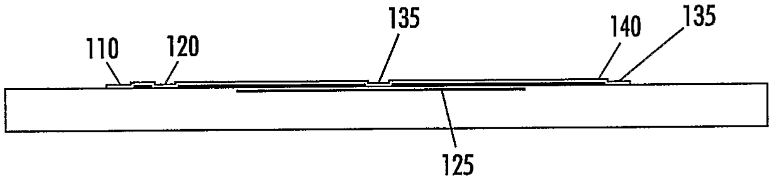

FIG. 36

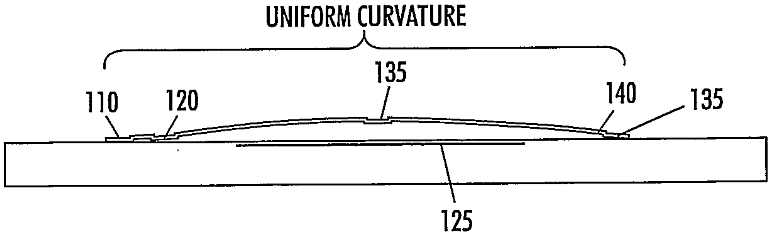

FIG. 37

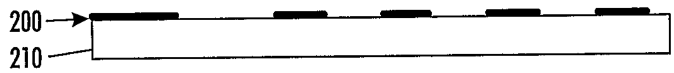

FIG. 38

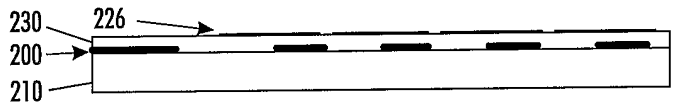

FIG. 39

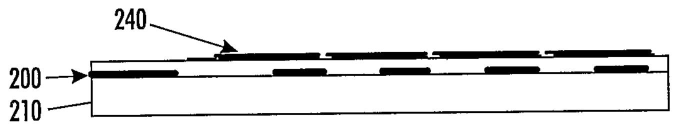

FIG. 40

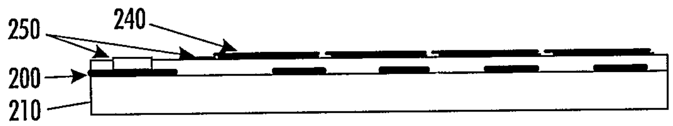

FIG. 41

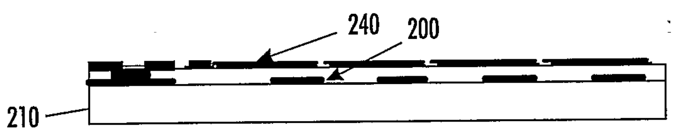

FIG. 42

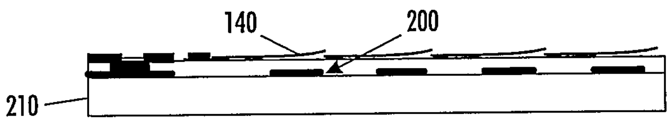

FIG. 43

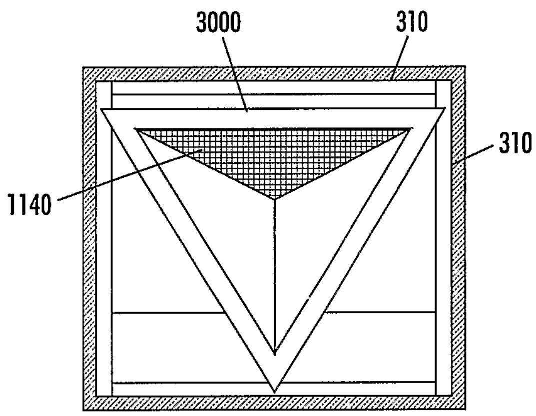

FIG. 44

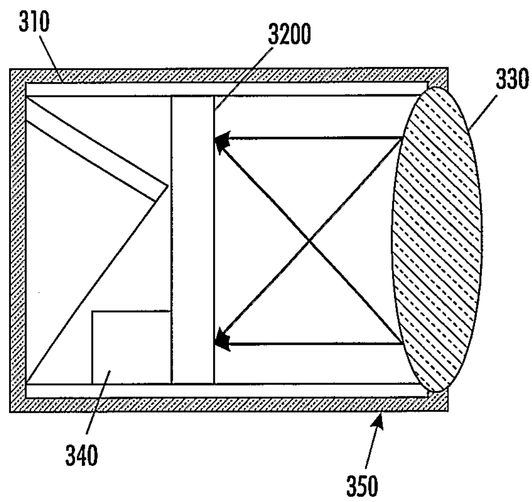

FIG. 45

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/018513

A. CLASSIFICATION OF SUBJECT MATTER
G01S17/74 G02B26/08 G02B5/122

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, COMPENDEX, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 233 088 B1 (ROBERSON MARK W ET AL) 15 May 2001 (2001-05-15) column 6, lines 20-40; figures 1-3 column 7, line 7 - column 8, line 25	1-5, 18-24
X	EP 1 318 426 A (C.R.F. SOCIETA CONSORTILE PER AZIONI) 11 June 2003 (2003-06-11) paragraphs [0010] - [0012]; figures 1,2	1-3
A	US 6 236 491 B1 (GOODWIN-JOHANSSON SCOTT HALDEN) 22 May 2001 (2001-05-22) cited in the application column 4, line 65 - column 7, line 5; figure 1	1-5, 18-24

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2005	22. 12. 2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hambach, D

4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2005/018513

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-5, 18-24

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-5, 18-24

   Switchable retroreflector

   ---

2. claims: 25-29,42-48

   Passive interrogatable sensor

   ---

3. claims: claims 49-53,66-72

   Optical identification system

   ---

4. claims: 6,7,30,31,54,55

   MEMS mirror membrane with reduced sticking

   ---

5. claims: 14-17,38-41,62-65

   Electrode design for low actuation voltage and low energy consumption

   ---

6. claims: 8,10-13,32,34-37,56,58-61

   MEMS mirror with two-dimensionally curved membrane electrode

   ---

7. claim: 87

   MEMS mirror with one-dimensionally curved membrane electrode

   ---

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/018513

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6233088	B1	15-05-2001	AU	3106799	A	11-10-1999
			EP	1064571	A2	03-01-2001
			JP	2002507759	T	12-03-2002
			US	6137623	A	24-10-2000
			WO	9947950	A2	23-09-1999
EP 1318426	A	11-06-2003	AT	276532	T	15-10-2004
			DE	60201247	D1	21-10-2004
			DE	60201247	T2	29-09-2005
			ES	2225716	T3	16-03-2005
			IT	TO20011142	A1	09-06-2003
			US	2003117733	A1	26-06-2003
US 6236491	B1	22-05-2001	AT	274196	T	15-09-2004
			AU	4857800	A	18-12-2000
			CA	2368129	A1	07-12-2000
			DE	60013118	D1	23-09-2004
			EP	1183566	A1	06-03-2002
			JP	2003501274	T	14-01-2003
			JP	2004312999	A	04-11-2004
			WO	0073839	A1	07-12-2000