

MICROELECTROMECHANICAL TELEVISION SCANNING DEVICE
AND METHOD FOR MAKING THE SAME

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1. Field of the Invention

5 This invention relates generally to mechanical television scanning mechanisms and more particularly to microelectromechanical television scanning mechanisms fabricated according to the principles used to fabricate monolithic integrated circuits, thus enabling the physical dimensions of the scanning mechanism to be submillimeter in scale.

2. Description of the Prior Art

Typically, prior art mechanical television scanning mechanisms are large, require external light sources or sensors, have limited operating frequencies and geometrical fields of view, and are fragile. Additionally, prior art mechanical
15 scanners generally include many components. Such mechanisms generally require extensive and intricate manufacturing processes, with associated high costs and low reliability.

Therefore, there is a need for a scanning mechanism that is
20 small in size, facilitates integral or other non-integral radiation sources or sensors, has a wide geometrical field of view, high operating frequency and is robust in construction. Of the known mechanical television scanning mechanisms, only the scanner provided by the present invention is fabricated in much
25 the same manner as monolithic integrated circuits, thus enabling the physical dimensions of the device to be exceedingly small.

GOTO, in U.S. Pat. No. 5,097,354, discloses a beam scanner which is an electrostatically actuated, torsionally supported two-dimensional scanning mirror. This scanner is constructed in



30 two components. In addition to its simplicity, the scanner features a torsional mirror mount which limits the range of angular deflection of the mirror. This patent also discloses transducers including a vibrating photoelectric sensor in the focal plane of a Fresnel lens.

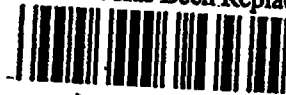
35 PETERSEN, in an article entitled "Silicon Torsional Scanning Mirror", IBM J. Res. Develop., Vol. 24, no. 5, September 1980, discloses a silicon torsional scanning mirror which is electrostatically actuated and torsionally supported on a single scanning axis. The device disclosed is constructed in two
40 components, including a scanning mirror element. The scanning mirror element is fabricated from single crystal silicon, which limits the precision of fabrication due to crystal plane etching.

LIDDIARD, in U.S. Pat. No. 4,708,420, discloses a focal plane scanning device which uses piezoelectric actuators and a
45 mirror rigidly fixed to a central compliant flexure member. This arrangement permits deflection about two axes.

BURKE, in U.S. Pat. No. 4,230,393, discloses a two-axis optical scanner which uses a compliant flexure member. The flexure member is compliant in two axes, with each axis having
0 an associated resonance. The flexure member is excited into oscillation at one end by a mechanical oscillator, and has a scanning mirror located at its other end. The scanning mirror scans in the two axes at the associated resonance frequencies in response to excitation by the mechanical oscillator.

55 LAKERVELD et al., in U.S. Pat. No. 4,073,567, disclose a pivoting mirror device which is actuated electromagnetically. The device includes an oscillating mirror that is centrally supported by a single point bearing, and the bearing permits the

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mirr to oscillate about two axes.

60 Finally, BAKER et. al., in U.S. Pat. No. 3,471,641, disclose a resonant scanning apparatus for deflecting a mirror which uses electromagnetic or piezoelectric actuators. This device includes a mirror rigidly fixed to a central compliant flexure member that is actuated by the actuators to permit deflection about two axes.

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SUMMARY OF THE INVENTION

The long-standing but heretofore unfulfilled need for a scanning device having the desirable features of small physical dimensions, integral light or other radiation sources or sensors, a wide geometrical field of view, high operating frequency, robust construction, easy manufacture, low cost and high reliability, is fulfilled by the invention disclosed and described in the detailed description which follows.

75 According to one aspect, the invention is a scanning device. The scanning device comprises a substrate made from a first material and a flexible joint located above the substrate. The flexible joint is made from a second material. The scanning device further comprises a support attached to the flexible joint. The support is made from a third material. In addition, the scanning device includes an actuator formed on at least one of the substrate, the flexible joint and the support. The actuator is able to cause the support to move relative to the substrate. Further, the scanning device includes an optical element or other energy processing element, such as an optical collimator, on the upper surface of the support. The materials mentioned previously may be the same or any combination of

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materials required for effective operation of the device.

In one embodiment, the scanning assembly is composed of a cross- (or other) shaped thin film plate of electrically conductive material (e.g., boron-doped polysilicon crystal). This plate is supported, generally centrally over a substrate, by a flexible member made from a material that is similar to the material from which the plate is made. The flexible member terminates at a fixed base, generally on the substrate, which contains four (or any other desired appropriate number) of electrostatic actuator electrodes. This flexible member extends perpendicularly from the center of the cross- (or other) shaped central plate and is of suitable length to permit sufficient angular displacement of the cross- (or other) shaped central plate.

The four (or other desired number) electrostatic electrodes (e.g., of deposited aluminum film) are located on the fixed base, directly below the four arms of the cross- (or other) shaped central plate, and act as electrostatic actuators of the cross- (or other) shaped central plate. Each conductive electrode has slightly smaller dimensions than the corresponding arm of (or is equal in size to) the cross- (or other) shaped central plate. Electrically conductive lines (e.g., made from deposited aluminum film) or junction isolated conductors from the conductive electrodes communicate with pads located on the fixed base. An insulating film (e.g., of silicon dioxide, or, preferably, of silicon nitride) is deposited between the conductive plates, the conductive lines and the fixed base. Attraction and repulsion forces are induced between the base and the cross- (or other) shaped central plate when a voltage is applied between the



conductive plates and the arms of the moving cross- (or other) shaped central plate. These forces can cause the cross- (or other) shaped central plate to move in directions about two distinct axes. The previously mentioned flexible member contains any number of electrically conductive lines (e.g., made from deposited aluminum film) or junction isolated conductors deposited on its outer surface. These lines communicate between any desired number of light or other radiation sources or sensors located on the top side of the cross- (or other) shaped central plate and the pads located on the fixed base.

A flexible member perpendicular to the fixed base is not the only way to support the moving cross- (or other) shaped central plate. In another embodiment of the invention, suspension of the cross- (or other) shaped central plate is accomplished by a thin film gimbal. In this embodiment a thin planar film of flexible material (e.g., polycrystalline silicon) is supported above the fixed base and perforated in such a manner as to form a gimbal ring supported externally by two thin, torsionally flexible collinear supports. In addition, the cross- (or other) shaped central plate is formed centrally by the perforations. The cross- (or other) shaped central plate is supported by two further thin, torsionally flexible, collinear supports that are positioned orthogonally to the aforementioned two collinear supports. In this manner the central plate is free to be rotated out of the plane of the thin film of flexible material in any desired direction. The cross- (or other) shaped central plate has any desired number of light or other radiation sources or sensors formed on its upper surface, with conductive lines communicating from the light or other radiation sources or



sens : to stationary electrodes located on the fixed base. The entire gimbal assembly is suspended above the fixed base, which contains the electrostatic actuator plates.

150 A further means of suspension of the moving cross- (or other) shaped central plate is by thin film spiral springs. In a preferred embodiment of the invention involving this method, a thin film of flexible material (e.g., polycrystalline silicon) is supported above the fixed base and perforated in such a manner as to form a series of spirals (smooth or rectilinearly
155 discontinuous) communicating from the internal edge of a circular (or rectangular) perforation to the outer edge of the cross- (or other) shaped central plate. In this manner the central plate is free to be rotated out of the plane of the thin film of flexible material in any desired direction. The cross- (or
160 other) shaped central plate has any desired number of light or other radiation sources or sensors formed on its upper surface, with conductive lines communicating from the light or other radiation sources or sensors to stationary electrodes located on the fixed base. The entire spring assembly is suspended above
165 the fixed base, which contains the electrostatic actuator plates. The electrostatic actuators may act in the same manner as in the gimbal plate mentioned above or in the following fashion. The electrostatic actuator base plates are formed of the same shape and are parallel to the spiral springs. When a voltage potential
170 is applied between the base plates and the springs, a continuous force is applied along the entire length of the spring. Since the spring is relatively long, the small force applied over the entire length of the spring induces a relatively large excursion at the point of connection to the central plate.



175 ctuation of any of the embodiments of the inventive device
mentioned above is not necessarily electrostatic. One possible
additional way of actuating the embodiment is magnetically. To
accomplish this, conductors of deposited aluminum film are shaped
to form spiralling coils on the arms of the cross- (or other)
180 shaped central plate. When the inventive device is placed in a
magnetic field of proper orientation, current passing through any
one of the coils produces a moment which deflects the cross- (or
other) shaped member in a known direction. A proper combination
of the currents through selected coils can cause the cross- (or
185 other) shaped central plate to deflect in the desired fashion.
While operating under the control of magnetic fields generated
by coils, the inventive device operates similarly to a moving
coil galvanometer, which is known in the prior art.

Still another additional way to actuate the cross- (or
190 other) shaped central plate involves piezoelectric actuators.
For piezoelectric action, four small blocks of conventional
piezoelectric crystal film (e.g., zinc oxide) are formed, one
block directly under each of the arms of the cross- (or other)
shaped central plate. The piezoelectric crystal films are
3 individually fixed between the base of the inventive device and
the arms of the cross- (or other) shaped central plate.
Actuation occurs when current is applied, in the manner known in
the prior art, across the piezoelectric crystal films. The
piezoelectric crystal films expand or contract in a direction
200 perpendicular to the plane formed by the arms of the cross- (or
other) shaped central plate in accordance with the polarity and
magnitude of voltage applied. When the motion of the
piezoelectric crystal films is properly coordinated, the desired



scaning motion of the cross- (or other) shaped central plate is
205 achieved.

Yet another way to actuate the cross-shaped central plate
uses forces that are created by thermal stress. By locally
heating the member that connects between the base and the
cross-shaped central plate (through resistive or optical means),
210 a temperature gradient causes a bending moment in the connecting
member. This bending moment causes the connecting member to bend
away from the source of heat, much in the same manner as a
bimetallic strip bends. By selectively heating different
positions on the connecting member, any desired scanning motion
215 of the cross-shaped central plate can be generated.

The transducers located on the top of the cross-shaped
central plate and/or on the fixed base can serve a variety of
functions regardless of how the cross-shaped central plate is
caused to scan. In the case where a laser diode or other
220 collimated radiation emitter is located on the moving
cross-shaped central plate and photoreceptors or other radiation
detectors (e.g., phototransistor, photodiode, etc.) are located
on the fixed base, the inventive device acts as a flying spot
scanner. The laser light or other radiation emitted from the
225 laser diode (or other) collimated radiation emitter is scanned
by the moving cross-shaped central plate across an object in a
raster pattern. The light or other radiation reflected from the
object is detected by the stationary photoreceptor radiation
detector, which converts the variations of the detected reflected
230 light (or other) radiation into a video signal. Additionally,
photoreceptors or other radiation detectors can be collocated on
the moving cross-shaped central plate with the laser diode or



othe collimated radiation emitter, permitting a more compact design.

235 When the diode laser or other collimated radiation emitter located on the top of the moving cross-shaped central plate is modulated and scanned in accordance with an incoming video signal, it is possible to use the inventive device as a television monitor. The television monitor constructs an image
240 by projecting the modulated collimated laser light or other radiation beam from the scanner onto a translucent or opaque screen.

If a photoreceptor (or other collimated radiation detector) replaces the laser diode (or other collimated radiation emitter)
245 on the moving cross (or other central plate) member, the inventive device can be used as an image dissector. Ambient light (or other radiation) from a self-contained source (such as a laser light emitting diode) can be reflected from the object being imaged and is then detected by the photoreceptor (or other
250 collimated radiation detector) which is scanned across the directions of the image by the moving cross-shaped central plate. Some form of light or other radiation collimator (e.g., a lens, a gradient index lens or tube made of deposited aluminum) can also be located on the moving cross-shaped central plate above
255 the photoreceptor or other radiation detector, thus providing further directional sensitivity to the photoreceptor or other radiation detector. High directional sensitivity of the photoreceptor or other radiation detector can be required in this mode of operation in order to dissect the image by one beamwidth
260 of the laser light beam per scanner pass.

A further embodiment of the inventive device includes a



combination of both a laser diode (or other collimated radiation emitter) and collimated photoreceptor (or other radiation detector) on the cross-shaped central plate. This combination of elements permits operation of the inventive device in any of the previously mentioned ways by activation of the laser diode (or other collimated radiation emitter) or photoreceptor (or other collimated radiation detector, or any combination thereof.

Also, if a reflective surface is formed or placed on the top surface of the cross-shaped central plate, a still further embodiment of the inventive device can be used as a reflective flying spot scanning device, with light or other radiation from a stationary light (or other collimated radiation) source (such as a laser diode) reflecting off the surface of the cross-shaped plate as it moves. The emitted, collimated radiation beam is scanned across the imaged object and radiation reflected off the object is detected by a stationary radiation detector.

Additionally, if the reflective surface is formed or placed on the top surface of the central plate, a still further embodiment of the inventive device can be used as a reflective television monitor, with radiation from a stationary modulated collimated radiation source (e.g., a laser diode) reflecting off the surface of the central plate as it moves. The emitted, modulated collimated radiation beam is scanned across a translucent or opaque screen and viewed by an observer.

Further, if incoming radiation from an object is reflected off the surface of the central plate to a collimated radiation detector, the device acts as a reflective image dissector.

Other objects of this invention will become apparent in the detailed description of the preferred embodiment of the



inve: on. The invention comprises the features of construction, combinations of elements and arrangements of parts that will be exemplified in the construction hereinafter set forth, and the scope of the invention will be determined by the claims.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a is an orthogonal view of a first preferred embodiment of the microelectromechanical television scanning device according to the invention, the first preferred embodiment having a central plate suspended cross-shaped plate on a flexible member.

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Figure 1a is an electrical schematic of the scanning device illustrated in Figure 1a.

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Figure 2 is a top view of a second preferred embodiment of the scanning device of the invention, the second embodiment having a gimbaled moving plate suspension.

Figure 2a is a top view of the actuator electrodes for the scanning device illustrated in Figure 2.

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Figure 2b is an electrical schematic of the scanning device illustrated in Figure 2.

Figure 3 is a top view of a third preferred embodiment of the scanning device of the invention, the third embodiment having an alternate spiral spring moving plate suspension.

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Figure 3a is a revision of the third embodiment of the invention.

Figure 4 is an orthogonal view of a fourth preferred embodiment of the scanning device of the invention, the fourth embodiment having a magnetically actuated configuration.

Figure 4a is an electrical schematic of the scanning device



320 ill trated in Figure 4.

Figure 5 is an orthogonal view of a fifth preferred embodiment of the scanning device of the invention, the fifth embodiment having a piezoelectrically actuated configuration.

325 Figure 5a is an electrical schematic of the scanning device illustrated in Figure 5.

Figure 6 is an orthogonal view of a sixth preferred embodiment of the scanning device of the invention, the sixth embodiment having a thermally actuated configuration.

330 Figure 6a is an electrical schematic of the scanning device illustrated in Figure 6.

Figure 7a illustrates a high amplitude action of the moving plate about a single axis.

Figure 7b illustrates a low amplitude action of the moving plate about a single axis.

335 Figure 7c illustrates a high amplitude action of the moving plate on a gimbal mount.

Figure 7d illustrates a low amplitude action of the moving plate on a gimbal mount.

0 Figure 8 is a detailed view of the electrical communication between a photoelectric device and a conductive line on a preferred embodiment of the invention.

Figure 9 is a detailed view of a scanning radiation emitter configuration in accordance with the present invention.

345 Figure 10 is a detailed view of an optically collimated radiation detector configuration in accordance with the present invention.

Figure 11 is a detailed view of a tube-collimated radiation detector configuration in accordance with the present invention.



Figure 11a is a detailed view of a combination laser and
350 gradient index lens collimated photoreceptor or detector for
other radiation in accordance with the present invention.

Figure 12 is a detailed view of a gradient index lens
collimated radiation detector configuration in accordance with
the present invention.

355 Figure 13 is a detailed view of a collimated radiation
emitter and collimated radiation detector configuration in
accordance with the present invention.

Figure 14 is an orthogonal view of a seventh preferred
embodiment of the scanning device of the invention, the seventh
360 embodiment having a reflective central plate.

Figure 14a is an electrical schematic of the scanning device
illustrated in Figure 14a.

Figure 15 illustrates the action of an embodiment of the
present invention in use as a television monitor.

365 Figure 16 illustrates the action of an embodiment of the
present invention in use as an image dissector.

Figure 16a is an orthogonal view of the scanner 158.

370 Figure 17 illustrates the action of an embodiment of the
present invention in use as a reflective flying spot scanner.

Figure 18 illustrates the action of an embodiment of the
present invention in use as a reflective image dissector.

Figures 19a and 19b are a flow chart of an exemplary process
375 for producing the illustrated embodiments of the present
invention.

Figure 20 is a first mask for use with the flow chart of



Figures 19a and 19b.

Figure 21 is a second mask for use with the flow chart of
380 Figures 19a and 19b.

Figure 22 is a third mask for use with the flow chart of
Figures 19a and 19b.

Figure 23 is a fourth mask for use with the flow chart of
Figures 19a and 19b.

385 Figure 24 is a fifth mask for use with the flow chart of
Figures 19a and 19b.

Figure 25 is a sixth mask for use with the flow chart of
Figures 19a and 19b.

390 Figure 26 is a side view of a preferred embodiment of the
invention.

Figure 27a is a top view of a glass wafer of the invention.

Figure 27b is a top view of a thin film of the invention.

Figure 28 is a side view of a configuration of the
invention.

395 Figure 29 is a top view of a thin film of the invention.

Figures 30a-d are a flow chart of an exemplary process for
producing the another illustrated embodiment of the present
invention.

400 Figure 31 is a first mask for use with the flow chart of
Figures 30a-d.

Figure 32 is a second mask for use with the flow chart of
Figures 30a-d.

Figure 33 is a third mask for use with the flow chart of
Figures 30a-d.

405 Figure 34 is a fourth mask for use with the flow chart of
Figures 30a-d.



Figure 35 is a fifth mask for use with the flow chart of Figures 30a-d.

410 Figure 36 is a sixth mask for use with the flow chart of Figures 30a-d.

Figure 37 is a seventh mask for use with the flow chart of Figures 30a-d.

Figure 38 is a eighth mask for use with the flow chart of Figures 30a-d.

415 Figure 39 is a ninth mask for use with the flow chart of Figures 30a-d.

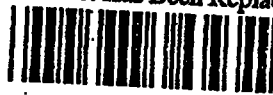
Figures 40a and 40b are views of the fabricated device from the flow chart of Figures 30a-d.

420 Figure 41 is a top view of an array of individual copies of the scanning device of the present invention.

Figure 41a is a close-up view of a portion of the array shown in Figure 40.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

425 Figure 1 is an orthogonal view of a first preferred embodiment of the microelectromechanical television scanning device according to the invention, the first preferred embodiment having a suspended cross- (or other) shaped central plate. The scanning cross-shaped central plate 30 (e.g., made from a
430 material such as deposited n-doped polysilicon) is affixed to a flexible shaft 32 preferably made from the same material as, and in electrical communication with, the scanning cross-shaped central plate 30. The flexible shaft 32 is anchored to a fixed base 34, preferably made of the same material as, and in
435 electrical communication with, the flexible shaft 32. The



scan ng cross-shaped central plate 30 has arms denoted by reference numerals 36, 38, 40 and 42. The fixed base 34 has electrodes 44, 46, 48 and 50 (e.g., made of deposited aluminum film) formed thereon. The electrodes 44, 46, 48 and 50
440 respectively attract or repel the moving cross arms 36, 38, 40 and 42, depending upon the voltage applied to them. A photoelectric device 52 (e.g., a laser diode (or other collimated radiation emitter) or collimated photoreceptor (or other radiation detector) is located on the top of the scanning
445 cross-shaped central plate 30. Electrical communication with the photoelectric device 52 is accomplished through a conductive line 54' (e.g., made of deposited aluminum film) and an electrode 54 preferably made from the same material as the conductive line 54'. Another photoreceptor radiation detector or photoemitter
450 56 may be located on the fixed base 34, with electrical communication established by a conducting line 57 (or junction isolated conductor, e.g., made of deposited aluminum film and an electrode 58 made from the same material or junction isolated conductor).

455 Figure 1a is an electrical schematic of the scanning device illustrated in Figure 1. Each schematic symbol represents the corresponding element with the same number as in Figure 1. Feedback controlled oscillators 65 drive the electrostatic actuator pairs 36 and 44, 38 and 46, 40 and 48, and 42 and 50.
460 A common ground 67 completes the device circuit. Devices 52 and 56 are either radiation emitters or radiation detectors.

Figures 2 and 2a are top views of a second preferred embodiment of the scanning device of the invention, the second embodiment having a gimbaled moving plate suspension. A thin



465 fil 60 of a flexible material (e.g., deposited n-doped polysilicon) is located above the fixed base 34, with the electrodes 44, 46, 48 and 50 being formed on the fixed base 34. The thin film 60 is perforated by perforations 62 in a manner that forms small torsionally flexible regions 64. Additionally, 470 a gimbal ring 66 and a central gimbal plate 68 is formed by the perforations 62. The gimbal ring 66 is free to rotate about the x-axis 66', and the central gimbal plate 68 is free to rotate about the y-axis 68'. Electrical communication between the outside electrode 54 and the photoelectric device 52 is 475 established by the conducting line 54'. Through holes 63 are cut in the thin film 60 to provide access to electrodes 44, 46, 48 and 50. The features shown in Figure 2 are suspended above the items in Figure 2a with sufficient spacing between them to permit free out-of-plane rotation of the gimbal ring 66 and the central 480 plate 68. As with the device illustrated in Figure 1, a stationary radiation detector 56 may be located on the flexible film 60 with an associated electrode 58.

* Other alternative forms of gimbaling mechanisms are also possible. In particular, it is possible to form a gimbal device 485 having hemispheric cylindrical bearings which are formed to create low-friction rolling-contact with a base plate. Such alternative forms of gimbaling bearing mechanisms or other mechanisms which allow a plate such as plate 60 to freely respond to forces such as those produced by the electromagnetic and other 490 mechanisms described herein, are considered to be encompassed by the present patent specification.

Figure 2b is an electrical schematic of the scanning device illustrated in Figures 2 and 2a. Each schematic symbol



represents the corresponding element with the same number as in
495 Figures 2 and 2a. Feedback controlled oscillators 65 drive the
electrostatic actuator pairs 36 and 44, 38 and 46, 40 and 48, and
42 and 50. A common ground 67 completes the device circuit.
Devices 52 and 56 are either radiation emitters or radiation
detectors.

500 Figure 3 is a top view of a third preferred embodiment of
the scanning device of the invention, the third embodiment having
an alternate spiral spring moving plate suspension, and Figure
3a is a revision of the third embodiment. The thin film 60 of
the flexible material is located above the fixed base 34, with
505 the electrodes 44, 46, 48 and 50 being formed on the fixed base
34, in the area covered by a central plate 72. The thin film 60
is perforated by the perforations 62 in a manner that forms long,
thin linear springs 70. Additionally, the modified scanning
cross-shaped central plate 72 is formed by perforations 62. The
510 scanning cross-shaped central plate 72 is free to rotate about
the x- or y-axis 68' and 64', respectively). Electrical
communication between the electrode 54 and the photoelectric
device 52 is established by the conducting line 54'. When a
voltage potential is applied between the lower electrodes 44, 46,
515 48 and 50 and springs 70, a continuous force is applied along the
entire length of the spiral springs 70. Since each spiral spring
70 is relatively long, the small force applied along the entire
length of the spring 70 induces a relatively large excursion at
the point of connection to the plate 72.

520 Figure 4 is an orthogonal view of a fourth preferred
embodiment of the scanning device of the invention, the fourth
embodiment having a magnetically actuated configuration. The



scanning cross-shaped central plate 30 includes a set of electrically conductive coils 74 and 76 (e.g., made of deposited aluminum film) formed on its upper surface. Electrodes 78 and 80 electrically communicate with the coils 74 and 76, respectively, through electrically conductive traces. When the scanning cross-shaped central plate 30 is positioned in a magnetic field 82 and electric current is modulated in the proper fashion in the coils 74 and 76, the scanning cross-shaped central plate 30 will scan in any desired motion.

Figure 4a is an electrical schematic of the scanning device illustrated in Figure 4. Each schematic symbol represents the corresponding element with the same number as in Figure 4. Feedback controlled oscillators 65 drive the moving magnetic coils 74 and 76. A common ground 67 completes the device circuit. Device 52 is either a radiation emitter or radiation detector.

Figure 5 is an orthogonal view of a fifth preferred embodiment of the scanning device of the invention, the fifth embodiment having a piezoelectrically actuated configuration. The piezoelectric crystals 84, 86, 88 and 90 (e.g., made of deposited zinc oxide film) are formed on the fixed base 34, and support the scanning cross-shaped central plate 30. Electrical communication is established between the electrodes 92, 94, 96 and 98 (e.g., made of deposited aluminum film), through the piezoelectric crystals 84, 86, 88 and 90, respectively, to the moving cross arms 36, 38, 40 and 42, respectively, and down through the flexible shaft 32. The electrodes 92, 94, 96 and 98 are electrically isolated from the fixed base 34.

Figure 5a is an electrical schematic of the scanning device



illustrated in Figure 5. Each schematic symbol represents the corresponding element as numbered in Figure 5. Feedback controlled oscillators 65 drive the piezoelectric actuator sets 36, 84 and 92; 38, 86 and 94; 40, 88 and 96; and 42, 90, and 98. A common ground 67 completes the device circuit. Device 52 is either a radiation emitter or radiation detector.

Figure 6 is an orthogonal view of a sixth preferred embodiment of the scanning device of the invention, the sixth embodiment having a thermally actuated configuration. The thermal lasers 100a-d emit corresponding light or other radiation beams 102a-d containing light or other radiation at a suitable wavelength, to heat the flexible shaft 32 at corresponding portions of an area 104. After the area 104 of the flexible shaft 32 is heated by the light or other radiation beam or beams selected from the set of beams 102a-d, the flexible shaft 32 bends away from the direction of the source of the heat, in this case away from the direction of the selected radiation beams 102a-d. By appropriately varying the heating and cooling of the area 104 by means of the lasers 100a-d, the scanning cross-shaped central plate 30 will scan in the desired direction.

Figure 6a is an electrical schematic of the scanning device illustrated in Figure 6. Each schematic symbol represents the corresponding element as numbered in Figure 6. A common ground 67 completes the device circuit. Device 52 is either a radiation emitter or radiation detector.

Two versions of the scanning mechanism are illustrated as represented by Figure 1 and by Figures 2 and 2a.

Figure 7a illustrates a high amplitude action of the moving

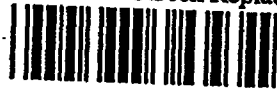


plat on a flexible shaft 32, about a single axis. The phantom view of the moving cross-shaped central plate 106 illustrates one extreme of excursion (showing the bent flexible shaft 32), while the solid view of the scanning cross-shaped central plate 30 illustrates the other extreme of excursion. The angle of view 108 experienced by the scanning cross-shaped central plate 30 in this situation is wide compared to the field of acceptance 109 that would pertain if the central plate 30 were equipped with a collimator.

Figure 7b illustrates a low amplitude action of the moving plate, on a flexible shaft, about a single axis. The phantom view of the scanning cross-shaped central plate 110 illustrates one extreme of excursion, while the solid view of the scanning cross-shaped central plate 30 illustrates the other extreme of excursion. The angle of view 112 experienced by the scanning cross-shaped central plate 30 in this situation is narrow, but is still somewhat large compared to the field of acceptance 113 that would pertain if the central plate 30 were equipped with a collimator.

Figure 7c illustrates a high amplitude action of the moving plate, on a gimbal mount supporting the gimbal plate 68. The phantom view of the moving gimbal plate 68 illustrates one extreme of excursion, while the solid view of the scanning gimbal plate 68 illustrates the other extreme of excursion. The angle of view 108 experienced by the scanning cross-shaped central plate 68 in this situation is wide compared to the field of acceptance 109 that would pertain if the central plate 68 were equipped with a collimator.

Figure 7d illustrates a low amplitude action of the moving



610 plat 68, on a gimbal mount, about a single axis. The phantom
view of the scanning central gimbal plate 68 illustrates one
extreme of excursion, while the solid view of the scanning gimbal
plate 68 illustrates the other extreme of excursion. The angle
of view 112 experienced by the scanning cross-shaped central
615 plate 68 in this situation is narrow, but is still somewhat large
compared to the field of acceptance 113 that would pertain if the
gimbal plate 68 were equipped with a collimator.

From Figures 7a-d, it is readily apparent that increasing
the amplitudes of the signals input to the actuating components
620 increases the angle of view of the scanner. Thus, the angle of
view of the scanner is easily and readily changed at will by
changing the signals to the scanning mechanism. This produces
the effect of a varying focal length lens (i.e., zoom lens)
without the associated complicated optics. Provision must be
625 made, however, to reduce the instantaneous field of view of the
collimator when reducing the overall field of view and vice
versa.

Figure 8 is a detailed view of the electrical communication
between a photoelectric device and a conductive line on a
preferred embodiment of the invention. It illustrates the
electrical communication between the photoelectric device 52 and
electrode 54 through the conductive line 54. An insulative
material 114 (e.g., made of deposited silicon oxide (or
preferably, silicon nitride film) electrically isolates the
635 conductive line 54' from the scanning cross-shaped central plate
30, the fixed base 34 and flexible shaft 32.

Figure 9 is a detailed view of a scanning laser
configuration in accordance with the present invention. The



640 bot: 1 of a stacked diode laser 116 is in electrical communication with the scanning cross-shaped central plate 30 and the flexible shaft 32. A conductive ring 118 electrically communicates with the top layer of the stacked diode laser 116 and the conductive line 54'. The insulative material 114 serves as both a mechanical support for the conductive ring 118 and an
645 electrical insulator for the conductive ring 118 and the conductive line 54'. The stacked diode laser 116 produces a light or other collimated radiation beam 120.

Figure 10 is a detailed view of an optically collimated photoreceptor or other radiation detector configuration in
650 accordance with the present invention. A lens 122, made of transparent material (e.g., made of deposited silicon oxide), focuses incoming light or other radiation rays 124 onto a photosensitive semiconductor junction 126 (e.g., made of p-doped silicon). The conductive line 54' and the insulative material
655 114 serve the same function as in Figure 8.

Figure 11 is a detailed view of a tube-collimated photoreceptor or other radiation detector configuration in accordance with the present invention. A tube 128, made of an electrically conductive material (e.g., made of deposited
660 aluminum), passes an incoming incident light or other radiation ray 130 onto a photosensitive semiconductor junction 126. The tube 128 simultaneously prevents any off-axis light or ray 132 or radiation from reaching the photosensitive semiconductor junction 126. The tube 128 has a field of view defined by angle
665 133. The tube 128 is electrically isolated from the scanning cross-shaped central plate 30 and the flexible shaft 32, but is in electrical communication with the photosensitive semiconductor



jun. on 126 and the conductive line 54'. The conductive line 54' and the insulative material 114 serve the same functions as they serve in Figure 8.

Figure 11a is a detailed view of a combination laser and gradient index lens collimated photoreceptor or detector for other radiation in accordance with the present invention. The gradient index refractive element 85 is located above the radiation detector 126. The gradient index refractive element 85 performs a similar function to that performed by the lens 122 in Figure 10. Light rays 83 are collimated and directed to the radiation detector 81. A gradient index refractive element is a very selective collimator which operates with only a relatively small distance between its front surface and the radiation detector 126. Figure 11a is also a side view of the configuration illustrated in Figures 2 and 2a. The electrode base 147 corresponds to 34 in Figure 2a.

Figure 12 is a detailed view of a moving reflector equipped with a combination collimated radiation emitter and a collimated radiation detector configuration in accordance with the present invention. The stacked diode laser 116 functions as it does in Figure 9, and the tube-collimated radiation detector 126 functions as in Figure 11. An additional conductive line 91 is required for electrical communication of the photosensitive semiconductor junction 126 with an external electrode.

Figure 13 is a detailed view of a moving reflector configuration in accordance with the present invention. The device is actuated in the same manner as described in Figure 1 except that a reflector 136 (e.g., made of deposited aluminum film) is substituted for the photoelectric device 52.

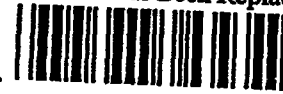


Figure 13a is an electrical schematic of the scanning device illustrated in Figure 13. Each schematic symbol represents the corresponding element with the same number as in Figure 13.

700 Feedback controlled oscillators 65 drive the electrostatic actuator pairs 36 and 44, 38 and 46, 40 and 48, and 42 and 50. A common ground 67 completes the device circuit.

Figure 14 illustrates the action of an embodiment of the present invention in use as a flying spot scanner. The scanner

705 138 is in the configuration detailed in Figure 9 with the photoreceptor 56 located on the fixed base 34. A light beam 140 emitted from the stacked diode laser 116 (See Figure 9) is scanned across an object 142 in a motion pattern such as the raster-scan motion indicated by the reference numeral 144. Any

710 light in the light beam 146 that is reflected from the object 142 is detected by the photoreceptor 56 located on the fixed base 34.

Figure 14a is an orthogonal view of the scanner 138. The components are substantially identical to the first preferred embodiment shown in Figure 14, and the corresponding parts have

715 corresponding reference numerals.

Figure 15 illustrates the action of an embodiment of the present invention in use as a television monitor. The scanner 148 is in the configuration detailed in Figure 9. A light beam 140 emitted from the stacked diode laser 116 is scanned across an

720 opaque screen 150 in a motion pattern such as the raster scan motion indicated by the reference numeral 144. Any light in the light beam 152 that is reflected from the opaque screen 150 can be observed by an observer 154 located in front of the opaque screen 150. If the opaque screen 150 is translucent, the image

725 produced on the opaque screen 150 can be observed by an observer



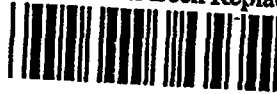
156 ocated behind the opaque screen 150.

Figure 16 illustrates the action of an embodiment of the present invention in use as an image dissector. A scanner 158 is in the configuration detailed in Figure 10 or Figure 11 with a
730 photoemitter 56 located on the fixed base 34. A beam 152 of ambient light reflected off an image field 164 is detected by the collimated photoreceptor 126 (See Figures 10 or 11). The collimated photoreceptor 126 is scanned across the image field 164 in a motion pattern such the raster scan motion indicated by
735 the reference numeral 166. The beam 152 of ambient light is supplied by either an external source 168 or a self contained photoemitter 160 located on the fixed base 34 of the scanner 158.

Figure 16a is an orthogonal view of the scanner 158. The components are substantially identical to the first preferred
740 embodiment shown in Figure 16, and the corresponding parts have corresponding reference numerals.

Figure 17 illustrates the action of an embodiment of the present invention in use as a reflective flying spot scanner. A scanner 170 is in the configuration detailed in Figure 13, with
745 the addition of a photoreceptor 56 located on the fixed base 34. A light beam 140 that is reflected off the object 142 (See Figure 17) is detected by the photoreceptor 56 located on the fixed base 34.

Figure 18 illustrates the action of an embodiment of the present invention in use as a reflective image dissector. The
750 scanner 170 is in the configuration detailed in Figure 13. A beam 162 of ambient light reflected off an object in the image field 164 is detected by a collimated photoreceptor 174. The collimated photoreceptor 174 is scanned across the image field



755 164 the motion indicated by the reference numeral 166. The
beam 162 of ambient light that is reflected from the object 99
is detected by the radiation detector 43 located on the fixed
base 32.

760 Figures 19a and 19b are a flow chart of an exemplary process
for producing the illustrated embodiments of the present
invention. The steps in the exemplary process are generally
conventional steps in a conventional process familiar to those
skilled in the art of producing microelectronic circuitry. The
process begins with a wafer of n-doped silicon material sliced
765 from an appropriately produced boule (step 200). This wafer
serves as the base for the microelectromechanical television
scanner of the invention. Next, a thin layer of silicon nitride
is deposited over the surface of the wafer of n-doped silicon
material (step 202). This produces an insulator between the base
770 and the actuator of the scanner of the present invention. Next
a layer of aluminum is deposited over the insulation layer placed
in step 202 (step 204). This serves as the material from which
the actuator (and specifically, the actuator electrodes 44, 46,
48 and 50) will be formed. Over the surface of the aluminum
5 layer is deposited a layer of photoresist (step 206) which is
exposed through the first mask (step 208).

Figure 20 is a first mask for use with the flow chart of
Figures 19a and 19b. The first mask causes the photoresist
deposited in step 206 of Figure 19a to make the aluminum layer
780 susceptible to etchants which cause the removal of the aluminum
layer and the nitride layer in all areas except those which are
not exposed through the mask shown in Figure 20. Therefore, the
first mask generates four generally arrowhead-shaped areas 180



to be masked while the rest of the nitride and aluminum layers
785 on the upper surface of the fixed base 34 to be made susceptible
to etchants.

Returning to the flow chart of Figures 19a and 19b, the
portions of the aluminum and silicon nitride layers which have
not been protected by the first mask to be respectively etched
790 away, in accordance with conventional processing techniques
(steps 210 and 212). Following this, the photoresist deposited
in step 206 is stripped from the upper surfaces of the remaining
portions of the uppermost aluminum layer (step 214).

Next a thick layer of silicon oxide is formed over the base,
795 silicon nitride and aluminum layers of the wafer (step 216). The
purpose of the layer of silicon oxide deposited in step 216 is
to electrically insulate the aluminum layer from the remainder
of the transducer, and its thickness is great enough to produce
the desired degree of electrical insulation. However, the
800 primary purpose of this layer is to provide a support for further
construction of the device. Eventually, this layer will be
removed by etching. Next, a second layer of photoresist is
formed over the thick layer of oxide, in accordance with the
pattern 182 of a second mask (step 218). Figure 21 is a second
805 mask for use with the flow chart of Figures 19a and 19b. It
defines the areas over the aluminum electrodes formed previously
which are to be electrically insulated and on which polysilicon
will be deposited.

Returning to the flow chart of Figure 19a, the photoresist
810 layer deposited in step 218 is exposed through the second mask
to define the shape of the insulation (preferably taking the form
of a thick layer of silicon dioxide placed over the aluminum



elec. nodes) (step 220). Next, the thick silicon oxide layer is etched from those areas exposed through the second mask (step 815 222), leaving the desired insulation (i.e., the thick silicon oxide patch). After the insulation patch has been formed, the photoresist deposited in step 218 is stripped away (step 224).

The next stages in the process described in the flow chart of Figures 19a and 19b define the gimbal of the second preferred 820 embodiment of the scanner of the present invention (see Figures 2 and 2a). A layer of conventional polysilicon is deposited over the insulated (by means of a thick silicon oxide layer placed over) aluminum electrodes (step 226) and a layer of photoresist formed over the upper surface of the layer of polysilicon (step 830 228). The layer of silicon polysilicon is exposed through a third mask (step 230). Figure 22 is a third mask for use with the flow chart of Figures 19a and 19b. The third mask defines the perforations 184 which create the gimbal mechanism, which allows the scanner to move mechanically in response to electrical signals which will be supplied to it. An additional area of polysilicon 186 is etched away which provides future attachment openings for the lower aluminum electrodes. The gimbal shown in Figure 22 has two pairs of pivot points arranged orthogonally to one another. If desired any other appropriate type of gimbal 835 device, such as the spiral gimbal shown in Figure 3 may be formed at this stage.

As shown in Figure 19a, the polysilicon layer deposited in step 226 is etched in accordance with the pattern produced by exposing the photoresist through the third mask (step 232) and 840 then the photoresist deposited in step 228 is stripped away (step 234).



In the next stage of processing, the photodiodes 126 on the upper surface of the scanner are produced (see Figures 10 and 11). The process begins with the deposit of a layer of photoresist over the entire upper surface of the device at this stage of its production (step 236). The deposited photoresist is then exposed through the fourth mask (step 238). Figure 23 is the fourth mask for use with the flow chart of Figures 19a and 19b. The fourth mask defines two small circles 180 at the center of the scanner. p-type ions are implanted through the two small circles 180 to produce the pn junction of the photodiode 126 (step 240) and the photoresist deposited in step 236 is stripped away (step 242).

The next stage of processing is to produce the insulated connections between the photodiode 126 formed in steps 236-242 and the external world. First, a thin silicon nitride layer is formed over the upper surface of the scanner as it exists at this stage of the process (step 244). This will serve as the insulator 114 between the interconnections and the remainder of the scanner (see Figures 10 and 11). Next an aluminum layer is deposited over the thin nitride layer formed in step 244 (step 246). After this, a layer of photoresist is deposited (step 248) and the photoresist exposed through a fifth mask (step 250).

Figure 24 is a fifth mask for use with the flow chart of Figures 19a and 19b. The fifth mask produces the electrical traces 190 between the photodiodes 192 formed previously and pads 194. The aluminum layer formed in step 246 is stripped away according to the pattern of the fifth mask (step 252), the nitride layer deposited in step 244 is stripped away (step 254) and the photoresist deposited in step 248 is then stripped away

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(st. 256).

In the next stage of the process shown in the flow charts of Figures 19a and 19b, the cross-shaped central plate and gimbal ring are formed by undercutting the oxide formed in step 216 to separate the resulting thin layer from the base layer formed by the original wafer of silicon material. This is accomplished by depositing a layer of a photoresist (step 258) and exposing the photoresist through a sixth mask (step 260). Figure 25 is an example of the sixth mask for use with the flow chart of Figures 19a and 19.

In accordance with the pattern 196 of photoresist deposited in step 258 and exposed in step 260, the thick oxide layer is etched away using a fast etchant (step 262). This causes the oxide under the photodiodes to be etched away, leaving only a thin layer of elevated polysilicon having the photodiodes formed thereon.

Now that the exemplary embodiment of the scanner of the present invention has been formed on the upper surface of the base material of n-doped wafer, it is separated from the remainder of the wafer by dicing the wafer (step 264). It is understood by those skilled in the art that many copies of scanners can be produced simultaneously by using conventional microcircuit processing techniques. Thereafter, the individual devices are mounted on bases (step 266) and appropriate electrical connections are made to the pads formed in steps 244-256 (step 268). The result is the desired scanner.

Figures 26, 27a and 27b are detailed views of a moving reflector configuration in accordance with the present invention. Figure 26 is a side view of the configuration. Light 270 emitted



900 fric the laser diode 116 is reflectively collimated by the
holographic optical element 272 which is made of deposited
aluminum or other dielectric reflector. The holographic optical
element 272 is fabricated on a transparent glass wafer 274 as
will be discussed below. The glass wafer 274 is suspended above
905 the thin film 60 by flip chip solder balls 276. Light reflected
and collimated by the holographic optical element 272 is directed
to the central scanning plate mirror 68 from which it is directed
through the transparent glass wafer 274 to the object being
imaged.

910 Figure 27a is a top view of the glass wafer 274. A
reflective covering 278 prevents stray light emission from the
laser diode 116. The holographic optical element 272 is
fabricated on the reflective covering 280.

Figure 27b is a top view of the thin film 60. An additional
915 stationary photodetector 282 connects to a pickup 284 for
electrical connection. This detector picks up light that is
reflected off the imaged object. The configuration of
photodetector 56 and electrode 58 is identical to that in Figure
2.

) Figures 28 and 29 are detailed views of a moving reflector
image dissector scanner configuration in accordance with the
present invention. Figure 28 is a side view of the
configuration. The device in Figures 28 and 29 is identical to
that in Figure 26 except for the light path 93, the radiation
925 detector 126 and the stationary radiation emitter 282 with an
associated electrode 284.

Figure 29 is a top view of the thin film 60. An additional
stationary radiation emitter 282 connects to an electrode 284 for



elec ical connection. The radiation emitter 282 illuminates the
 930 subject being imaged. The lower electrode configuration is
 identical to that in Figure 2a. The electrode base 147
 corresponds to 34 in Figure 2a.

Figures 30a-d are a flow chart of another exemplary process
 for producing an illustrated embodiment of the present invention.
 935 The steps in the exemplary process are generally conventional
 steps in a conventional process familiar to those skilled in the
 art of producing microelectronic circuitry. The process begins
 with a wafer of n-doped silicon material sliced from an
 appropriately produced boule (step 300).

940 A photoresist is then deposited on the silicon wafer (step
 302) and exposed to mask 1a (Figure 31) (step 304). The
 photoresist is then developed (step 306). The silicon wafer is
 then ion implanted (step 308) to create a p-doped region
 according to the areas exposed by the developed photoresist. The
 945 photoresist is then stripped (step 310) from the silicon wafer.
 Steps 302 through 310 form a p-doped region 285 which will
 electrically isolate the n-p junction photodiode 126 from the
 surrounding wafer.

A photoresist is then deposited on the silicon wafer (step
 950 312) and exposed to mask 2a (Figure 32) (step 314). The
 photoresist is then developed (step 316). The silicon wafer is
 then ion implanted (step 318) to create an n-doped region
 according to the areas exposed by the developed photoresist. The
 photoresist is then stripped (step 320) from the silicon wafer.
 955 Steps 312 through 320 form an n-doped region 286 which will
 become the n-side of the n-p junction photodetector from the
 silicon wafer.



layer of polysilicon is deposited on the face of the silicon wafer (step 322). A photoresist is then deposited on the silicon wafer (step 324) and exposed to mask 3a (Figure 33) (step 326). The photoresist is then developed (step 328). The layer of polysilicon is then etched (step 330) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 332) from the layer of polysilicon. Steps 322 through 332 form a polysilicon layer with through etched area 288 which is cleared for the n-p junction photodiode 126, areas 290 which are cleared for through holes for lead connectivity to lower electrostatic actuator electrodes and areas 291 for gimbal construction.

A layer of thin silicon nitride is deposited on the face of the silicon wafer (step 334). A photoresist is then deposited on the silicon wafer (step 336) and exposed to mask 4a (Figure 34) (step 338). The photoresist is then developed (step 340). The layer of thin silicon nitride is then etched (step 342) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 344) from the layer of thin silicon nitride. Steps 334 through 344 form an insulating layer with through holes 292 cleared for access to the n-p junction isolated photodetector 126.

A layer of aluminum is deposited on the face of the silicon wafer (step 346). A photoresist is then deposited on the silicon wafer (step 348) and exposed to mask 5a (Figure 35) (step 350). The photoresist is then developed (step 352). The layer of aluminum is then etched (step 354) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 356) from the layer of aluminum. Steps 346 through 356



for a conductor 293 from the n-doped region of the n-p photodetector, a conductor 294 for the p-doped region of the n-p photodetector, flip chip bonding pads 295, and the scanning mirror reflective surface 296.

The silicon wafer is then rotated to process the backside of the silicon wafer (step 358). A photoresist is then deposited on the backside of the silicon wafer (step 360) and exposed to mask 6a (Figure 36) (step 362). The photoresist is then developed (step 364). The silicon wafer is then etched (step 366) through to the polysilicon layer according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 368) from the silicon layer backside. Steps 358 through 368 form a deep well 297 from the backside of the wafer to the polysilicon layer. This deep well 297 permits the gimbal to rotate out of plane of the polysilicon layer in addition to providing lead access to the lower electrostatic actuator pads.

Next, the silicon wafer is diced (step 370) to separate the individual scanner units for further processing.

The lower layer containing the electrostatic actuator electrodes is formed on a glass wafer 298 of similar dimensions to the silicon wafer used in steps 300-370.

A layer of aluminum is deposited on the face of the glass wafer (step 374). A photoresist is then deposited on the glass wafer (step 376) and exposed to mask 7a (Figure 37) (step 378). The photoresist is then developed (step 380). The layer of aluminum is then etched (step 382) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 384) from the layer of aluminum. Steps 374 through 384 form the lower electrostatic electrodes 430, 432, 434 and 436.



1020 The glass wafer is then diced (step 386) to the same dimensions as the silicon wafer scanner components diced in step 370.

The upper layer containing the optical elements of the scanner are formed on a smaller glass wafer relative to the silicon wafer used in steps 300-370. This glass wafer is then rotated to permit backside processing (step 372).

1025 A layer of aluminum is deposited on the back face of the silicon wafer (step 392). A photoresist is then deposited on the glass wafer (step 394) and exposed to mask 8a (Figure 38) (step 396). The photoresist is then developed (step 398). The layer of aluminum is then etched (step 400) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 402) from the layer of aluminum. Steps 392
1030 through 402 form the flip chip bonding pads 438 for eventual assembly use. The glass wafer is then rotated to the front side for further processing.

1035 A layer of aluminum is deposited on the front face of the glass wafer (step 406). A photoresist is then deposited on the glass wafer (step 408) and exposed to mask 9a (Figure 39) (step 400). The photoresist is then developed (step 412). The layer of aluminum is then etched (step 414) according to the areas exposed by the developed photoresist. The photoresist is then stripped (step 416) from the layer of aluminum. Steps 406
1040 through 414 form the reflective opaque area 440, the holographic optical element 442 and the clear area 444.

Finally, the smaller glass wafer is diced to a dimension slightly smaller than the wafers diced in steps 370-386.

Final assembly of the device includes mounting the diced lower



1045 ele. code chip formed in steps 372-386 to the diced silicon chip
fabricated in steps 300-370. The chips are aligned and bonded
using adhesives, welding or electrobonding techniques known in
prior art. The backside of the upper optical chip of the device
is bonded with the front side of the diced silicon chip (step
1050 422). The bonding method used is flip chip bonding which is
known in prior art. The bonding pads formed in steps 350 and 396
are used in the flip chip bonding process.

The entire assembly is then bonded to a packaging assembly
(step 426) with the scanning mirror 88 exposed to the outer
1055 environment. Finally, lead wires are bonded (step 428) to the
assembly for connection to external devices.

Figures 40a and 40b are top views of the silicon chip and
upper optical chip respectively. This device is very similar to
the device illustrated in Figures 29 and 29a, respectively. The
1060 differences are the absence of the radiation source 282, the
associated electrode 284, and the addition of a junction isolated
n-p junction photodetector 450 with ground lead 452 and active
lead 454. Photodetector 450 is made from n-doped silicon and
active lead 454 is made from p-doped silicon. This configuration
1 prevents electrical interference from actuator signals.

Figure 41 is a top view of an array of individual copies of
the scanning device of the present invention. The array 450 can
typically consist of a rectangular orientation of the scanning
devices, which share their edges with other copies of the
1070 scanning devices. The individual copies of the scanning devices
can be operated separately, or under coordinated control of a
controller, such as a programmed computer to achieve such effects
as pseudo-three-dimensional visual displays. Similarly, an array



450 the scanning devices can much more rapidly sample a visual
1075 scene than can an individual scanner.

Figure 41a is a close-up view of a portion of the array 450
shown in Figure 40. As can be seen by reference to Figure 41a,
the individual copies of the inventive scanner have the features
of an individual scanner, such as that shown in Figure 1.

1080 It will thus be seen that the objects set forth above, and
those made apparent in the foregoing description, are effectively
attained and since certain changes may be made in the above
construction without departing from the scope of the invention,
all matters contained in the foregoing description or shown in
1085 the accompanying drawings should be interpreted as illustrative
and not in a limiting sense.

It is also understood that the following claims are intended
to cover all of the generic and specific features of the
invention herein described, and all statements of the scope of
1090 the invention which, as a matter of language, might be said to
fall therebetween.

Claims

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1. A scanning device, comprising:

5 a substrate;

a flexible joint located above the substrate;

a support attached to the flexible joint;

10 an actuator formed on at least one of the substrate, the flexible joint and the support, the actuator being able to cause the support to move relative to the substrate; and

a radiation collimating element on the upper surface of the support.

15 2. The scanning device of claim 1 wherein the optical element is a radiation detecting device, the scanning device further comprising at least one electrical conductor passing from the substrate to the radiation detecting device.

20 3. The scanning device of claim 2, further comprising a radiation collimator that collimates radiation before the radiation reaches the radiation detecting device.

25 4. The scanning device of claim 3 wherein the collimator is a cylindrical aperture formed in the support, the axial dimension of the cylindrical aperture being many times longer than the largest dimension of the cylindrical aperture in any direction perpendicular to the axial dimension of the cylindrical aperture.

30



5. The scanning device of claim 1 wherein the optical element is a collimated radiation-emitting device, the scanning device further comprising at least one electrical conductor passing from the substrate to the collimated radiation -emitting device.

35

6. The scanning device of claim 5 wherein the collimated radiation-emitting device is a laser.

40

7. The scanning device of claim 6 wherein the laser is a semiconductor laser formed in the support.

8. The scanning device of claim 1 wherein the optical element is a radiation-reflective device.

45

9. The scanning device of claim 8 wherein the radiation-reflective device is combined with an integrated stationary collimated radiation emitter.

50

10. The scanning device of claim 8 wherein the radiation-reflective device is combined with an integrated stationary collimated radiation detector.

55

11. The scanning device of claim 1 wherein the actuator includes an electrostatic transducer for converting an electrical signal into electrostatic energy.

12. The scanning device of claim 1 wherein the actuator includes a transducer for converting an electrical signal into thermal energy.





60 13. The scanning device of claim 1 wherein the actuator includes a piezoelectric transducer for converting an electrical signal into mechanical energy.

65 14. The scanning device of claim 1 wherein the actuator includes a transducer for converting an electrical signal into electromagnetic energy.

70 15. The scanning device of claim 11, wherein the support includes a central member having four arms formed in two pairs, the transducer being able to act on each of the pairs of opposing arms independently.

75 16. The scanning device of claim 1 wherein the flexible joint allows the actuator to cause at least one of the substrate, the flexible joint and the support to move in at least one dimension.

17. The scanning device of claim 13 wherein the flexible joint includes a gimbal joint formed between the substrate and the support, the gimbal joint allowing the support to move in two dimensions relative to the substrate.

85 18. The scanning device of claim 13 wherein the flexible joint includes a spiral spring suspension formed between the substrate and the support, the spiral spring suspension allowing the support to move in two dimensions relative to the substrate.

19. The scanning device of claim 13 wherein the flexible joint



inc les a structure that is attached to and rises above the
90 substrate.

20. The scanning device of claim 1 wherein the optical element
is responsive to at least two separate wavelength of radiation,
and produces signals representative of its responses to the at
95 least two wavelengths of radiation.

21. A method for forming a scanning device, comprising the steps
of:

a) forming a substrate;

100 b) forming a flexible joint over the substrate, the
flexible joint being made from a second material];

c) attaching a support to the flexible joint;

d) forming an actuator on at least one of the substrate,
the flexible joint and the support, the actuator being able to
105 cause the support to move relative to the substrate; and

e) forming a radiation collimating element on the upper
surface of the support.

110 22. A scanning device, comprising:

a substrate made from a first material;

a flexible joint located above the substrate, the flexible
joint being made from a second material;

a support attached to the flexible joint, the support being
115 made from a third material;

an actuator formed on at least one of the substrate, the
flexible joint and the support, the actuator being able to cause



the support to move relative to the substrate; and
an optical element on the upper surface of the support.

120

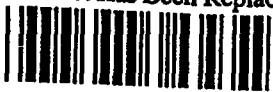
23. The scanning device of claim 22 wherein the optical element is a photosensitive device, the scanning device further comprising at least one electrical conductor passing from the
125 substrate to the photosensitive device.

24. The scanning device of claim 23, further comprising a light collimator that collimates light before the light reaches the
130 photosensitive device.

25. The scanning device of claim 24 wherein the collimator is a cylindrical aperture formed in the support, the axial dimension
135 of the cylindrical aperture being many times longer than the largest dimension of the cylindrical aperture in any direction perpendicular to the axial dimension of the cylindrical aperture.

26. The scanning device of claim 22 wherein the optical element
140 is a light-emitting device, the scanning device further comprising at least one electrical conductor passing from the substrate to the light-emitting device.

27. The scanning device of claim 26 wherein the light-emitting
145 device is a laser.



28. The scanning device of claim 27 wherein the laser is a semiconductor laser formed in the support.

150 29. The scanning device of claim 22 wherein the optical element is a light-reflective device.

30. The scanning device of claim 22 wherein the actuator includes a transducer for converting an electrical signal into
155 thermal energy.

31. The scanning device of claim 22 wherein the actuator includes a piezoelectric transducer for converting an electrical signal into mechanical energy.

160 32. The scanning device of claim 22 wherein the actuator includes a transducer for converting an electrical signal into electromagnetic energy.

165 33. The scanning device of claim 32, wherein the support includes a cross-shaped member having four arms formed in two pairs, the transducer being able to act on each of the pairs of opposing arms independently.

170 34. The scanning device of claim 22 wherein the flexible joint allows the actuator to cause at least one of the substrate, the flexible joint and the support to move in at least one dimension.

175 35. The scanning device of claim 34 wherein the flexible joint includes a gimbal joint formed between the substrate and the



support, the gimbal joint allowing the support to move in two dimensions relative to the substrate.

180 36. The scanning device of claim 34 wherein the flexible joint includes a spiral spring suspension formed between the substrate and the support, the spiral spring suspension allowing the support to move in two dimensions relative to the substrate.

185 37. The scanning device of claim 34 wherein the flexible joint includes a structure that is attached to and rises above the substrate.

190 38. The scanning device of claim 22 wherein the optical element is responsive to at least two separate wavelength of light, and produces signals representative of its responses to the at least two wavelengths of light.

39. A method for forming a scanning device, comprising the steps of:

- 195 a) forming a substrate from a first material;
- b) forming a flexible joint over the substrate, the flexible joint being made from a second material;
- c) attaching a support to the flexible joint, the support being made from a third material;
- 200 d) forming an actuator on at least one of the substrate, the flexible joint and the support, the actuator being able to cause the support to move relative to the substrate; and
- e) forming an optical element on the upper surface of the support.