

SEMICONDUCTOR MECHANICAL STRUCTURE

[DETAILED DESCRIPTION OF THE INVENTION]

[TECHNICAL FIELD]

[0001]

The present invention relates to a semiconductor mechanical structure formed on a semiconductor substrate and having a moving unit which is pivoted by hinges and configured swingable.

[BACKGROUND ART]

[0002]

Conventionally, it is known that some optical instruments such as bar-code readers or projectors use a light scanning mirror to scan light beams incident to a mirror by swinging a moving unit to which the mirror is provided (see patent document 1, for example). As for the light scanning mirror, a miniature one having a semiconductor mechanical structure formed by using micro-machining technology is known. Such a semiconductor mechanical structure has a moving unit to which a mirror face is formed when it is used as a light scanning mirror and a stationary frame which supports the moving unit. The moving unit and the stationary frame are coupled by hinges each other. The moving unit is driven by a pair of comb tooth electrodes interdigitated each other formed between the moving unit and the stationary frame. The comb tooth electrodes are formed so that comb teeth of them are interdigitated with a distance of several μ m, for example, and to generate an electrostatic force be

being applied a voltage between the electrodes of them. The moving unit rotates with respect to the stationary frame while twisting the hinges so as to swing around the hinges serving as the axes by applying a driving force generated by the comb tooth electrodes.

[0003]

By the way, in such a light scanning mirror, in order to assure swing angle necessary to scan light by a small driving voltage, it is sufficient to decrease a spring constant of the hinges in torsion direction by thinning the hinges. However, when thinning the hinges, the hinges become weak for a physical shock, and the hinges may be broken when a mechanical shock is applied from outside, and thus, the light scanning mirror may become immovable. Although a structure of a light scanning mirror in which a cover substrate is joined to a semiconductor substrate is disclosed in patent document 1, displacement of the moving unit is not restrained even when the cover substrate is provided, so that when a mechanical shock is applied from outside, the hinges may be broken before the moving unit contacts the cover substrate.

[PARENT DOCUMENT 1] JP 2004-109651A

[DISCLOSURE OF INVENTION]

[PROBLEMS THAT THE INVENTION IS GOING TO SOLVE]

[0004]

The present invention is conceived in consideration of the above mentioned problem and purposed to provide a semiconductor mechanical structure, which can prevent breakage of the hinges and

be manufactured easily and has a high crashworthy even when an impact shock is applied from outside.

[MEANS TO SOLVE THE PROBLEMS]

[0005]

For achieving the above mentioned purpose, the invention of claim 1 relates to a semiconductor mechanical structure wherein a moving unit, twin hinges constituting an axis of swing motion of the moving unit wherein an end of each hinge is connected to the moving unit, and a stationary frame to which another end of each of the twin hinges is connected and which supports the hinges are formed on a semiconductor substrate, and the moving unit is configured with respect to the stationary frame while twisting the twin hinges, characterized in that a protection substrate for protecting the moving unit is joined to at least one face of the semiconductor substrate; and the protection substrate has stoppers formed to protrude toward a center axis of swing motion of the moving unit, and thus, displacement of the moving unit in a direction perpendicular to the semiconductor substrate is restrained.

[0006]

The invention of claim 2 is characterized in that the stoppers are formed distant from the hinges so as not to contact the hinges when the moving unit is displaced, in the invention of claim 1.

[EFFECTS OF THE INVENTION]

[0007]

According to the invention of claim 1, the displacement of the

moving unit in a direction perpendicular to the semiconductor substrate is restrained, so that breakage of the hinges can be prevented even when an impact is applied from outside, and thus, crashworthy of the semiconductor mechanical structure can be enhanced. Since the stoppers are formed to protrude toward the axis of the swing at which displacement of the moving unit is smaller in the swing motion of the moving unit, it is possible to approach the stoppers to the moving unit without interfering the wing motion of the moving unit around the hinges serving as the axis, and thus, the displacement of the moving unit in the direction perpendicular to the semiconductor substrate can be restrained effectively.

[0008]

According to the invention of claim 2, since the stoppers do not contact the hinges, it is possible to prevent a trouble of breakage of the hinges by contacting of the stoppers.

[BEST MODE FOR CARRYING OUT THE INVENTION]

[0009]

Hereinafter, an embodiment of the present invention is described below with reference to figures. FIG. 1, FIGS. 2(a), (b) and FIG. 3 show an example of a light scanning mirror (a semiconductor mechanical structure) in accordance with this embodiment. The light scanning mirror 1 is a miniature one which is to be mounted on an optical instrument such as a bar-code reader, a projector apparatus which projects an image on an external screen, or a light switch, and has a function to scan light beams which are

incident from external light source or the like (not shown in the figures).

[0010]

First, a configuration of the light scanning mirror 1 is described. As shown in FIG. 1, the light scanning mirror 1 has a semiconductor unit 100 which is configured of a triple-layered SOI (Silicon on Insulator) substrate (a semiconductor substrate) 200 consisting of a first silicon layer (activated layer) 200a and a second silicon layer (substrate layer) 200b having electric conductivity which are joined via a silicon oxidation film (BOX (Buried Oxide) layer) 220. Since the oxidation film 220 has electric insulation characteristic, the first silicon layer 200a and the second silicon layer 200b are electrically insulated each other. A thickness of the first silicon layer 200a is about 30 μ m, and a thickness of the second silicon layer 200b is about 400 μ m. In addition, an oxidation film 220b is formed on a part of a top face of the SOI substrate 200 (it is illustrated in FIG. 3). As shown in FIG. 2(a), the light scanning mirror 1 is a rectangular solid device that top face is substantially square or substantially rectangular of about several mm in planar view, and configured by the semiconductor unit 100, an upper protection substrate (protection substrate) 110 joined to a top face of the first silicon layer 200a, a lower protection substrate (protection substrate) 120 joined to a bottom face of the second silicon layer 200b, and so on.

[0011]

As shown in FIG. 1, the semiconductor unit 100 comprises a mirror unit 2 having substantially a rectangular shape in planar view and a mirror face 20 formed on a top face thereof, a moving frame 3 formed to be a substantially rectangular ring shape to surround peripheries of the mirror unit 2, and a stationary frame 4 formed to surround peripheries of the moving frame 3 and to serve as side peripheries of the light scanning mirror 1. The moving frame 3 and the stationary frame 4 are coupled by bean shaped twin first hinges 5 which are formed from two side faces of the stationary frames 4 facing each other to cross at right angle to the faces to serve as an axis by arranged each other. On the other hand, the mirror unit 2 and the moving frame 3 are coupled by beam shaped twin second hinges 6 which are formed to serve as an axis by arranged each other in a direction crossing a longitudinal direction of the first hinges 5 at right angle. The first hinges 5 and the second hinges 6 are formed so that the axes formed by them pass through a center of gravity of the mirror unit 2 in planar view. Width dimensions of the first hinges 5 and the second hinges are respectively about $5\mu\text{m}$ and $30\mu\text{m}$, for example. The mirror unit 2 is supported by the moving frame 3 to be swingable with respect to the moving frame 3 around the second hinges 6 serving as an axis of the swing motion. On the other hand, the moving frame 3 is supported by the stationary frame 4 to be swingable with respect to the stationary frame 4 around the first hinges 5 serving as an axis of the swing motion. In other words, in this light scanning mirror 1, the mirror unit 2 and the moving frame 3

constitute a moving unit 50 which is swingable with respect to the stationary frame 4 around the axis configured by the first hinges 5. The mirror unit 2 is configured to be two-dimensionally swingable around two axes of the swing motions respectively configured by the first hinges 5 and the second hinges 6. As shown in FIG. 2(b), a supporting member 9, which is joined to the moving frame 3 so as to be swingable integrally with the moving frame 3, is provided on the bottom face of the moving frame 3. In addition, three through-hole connection areas 10a, 10b and 10c are formed on the stationary frame 4. Hereinafter, a longitudinal direction of the second hinges 6 is called X-direction, a longitudinal direction of the first hinges 5 is called Y-direction, and a direction perpendicular to the X-direction and the Y-direction is called Z-direction. In addition, the shapes of the mirror unit 2, the mirror face 20 or the moving frame 3 is not limited to a rectangle, and, it may be a circle or an oval, for example. [0012]

The light scanning mirror 1 swings the mirror unit 2 by electrostatic forces as driving forces, for example. In the semiconductor unit 100, first comb tooth electrodes 7 are formed at regions between the moving frame 3 and the stationary frame 4 where the first hinges 5 are not formed, and second comb tooth electrodes 8 are formed at regions between the mirror unit 2 and the moving frame 3 where the second hinges 6 are not formed. The first comb tooth electrodes 7 are configured so that electrodes 3b respectively formed to be comb tooth shape on two side faces of the moving frame 3

substantially perpendicular to the X-direction are arranged to engage electrodes 4a respectively formed at positions on the stationary frame 4 facing the electrodes 3b. The second comb tooth electrodes 8 are configured so that electrodes 2a respectively formed to be comb tooth shape on two side faces of the mirror unit 2 substantially perpendicular to the Y-direction are arranged to engage electrodes 3a respectively formed to be comb tooth shape at positions on the moving frame 3 facing the electrodes 2a. In the first comb tooth electrodes 7 and the second comb tooth electrodes 8, gaps between the electrodes 3b and 4a, and gaps between the electrodes 2a and 3a are configured to be from $2\mu\text{m}$ to $5\mu\text{m}$, for example. The first comb tooth electrodes 7 and the second comb tooth electrodes 8 generate electrostatic forces acting in a direction of gravitation each other between the electrodes 3b and 4a or electrodes 2a and 3a when applying voltages between the electrodes 3b and 4a or electrodes 2a and 3a.

[0013]

The mirror unit 2, the moving frame 3, the stationary frame 4 and so on are formed by processing an SOI substrate 200 with micro machining technology, which will be mention later. Each portion of the semiconductor unit 00 including each layer of the SOI substrate 200 will be described below.

[0014]

The mirror unit 2 and the moving frame 3 are formed on a first silicon layer 200a. The mirror face 20 is a thin film of aluminum,

for example, and formed on a top face of the mirror unit 2 to reflect light beams incident from outside. The mirror unit 2 is formed substantially symmetrical with respect to a perpendicular plane passing the second hinges 6 (a plane in parallel with z-x plane), and configured swingable around the second hinges 6, smoothly. As shown in FIG. 3, trenches 101a, which communicate from a top end to a bottom end of the first silicon layer 200a and constitute groove-shaped spaces reaching to an oxidation film 220, are formed on the first silicon layer 200a. By forming the trenches 101a, the moving frame 3 is divided into five regions of a region which is connected to one of the first hinges 5 and integrated with the electrodes 3a and 3b, a region consisting of two pivoting portions 3c which support the second hinges 6 and a pivoting portion 3e which is connected to the pivoting portions 3c via a conductive portion 3d and pivoted by the other of the first hinges 5, and three balancing regions 3f formed to be point symmetrical to the conductive portion 3d with respect to a center of the mirror unit 2. Since the trenches 101a divide the first silicon layer 200a, these five regions are electrically insulated each other. In addition, the balancing regions 3f are not necessarily formed.

[0015]

The supporting member 9 is configured of the oxidation film 220 and a second silicon layer 200b below the moving frame 3 (z-direction). The five regions of the moving frame 3 divided by the trenches 101a are joined with the supporting member 9. In other

words, the supporting member 9 is formed below the regions of the moving frame 3 where the trenches 101a are formed while being joined with the first silicon layer 200a. In this way, the moving frame 3 and the supporting member 9 are configured to be swingable integrally around the first hinges 5 as the axis of the swing motion by joining the five regions on the supporting member 9. As shown in FIG. 2(b), the supporting member 9 is formed circularly to be substantially symmetrical with respect to the first hinges 5 in planar view to cover the regions of the bottom face of the moving frame 3 except the electrodes 3a and 3b, in this embodiment. In addition, a thickness of the region of the supporting member 9 consisting of the second silicon layer 200b is formed to be substantially the same as a thickness of the region of the stationary frame 4 consisting of the second silicon layer 200b. In other words, the supporting member 9 is formed substantially symmetrical shape with respect to a perpendicular plane passing the first hinges 5 (a plane in parallel with a y-z plane). In addition, the trenches 101a of the moving frame 3 are provided at positions with shapes to be substantially symmetrical with respect to the perpendicular plane passing the first hinges 5 for forming the balancing regions 3f. Thereby, a center of gravity of the moving unit 50 including the supporting member 9 substantially coincides with the axis of the swing motion consisting of the first hinges 5 in planar view, so that the moving unit 50 including the supporting member 9 is configured to swing around the first hinges 5 smoothly and to perform scanning by the light scanning mirror 1

properly. In addition, the thickness of the portion of the supporting member 9 consisting of the second silicon layer 200b may be formed thinner or thicker than the thickness of the portion of the stationary frame 4 consisting of the second silicon layer 200b.

[0016]

The stationary frame 4 is configured by the first silicon layer 200a, the oxidation film 220 and the second silicon layer 200b. Three through-hole connection area 10a, 10b and 10c are formed and arranged on a top face of the stationary frame 4. Trenches 101b (grooves) are formed on the stationary frame 4 to divide the first silicon layer 200a into a plurality of regions, similar to the trenches 101a. Since the oxidation film 220 and the second silicon layer 200b are joined below the first silicon layer 200a and the trenches 101b are formed on only the first silicon layer 200a, entire of the stationary frame 4 is formed integrally.

[0017]

The trenches 101b divide the first silicon layer 200a of the stationary frame 4 into three regions which are electrically insulated each other and become substantially the same electric potentials as those of the through-hole connection areas 10a, 10b and 10c. Among these areas, an area to be the same electric potential as the through-hole connection area 10a has the pivoting portion 4d which supports one of the regions connected to the pivoting portions 3e of the moving frame 3 and distant farther from the through-hole connection area 10a. The through-hole connection area 10a and the

pivoting portion 4d are connected by a conductive portion 4e which is formed narrower by forming the trenches 101b. In addition, the region which is to be substantially the same electric potential as that of the through-hole connection area 10b has the pivoting portion 4f which supports the other of the first hinges 5. The region which is to be substantially the same electric potential as that of the through-hole connection area 10c is the region of the stationary frame 4 except the above mentioned two regions to be the same electric potentials as those of the through-hole connection areas 10a and 10b, and the electrodes 4a are formed at this region.

[0018]

In this way, three regions are provided on the first silicon layer 200a by forming the trenches 101a and 101b to include a region on which the through-hole connection area 10a is formed and which is to be substantially the same electric potential as that of the electrodes 2a, another region on which the through-hole connection area 10b is formed and which is to be substantially the same electric potential as that of the electrodes 3a and 3b of the moving frame 3, and still another region on which the through-hole connection area 10c is formed and which is to be substantially the same electric potential as that of the electrodes 4a of the stationary frame 4. Electric potentials of the through-hole connection areas 10a, 10b and 10c are variable from outside, which will be described later, and the first comb tooth electrodes 7 and the second comb tooth electrodes 8 are driven by varying the electric potentials of these through-hole

connection areas 10a, 10b and 10c so that the light scanning mirror 1 can be driven. In other words, in this embodiment, the three regions of the first silicon layer 200a respectively including the through-hole connection areas 10a, 10b and 10c and electrically insulated each other constitute voltage application areas to apply voltages to the first comb tooth electrodes 7 and the second comb tooth electrodes 8. In addition, these three regions of the voltage application areas are electrically insulated by insulation areas including the trenches 101a and 101b, gaps between the mirror unit 2 and the moving frame 3 and gaps between the moving frame 3 and the stationary frame 4 formed on the first silicon layer 200a.

[0019]

The upper protection substrate 110 and the lower protection substrate 120 are respectively joined to the top face of the first silicon layer 200a and the bottom face of the second silicon layer 200b of the stationary frame 4. The upper protection substrate 110 has a joint portion 111 which is joined to the stationary frame 4, a light transmission portion 112 located above the moving unit 50, and three through-holes 113 respectively formed at positions corresponding to the through-hole connection areas 10a, 10b and 10c. As shown in FIG. 3, the light transmission portion 112 has a cavity structure, and a recess 112a which is graved from the bottom face side, that is, the semiconductor unit 100 side is formed so as not to block the swing motion of the moving unit 50. Two stoppers 115 are formed on the recess 112a. The through-holes 113 are formed so that the

through-hole connection areas 10a, 10b and 10c are exposed on the top face in a state that the upper protection substrate 110 is joined to the semiconductor unit 100. In other words, the through-holes 113 serve as penetration electrodes to apply voltages to the through-hole connection areas 10a, 10b and 10c, so as to enable to apply voltages to the through-hole connection areas 10a, 10b and 10c while covering the top face of the semiconductor unit 100 by the upper protection substrate 110. The through-holes 113 are located substantially at centers of the through-hole connection areas 10a, 10b and 10c, and diameters of them are preferably smaller than dimensions of the through-hole connection areas 10a, 10b and 10c, and it should be about 0.5mm, for example.

[0020]

In this embodiment, the stoppers 115 are provided to restrain the displacement of the moving unit 50 in the z-direction other than torsion direction. The stoppers 115 are provided to protrude toward the stationary frame 3 from portions of the recess 112a above the regions of the moving frame 3 where two of the first hinges 5 are respectively connected. In other words, the two stoppers 115 are respectively provided on the recess 112a to protrude toward the center axis of the swing motion of the moving unit 50. The stoppers 115 are formed so that the moving unit 50 does not approach to the first hinges 5 not to contact the first hinges 5 when it displaces. Therefore, it is possible to prevent the trouble of breakage of the first hinges 5 by contacting the stoppers 115 in the displacement of the

moving unit 50. In addition, the stoppers 115 are arranged so as not to block the swing motion of the mirror unit 2. Bottom ends of the stoppers 115 serve as contacting portions which can contact the moving unit 50 when the moving unit 50 displaces in the z-direction. Since the mirror unit 2 and the moving unit 50 are driven with swing angles about 10 degrees, for example, the stoppers 115 are formed as shapes in consideration with a scope where the mirror unit 2 and the moving unit 50 displace in the swing motion. For example, it is formed that dimensions in the x-direction are to be 100 μ m to 400 μ m, and dimensions in the y-direction are to be 100 μ m to 300 μ m. Lower limits of these dimensions are set to enable to support the moving unit 50 by the stoppers 115 when the moving unit 50 contacts the stoppers 115. In addition, the stoppers 115 are formed to have gaps of about 10 μ m to 30 μ m in the z-direction between the top face of the moving unit 50 and it when the moving unit 50 is in a balanced position. In this way, by providing the stopper 115 on the upper protection substrate 110 proximate to the moving unit 50, the displacement of the moving unit 50 in the z-direction, that is, in the direction perpendicular to the semiconductor substrate is restrained. In addition, by forming the stoppers 115 in consideration with the scope of the displacement of the mirror unit 2 and the moving unit 50 in the swing motion, the swing motions of the mirror unit 2 and the moving unit 50 are never blocked in normal driving.

[0021]

The lower protection substrate 120 has a cavity structure

similar to the upper protection substrate 110, and a recess 121 which is graved at a portion corresponding to the moving unit 50 and the supporting member 9 from the top face, that is, the semiconductor unit 100 side so as not to block the swing motion of the moving unit 50.

[0022]

In this embodiment, a stopper 125 is provided on the lower protection substrate 120 similar to the upper protection substrate 110 to restrain the displacement of the moving unit 50 in the z-direction other than the torsion. The stopper 125 is provided only one to protrude as a rib shape along the swing axis of the first hinges 5 in the recess 121. In other words, the stopper 125 is provided to protrude as the rib shape toward the center axis of the swing motion of the moving unit 50. A top end of the stopper 125 serves as a contacting portion which can contact the supporting member 9 displacing integrally with the moving unit 50 in the displacement of the moving unit 50. A shape of the stopper 125 is set so as to support the moving unit 50 surely when the moving unit 50 contacts thereto in consideration with the scope of the displacement in the swing motion of the moving unit 50. For example, a dimension in the x-direction is set to be about 100 μ m to 400 μ m. In addition, the stopper 125 is formed to have a gap about 10 μ m to 30 μ m in the z-direction between the moving unit 50 and it when the moving unit 50 is in the balanced state. Since the stopper 125 is provided near to the moving unit 50, the displacement of the moving unit 50 in the z-direction, that is, the

direction perpendicular to the semiconductor substrate is restrained. In addition, since the stopper 125 is formed in consideration with the scope of the displacement in the swing motion of the moving unit 50, the swing motion of the moving unit 50 in the normal driving is never blocked. Besides, a dimension of protrusion of the stopper 125 may be modified preferably corresponding to existence or nonexistence of the supporting member 9 or the thickness of the supporting member 9 so as to restrain the quantity of the displacement of the moving unit 50 effectively. When the supporting member 9 is not provided or the thickness of the supporting member 9 is thin, it is preferable to form the stopper 125 so as not to block the swing motions of the mirror unit 2 and the moving unit 50 and not contact the first hinges 5 when the moving unit 50 displaces in the z-direction, similar to the stoppers 115.

[0023]

In addition, since the upper protection substrate 110 and the lower protection substrate 120 protect internal semiconductor unit 100, it is sufficient to select the thickness about 0.5mm to 1.5mm, but it is preferable to be about 0.6mm, for example, in consideration with the size after the joining. In addition, it is preferable to select the depths of the recesses 112a and 121 to be about 0.3mm, for example, so as not to block the swing motion of the moving unit 50.

[0024]

Furthermore, it is preferable that the upper protection substrate 110 should be a glass substrate because of the light transparency and

the easiness to join it with the first silicon layer 200a. For example, when using a Pyrex (registered trademark) glass by Corning, it is superior in the transparency and it can be joined easily with the silicon by the anode joining because sodium is included in the glass. The upper protection substrate 110 may be formed integrally to include the recess 112a, the through-holes 113 and the stoppers 115 with using the glass substrate by molding method, bonding method, etching method or blast method. In addition, as for the lower protection substrate 120, a glass substrate can be used similar to the upper protection substrate 110. Besides, the materials of the upper protection substrate 110 and the lower protection substrate 120 are not limited to this. In addition, the stoppers 115 and the stopper 125 may be formed of a material different from that of the main bodies of the upper protection substrate 110 and the lower protection substrate 120 each, and they may be joined to the main bodies of the upper protection substrate 110 and the lower protection substrate 120. As for the upper protection substrate 110, it should be configured that at least the light transmission portion 112 is formed of a material which can transmit light beams to be scanned by the light scanning mirror 1. On the other hand, since the lower protection substrate 120 is not required the transparency other than the upper protection substrate 110, it can be configured of a material such as silicon which is easy to process.

[0025]

Subsequently, the motion of the light scanning mirror 1 is

described. The first comb tooth electrodes 7 and the second comb tooth electrodes 8 respectively serve as so-called perpendicular electrostatic combs, so that the mirror unit 2 is driven by generating driving forces at predetermined driving frequencies by the first comb tooth electrodes 7 and the second comb tooth electrodes 8. The first comb tooth electrodes 7 and the second comb tooth electrodes 8 are driven by varying the electric potentials of the electrodes 2a and the electrode 4a periodically in a state that the electrodes 3a and 3b are connected to the standard electric potential, for example, so that they generate electrostatic forces. In this light scanning mirror 1, the first comb tooth electrodes 7 and the second comb tooth electrodes 8 are respectively configured to generate the driving forces periodically by being applied voltages of rectangular waveforms, for example.

[0026]

The mirror unit 2 and the moving frame 3 formed as above do not take level postures and are inclined a little in a state of rest due to occurrence of internal stresses at the time of forming in many cases, generally. Therefore, when the first comb tooth electrodes 7 are driven from the state of rest, the driving forces act on the mirror unit 2 in the direction substantially perpendicular to it, and thus, the mirror unit 2 rotates around the second hinges 6 serving as the rotation axis while twisting the second hinges 6, for example.

Subsequently, when the driving forces of the second comb tooth

electrodes 8 are released in a state of the mirror unit 2 takes a posture that the electrodes 2a and the electrodes 3a completely overlap, the mirror unit 2 continues to rotate while twisting the second hinges 32 by inertia force thereof. When the inertia force of the mirror unit 2 in a rotational direction becomes equal to the restitution forces of the second hinges 6, the rotation of the mirror unit 2 in the direction stops. At this time, the second comb tooth electrodes 8 are driven again, and the mirror unit 2 starts to rotate in the opposite direction by the restitution forces of the second hinges 6 and the driving forces of the second comb tooth electrodes 8. The mirror unit 2 is swung by repeating such rotations due to the driving forces of the second comb tooth electrodes 8 and the restitution forces of the second hinges 6. The moving frame 3 repeats the rotation due to the driving forces of the first comb tooth electrodes 7 and the restitution forces of the first hinges 5, similar to the swing motion of the mirror unit 2, and thus, it swings integrally with the supporting member 9. At this time, the moving unit 50 including the supporting member 9 swings entirely, and the posture of the mirror unit 2 varies. Thereby, the mirror unit 2 repeats two-dimensional swing motion.

[0027]

The second comb tooth electrodes 8 are driven by applying the voltages having a frequency about two times as large as a resonance frequency of a vibration system configured of the mirror unit 2 and the second hinges 6. In addition, the first comb tooth electrodes 7 are driven by being applied the voltages having a frequency about two

times as large as a resonance frequency of a vibration system configured of the mirror unit 2, the moving frame 3, the supporting member 9 and the first hinges 5. Thereby, the mirror unit 2 is configured to be driven with resonance phenomenon so as to enlarge the swing angle thereof. In addition, since application manner and frequencies of the voltages of the first comb tooth electrodes 7 and the second comb tooth electrodes 8 are not limited to the above, it may be configured that the driving voltages are applied as sinusoidal wave forms, or it may be configured that the electric potentials of the electrodes 3a and 3b are varied with the electric potentials of the electrodes 2a and the electrodes 4a.

[0028]

Manufacturing processes of the light scanning mirror 301 is described below with reference to FIG. 4 to FIG. 9. In addition, FIG. 4 to FIG. 9 are cross-sectional views of the region substantially the same region shown in FIG. 3. First, oxidation films are formed on both of top and bottom faces of an SOI substrate 200 in a diffusion furnace of oxygen and a steam atmosphere (FIG. 4). Subsequently, a resist (not illustrated) is patterned by photo lithography in the shapes of the moving unit 50, the first hinges 5 and the second hinges 6 on a surface of the oxidation film 220b formed on a top face of an activation layer, that is, a first silicon layer 200a. After that, regions of the oxidation film 220b which is not masked by the resist is removed by RIE (Reactive Ion Etching) so as to expose the regions of the first silicon layer 200a in which the moving unit 50 and so on are

not formed, and the resist is removed in oxygen plasma (FIG. 5). An aluminum film is formed on the top face of the first silicon layer 200a by sputtering aluminum, for example. The aluminum film is formed so that a thickness thereof becomes about 5,000 angstrom, for example. Then, after patterning a resist (not illustrated) by photolithography, the RIE is performed to remove a portion of the aluminum film other than the mirror face 20, and the resist is removed (FIG. 6). Thereby, the mirror face 20 is formed.

[0029]

After forming the mirror face 20, a resist 230 is patterned on the first silicon layer 200a, and etching an exposed portion of the top face of the first silicon layer 200a by performing D-RIE (Deep Reactive Ion Etching). Since an etching rate of the oxidation film 220 of the SOI substrate 200 is less than 1% of an etching rate of the first silicon layer 200a, the oxidation film 220b on the surface of the first silicon layer and the oxidation film 220 are rarely etched. Thereby, shapes to be the moving unit 50, the first hinges 5, the second hinges 6, the first comb tooth electrodes 7 and the second comb tooth electrodes 8 are formed on the first silicon layer 200a. Simultaneously, the trenches 101a are formed in a region to be the moving unit 50, and, the trenches 101b are formed in a region to be the stationary frame 4 (FIG. 7). The resist 230 is removed in oxygen plasma.

[0030]

Subsequently, a second silicon layer 200b (bottom face side) of

the SOI substrate 200 serving as a supporting substrate is processed. The processing of the bottom face side is performed by covering the top face of the first silicon layer 200a which is the top face side by the resist 230 for protection, for example. First, a resist 232 is patterned on a surface of the oxidation film 220b formed on a surface of the second silicon layer 220b by photo lithography. The resist 232 is formed in shapes corresponding to the supporting member 9 and the stationary frame 4. Then, regions of the oxidation film 220b in which the resist 232 is not formed is etched by RIE and the exposed second silicon layer 200b is grinded by D-RIE (FIG. 8). At this time, the second silicon layer 200b is grinded to the oxidation film 220 due to the difference of the etching rates, similar to the above, and the oxidation film 220 is rarely etched. After that, the resist 232 is removed in oxygen plasma. In addition, it may be configured that the resist 232 is removed during etching of the second silicon layer 200b, and in that case, manufacturing processes can be simplified. Furthermore, it is possible to adjust a thickness of the resist 232 corresponding to the supporting member 9 so that the supporting member 9 is etched a little when the etching is completed, and thus, the thickness of the supporting member 9 is made smaller.

[0031]

Subsequently, the oxidation film membrane 220 exposed below the semiconductor unit 100 is removed by RIE. Thereby, the moving unit 50 and the mirror unit 2 become swivelable through the first hinges 5 and the second hinges 6. In addition, thereby, the

supporting member 9 consisting of the oxidation film 220 and the second silicon layer 200b is formed below the trenches 101a in a state that a plurality of regions of the moving frame 3 insulated and divided by the trenches 101 are joined. In addition, the oxidation film 220b on the surface of the second silicon layer 200b is removed, simultaneously. After that, the semiconductor unit 100 is completed by removing the resists 230 and 232 above and below the semiconductor unit 100.

[0032]

After completion of the semiconductor unit 100, the upper protection substrate 110 and the lower protection substrate 120 are joined to the semiconductor unit 100. In this embodiment, it is described the case of using the glass substrates as the upper protection substrate 110 and the lower protection substrate 120. The glass substrates and the SOI substrate 200 can be joined easily and surely by the anode joining, for example.

[0033]

The joining processes of the upper protection substrate 110 and the lower protection substrate 120 are performed so that the upper protection substrate 110 is joined to top side of the semiconductor unit 100 first in consideration with protection of the mirror face 20 and the lower protection substrate 120 is joined to the bottom side of the semiconductor unit 100 afterward. In the joining process of the upper protection substrate 110, the glass substrate to which the recess 112a and the through-holes 113 are formed is superposed on the SOI

substrate 200 of the semiconductor unit 100 first and heated to about several hundred degrees Celsius under vacuum environment of lower than 10 Pa. At this time, degree of vacuum after joining can be enhanced much higher by making the environment less than 1 Pa, preferably. In addition, it is preferable to keep the temperature about 300 degrees Celsius to 400 degrees Celsius. After that, when the glass substrate and the SOI substrate 200 became desired temperature, a voltage of about 400V to 800V with respect to the silicon layer, that is, the first silicon layer 200a of the SOI substrate 200 to be joined is applied to the glass substrate. By keeping the state of applying the voltage in about 20 minutes to 60 minutes, the upper protection substrate 110 properly joined to the semiconductor unit 100. After joining the upper protection substrate 110, the lower protection substrate 120 is joined to the second silicon layer 200b of the semiconductor unit 100 by the anode joining similar to the above (FIG. 9), so that the light scanning mirror 1 shown in FIG. 3 is completed. In addition, the joining method is not limited to the anode joining, and it is possible to join by using various kinds of methods.

[0034]

As mentioned above, since the displacement of the moving unit 50 in the z-direction is restrained by the stoppers 115 and 125 in this embodiment, it is possible to prevent the breakage of the first hinges 5 and to enhance the crashworthy of the light scanning mirror 1 even when a mechanical shock is applied to the light scanning mirror 1 from outside. Since the stoppers 115 and 125 are formed to

protrude toward the axis of the swing motion at which displacement of the moving unit 50 is small in the displacement of the moving unit 50, it is possible to configure the stoppers proximate to the moving unit 50, and to restrain the displacement of the moving unit 50 in the z-direction effectively. Since the stoppers 115 and 125 are disposed above and below the moving unit 50 in this embodiment, effect to enhance the crashworthy can be obtained effectively.

[0035]

In addition, the present invention is not limited to the configuration of the above mentioned embodiment, and it is possible to modify in various manners in a scope not to change the purpose of the invention, in the seventh embodiment. For example, structures, positions and number of the stopper 115 and the stopper 125 are not limited to those in the embodiment, and they can select optimum ones in consideration with the swing motion of the light scanning mirror. In addition, the light scanning mirror is not limited to biaxial gimbals type in the above mentioned embodiment, and, it may be one which can swing around a single axis having a structure that a moving unit to which a mirror face is formed is supported by twin hinges on a stationary frame, for example. In this case, by forming stoppers on a protection substrate to protrude an axis of swing motion of the moving unit, the crashworthy of the light scanning mirror can be enhanced, similarly. Still furthermore, the protection substrate may be joined to at least one face of the semiconductor unit 100, and the stoppers may be disposed at least a side of the semiconductor unit 100

to restrain the displacement of the moving unit. When the stoppers are provided on only a side, the displacement of the moving unit in the z-direction can be restrained by the stoppers, and thus, it is possible to prevent the breakage of the hinges and to enhance the crashworthy. Still furthermore, the semiconductor unit 100 may be a single silicon substrate or a metal plate other than the SOI substrate, the driving forces to swing the mirror unit 2 and the moving unit 50 may be electrostatic forces acting between flat electrodes, electromagnetic forces, electrostriction forces or heatstriction forces instead of the electrostatic forces acting between comb tooth electrodes. In any case, by forming the stoppers on the protection substrate to protrude toward the axis of the swing motion of the moving unit, it is possible to restrain the displacement of the moving unit in the z-direction, and thus, it is possible to prevent the breakage of the hinges and to enhance the crashworthy of the semiconductor unit.

[0036]

Still furthermore, the present invention is not limited to a light scanning mirror having a mirror face to scan light beams, and it is widely applicable to a semiconductor mechanical structure that a moving unit which is configured swingable with respect to a stationary frame by twin hinges is formed on a semiconductor substrate. In other words, it is possible to enhance crashworthy of the semiconductor mechanical structure by providing stoppers on a protection substrate provided on at least one face of the

semiconductor substrate to restrain a displacement of the moving unit in a direction perpendicular to the semiconductor substrate.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[0037]

[FIG. 1] Perspective view showing a light scanning mirror which is a semiconductor mechanical structure in accordance with an embodiment of the present invention

[FIG. 2] (a) is a perspective view showing an upper side of the light scanning mirror, and (b) is a perspective view showing a lower side of the light scanning mirror.

[FIG. 3] A-A sectional view in FIG. 2(a)

[FIG. 4] Cross-sectional side view in a manufacturing process of a semiconductor unit of the light scanning mirror

[FIG. 5] Cross-sectional side view in the manufacturing process of the semiconductor unit of the light scanning mirror

[FIG. 6] Cross-sectional side view in the manufacturing process of the semiconductor unit of the light scanning mirror

[FIG. 7] Cross-sectional side view in the manufacturing process of the semiconductor unit of the light scanning mirror

[FIG. 8] Cross-sectional side view in the manufacturing process of the semiconductor unit of the light scanning mirror

[FIG. 9] Cross-sectional side view in the manufacturing process of the semiconductor unit of the light scanning mirror

[LIST OF MARKS]

[0038]

- 1 light scanning mirror (semiconductor mechanical structure)
- 4 stationary frame
- 5 first hinges (hinges)
- 50 moving unit
- 110 upper protection substrate (protection substrate)
- 120 lower protection substrate (protection substrate)
- 200 SOI substrate (semiconductor substrate)

[CLAIMS]

[Claim 1]

A semiconductor mechanical structure wherein a moving unit, twin hinges constituting an axis of swing motion of the moving unit wherein an end of each hinge is connected to the moving unit, and a stationary frame to which another end of each of the twin hinges is connected and which supports the hinges are formed on a semiconductor substrate, and

the moving unit is configured with respect to the stationary frame while twisting the twin hinges, characterized in that

a protection substrate for protecting the moving unit is joined to at least one face of the semiconductor substrate; and

the protection substrate has stoppers formed to protrude toward a center axis of swing motion of the moving unit, and thus, displacement of the moving unit in a direction perpendicular to the semiconductor substrate is restrained.

[Claim 2]

The moving structure in accordance with claim 1, characterized in that the stoppers are formed distant from the hinges so as not to contact the hinges when the moving unit is displaced.