A method of making a mirror from a single crystal blank may include fine grinding top and bottom surfaces of the blank to be parallel. The blank may then be heat treated to near its melting temperature. An optical surface may be created on an optical side of the blank. A protector may be bonded to the optical surface. With the protector in place, the blank may be light weighted by grinding a non-optical surface of the blank using computer controlled grinding. The light weighting may include creating a structure having a substantially minimum mass necessary to maintain distortion of the mirror within a preset limit. A damaged layer of the non-optical surface caused by light weighting may be removed with an isotropic etch and/or repaired by heat treatment. If an oxide layer is present, the entire blank may then be etched using, for example, hydrofluoric acid. A reflecting coating may be deposited on the optical surface.
Fig. 1
Prior Art
METHOD OF MAKING LIGHTWEIGHT, SINGLE CRYSTAL MIRROR

ORIGIN OF INVENTION

This invention was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefore.

FIELD OF THE INVENTION

The invention relates to single crystal, lightweight mirrors.

BACKGROUND

Lightweight mirrors are needed for a wide variety of applications, for example, in the space and aeronautics industries. Particularly in space and aeronautics applications, it is important to reduce the overall weight of the system. It is also important to produce precise optical components.

U.S. Pat. No. 7,145,739 issued on Dec. 5, 2006 and is entitled “Lightweight Optical Mirrors Formed in Single Crystal Substrate.” The entire contents of U.S. Pat. No. 7,145,739 are expressly incorporated by reference herein. The ‘739 patent discloses lightweight optical mirrors formed in a single crystal substrate. Mirrors made by the ‘739 process may be high quality. According to the ‘739 process, a mirror surface is polished, and then ultrasonic machining is used to light weight the mirror. But, ultrasonic machining is a relatively high quality, lightweight mirrors from a single crystal substrate.

A primary function of the isogrid web structure may be to provide stiffness. In particular, the isogrid web structure may provide the stiffness that is necessary to support the mirror while the optical surface is ground and polished. However, because the optical surface may be ground and polished before light weighting, the isogrid web structure may not be needed to supply the stiffness needed for grinding and polishing. Thus, a mirror may only need to be stiff enough to resist self-weight deflection and distortion induced by mounting.

A novel method of making a mirror may not produce the isogrid web structure. A mirror that may be stiff enough to resist self-weight deflection and distortion induced by mounting may not require the isogrid web structure. The isogrid web structure may be eliminated and a simpler structure that may be less expensive to create may be used. The simpler structure may also have less mass than the isogrid structure.

As disclosed in the ‘739 patent, a single crystal mirror’s optical surface may be ground and polished before light weighting via ultra-sonic machining. FIG. 1 is a perspective view of a mirror 10 produced by a conventional process, viewed from the non-optical side of the mirror. FIGS. 2A, 2B, and 2C are rear perspective, front and side views, respectively, of a single crystal blank for making a mirror. FIG. 3 is a side view of a mirror blank and a protector. FIG. 4 is a perspective view of an embodiment of a novel mirror, viewed from the non-optical side of the mirror. FIG. 5 is a perspective view of another embodiment of a novel mirror, viewed from the non-optical side of the mirror.

DETAILED DESCRIPTION

In one aspect, a method of making a mirror may include providing a single crystal blank and creating an optical surface on the blank. The single crystal blank may be a single crystal silicon blank. A protector may be placed on the optical surface and the blank may be light-weighted by grinding a non-optical surface of the blank. Distortion of the optical surface caused by the light weighting may be reduced by one or more of: (a) removing at least a portion of a damaged layer of the non-optical surface of the blank by etching the non-optical surface with an isotropic etch, and (b) repairing at least a portion of a damaged layer of the non-optical surface of the blank by heat treating the blank. A reflecting coating may be deposited on the optical surface.

Light weighting the blank may include creating a structure having a substantially minimum mass necessary to maintain distortion of the mirror within a preset limit. The structure that is created may be, for example, substantially only a circumferential rim, or, for another example, substantially only a circumferential rim and radial webs.

The invention will be better understood, and further objects, features, and advantages thereof will become more
After fine grinding, blank 14 may be heat treated to near the melting temperature of blank 14. Silicon, for example, may have a melting temperature of about 1410°C. Thus, heat treatment near the melting temperature for silicon may be, for example, in a range of about 1100°C to about 1250°C. In one embodiment, blank 14 may be heat treated at 1250°C. The temperature may be slowly raised from ambient to 1250°C over a period of time, for example, at least about six hours. Blank 14 may be held at 1250°C for a period of time, for example, about twelve hours. Blank 14 may be slowly cooled back to ambient temperature over a period of time, for example, at least about six hours. The heat treatment process may heal or repair crystalline damage caused by sawing and grinding processes that may be used to fabricate blank 14.

An optical surface may be created on side 18 by, for example, conventional grinding and polishing or by single point diamond turning. If the optical surface that is created is deeply curved, blank 14 may be heat treated again. The heat treatment may be, for example, as described above.

FIG. 3 is a side view of blank 14 and a protector 20. Protector 20 may be made from, for example, Pyrex. Protector 20 may have a ground surface 22 that may be curved opposite to optical surface 24 of blank 14. If blank 14 needs to be cut, for example, to form a central hole, protector 20 may be made of polycrystalline silicon. With protector 20 made from polycrystalline silicon, wire electrical discharge machining (EDM) may be used to cut both protector 20 and blank 14 together. Protector 20 may be bonded to optical surface 24 using, for example, wax 26. Number 5 stacking solvent, for example, acetone. The back side structures shown in FIGS. 4 and 5 are similar to the isogrid structure of FIG. 1. The structures in FIGS. 4 and 5 may be formed by computer controlled grinding, which may be faster and less expensive than the ultrasonic machining used to produce the mirror 10 of FIG. 1.

While the invention has been described with reference to certain preferred embodiments, numerous changes, alterations and modifications to the described embodiments are possible without departing from the spirit and scope of the invention as defined in the appended claims, and equivalents thereof.

What is claimed is:
1. A method of making a mirror, comprising:
   - providing a single crystal blank with a back, non-optical side and a front, optical side, further the blank of cylindrical shape with the material of the blank made from boron-doped single crystal silicon composed of non dislocation free (non-slip) material; then creating an optical surface on the blank; then placing a protector on the optical surface made from Pyrex with a around surface curved opposite to optical surface of the front of the blank; then light weighting the blank by grinding a non-optical surface of the blank; then reducing distortion of the optical surface caused by the light weighting; and then depositing a reflecting coating on the optical surface wherein the non-optical side includes a circumferential rim with a plurality of equally spaced radial webs for
stiffness with multiple mounting holes, each mounting hole radially aligned with a respective radial web to prevent excessive distortion of the mirror with the rim thickened in areas of each mounting hole.

2. The method of claim 1, wherein providing includes fabricating a single crystal silicon blank.

3. The method of claim 1, wherein providing includes providing a single crystal silicon blank that is generally cylindrical in shape.

4. The method of claim 1, wherein providing includes providing a single crystal silicon blank comprising boron-doped silicon.

5. The method of claim 1, wherein creating the optical surface includes creating the optical surface by grinding and polishing.

6. The method of claim 1, wherein creating the optical surface includes creating the optical surface by single point diamond turning.

7. The method of claim 1, further comprising, after creating the optical surface, heat treating the blank.

8. The method of claim 1, wherein placing the protector includes bonding the protector to the optical surface with wax.

9. The method of claim 1, wherein light weighting the blank by grinding the non-optical surface of the blank includes computer controlled grinding of the non-optical surface of the blank.

10. The method of claim 1, further comprising, before depositing, removing the protector.

11. The method of claim 1, wherein reducing distortion of the optical surface caused by the light weighting includes removing at least a portion of a damaged layer of the non-optical surface of the blank by etching the non-optical surface with an isotropic etch.

12. The method of claim 1, wherein reducing distortion of the optical surface caused by the light weighting includes repairing at least a portion of a damaged layer of the non-optical surface of the blank by etching the non-optical surface of the blank using computer controlled grinding, the light weighting including creating a structure having a substantially minimum mass necessary to maintain distortion of the mirror within a preset limit; wherein heat treating the blank

13. The method of claim 1, wherein depositing includes vacuum depositing a reflective coating on the optical surface.

14. The method of claim 1, further comprising, before depositing, etching the entire blank, including the optical surface.

15. The method of claim 3, wherein providing includes providing a single crystal silicon blank that is cylindrical in shape and has a diameter to thickness ratio of about 8:1.

16. The method of claim 5, further comprising, after fine grinding, heat treating the blank to near its melting temperature.

17. The method of claim 9, wherein light weighting the blank by grinding the non-optical surface of the blank includes creating a structure having a substantially minimum mass necessary to maintain distortion of the mirror within a preset limit.

18. The method of claim 11, wherein reducing distortion of the optical surface caused by the light weighting includes repairing at least a portion of the damaged layer of the non-optical surface of the blank by heat treating the blank.

19. The method of claim 17, wherein the distortion is due to one of self-weight and mounting errors of the mirror.

20. The method of claim 17, wherein the structure comprises substantially only a circumferential rim.

21. The method of claim 17, wherein the structure comprises substantially only a circumferential rim and three radial webs spaced equally apart.

22. The method of claim 18, wherein heat treating the blank to repair at least a portion of the damaged layer of the non-optical surface of the blank includes heat treating the blank to near its melting temperature.

23. A method of making a mirror, comprising:

- providing a single crystal silicon blank with a back, non-optical side and a front, optical side, further the blank of cylindrical shape with the material of the blank made from boron-doped single crystal silicon composed of non dislocation free (non-slip) material that is generally cylindrical in shape; then
- fine grinding top and bottom surfaces of the blank to be parallel; then
- heat treating the blank to near its melting temperature; then creating an optical surface on the blank; then placing a protector on the optical surface made from Pyrex with a ground surface curved opposite to optical surface of the front of the blank; then
- light weighting the blank by grinding a non-optical surface of the blank using computer controlled grinding, the light weighting including creating a structure having a substantially minimum mass necessary to maintain distortion of the mirror within a preset limit; wherein the non-optical side includes a circumferential rim with a plurality of equally spaced radial webs for stiffness with multiple mounting holes, each mounting hole radially aligned with a respective radial web to prevent excessive distortion of the mirror with the rim thickened in areas of each mounting hole; then
- reducing distortion of the optical surface caused by the light weighting by at least one of a) removing a damaged layer of the non-optical surface of the blank by etching the non-optical surface with an isotropic etch and b) repairing a damaged layer of the non-optical surface using heat treatment; and then
- depositing a reflecting coating on the optical surface.