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(54) **OPTICAL REFLECTOR AND OPTICAL COLLECTION SYSTEM**

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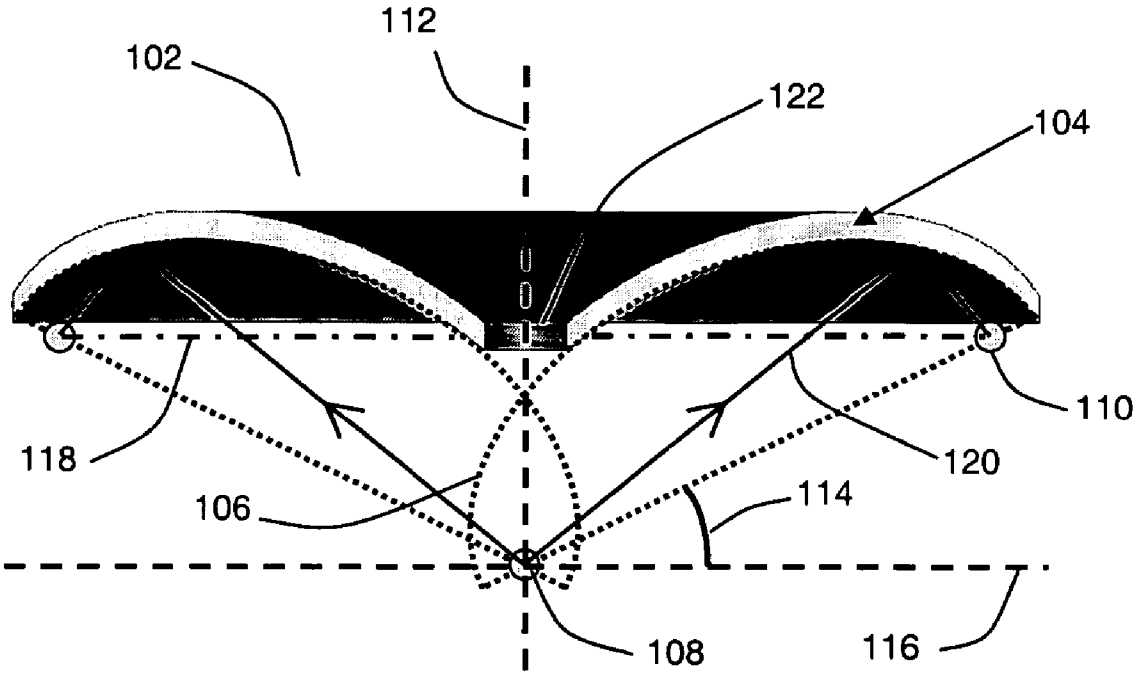
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(57) **ABSTRACT**

An optical reflector comprising a rotationally symmetric reflecting surface disposed around a rotational axis of the reflector and having a radial profile; wherein the radial profile follows a portion of an ellipse profile, the ellipse profile being off-axis with respect to the rotational axis.



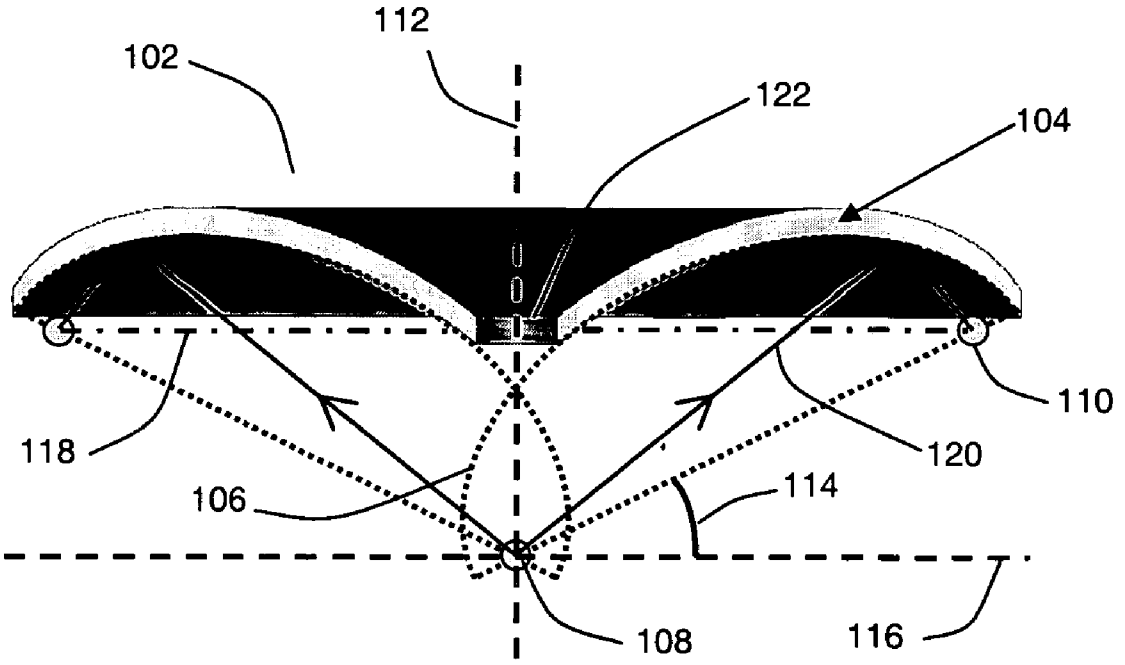


Fig. 1

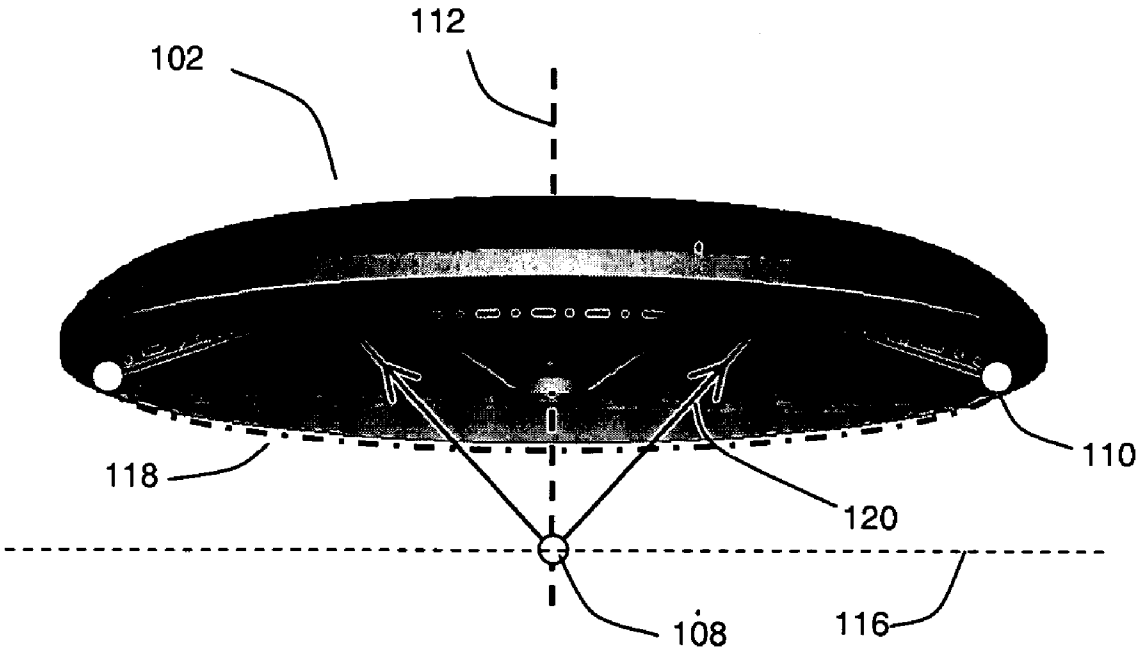


Fig. 2

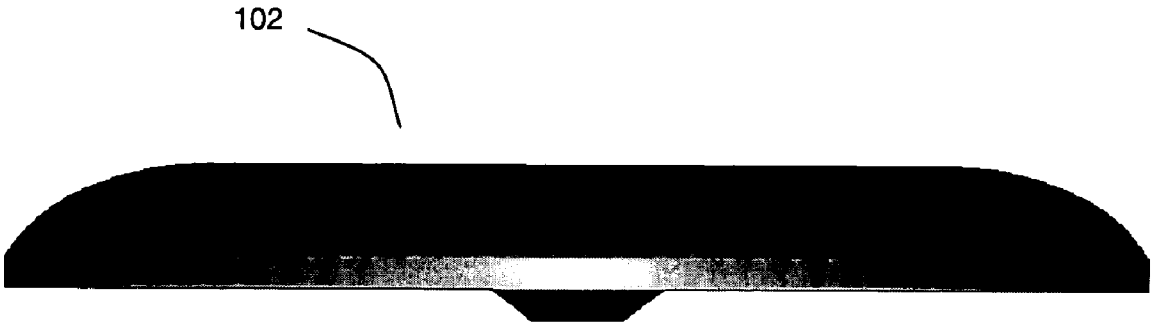


Fig. 3

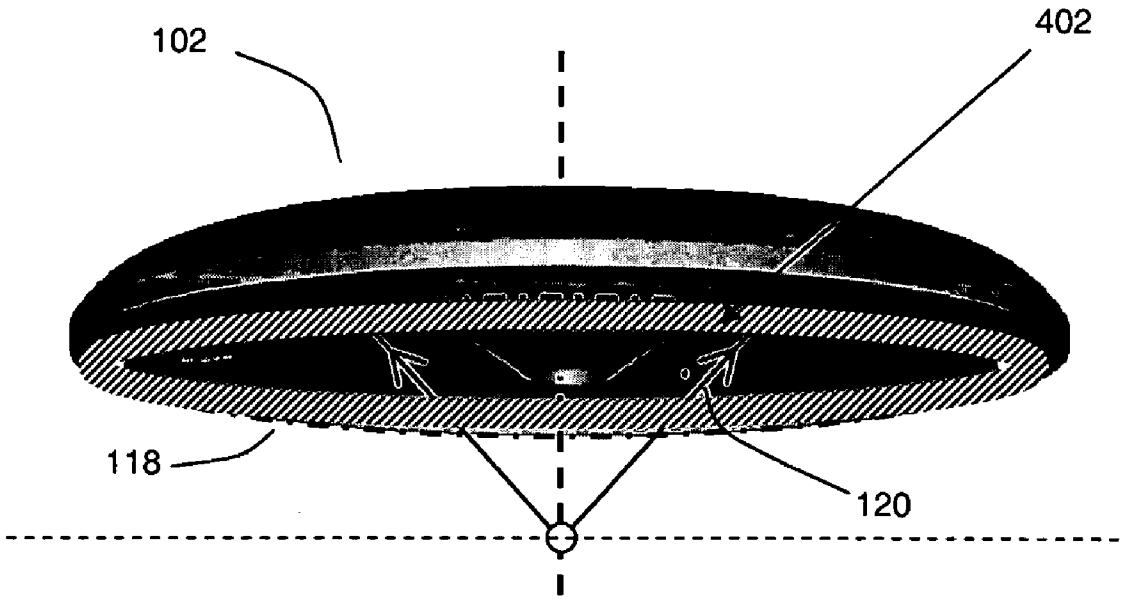


Fig. 4

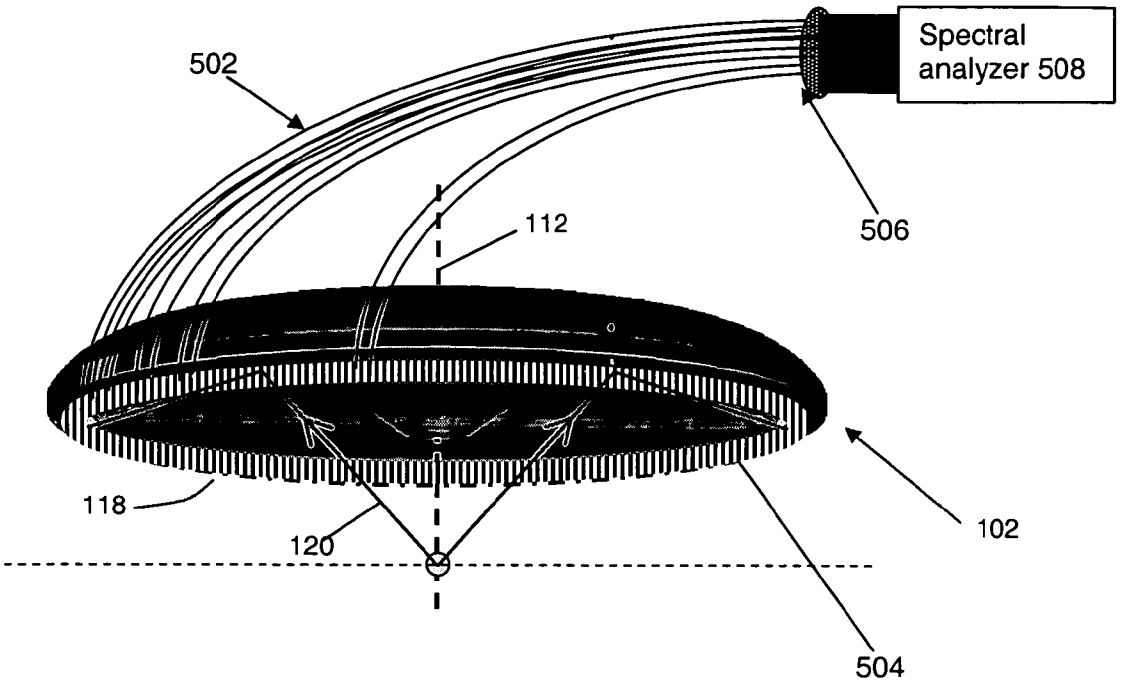


Fig. 5

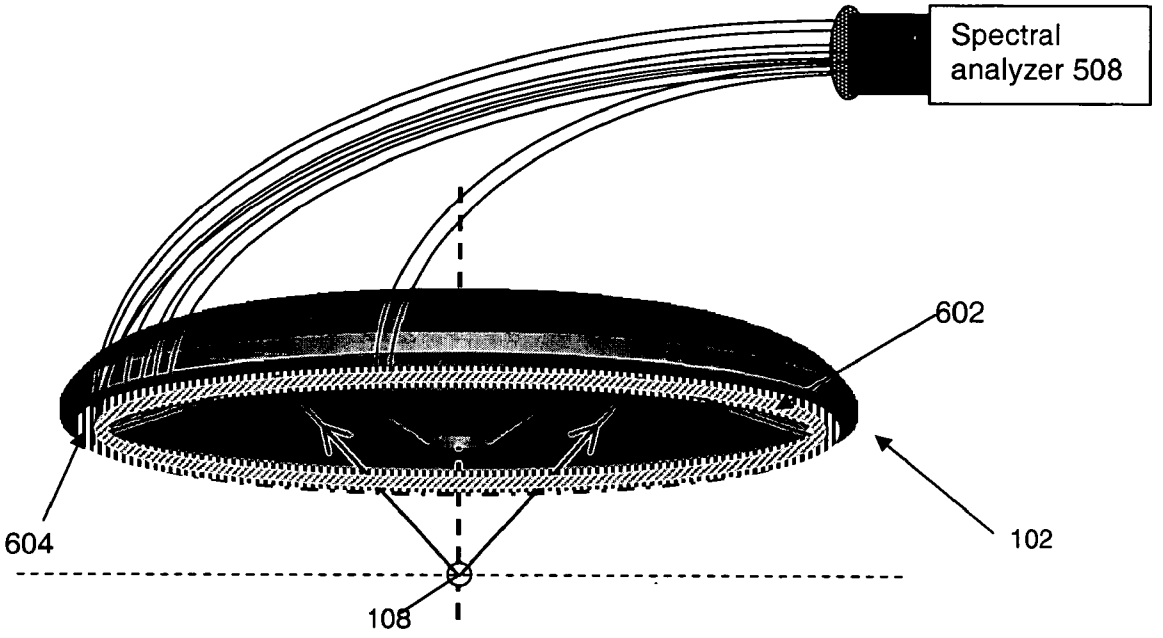


Fig. 6

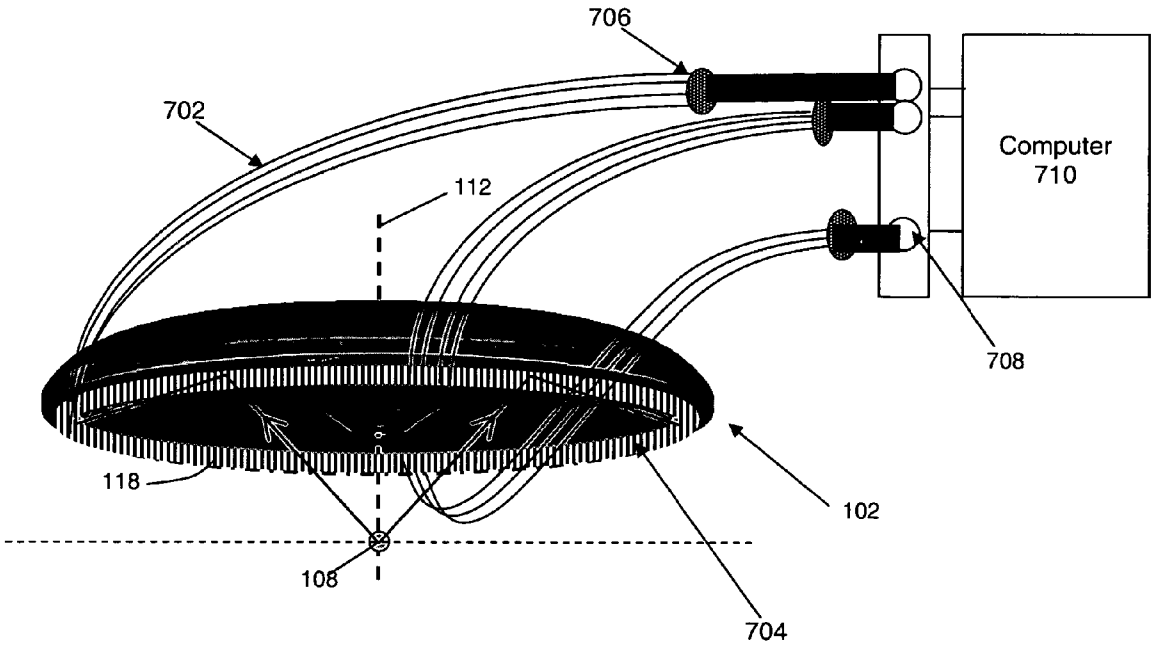


Fig. 7

OPTICAL REFLECTOR AND OPTICAL COLLECTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 60/605,831 filed Aug. 30, 2004, the disclosure of which is incorporated herein by reference

FIELD OF INVENTION

[0002] The present invention relates broadly to an optical reflector and optical collection system.

BACKGROUND

[0003] High efficiency optical collection systems for detecting light emission from small vicinity of a luminescence specimen have been utilizing concave mirror surface of semi-ellipsoidal or parabolic shapes as light reflector and collector. Typical applications of these devices are in cathodoluminescence (CL) detection as in the field of Scanning Electron Microscopy (SEM), electroluminescence (EL) in Photon Emission Microscopy (PEM), photoluminescence (PL) microscopy and ionoluminescence (IL) in Nuclear Microscopy. The collection efficiency of such collection systems is about 90% or more. One feature of these collection systems is their capability for spectroscopy analysis. In semi-ellipsoidal mirror systems, light emitted at one focal point is reflected off its mirror surface and focused onto another focal point. In the case of parabolic mirror, light emitted at its focal point is reflected into parallel light rays which can be focused using optical lenses. The collected light can be guided to a spectral analysis system for spectroscopic observation of the light emission.

[0004] The high collection efficiency of such systems is achieved by placing the mirror in very close proximity to the specimen surface. In a typical system, the working distance between the mirror and the specimen is only about 0.1 cm or less in order to ensure coverage over a large collection angle, i.e. a high numerical aperature for the collection mirror, for achieving high collection efficiency. The working distance may be defined as the shortest distance of one part of the mirror from the specimen surface, i.e. typically at the outer perimeter of the concave mirrors. This short working distance introduces some disadvantages of using these mirrors such as difficulty in mirror alignment with respect to the specimen, inadvertent possibility of collisions between the mirror and the specimen, the difficulty in using a bulky electrical probing system on the specimen and in some cases the blocking of other emitted signals. For example, when observing a packaged integrated circuit (IC) that has the IC die recessed deep below its top surface, it can be difficult to align the mirror focal point on to the recessed surface of the IC die due to the short working distance of the mirror. This can cause serious light collection losses. In the example of flat specimens, the problem very commonly relates to inadvertent operation that causes potential destructive collisions between the mirror and the specimen surface during the mirror alignment process. The short working distance of the mirror also prevents the investigation of integrated circuits that require electrical bias using probes as these are often too bulky to be inserted in between the mirror and the specimen. In the example of CL detection, as the mirror is placed very close to the specimen surface, the coverage of the mirror on the specimen decreases the escape of other emitted signals such as the secondary electrons (SE) thus deteriorating the SE image quality.

[0005] There is thus a need to provide an optical light reflection and collection mirror that addresses at least one of the above-mentioned problems.

SUMMARY

[0006] In accordance with a first aspect of the present invention, there is provided an optical reflector comprising, a rotationally symmetric reflecting surface disposed around a rotational axis of the reflector and having a radial profile; wherein the radial profile follows a portion of an ellipse profile, the ellipse profile being off-axis with respect to the rotational axis.

[0007] The ellipse profile may be off-axis with respect to the rotational axis to an extent such that one focal point of the reflecting surface is located on the rotational axis.

[0008] The reflecting surface may further have a focal ring concentric around the rotational axis.

[0009] The focal point may lay outside of a plane of the focal ring.

[0010] The focal ring may lay in a plane located in a space between, and including, the focal point and the reflecting surface.

[0011] An opening may be formed in the reflecting surface around the rotational axis.

[0012] In accordance with a second aspect of the present invention, there is provided a collection system comprising, a rotationally symmetric reflecting surface disposed around a rotational axis and having a radial profile following a portion of an ellipse profile, the ellipse profile being off-axis with respect to the rotational axis; and a collector for collecting at least a portion of a signal reflected from the reflecting surface.

[0013] The collector may be a photo-detector.

[0014] The collector may comprise an array of optical fibres, the optical fibres may be arranged in a circular manner with a first end of each fibre pointing towards the rotational axis of the reflecting surface.

[0015] The collector may comprise a ring aperture to limit the portion of the signal collected from the reflecting surface.

[0016] The collection system may further comprise an analyser coupled to the collector.

[0017] The analyser may comprise a spectral analyser.

[0018] The collection system may further comprise one or more dispersive elements disposed between the collector and the analyser for analysing of monochromatic signals.

[0019] The reflecting surface may have a focal ring concentric with the rotational axis.

[0020] The collector may be disposed substantially at the focal ring.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[0022] **FIG. 1** is a three dimensional cross-section view illustrating the cross-section optics of an example embodiment.

[0023] **FIG. 2** is an elevated three dimensional view of the embodiment in **FIG. 1** further illustrating the cross-section optics.

[0024] **FIG. 3** is a schematic three-dimensional front view of an example embodiment.

[0025] **FIG. 4** is an elevated three dimensional view of an example embodiment fitted with a ring-shaped photodiode.

[0026] **FIG. 5** is an elevated a three dimensional view of an example embodiment coupled to an array of optical fibres.

[0027] **FIG. 6** is an elevated a three dimensional view of an example embodiment coupled to an array of optical fibres and a ring aperture.

[0028] **FIG. 7** is an elevated three dimensional view of an example embodiment coupled to an array of optical fibres and dispersive elements.

DETAILED DESCRIPTION

[0029] **FIGS. 1 and 2** show a three dimensional cross-sectional view and a three dimensional perspective view respectively of an example embodiment. A concave elliptical-disc mirror **102** is provided. The radial profile **104** of the concave elliptical-disc mirror **102** follows a portion of a semi-ellipse profile **106** having a first focal point **108** and a second focal point **110**, and revolves around a vertical axis **112** which passes through the first focal point **108**. In other words, the semi-ellipse profile is off-axis with respect to the vertical axis **112**. In the example embodiment, the semi-ellipse profile **106** is off-axis to an extend such that the first focal point is located on the vertical axis **112**. In this example embodiment, the semi-ellipse profile **106** is tilted or inclined at an angle **114** such that the second focal point **110** is elevated above the horizontal axis **116** which passes through the first focal point **108**. A full revolution of the semi-ellipse profile **106** around the vertical axis **112** produces the concave elliptical-disc mirror **102** having a circular focus **118** that passes through each of the second (radial) focal points **110**. With this configuration, a light signal emitted at the first focal point **108** having rays as represented by ray path **120** reflects off the surface of the elliptical-disc mirror **102** onto the circular focus **118**, lying in a plane above the first focal point **108**.

[0030] In typical applications such as in CL in SEM, an open hole **122** may be provided in the centre of the mirror **102** along the vertical axis **112** to allow electron beam access to a specimen (not shown) placed at the first focal point **108**. The resultant CL emissions can be reflected onto the circular focus **118** for direct detection using a photo-detector such as a photodiode array (not shown), or transmitted through an optical fiber array (not shown) to a spectral analyzer (not shown), either array being configured at the circular focus **118**.

[0031] The optical parameters such as the tilt angle **114**, the first focal point **108**, the second focal point **110**, and the semi-ellipse profile **106** for producing the elliptical-disc mirror **102** in **FIGS. 1 and 2** are given to illustrate the example embodiment described here. However, various alternate embodiments will be apparent to those skilled in the art upon reading the present disclosure. For example, the focal ring may lay in any plane located in a space between, and including, the first focal point and the reflecting surface. It will be appreciated by a person skilled in the art that a variety of detection techniques may be used in example embodiments. The collected light along the circular focus **118**, may be collected in a panchromatic or monochromatic manner, may be detected directly or indirectly, and may be detected partially or integrally.

[0032] **FIG. 3** is a schematic three-dimensional front view of the example embodiment.

[0033] In one example embodiment, referring to **FIG. 4**, a donut or ring shaped photodiode **402** can be used to directly and panchromatically detect the light e.g. **120** arriving at circular focus **118**.

[0034] In another example embodiment, with reference to **FIG. 5**, an array of optical fibers e.g. **502** is arranged horizontally in a circular manner such that one end e.g. **504** of each optical fiber e.g. **502** is aligned substantially on circular focus **118** and pointing towards the centre vertical axis **112**. The other ends e.g. **506** of the respective optical fibers e.g. **502** may be bundled together. This example embodiment allows light rays e.g. **120** arriving at circular focus **118** to be coupled into the optical fibres e.g. **502** substantially at the circular focus **118** and transmitted to the bundle end e.g. **506** of the optical fibers, e.g. for panchromatic coupling into a spectral analyzer **508** for spectral analysis. In **FIG. 5**, only some of the optical fibres e.g. **502** are shown for clarity.

[0035] With reference to **FIG. 6**, a ring aperture **602** may be placed immediately in front of the photodiode array or the optical fiber array **604** in a different embodiment as a means for controlling the effective size of the area or volume of the emission from the first focal point **108**. In **FIG. 6**, only some of the optical fibres of the array **604** are shown for clarity.

[0036] In another example embodiment, with reference to **FIG. 7**, an array of optical fibers e.g. **702** may again be arranged horizontally in a circular manner such that one end e.g. **704** of each optical fiber e.g. **702** is aligned substantially on the circular focus **118** of the mirror **102** and pointing towards the centre vertical axis **112** for collecting the reflected light. The optical fibers e.g. **702** on the circular perimeter are divided by e.g. 3 equal sections, and the other ends of the optical fibers e.g. **702** in the respective sections are bundled together thus giving three fiber bundles e.g. **706**. The three fiber bundles, each transmitting one-third of the total amount of light emitted from the first focal point **108**, can be used as a means to separate the detected light into monochromatic signals, for example for each of three basic colors. This may be achieved by passing the transmitted light through a set of dispersive elements, such as Red, Green and Blue (R,G,B) filters. The filtered light at the end of each fiber bundle can then be detected by three independent photo detectors e.g. **708** for conversion of the respective monochromatic signals into electronic values for analyzing and further color processing using a computer **710**, in

the example embodiment. In **FIG. 7**, only some of the optical fibres e.g. **702** are shown for clarity.

[**0037**] In the example embodiments described above, the radial profile **104** of the mirror **102** follows a portion of an off-axis semi-ellipse profile **106** with its first focal point **108** on the rotational axis of the disc. This creates a circular focal ring **118** of the rotationally symmetric mirror **102** which passes through second focal points **110** of the semi-ellipse profile **106**. In the example embodiments, the combination of having the semi-ellipse profile **106** and thus the radial profile **104** of the mirror **102** tilted against the horizontal axis **116**, and the rotational symmetry of the mirror **102** around the axis **112** can provide a relatively large mirror-specimen working distance while maintaining relatively high luminescence collection efficiency.

[**0038**] In the example embodiments, the collector mirror **102** can be used in conjunction with a ring photo detector or ring optical fiber for efficient luminescence detection. In the case of a ring photo detector, panchromatic luminescence signals may be detected directly, whereas in the case of a ring optical fiber detector, monochromatic signal can be obtained by passing the transmitted signal through a light dispersive element followed by a photo detector.

[**0039**] The example embodiments described above can provide a longer working distance optical mirror, compared to existing mirrors, for use in the observation of bulky specimens while reducing or eliminating difficulties such as mirror alignment, collisions between the mirror and the specimen, implementation of electrical probes on the specimen and blocking of other emitted signals that are encountered by existing mirrors of relatively shorter working distance. Additionally, the example embodiments can allow a longer working distance to be achieved without sacrificing optical collection efficiency.

[**0040**] The disc-shaped concave mirror in the example embodiments is termed herein as an Elliptical-Disc mirror. The Elliptical-Disc mirror in example embodiments can make the focus alignment process relatively easier and the analysis of bulky specimens possible. Using the circular focus of the Elliptical Disc Mirror in example embodiments, e.g. in the case of CL, unlike the prior art that requires three identical collection mirrors to perform color separation of the total emitted CL, the Elliptical-Disc mirror can be used to reflect CL onto a circular focus. The reflected CL can be separated uniformly into basic colors such as red, green and blue (RGB) for constructing color CL images more efficiently.

[**0041**] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

1. An optical reflector comprising:

a rotationally symmetric reflecting surface disposed around a rotational axis of the reflector and having a radial profile;

wherein the radial profile follows a portion of an ellipse profile, the ellipse profile being off-axis with respect to the rotational axis.

2. The optical reflector as claimed in claim 1, wherein the ellipse profile is off-axis with respect to the rotational axis to an extent such that one focal point of the reflecting surface is located on the rotational axis.

3. The optical reflector as claimed in claim 2, wherein the reflecting surface further has a focal ring concentric around the rotational axis.

4. The optical reflector as claimed in claim 3, wherein the focal point lies outside of a plane of the focal ring.

5. The optical reflector as claimed in claim 4, wherein the focal ring lies in a plane located in a space between, and including, the focal point and the reflecting surface.

6. The optical reflector as claimed in any one of the preceding claims, wherein an opening is formed in the reflecting surface around the rotational axis.

7. A collection system comprising:

a rotationally symmetric reflecting surface disposed around a rotational axis and having a radial profile following a portion of an ellipse profile, the ellipse profile being off-axis with respect to the rotational axis; and

a collector for collecting at least a portion of a signal reflected from the reflecting surface.

8. The collection system as claimed in claim 7, wherein the collector is a photo-detector.

9. The collection system as claimed in claim 7, wherein the collector comprises an array of optical fibres, the optical fibres being arranged in a circular manner with a first end of each fibre pointing towards the rotational axis of the reflecting surface.

10. The collection system as claimed in any one of claims 7 to 9, wherein the collector comprises a ring aperture to limit the portion of the signal collected from the reflecting surface.

11. The collection system as claimed in any one of claims 7 to 10, further comprising an analyser coupled to the collector.

12. The collection system as claimed in claim 11, wherein the analyser comprises a spectral analyser.

13. The collection system as claimed in claims **11** or **12**, further comprising one or more dispersive elements disposed between the collector and the analyser for analysing of monochromatic signals.

14. The collection system as claimed in any one of claims 7 to 13, wherein the reflecting surface has a focal ring concentric with the rotational axis.

15. The collection system as claimed in claim 13, wherein the collector is disposed substantially at the focal ring.

* * * * *