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Specification

RETRACTABLE CATHODOLUMINESCENCE DETECTOR WITH HIGH ELLIPTICITY

BACKGROUND OF THE INVENTIONField of the Invention

This invention relates generally to a cathodoluminescence (CL) detection device and more particularly to a CL detection device utilizing a concave mirror of semi-ellipsoidal shape with high ellipticity. The mirror material is of low effective atomic number, which ensures that most of the backscattered electrons (BSEs) emitted simultaneously with CL emissions are absorbed.

Brief Description of the Prior Art

Cathodoluminescence is the emission of radiation from materials due to an incident electron beam. The phenomenon can be used to provide information on the properties of materials and devices. When the beam strikes the specimen, the spectrum of the emissions from the specimen can be obtained with a CL detection device fitted with a wavelength selector and a

1 suitable emission sensitive detector. Monochromatic and
2 panchromatic CL images can be obtained with an appropriate image
3 recording instrument. For monochromatic imaging, a wavelength
4 selector is inserted to select a particular wavelength or a
5 range of wavelengths of emissions with which to form the image.
6 For panchromatic imaging, the wavelength selector is bypassed.

7 Due to the difficulties in mirror design, most existing CL
8 detectors are unable to perform both spectroscopy and
9 microscopy. For example, the CL detectors described by Phang,
10 et al. in U.S. Patent No. 5,264,704 and Braglia, et al. in U.S.
11 Patent No. 5,010,253 lack spectroscopic abilities due to their
12 direct detection of emitted radiation without passing through a
13 wavelength selector. A further disadvantage of these CL
14 detectors is that they have to use solid state detectors which
15 are less sensitive than a photomultiplier tube (PMT).

16 The most important issue for spectroscopic CL applications
17 lies in the efficiency of the detector in transmitting the
18 collected radiation to a radiation sensitive device. The way in
19 which the radiation is collected and transmitted seriously
20 affects the sensitivity as well as the flexibility of the CL
21 detector. Efficient transmission of radiation from the mirror
22 to the radiation guide and the wavelength selector requires the
23 incoming radiation to be confined within a small cone with an
24 angle which is less than a critical value. Radiation outside

1 the cone is not collected and losses in transmission will be
2 incurred. The problems of designing a CL detector with both
3 spectroscopic and imaging capabilities without losing collection
4 and transmission efficiencies are described by Steyn, et al. in
5 107 J. Microscopy Pt. 2, 107-128 (July, 1976) ("An efficient
6 spectroscopic detection system for cathodoluminescence mode
7 scanning electron microscopy (SEM)"). The systems described by
8 Vahala, et al. (U.S. Patent No. 4,929,041), Schafer, et al.
9 (U.S. Patent No. 4,900,932) and Horl, et al. (U.S. Patent No.
10 3,790,781) relate to CL detectors having this problem of
11 transmission inefficiency arising from poor coupling from the
12 mirror to the radiation guide and the wavelength selector. The
13 systems of Vahala, et al. and Horl, et al. are also limited in
14 terms of the specimen size which can be observed. Furthermore,
15 these detectors are not easily retractable from the path of the
16 electron beam and therefore do not allow other modes of electron
17 beam imaging without extensive modifications to the system.

18 The height of the mirror in a CL system limits the minimum
19 distance between the specimen and the electron beam generator
20 unit. This has an impact on the spatial resolution performance
21 of the system. For this reason, in CL observations requiring
22 high spatial resolution, the height of the mirror must be kept
23 small. Apart from the CL detector described by Braglia, et al.,

1 all of the patents discussed above are severely limited in this
2 aspect.

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SUMMARY OF THE INVENTION

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It is a primary object of the present invention to provide
6 a cathodoluminescence detection system with both spectroscopic
7 and imaging capabilities, having high collection and
8 transmission efficiencies as well as low mirror height to allow
9 high spatial resolution from an electron beam generator system.

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Another object of the present invention is to provide an
11 efficient CL detector with a mirror having as low an atomic
12 number as possible so that BSEs can be absorbed, thereby
13 reducing stray CL signals produced by BSEs.

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A further object of the present invention is to provide a
15 CL system which can perform simultaneous observation of CL
16 signals with other signal modes, for example secondary
17 electrons, thereby enabling a comparative study of different
18 signals at the same time and on the same region on the specimen.

19

Still another object is to provide a CL system which is
20 suitable for large specimen size and which is easily retractable
21 from the path of the electron beam.

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Briefly, the preferred embodiment of the present invention
23 is a CL detector system including a semi-ellipsoidal mirror of
24 high ellipticity, with the mirror constructed of material of low

1 atomic number to minimize interference caused by BSEs. A
2 radiation guide is mounted in line with the axis of rotation of
3 the mirror to optimize CL radiation collection, to minimize
4 detector height for large area specimens, and to obtain high
5 spatial resolution from electron beam generator systems.

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IN THE DRAWING

8 Fig. 1 is a cross-section illustrating details of the
9 cathodoluminescence detection system of the present invention.

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DESCRIPTION OF THE PREFERRED EMBODIMENT

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13 Electron beam systems with cathodoluminescence detection
14 systems are well known in the prior art, and the references
15 discussed above show typical arrangements of such systems.

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17 The most essential part of a CL detection system lies in
18 its collector design. Due to the lack of detailed calculations,
19 previous CL detector designs were not optimized. In this
20 invention, detailed computation was carried out using a two-
21 dimensional ray tracing program as a design tool. This resulted
22 in the invention of a concave mirror of semi-ellipsoidal shape
23 with the following features: (i) high coupling and transmission
efficiencies for the radiation guide and the wavelength
selector, (ii) compatibility with large specimen size, and (iii)

1 compatibility with the short working distance requirement of
2 electron beam systems.

3 As noted in the discussion of prior art, efficient
4 transmission of radiation requires that radiation collected by
5 the mirror be confined within a cone with an angle less than a
6 critical value. We have found that a semi-ellipsoidal mirror of
7 high ellipticity should be used. In particular, when
8 ellipticity of an ellipse "e" is defined as:

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$$e^2 = 1 - b^2/a^2$$

10 with "a" the major semiaxis of the ellipse and "b" the minor
11 semiaxis of the ellipse, ellipticity "e" greater than 0.8 is
12 preferred. Our calculations also showed that at high
13 ellipticities, if the emission collection means (preferably a
14 radiation guide such as an optical fiber, leading to a remote
15 spectrometer/emission sensitive detector, but alternatively an
16 emission sensitive detector) are positioned at one focal point
17 of the mirror, and aligned such that the face of the emission
18 collection means is centered upon and substantially
19 perpendicular to the axis connecting the focal points of the
20 mirror (the axis of rotation of the emission collection means in
21 line with the axis of rotation of the mirror), then radiation
22 from a much wider area of the specimen can be detected
23 efficiently. This advantageous arrangement gives the CL

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detector both spectroscopic and imaging capabilities without losing the collection and transmission efficiencies.

Referring now to Fig. 1, the details of the CL system of the present invention are schematically illustrated. The main components of the system are concave mirror 1 and radiation guide 2, located within the electron microscope vacuum chamber. Radiation guide 2 is preferably an optical fiber or optical a fiber bundle with a diameter of approximately 3 mm. Radiation guide 2 serves as a portion of the CL detection means, as it directs radiation collected from mirror 1 to the spectrometer (if used) and radiation sensitive detector (the spectrometer and detector are not shown). A particular advantage of the configuration shown in Fig. 1 is that the mirror and radiation guide can easily be inserted and fully retracted out from the electron beam path by means of a retractable attachment (not shown). The retractable attachment is further engaged onto a movable holder (not shown) that provides a focusing function of the mirror.

Concave mirror 1 is preferably substantially a semi-ellipsoid (i.e., substantially a 180 degree rotational cross section around the axis joining the first and second ellipse focal points f_1 and f_2). The major semiaxis of the mirror is identified by the length "a" along axis x and the minor semiaxis of the mirror is identified by the length "b" along axis y_1 . In the preferred embodiment, a is approximately 21 mm and b is approximately 7.7 mm. Above focal point f_1 , a cylindrical hole with diameter d

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is opened along the axis y_2 through the body of the mirror
f or the electron probe to access the specimen. An
expanded view is shown in Fig. 2. Diameter d is typically
on the order of 1 mm. The specimen is sited at f_1 with
5 its surface in line with the axis x , and below the mirror
at an elevation c (typically 0.5 mm). A small portion may
be removed from the bottom of the rotational ellipsoid
mirror to obtain elevation c (ie. the mirror need not be a
full one half rotational ellipsoid).

10 The center of the cathodoluminescence radiation
emission collection means is preferably sited on focal
point f_2 with the collection face of the emission
collection means substantially perpendicular to the axis
connecting focal points f_1 and f_2 . In is the preferred
15 embodiment as shown in Fig. 1, the emission collection
means is an optical fiber radiation guide 2, which directs
the collected CL to a radiation sensitive detector.
Alternatively, the emission detection means can be a
radiation sensitive detector sited at f_2 . This
20 advantageous arrangement, which results in horizontal
positioning of the radiation guide (or other emission
collection means), also leads to compatibility with large
specimens. Since the radiation guide is horizontal, the
guide is less likely to interfere with a specimen.

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1 As noted above, for CL observation requiring high spatial
2 resolution, the height of the mirror must be kept small. The
3 present invention achieves high resolution CL performance
4 because the height of the mirror has been made compatible to the
5 required working distance between the specimen and the electron
6 beam radiator unit. High ellipticity of the mirror allows a
7 relatively smaller mirror height to be used than those of
8 previous designs.

9 The combination of the high ellipticity and small height of
10 the semi-ellipsoid mirror is difficult to fabricate. The
11 mirror of the present invention has successfully been fabricated
12 by the procedure described below.

13 As a first consideration in mirror fabrication, a low
14 atomic number material is used for producing the mirror. Low
15 atomic number material reduces BSE effects to a negligible
16 level. Materials of atomic number less than 18 are preferred.
17 In particular, plastic polymers (typically comprising carbon,
18 hydrogen, and oxygen) are well-suited because they are easily
19 molded. Examples of such polymers are polymethyl-methacrylate
20 (PMMA) and Araldite.

21 The mirror can be fabricated using a plastic molding
22 technique. A convex mold of the required semi-ellipsoidal shape
23 is machined using a computer-controlled lathe. The mold is then
24 polished to mirror finish so that no further polishing is

1 required for the surface of the concave mirror molded out in
2 this way. A plastic material in moldable form is used to cast
3 out the desired substance from the mold. The concave surface is
4 then made reflective by evaporation of a thin layer of
5 a conducting and highly reflective material, such as aluminum. It
6 is important to cover all exposed areas (in addition to the
7 concave surface) on the mirror body with conductive material in
8 order to prevent charging effects. Charging can cause undesired
9 deflection of the electron probe which leads to a loss in
10 resolution.

11 The mirror described above, when used with a radiation
12 guide aligned as described above, collects most of the CL
13 emission from a specimen bombarded by an electron beam into the
14 radiation guide with high optical coupling and transmission
15 efficiencies. The detector system is compatible with a field
16 emission scanning electron microscope (FESEM) which has high
17 spatial resolution where CL emissions are low due to the low
18 total probe current.

19 Although the present invention has been described above in
20 terms of a specific embodiment, it is anticipated that
21 alterations and modifications thereof will no doubt become
22 apparent to those skilled in the art. It is therefore intended
23 that the following claims be interpreted as covering all such



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CLAIMS

- 1 1. A CL detection system for collecting light
2 emitted from a specimen irradiated by an electron beam, the CL
3 detector comprising:
4 a concave mirror of semi-ellipsoidal shape with an
5 ellipticity which is greater than 0.8, said mirror having first
6 and second focal points; and
7 collection means sited at the second focal point
8 of the said mirror in such a manner that the axis of rotation of
9 the collection means is in line with the axis of rotation of the
10 mirror.
- 1 2. A CL detector of claim 1, wherein said concave mirror has
2 small minor axis b corresponding to the required working
3 distance in an electron probe generator suitable for high
4 resolution operation, and a typical advantageous dimension being
5 $b=7.7\text{mm}$;
- 1 3. A CL detector of claim 1, wherein said concave mirror has
2 large said major axis a to be compatible with large area
3 specimens, and a typical advantageous dimension being $a=21\text{ mm}$;



Date: 21/12/98

CLAIMS

1 1. A cathodoluminescence detector for collecting light
2 emitted from a specimen irradiated by an electron beam,
3 comprising:

4 (a) a concave ellipsoidal mirror with an ellipticity
5 greater than 0.8, the mirror having first and second focal
6 points; and

7 (b) collection means located at the second focal point
8 of the mirror, whereby emissions from the first focal point
9 are focused to the second focal point and collected by said
10 collection means.

1 2. The detector of claim 1, wherein the collection face of
2 said collection means is centered upon and substantially
3 perpendicular to the axis connecting the first and second
4 focal points.

1 3. The detector of claim 1, wherein the major axis "a" of
2 the mirror is from 15 mm to 30 mm, and the minor axis "b" of
3 the mirror is from 5 mm to 10 mm.



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1 4. The detector of claim 1, wherein the mirror is comprised
2 of materials having atomic number less than 18.

1 5. The detector of claim 1, wherein the inner surface of
2 the mirror is coated with a highly reflective and conductive
3 material.

1 6. The detector of claim 1, wherein the mirror is a semi-
2 ellipsoid.

1 7. The detector of claim 2, wherein the collection means
2 comprises a radiation guide which collects emissions at the
3 second focal point and transmits the emissions to remote
4 detection means.

1 8. The detector of claim 7, wherein the remote detection
2 means comprises wavelength selection means and a radiation
3 sensitive detector.

1 9. The detector of claim 6, wherein the collection face of
2 said collection means is centered upon and substantially
3 perpendicular to the axis connecting the first and second
4 focal points.



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1 10. The detector of claim 6, wherein the major axis "a" of
2 the mirror is from 15 mm to 30 mm, and the minor axis "b" of
3 the mirror is from 5 mm to 10 mm.

1 11. The detector of claim 6, wherein the mirror is comprised
2 of materials having atomic number less than 18.

1 12. The detector of claim 6, wherein the inner surface of
2 the mirror is coated with a highly reflective and conductive
3 material.

1 13. The detector of claim 9, wherein the collection means
2 comprises a radiation guide which collects emissions at the
3 second focal point and transmits the emissions to remote
4 detection means.

1 14. The detector of claim 13, wherein the remote detection
2 means comprises wavelength selection means and a radiation
3 sensitive detector.

1 15. The detector of claim 14, wherein the major axis "a" of
2 the mirror is from 15 mm to 30 mm, and the minor axis "b" of
3 the mirror is from 5 mm to 10 mm.



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1 16. The detector of claim 14, wherein the mirror is
2 comprised of materials having atomic number less than 18.

1 17. The detector of claim 14, wherein the inner surface of
2 the mirror is coated with a highly reflective and conductive
3 material.

