

1

2

3

4

5

6

7

8

9

10

17

18

19

20

21

22

23

24

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.

3

4 SUMMARY OF THE INVENTION

5 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.

10 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.

14 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.

22 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.

6

7

IN THE DRAWING

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

10

11

DESCRIPTION OF THE PREFERRED EMBODIMENT

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

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

9
$$e^2 = 1 - b^2/a^2$$

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



-7-

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

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

19 Concave mirror 1 is one quarter of a rotational ellipsoid
20 having focal points f_1 and f_2 . The major axis of the mirror is
21 identified by the length "a" along axis x and the minor axis of
22 the mirror is identified by the length "b" along axis y_1 . In
23 the preferred embodiment, a is approximately 21 mm and b is
24 approximately 7.7 mm. Above focal point f_1 , a cylindrical hole



-8-

1 with diameter d is opened along the axis y_2 through the body of
2 the mirror for the electron probe to access the specimen. An
3 expanded view is shown in Fig. 2. Diameter d is typically on
4 the order of 1 mm. The specimen is sited at f_1 with its surface
5 in line with the axis x , and below the mirror at an elevation c
6 (typically 0.5 mm). A small portion may be removed from the
7 bottom of the rotational ellipsoid mirror to obtain elevation c
8 (i.e. the mirror need not be a full one quarter rotational
9 ellipsoid). The length of the mirror is approximately 15 mm in
10 the preferred embodiment, and its height is approximately 8 mm.

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

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



-12-

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 $a=21\text{ mm}$;





-13-

- 1 4. A CL detector of claim 1, wherein said concave mirror being
2 a quarter of a rotational ellipsoid having high a/b ratio with
3 typical advantageous dimensions of a=21 mm and b=7.7 mm;
- 1 5. A CL detector of claim 1, wherein said concave mirror being
2 made of low atomic number material for absorbing BSEs;
- 1 6. A CL detector of claim 1, wherein said concave mirror has
2 its inner surface coated with a thin layer of highly reflecting
3 and conducting material;
- 1 7. A CL detector of claim 1, wherein the said radiation guide
2 being mounted with its axis of rotation in line with the axis of
3 rotation of the said concave mirror.
- 1 8. A CL detector of claim 1, wherein one end of the said
2 radiation guide is positioned at the second focal point of the
3 said concave mirror.
- 1 9. A CL detector of claim 1, wherein the specimen under
2 observation is positioned at the first focal point of the said
3 concave mirror.



* C L M S *



-14-

- 1 10. A CL detector arrangement for collecting light emitted from
2 a specimen irradiated by an electron beam, the CL detector
3 comprising:
4 a concave mirror of semi-ellipsoidal shape with an
5 ellipticity which is greater than 0.8 having first and second
6 focal points;
7 an emission radiation sensitive device mounted in such a
8 manner that the center of the active region of the said
9 sensitive device is sited at the second focal point of the said
10 mirror;
- 1 11. A CL detector of claim 10, 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 12. A CL detector of claim 10, 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 $a=21\text{mm}$;
- 1 13. A CL detector of claim 10, wherein said concave mirror
2 being a quarter of a rotational ellipsoid having high a/b ratio
3 with typical advantageous dimensions of $a=21\text{mm}$ and $b=7.7\text{mm}$;



* C L M S *



-15-

1 14. A CL detector of claim 10, wherein said concave mirror
2 being made of low atomic number material for absorbing BSEs;

1 15. A CL detector of claim 10, wherein said concave mirror has
2 its inner surface coated with a thin layer of highly reflecting
3 and conducting material;

1 16. A CL detector of claim 10, wherein the center of the active
2 region of the said radiation sensitive device is positioned at
3 the second focal point of the said concave mirror.

1 17. A CL detector of claim 10, wherein the specimen under
2 observation is positioned at the first focal point of the said
3 concave mirror.

