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SPECIFICATION

INTEGRATED EMISSION MICROSCOPE FOR PANCHROMATIC IMAGING,
CONTINUOUS WAVELENGTH SPECTROSCOPY AND SELECTIVE AREA
SPECTROSCOPIC MAPPING

Inventors: WAI CHIN CHIM
 DANIEL SIU HUNG CHAN
 JACOB CHEE HONG PHANG
 JING MEI TAO
 YONG YU LIU

Assignee: Industry & Technology Relations Office
 National University Of Singapore
 10 Kent Ridge Crescent
 The Innovation Centre
 Singapore 0511

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1 mapping of emissions. The device has extremely high
2 sensitivity due to its high collection, high optical
3 coupling and high transmission efficiencies.

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5 BACKGROUND OF THE INVENTION

6 Some semiconductor integrated circuits, when
7 connected to an electrical source, emit radiation from
8 certain surface locations. This phenomenon is still
9 being investigated and its physical mechanism has not
10 been fully understood, although numerous possible
11 mechanisms have been proposed. While good quantitative
12 measurement techniques have not been available,
13 currently available apparatus and techniques have been
14 used to make qualitative measurements of these emissions
15 for aiding in failure analysis and reliability studies.

16 The equipment for making qualitative measurements
17 has included various types of sensitive radiation
18 detectors, such as charge-coupled devices (CCD) and
19 image intensifiers. These devices, when attached to a
20 conventional optical microscope, form an emission

1 microscope capable of detecting emitted radiation and
2 are normally suitable for imaging in panchromatic mode,
3 which is the formation of an image using all the
4 wavelengths of emitted radiation within the detection
5 range of the instrument. In current practice, when such
6 a system is used for more sophisticated studies that
7 involve extracting spectral information, discrete
8 radiation filters are inserted in the radiation path.
9 This results in an ineffective system since numerous
10 filters have to be inserted and replaced in sequence for
11 obtaining a range of spectral response, and the band
12 passed by a filter is relatively wide. Furthermore,
13 after filtering off the unwanted wavelengths, the
14 desired wavelength may be severely attenuated. In
15 addition, the collection efficiencies of conventional
16 optical and emission microscopes are relatively poor,
17 resulting in inefficient spectroscopic detection.

18 Besides spectral resolution, the limitations on
19 spatial resolution of conventional optical and emission
20 microscopes have discouraged their use in imaging of

1 very small features. Limitations of currently available
2 emission microscopes are described below.

3 The emission microscope system disclosed in U.S.
4 Patent No. 4,680,635 has the disadvantage of being
5 unable to perform spectral analysis work. A similar
6 system was disclosed in U.S. Patent No. 4,811,090
7 incorporating a noise reduction algorithm for improving
8 image quality in noisy situations. European Patent
9 Application No. 0 510 887 A2 utilized an emission
10 microscope of the same type but with the addition of a
11 means for analyzing defective portions of semiconductor
12 devices. This apparatus suffers from poor collection
13 efficiency. U.S. Patent No. 4,755,874 relates to a
14 system similar to those mentioned above, but with better
15 means of locating defects on the device under test.

16 Systems incorporating discrete filters into an
17 emission microscope for obtaining spectral information
18 are described in "Quantitative Emission Microscopy", J.
19 Kölzer, et al., J. Appl. Phys. 71(11), 1 June 1992, p.
20 R23; "New Detection Method of Hot-Carrier Degradation

1 *Using Photon Spectrum Analysis of Weak Luminescence on*
2 *CMOS VLSI", N. Tsutu et al., Proc. IEEE 1990 Int.*
3 *Conference on Microelectronic Test Structure, Vol. 3,*
4 *March 1990, p. 143; and "Advanced Method of Failure*
5 *Analysis Using Photon Spectrum of Emission Microscopy",*
6 *H. Ishizuka et al., Proceeding of The International*
7 *Symposium For Testing and Failure Analysis, 1990, p. 13.*

8 Another system reported in "*Luminescence spectra of*
9 *an n-channel metal-oxide-semiconductor field-effect*
10 *transistor at breakdown*", N.C. Das et al.,
11 *Appl.Phys.Lett. 56 (12), 19 March 1990, p. 1152*, has the
12 problem of inflexibility associated with it. The system
13 uses a monochromator for continuous wavelength
14 selection, but requires the device under test to be
15 mounted close to the entrance of the monochromator. A
16 photomultiplier is attached at the monochromator output
17 as a radiation detector. This arrangement results in a
18 bulky unit, and spectral work has to be performed
19 outside the conventional optical microscope imaging
20 path. In conclusion, an efficient emission

1 microscope system with the capability of providing
2 spectral analysis with high spectral and spatial
3 resolution does not exist.

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5 Summary of the Invention

6 It is, therefore, an object of the present
7 invention to provide an emitted radiation detection
8 system capable of highly efficient light collection and
9 transmission to a radiation sensitive detector, thereby
10 allowing high spectral and spatial resolution;

11 It is another object of the present invention to
12 provide an emitted radiation detection system having
13 high radiation detection sensitivity, useful in
14 resolving and analyzing very weak emissions from
15 selected small areas;

16 It is a further object of the present invention to
17 provide an emitted radiation detection system having the
18 capability of both high spectral resolution and
19 continuous wavelength capability;

1 It is a still further object of the present
2 invention to provide an emitted radiation detection
3 system providing the capability of analyzing large
4 devices; and

5 It is another object of the present invention to
6 provide an emitted radiation detection system having an
7 emitted radiation detector that can be removed from and
8 inserted into the viewing path of an optical or emission
9 microscope.

10 Briefly, the preferred embodiment of the present
11 invention includes a radiation detection system for
12 collecting and measuring radiation from a device under
13 test. The system includes a semi-ellipsoidal mirror of
14 high ellipticity with first and second focal points.
15 The area of the device to be inspected is first
16 identified with an optical microscope or a conventional
17 emission microscope, with the specific area of emission
18 to be inspected positioned at the first focal point of
19 the mirror. The mirror very efficiently directs emitted
20 radiation from the device under test to the second focal

1 point, from which a radiation guide passes the collected
2 emitted radiation to a spectral analyzer. An aperture
3 may be used before the radiation guide to enhance
4 spatial resolution.

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6 In the Drawing

7 Fig. 1 is a block diagram showing the various
8 components of the emitted radiation detection system of
9 the present invention;

10 Fig. 2 is a cross sectional view showing further
11 detail of the semi-ellipsoidal mirror, aperture and
12 radiation guide;

13 Fig. 3 is an expanded, detailed view of the
14 aperture;

15 Fig. 4 illustrates characteristic emission spectra
16 for various semiconductor integrated circuit device
17 defects; and

18 Fig. 5 shows an emission spectrum from an emission
19 spot from a failed semiconductor device, indicating hot-
20 electron effects.



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2 Detailed Description of the Preferred Embodiment

3 The disclosure of U.S. Patent Application Serial
4 No. _____ for "Retractable Cathodoluminescence
5 Detector with High Ellipticity and High Backscattered
6 Electron Rejector Performance for Large Area Specimens"
7 is incorporated herein by reference.

8 The present invention integrates a mirror of the
9 semi-ellipsoidal shape described in Application Serial
10 No. _____ with a conventional optical microscope or
11 emission microscope and a scanning stage. An aperture
12 is preferably used before the radiation guide. The
13 resultant system is capable of panchromatic imaging,
14 continuous wavelength spectroscopy, and selective area
15 spectroscopic mapping. As a consequence of the
16 optimized collection, coupling and transmission
17 efficiencies achieved by the present invention, high
18 radiation detection sensitivity is achieved, which is
19 useful in resolving very weak emitted radiation.
20 Spectroscopic analysis can now be performed at higher

1 spectral resolution with continuous wavelength
2 capability, which is not obtainable in conventional
3 emission microscope set-ups. When an aperture is
4 incorporated at the second focal point of the mirror,
5 and the device under test is mounted on a high
6 resolution scanning stage, high spatial resolution
7 selected area spectroscopic analysis, panchromatic
8 imaging, as well as spectroscopic mapping of the emitted
9 radiation from the device under test may be attained.

10 Fig. 1 shows a diagram of a preferred embodiment of
11 the present invention. An optical/emission microscope
12 10, with an imaging camera 12 and microscope probe body
13 14, is used for viewing a device under test (DUT) 22. A
14 positioning apparatus 20 locates DUT 22 relative to the
15 optical/emission microscope and a collector 18. A hole
16 40 in collector 18 allows direct viewing of DUT 22
17 through microscope 10 while collector 18 is in place.
18 Collector 18 directs emitted radiation from DUT 22 to a
19 radiation guide 30, which transmits the radiation to
20 radiation analyzer 28. Electrical bias to DUT 22 is

1 provided by module 24 through interconnections 26.
2 Positioning apparatus 20 includes a device holder 34 for
3 mounting DUT 22, and a high resolution scanning stage 36
4 in conjunction with a low resolution positioning stage
5 38, which provide controlled positioning of the device
6 under test.

7 Operation of the system involves mounting DUT 22 on
8 holder 34. DUT 22 is positioned and brought into focus
9 of the optical/emission microscope 10, through aperture
10 40 in collector 18. Once the optical image is in focus,
11 an electrical bias is applied to DUT 22 by way of supply
12 24 and interconnection 26. A particular point emission
13 of interest may then be identified through imaging
14 camera 12 of the optical/emission microscope 10. The
15 point emission of interest is then positioned at the
16 focal point 52 of collector 18 to optimize collection
17 efficiency (as described below). Note that the
18 embodiment of Figs. 1 and 2 shows a collector 18 with an
19 aperture 40 for use of an optical/emission microscope
20 while the collector is positioned over DUT 22.

1 Alternatively, a collector without an aperture may be
2 used: DUT 22 is positioned with positioning apparatus 20
3 after the emission point of interest is identified with
4 microscope 10, and then collector 18 is moved into
5 position over DUT 22.

6 Once the emission point of interest is positioned
7 beneath collector 18, the collector guides emitted
8 radiation from the point of interest to optical guide 30
9 (preferably an optical fiber) which transmits the
10 collected radiation to radiation analyzer 28. Analyzer
11 28 is usually a spectral type and normally includes a
12 wavelength selector such as a monochromator, and a
13 radiation sensitive detector such as a photomultiplier
14 tube. Alternately, analyzer 28 can be a panchromatic
15 detector.

16 The high efficiency of the collector design of the
17 present invention allows detection and spectroscopic
18 mapping of very weak emissions. Emission microscopes of
19 the prior art collect on the order of 5% of emitted
20 radiation. The design of the present invention captures

1 on the order of 85% of emitted radiation. This high
2 efficiency permits more precise and much faster emission
3 characterization (e.g., an emission spectrum may be
4 gathered in five minutes, instead of several hours as
5 previously required).

6 A concave mirror is used as the collector,
7 preferably having semi-ellipsoidal shape with a high
8 ellipticity. This provides high collection efficiency,
9 as well as compatibility with large sized test devices
10 (from the long cross section). A further advantage of
11 the high ellipticity of mirror 18 is the resulting low
12 height structure which allows mirror 18 to be inserted
13 between optical/emission microscope 10 and DUT 40.
14 Efficient transmission of radiation requires that
15 radiation collected by the mirror be confined within a
16 cone with an angle less than a critical value. In order
17 to accomplish this, it has been found that a semi-
18 ellipsoidal mirror of high ellipticity is preferred. In
19 particular, with ellipticity "e" defined as:

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

1 where "a" is the major semiaxis and "b" the minor
2 semiaxis of the ellipse, an ellipticity "e" greater than
3 0.8 is preferred. Radiation emitted from a first focal
4 point of the ellipse is focused by the mirror at the
5 second focal point. The collection of radiation from
6 the second focal point is accomplished with emission
7 collection means (preferably a radiation guide such as
8 an optical fiber leading to a remote emission analyzer).

9 The face of the emission collection means is positioned
10 at the second focal point of the mirror, and aligned
11 such that the face of the emission collection means is
12 centered upon and substantially perpendicular to the
13 axis connecting the focal points of the mirror. This
14 advantageous arrangement gives the detector both
15 spectroscopic and imaging capabilities without losing
16 collection and transmission efficiencies.

17 Figure 2 shows further detail of the radiation
18 collection system, including concave collector mirror
19 18, radiation guide 30, and aperture 46. Mirror 18 has
20 a highly reflective surface 48 preferably of ellipsoidal

1 shape, the figure showing a longitudinal cross section
2 view. Mirror surface 48 is preferably a semi-ellipsoid
3 (a 180° rotational cross section around axis 50 joining
4 first and second ellipse focal points 52 and 54). The
5 major semi-axis of the mirror is identified by the
6 length "a" and the minor semiaxis of the mirror is
7 identified by the length "b". In the preferred
8 embodiment, a is approximately 61 mm and b is
9 approximately 13 mm. With these dimensions, a is
10 compatible with large area specimens and b fits with the
11 required working distance of conventional optical and/or
12 emission microscopes. As an alternate embodiment, the
13 mirror is also functional if constructed to be less than
14 a full semi-ellipsoid. For example, a quarter ellipsoid
15 including the half of the semi-ellipsoid on the side of
16 the first focal point 52 in Fig. 2 would be functional
17 to focus a large percentage of emitted radiation from
18 the first focal point 52 to the second focal point 54.
19 The use of less than a full semi-ellipsoid, however,

1 will result in a reduction in collection efficiency
2 (which is critical in the case of weak emissions).

3 Radiation guide 30 is preferably an optical fiber
4 or optical fiber bundle with a diameter of approximately
5 3mm. The face of guide 30 is located at focal point 54
6 of mirror 18. The point of interest on DUT 22 (see
7 Fig. 1) is positioned at focal point 52 of mirror 18.
8 Above focal point 52, a cylindrical hole 40 with
9 diameter d is opened to provide optical access for
10 viewing with an optical/emission microscope along line
11 56. Diameter d is typically on the order of 1mm.

12 DUT 22 is preferably positioned with its surface in
13 line with the axis 50, and below the mirror at an
14 elevation " c " (typically 1mm). A small portion may be
15 removed from the bottom of the semiellipsoidal mirror 18
16 to obtain elevation " c ", required in order to allow the
17 surface of a DUT 22 to move along the axis 50. A relief
18 60 is required at the other end of mirror 42 for
19 radiation guide 44.

1 As noted above, the center of the emission
2 collection means, preferably radiation guide 30, is
3 sited on second focal point 54 with the collection face
4 substantially perpendicular to the axis connecting focal
5 points 52 and 54. Aperture 46 is centered just before
6 second focal point 54, and serves to select out an area
7 of emission resulting in spectral analysis with a high
8 degree of spatial resolution. High collection efficiency
9 is achieved by ensuring that the equivalent numerical
10 aperture or the F number of mirror 18 is matched to the
11 effective numerical aperture or F number of the
12 radiation guide 30 and wavelength selector system
13 (spectral analyzer). Aperture 46 limits aberration
14 effects at the second focal point 54 due to off focus
15 emission from near first focal point 52 of the mirror
16 18. When a point of emission is away from first focal
17 point 52, there is a much larger deviation of the
18 reflected radiation from second focal point 54. If an
19 aperture 46 such as in Fig. 3 with an appropriate
20 diameter 51 is placed in front of radiation guide 30

1 with its center 57 aligned with second focal point 54,
2 only radiation from an emission point close to the first
3 focal point 52 will be detected while other off focus
4 emissions will be blocked. The size of the required
5 opening 59 of an aperture 46 is significantly larger
6 than the emission area being resolved. In other words,
7 even if a big spot or area is emitting radiation, it can
8 be resolved spatially to the required resolution,
9 depending on the size of the aperture 46 and opening 59
10 used.

11 Thus, when DUT 22 emits radiation at first focal
12 point 52, the radiation is reflected from mirror surface
13 48 to second focal point 54. Aperture 46 spatially
14 restricts the radiation reaching radiation guide 30.
15 Use of the aperture and high resolution scanning stage
16 36 permit high spatial resolution selected area
17 spectroscopic analysis, panchromatic imaging, and
18 spectroscopic mapping of the emitted radiation from DUT
19 22.

1 An alternate embodiment for accomplishing a
2 measurement of total emitted light (panchromatic
3 imaging) is achieved by simply replacing radiation guide
4 30 and spectral analyzer 28 with a radiation sensitive
5 detector at second focal point 54. The collected
6 radiation in such a case will be higher than in
7 spectroscopic analysis since the total radiation from
8 all detectable wavelengths will be measured.

9 Fig. 4 illustrates the characteristic spectra for
10 various semiconductor IC failure mechanisms. As is
11 apparent from Fig. 4, the ability to characterize an
12 emission spectrum may permit a failure mechanism to be
13 identified. Once such identification is made, the IC
14 manufacturing process can be modified to eliminate the
15 failure. Fig. 5 is an emission spectrum from an
16 emission spot of a failed IC device obtained with the
17 system of the present invention. The emission spectrum
18 indicates hot electron effects (compare Fig. 5 with
19 Curve A of Fig. 4).

1 Mirror 18 has successfully been fabricated by the
2 procedure described below. Plastic polymers are well-
3 suited because they are easily molded. Examples of such
4 polymers are polymethyl-methacrylate (PMMA) and
5 Araldite. The mirror can be fabricated using a plastic
6 molding technique. A convex mold of the required semi-
7 ellipsoidal shape is machined using a computer-
8 controlled lathe. The mold is then polished to mirror
9 finish so that no further polishing is required for the
10 surface of the concave mirror molded out in this way. A
11 plastic material in moldable form is used to cast out
12 the desired substance from the mold. The concave
13 surface is then made reflective by evaporation of a thin
14 layer of a highly reflective material, such as aluminum.

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

1 modifications as fall within the true spirit and scope
2 of the invention.

3 What is claimed is:



CLAIMS

1 1. An emission microscope system for collecting and
2 analyzing light emitted from an emission point of
3 interest on a device under test, comprising:

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

7 (b) means for positioning the emission point of
8 interest at the first focal point; and

9 (c) emission collection means located at the
10 second focal point of the mirror, whereby emissions from
11 the emission point of interest are focused to the second
12 focal point and collected by said collection means.

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



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

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

1 5. The system of claim 3, further comprising an
2 aperture located adjacent to the collection face of the
3 collection means, said aperture centered upon and
4 substantially perpendicular to the axis connecting the
5 first and second focal points, whereby said aperture
6 blocks off focus emission from near the first focal
7 point before it reaches said collection face.

1 6. The system of claim 1, wherein said mirror is a
2 semi-ellipsoid.



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

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

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

1 10. The system of claim 8, further comprising an
2 aperture located adjacent to the collection face of the
3 collection means, said aperture centered upon and
4 substantially perpendicular to the axis connecting the
5 first and second focal points, whereby said aperture



6 blocks off focus emission from near the first focal
7 point before it reaches said collection face.

1 11. An integrated emission microscope system for
2 collecting and analyzing light emitted from an emission
3 point of interest on a device under test, comprising:

4 (a) a first stage optical/emission microscope
5 system for positioning identifying an emission point of
6 interest on a device under test;

7 (b) a concave ellipsoidal mirror with an
8 ellipticity greater than 0.8, the mirror having first
9 and second focal points;

10 (c) means for positioning the emission point of
11 interest at the first focal point of the mirror; and

12 (d) emission collection means located at the
13 second focal point of the mirror, whereby emissions from
14 the emission point of interest are focused to the second
15 focal point and collected by said collection means.



1 12. The system of claim 11, wherein the collection face
2 of said collection means is centered upon and
3 substantially perpendicular to the axis connecting the
4 first and second focal points.

1 13. The system of claim 12, wherein the collection
2 means comprises a radiation guide which collects
3 emissions at the second focal point and transmits the
4 emissions to remote detection means.

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

1 15. The system of claim 13, further comprising an
2 aperture located adjacent to the collection face of the
3 collection means, said aperture centered upon and
4 substantially perpendicular to the axis connecting the
5 first and second focal points, whereby said aperture



6 blocks off focus emission from near the first focal
7 point before it reaches said collection face.

1 16. The system of claim 11, wherein said mirror is a
2 semi-ellipsoid.

1 17. The system of claim 16, wherein the collection face
2 of said collection means is centered upon and
3 substantially perpendicular to the axis connecting the
4 first and second focal points.

1 18. The system of claim 17, wherein the collection
2 means comprises a radiation guide which collects
3 emissions at the second focal point and transmits the
4 emissions to remote detection means.

1 19. The system of claim 18, wherein the remote
2 detection means comprises wavelength selection means and
3 a radiation sensitive detector.



1 20. The system of claim 18, further comprising an
2 aperture located adjacent to the collection face of the
3 collection means, said aperture centered upon and
4 substantially perpendicular to the axis connecting the
5 first and second focal points, whereby said aperture
6 blocks off focus emission from near the first focal
7 point before it reaches said collection face.