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(57) **ABSTRACT**

A microscope comprising: a light sampler for collecting light from a measurement area of a sample; a multi-element detector having a plurality of photoelectric elements, for detecting the light collected by the light sampler, each photoelectric element corresponding to a minute measurement region in the measurement area with one-to-one correspondence; a Fourier transform spectrophotometer as a spectroscope; a data sampler for concurrently sampling intensity data sent from each photoelectric element of the multi-element detector at a timing determined by the Fourier transform spectrophotometer; and a data processor for obtaining time-resolved spectrum data for each minute measurement region according to temporally changed interference light data obtained by the data sampler.
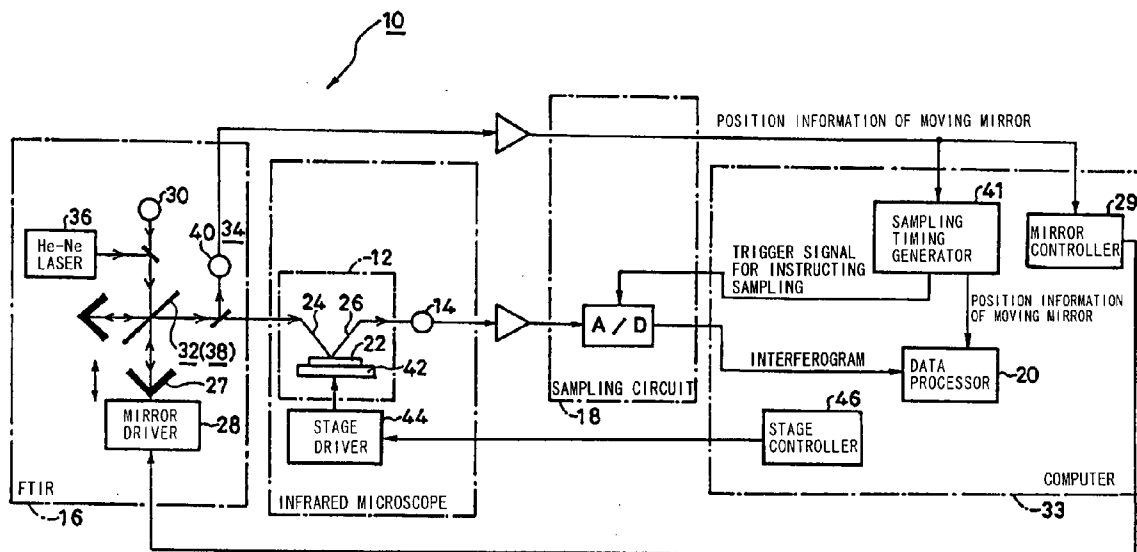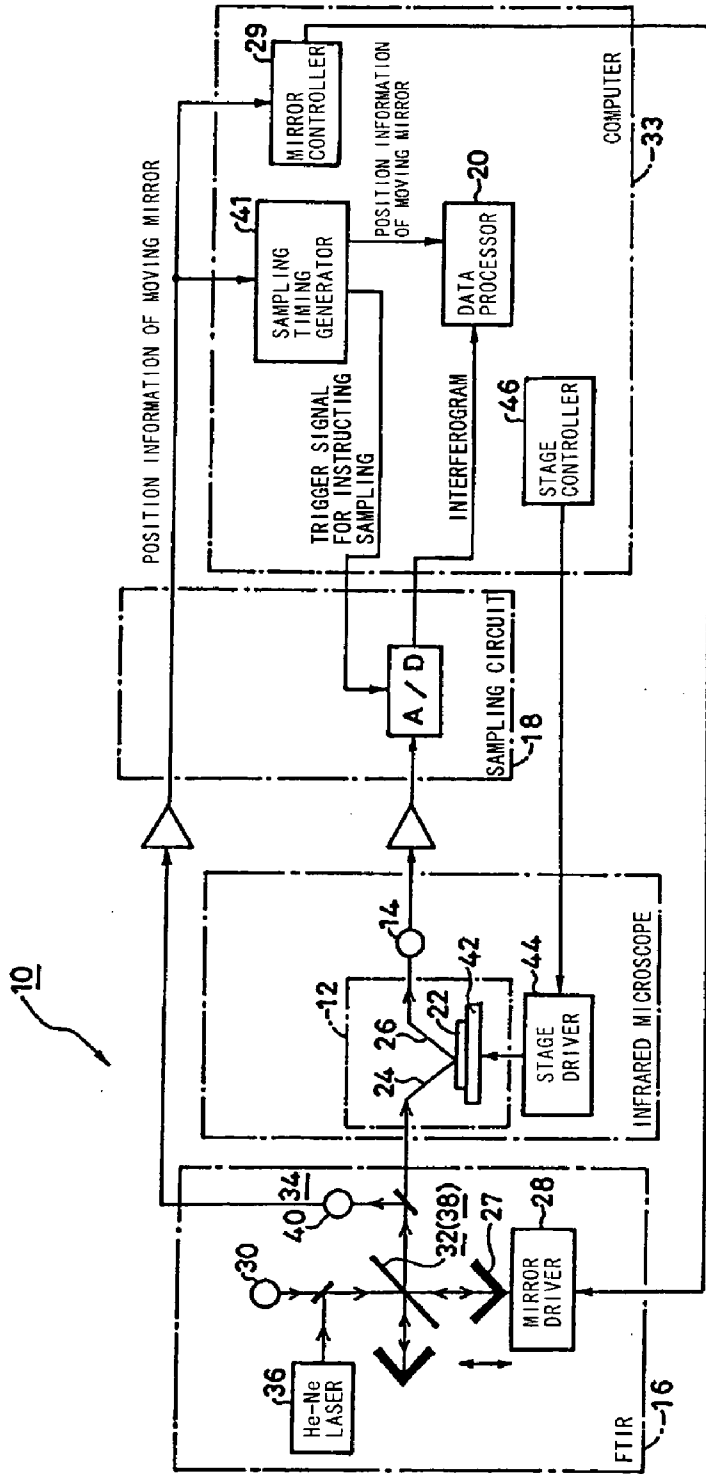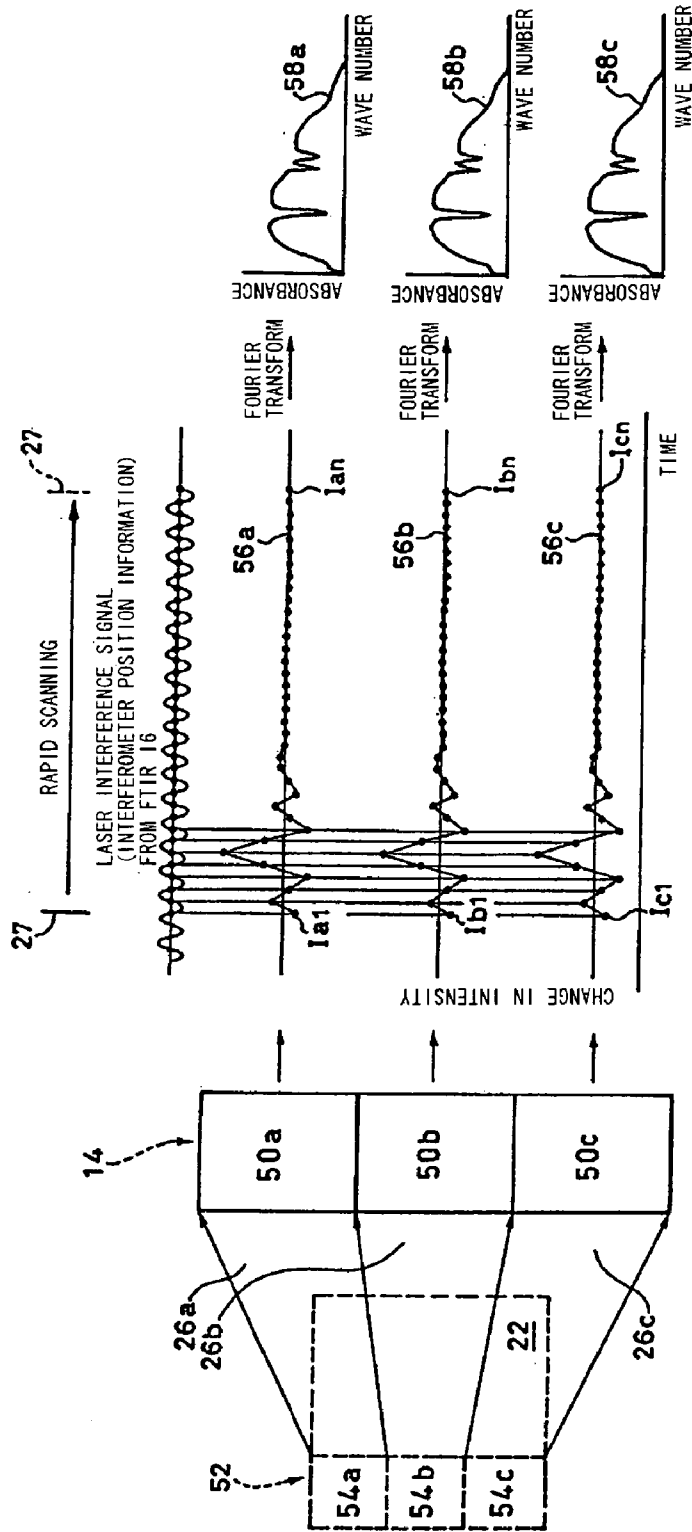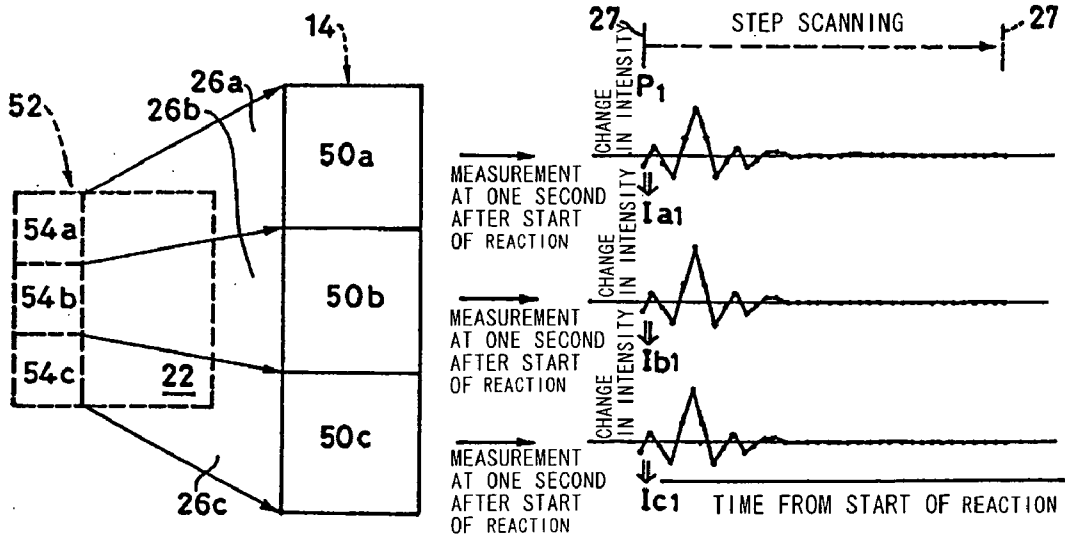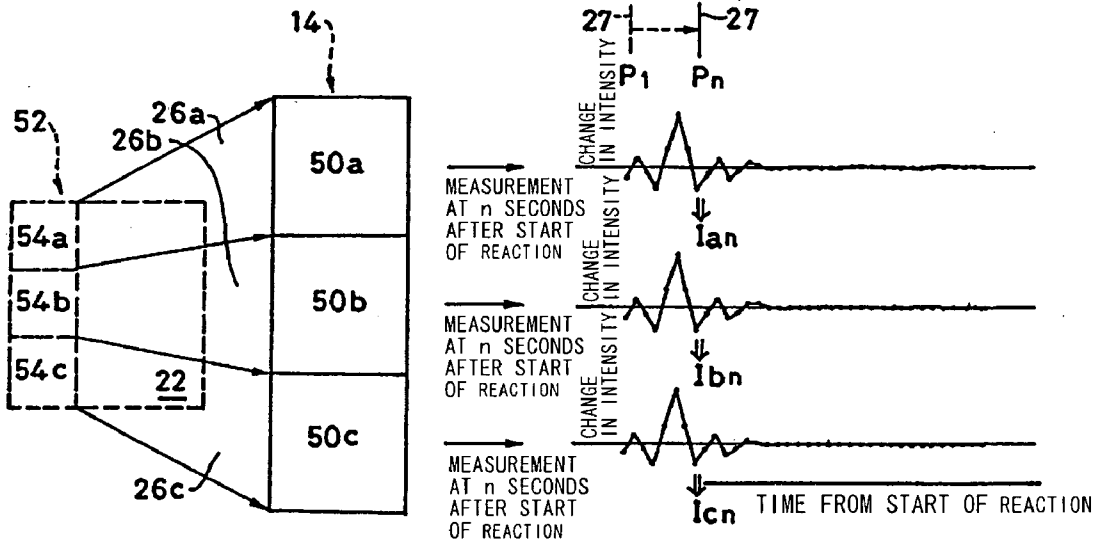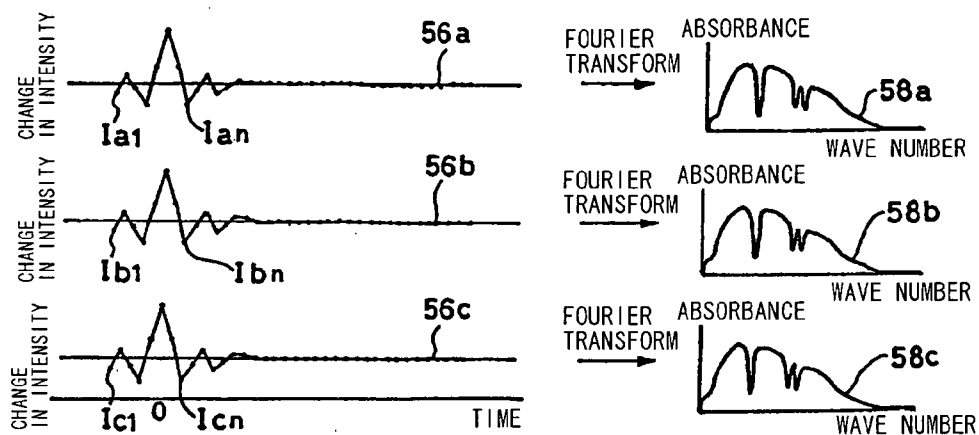
FIG. 1

FIG. 2

FIG. 3A

FIG. 3B

FIG. 3C

MICROSCOPE

RELATED APPLICATIONS

[0001] This application claims priority to the Japanese Patent Application 2004-352556 dated on Dec. 6, 2004 and is hereby incorporated with reference for all purposes.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to microscopes, and more particularly, to a mechanism therein for obtaining a time-resolved spectrum.

[0004] 2. Prior Art

[0005] Time-resolved measurement apparatuses are used to measure temporal changes in samples. In the time-resolved measurement apparatuses, the entire sample is illuminated with interference light sent from an interferometer, and interference light coming from the sample is detected to obtain the temporally changed spectrum (for example, see Japanese Unexamined Patent Application Publication No. Hei-5-223640).

[0006] Recently, time-resolved measurement is also demanded for microscopes that perform imaging analysis of minute measurement regions.

[0007] In time-resolved measurement, it is necessary to measure spectra that change, for example, in microseconds to nanoseconds. To follow such spectral changes, the measurement speed of microscopes needs to be improved, but conventionally, there have been no technologies to make such an improvement.

SUMMARY OF THE INVENTION

[0008] The present invention was conceived in light of the above problem of the prior art, and the object thereof is to provide a microscope that can obtain time-resolved spectrum.

[0009] The microscope of the present invention to achieve the above object is a microscope comprises a light sampler and a multi-element detector. The multi-element detector has a plurality of photoelectric elements, each photoelectric element corresponding to a minute measurement region in the measurement area with one-to-one correspondence. The microscope comprises a Fourier transform spectrophotometer, a data sampler and a data processor.

[0010] The microscope unit collects light from a measurement area of a sample.

[0011] The multi-element detector has a plurality of photoelectric elements, detects the light collected by the light sampler.

[0012] The Fourier transform spectrophotometer has a moving mirror serving as an optical path difference generator in an interferometer. The Fourier transform spectrophotometer serves as a spectroscope for light incident on the measurement area and/or light coming from the measurement area.

[0013] The data sampler concurrently samples intensity data sent from each photoelectric element of the multi-element detector at a timing determined according to posi-

tion information of the moving mirror, which is sent from the Fourier transform spectrophotometer.

[0014] The data processor obtains time-resolved spectrum data for each minute measurement region according to temporally changed interference light data obtained by the data sampler.

Multi-Element Detector

[0015] In this invention, it is preferred that the plurality of photoelectric elements of the multi-element detector is placed in one dimension.

[0016] This is because such a structure is advantageous in that intensity data from each photoelectric element can be concurrently sampled at a higher speed.

Rapid-Scanning Mode

[0017] In this invention, the Fourier transform spectrophotometer continuously moves the moving mirror at a high speed in a rapid-scanning mode. The data sampler concurrently samples the intensity data sent from each photoelectric element of the multi-element detector every time the moving mirror is moved by a constant distance, starting at a predetermined position. The data processor obtains the temporally changed interference light data according to intensity data at each sampling position in the rapid-scanning mode and further obtains the time-resolved spectrum data, for each minute measurement region.

Step-Scanning Mode

[0018] In this invention, the Fourier transform spectrophotometer discretely moves the moving mirror in a step-like manner in a step-scanning mode in order to perform time-resolved measurement for a periodic reaction. The data sampler concurrently samples the intensity data sent from each photoelectric element of the multi-element detector at each stop position of the moving mirror in the step-scanning mode every time a predetermined time elapses, starting at the beginning of the periodic reaction. The data processor obtains the temporally changed interference light data according to intensity data at each elapsed time, starting at the beginning of the periodic reaction and further obtains the time-resolved spectrum data, for each minute measurement region.

Measurement-Area Moving Unit

[0019] In this invention, the microscope further comprises a measurement-area moving unit for moving the measurement area. The measurement-area moving unit comprises a stage, a stage driver and a stage controller. The measurement area in the sample is moved by the movement of the stage.

[0020] The stage on which the sample is placed.

[0021] The stage driver moves the stage horizontally.

[0022] The stage controller controls the movement of the stage performed by the stage driver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a view showing an outlined structure of an infrared microscope according to an embodiment of the present invention.

[0024] **FIG. 2** is a view showing the acquisition of a time-resolved spectrum performed when a Fourier transform spectrophotometer shown in **FIG. 1** operates in a rapid-scanning mode.

[0025] **FIGS. 3A** to **3C** are views showing the acquisition of a time-resolved spectrum performed when the Fourier transform spectrophotometer shown in **FIG. 1** operates in a step-scanning mode.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] A preferred embodiment will be described below by referring to the drawings.

[0027] **FIG. 1** shows an outlined structure of a multi-channel infrared microscope **10** according to an embodiment of the present invention.

[0028] In addition to an infrared microscope having a microscope unit (light sampler) **12** and a multi-element infrared detector (multi-element detector) **14**, the multi-channel infrared microscope (microscope) **10** includes a Fourier transform infrared spectrophotometer (FTIR) **16**, a sampling circuit (data sampler) **18**, and a data processor **20**.

[0029] The microscope unit **12** illuminates a measurement area of a sample **22** with interference light **24** and obtains interference light **26** coming from the measurement area.

[0030] The multi-element infrared detector **14** has a plurality of photoelectric elements disposed in one dimension and detects the interference light **26** coming from the measurement area.

[0031] An advantageous feature of the present invention is that a temporal change in each minute measurement region of the sample **22** can be measured in the infrared microscope of the multi-channel infrared microscope **10**. To obtain this feature, as described above, the multi-element infrared detector **14** provided for the infrared microscope is combined with the Fourier transform infrared spectrophotometer **16** in the present embodiment. In addition, the sampling circuit **18** is provided in the present embodiment.

[0032] In the present embodiment, each photoelectric element in the multi-element infrared detector **14** handles a minute measurement region in the measurement area with one-to-one correspondence. The multi-element infrared detector **14** used in the present embodiment has a plurality of photoelectric elements disposed in one dimension because this allows intensity data to be sampled from the photoelectric elements more concurrently at a higher speed.

[0033] The Fourier transform infrared spectrophotometer **16** has a moving mirror **27**. A moving mirror driver **28** and a moving mirror controller **29** are used to operate the moving mirror **27** in a rapid-scanning mode and a step-scanning mode.

[0034] The Fourier transform infrared spectrophotometer **16** further includes an infrared light source **30**, a main interferometer **32**, and a position detector **34** for obtaining position information of the moving mirror **27**. The position detector **34** includes a He—Ne laser **36**, a control interferometer **38** also serving as the main interferometer **32**, and a He—Ne detector **40**.

[0035] The sampling circuit **18** samples intensity data at a high speed from each photoelectric element of the multi-element infrared detector **14** concurrently by the use of a sampling timing generator **41**.

[0036] The data processor **20** includes, for example, a computer **33** and obtains time-resolved spectrum data of each minute measurement region according to temporally changed interference light data sent from the sampling circuit **18**.

[0037] In the present embodiment, a stage **42**, a stage driver **44**, and a stage controller **46** are also provided. The sample **22** is placed on the stage **42**, and the stage **42** is moved to move the measurement area of the sample **22**.

[0038] The stage driver **44** moves the stage **42** horizontally. The stage controller **46** controls the movement of the stage **42** performed by the stage driver **44**.

[0039] In the present embodiment, microscopic measurement of temporal changes can be performed accurately, which was very difficult to conduct in conventional infrared microscopes.

[0040] Conventionally, a multi-element infrared detector is used to obtain temporally changed interference light data of one measurement area in a time-sequential manner. More specifically, the photoelectric elements of the multi-element infrared detector are sequentially scanned to output intensity data corresponding to each photoelectric element in a time-sequential manner. Based on the time-sequential data obtained in this way, temporally changed spectrum data of the entire sample is obtained.

[0041] In contrast, in the present embodiment, to obtain temporally changed spectrum data of each minute measurement region in a sample, a combination of an existing multi-element infrared detector in an infrared microscope and a Fourier transform infrared spectrophotometer is employed.

<Multi-Element Infrared Detector>

[0042] In the present embodiment, the multi-element infrared detector **14** is used not to obtain intensity data of the entire sample in a time-sequential manner but to obtain a surface intensity distribution. Each photoelectric element of the multi-element infrared detector **14** corresponds to one minute measurement region of the measurement area with one-to-one correspondence.

<Sampling>

[0043] In the present embodiment, the sampling circuit **18** is used not to sequentially scan the photoelectric elements of the multi-element infrared detector but to concurrently sample data from each photoelectric element at a timing determined by the Fourier transform infrared spectrophotometer.

<Data Processing>

[0044] In the present embodiment, the data processor **20** obtains temporally changed interference light data from intensity data of each minute measurement region of the measurement area, obtained by the sampling circuit **18**. The data processor **20** applies a Fourier transform to the temporally changed interference light data for each minute measurement region of the measurement area to obtain time-resolved spectrum data.

[0045] As a result, a temporal change in each minute measurement region of the sample 22 can be measured in the present embodiment.

Rapid-Scanning Mode

[0046] The acquisition of a time-resolved spectrum in the rapid-scanning mode of the moving mirror 27 will be described next.

[0047] The Fourier transform infrared spectrophotometer 16 continuously moves the moving mirror 27 at a high speed.

[0048] The sampling circuit 18 concurrently samples intensity data from each photoelectric element of the multi-element infrared detector 14 every time the moving mirror 27 moves by a constant distance, starting at a predetermined position. The zero-crossing points of a laser interference signal (position information of the moving mirror 27) obtained from the position detector 34 and the sampling timing generator 41 are used as timing points sent from the Fourier transform infrared spectrophotometer 16, which are used to control the sampling of the intensity data.

<Data Processing>

[0049] The data processor 20 obtains temporally changed interference light data from the intensity data for each minute measurement region at each sampling position in the rapid-scanning mode. The data processor 20 applies a Fourier transform to the temporally changed interference light data to obtain time-resolved spectrum data.

[0050] The acquisition of the time-resolved spectrum data will be described more specifically by referring to **FIG. 2**.

[0051] In **FIG. 2**, photoelectric elements 50a to 50c of the multi-element infrared detector 14 correspond to minute measurement regions 54a to 54c of a measurement area 52 with one-to-one correspondence.

[0052] The photoelectric element 50a samples the intensity of interference light 26a coming from the minute measurement region 54a. The photoelectric element 50b samples the intensity of interference light 26b coming from the minute measurement region 54b. The photoelectric element 50c samples the intensity of interference light 26c coming from the minute measurement region 54c.

<Sampling>

[0053] In the present embodiment, at time t_1 from the start of sampling, for example, intensity data I_{a1} from the photoelectric element 50a, intensity data I_{b1} from the photoelectric element 50b, and intensity data I_{c1} from the photoelectric element 50c are concurrently sampled at a high speed. This operation is performed at a predetermined number of points every time the moving mirror 27 is moved by the constant distance. At time t_n, intensity data I_{an} from the photoelectric element 50a, intensity data I_{bn} from the photoelectric element 50b, and intensity data I_{cn} from the photoelectric element 50c are concurrently sampled at a high speed. This operation is performed at the predetermined number of points every time the moving mirror 27 is moved by the constant distance.

[0054] With the foregoing sampling, n temporally changed interference light data items are obtained at constant time intervals for each minute measurement region.

<Data Processing>

[0055] The computer 33 obtains the temporally changed interference light data for each minute measurement region as described above.

[0056] The computer 33 then applies a Fourier transform to each of the n temporally changed interference light data items obtained at constant time intervals (at t_1, t_2, . . . , and t_n) for each minute measurement region to obtain time-resolved spectrum data.

[0057] The computer 33 applies a Fourier transform to interferogram data 56a corresponding to the minute measurement region 54a to obtain time-resolved spectrum data 58a. The computer 33 applies a Fourier transform to interferogram data 56b corresponding to the minute measurement region 54b to obtain time-resolved spectrum data 58b. The computer 33 applies a Fourier transform to interferogram data 56c corresponding to the minute measurement region 54c to obtain time-resolved spectrum data 58c.

[0058] As described above, according to the multi-channel infrared microscope 10 of the present embodiment, microscopic measurement of temporal changes can be performed in the form of images. The above-described time-resolved measurement is performed in the present embodiment with the use of the infrared microscope having the multi-element infrared detector 14, and the Fourier transform infrared spectrophotometer 16 capable of rapid scanning. As a result, in the rapid scanning mode, a surface distribution can be obtained in time-resolved measurement of millisecond-order for one-time reactions.

Step Scanning Mode

[0059] In the present embodiment, it is preferred as described above that the moving mirror 27 be operated in the rapid scanning mode. It is also preferred that the step scanning mode be used to measure a temporal change of periodic reactions.

[0060] Conventionally, in the step scanning mode, intensity data obtained from all elements of a multi-element infrared detector is sequentially scanned at each stop position of a moving mirror to obtain intensity data corresponding to each element in a time-sequential manner. The time-resolved spectrum data of the entire sample is obtained from the intensity data obtained in that way.

[0061] In contrast, in the present embodiment, to obtain time-resolved spectrum data not for the entire sample but for each minute measurement region, it is preferred that the following time-resolved measurement be performed.

[0062] The acquisition of a time-resolved spectrum in the step-scanning mode of the moving mirror 27 of the interferometer will be described next, specifically by referring to **FIG. 3A** to **FIG. 3C**.

[0063] The Fourier transform infrared spectrophotometer 16 moves the moving mirror 27 discretely in a step-like manner.

<Sampling>

[0064] The sampling circuit 18 concurrently samples intensity data from each photoelectric element of the multi-element infrared detector 14 at each stop position of the

moving mirror **27** at predetermined time intervals, starting at the beginning of a periodic reaction.

[0065] At a stop position P_1 of the moving mirror **27**, as shown in **FIG. 3A**, intensity data I_{a1} from the photoelectric element **50**a, intensity data I_{b1} from the photoelectric element **50**b, and intensity data I_{c1} from the photoelectric element **50**c are concurrently measured at predetermined time intervals, starting at the beginning of the periodic reaction.

[0066] At a stop position P_n of the moving mirror **27**, as shown in **FIG. 3B**, intensity data I_{an} from the photoelectric element **50**a, intensity data I_{bn} from the photoelectric element **50**b, and intensity data I_{cn} from the photoelectric element **50**c are concurrently measured at predetermined time intervals, starting at the beginning of the periodic reaction.

<Data Processing>

[0067] The computer **33** obtains an interferogram (temporally changed interference light data) formed of the intensity data corresponding to the stop positions (P_1, P_2, . . . , and P_n) of the moving mirror **27** for each minute measurement region according to the intensity data obtained at each stop position of the moving mirror **27** at each sampling time.

[0068] More specifically, the computer **33** obtains an interferogram (temporally changed interference light data) **56**a formed of the intensity data (I_{a1}, I_{a2}, . . . , and I_{an}) corresponding to the stop positions (P_1, P_2, . . . , and P_n) of the moving mirror **27** for the minute measurement region **54**a, as shown in **FIG. 3C**. The computer **33** obtains an interferogram (temporally changed interference light data) **56**b formed of the intensity data (I_{b1}, I_{b2}, . . . , and I_{bn}) corresponding to the stop positions (P_1, P_2, . . . , and P_n) of the moving mirror **27** for the minute measurement region **54**b, as shown in **FIG. 3C**. The computer **33** obtains an interferogram (temporally changed interference light data) **56**c formed of the intensity data (I_{c1}, I_{c2}, . . . , and I_{cn}) corresponding to the stop positions (P_1, P_2, . . . , and P_n) of the moving mirror **27** for the minute measurement region **54**c, as shown in **FIG. 3C**.

[0069] In the present embodiment, when intensity data each having a predetermined time delay from the periodic reaction have been sampled a predetermined number of times at a certain stop position of the moving mirror **27**, the moving mirror **27** is moved to the next stop position, and intensity data having a time delay corresponding to the next stop position is sampled in the same way. Sampling is performed with a time delay corresponding to each stop position, and measurement is conducted a target number of times. An interferogram formed of intensity data with each time delay is obtained for each minute measurement region.

[0070] Then, the computer **33** obtains time-resolved spectrum data according to each interferogram, as shown in **FIG. 3C**.

[0071] Specifically, the computer **33** applies a Fourier transform to the interferogram data **56**a corresponding to the minute measurement region **54**a to obtain time-resolved spectrum data **58**a. The computer **33** applies a Fourier transform to the interferogram data **56**b corresponding to the minute measurement region **54**b to obtain time-resolved spectrum data **58**b. The computer **33** applies a Fourier

transform to the interferogram data **56**c corresponding to the minute measurement region **54**c to obtain time-resolved spectrum data **58**c.

[0072] Microscopic measurement of temporal changes is performed in the present embodiment with the use of the infrared microscope having the multi-element infrared detector **14**, and the Fourier transform infrared spectrophotometer **16** capable of step scanning. As a result, a surface distribution can be obtained in time-resolved measurement of microsecond-order for periodic reactions.

[0073] In the present embodiment, to maintain reproducibility of the start of the periodic reaction, it is preferred that an excitation light source, such as a unit emitting short pulses, be used. To perform successful sampling, it is also preferred in the present embodiment that a delay unit capable of specifying a time delay for a sampling time according to each stop position of the moving mirror **27** be provided.

<Measurement-Area Moving Unit>

[0074] It is also important in the above-described structure that the measurement area can be moved in order to obtain a surface distribution over a wider area of a sample. For this purpose, the stage **42**, the stage driver **44**, and the stage controller **46** serve as a measurement-area moving unit.

[0075] When measurement has been finished at a certain measurement area, the measurement-area moving unit moves the sample so that measurement can be performed at the next measurement area. Then, time-resolved measurement is performed at the next measurement area in the same way. Time-resolved measurement at each measurement area and changing the movement area by the measurement-area moving unit are repeated until time-resolved measurement is finished for all target areas.

<Selection of Multi-Element Detector>

[0076] In the above-described embodiment, a multi-element detector in which the photoelectric elements are disposed in one dimension is used. This is because such a structure is advantageous in that intensity data from each photoelectric element can be concurrently sampled at a higher speed. A multi-element detector in which all photoelectric elements are disposed two dimensionally can be used instead.

[0077] Although a multi-element detector having photoelectric elements disposed in one dimension is slightly affected by light coming from adjacent measurement regions, it can concurrently measure a smaller number of measurement regions than a multi-element detector having photoelectric elements disposed two dimensionally. Since highly precise measurement is especially important in the above-described embodiment compared with a reduction in measurement time, it is preferred that a multi-element detector having photoelectric elements disposed in one dimension be used.

[0078] A multi-element detector having photoelectric elements disposed two dimensionally can concurrently measure a larger number of measurement regions than a multi-element detector having photoelectric elements disposed in one dimension, but it is significantly affected by light coming from adjacent measurement regions. When a reduction in measurement time is especially important in the

above-described embodiment compared with highly precise measurement, a multi-element detector having photoelectric elements disposed two dimensionally can be used.

Effectiveness

[0079] As described above, the microscope of the present invention includes the multi-element detector, the Fourier transform spectrophotometer serving as the spectroscope, and the data sampler for concurrently sampling intensity data from each photoelectric element of the multi-element detector at timing determined by the spectrophotometer. As a result, the time-resolved spectrum is obtained in the present invention.

[0080] In combination with the measurement-area moving unit, sample-surface analysis can be performed at a high speed in the present invention.

What is claimed is:

1. A microscope comprising:

a light sampler for collecting light from a measurement area of a sample;

a multi-element detector having a plurality of photoelectric elements, for detecting the light collected by the light sampler, each photoelectric element corresponding to a minute measurement region in the measurement area with one-to-one correspondence;

a Fourier transform spectrophotometer having a moving mirror serving as an optical path difference generator in an interferometer, the Fourier transform spectrophotometer serving as a spectroscope for light incident on the measurement area and/or light coming from the measurement area;

a data sampler for concurrently sampling intensity data sent from each photoelectric element of the multi-element detector at a timing determined according to position information of the moving mirror, which is sent from the Fourier transform spectrophotometer; and

a data processor for obtaining time-resolved spectrum data for each minute measurement region according to temporally changed interference light data obtained by the data sampler.

2. A microscope according to claim 1,

wherein the plurality of photoelectric elements of the multi-element detector is placed in one dimension.

3. A microscope according to claim 1,

wherein the Fourier transform spectrophotometer continuously moves the moving mirror at a high speed in a rapid-scanning mode;

the data sampler concurrently samples the intensity data sent from each photoelectric element of the multi-element detector every time the moving mirror is moved by a constant distance, starting at a predetermined position; and

the data processor obtains the temporally changed interference light data according to intensity data at each sampling position in the rapid-scanning mode and further obtains the time-resolved spectrum data, for each minute measurement region.

4. A microscope according to claim 1,

wherein the Fourier transform spectrophotometer discretely moves the moving mirror in a step-like manner in a step-scanning mode in order to perform time-resolved measurement for a periodic reaction;

the data sampler concurrently samples the intensity data sent from each photoelectric element of the multi-element detector at each stop position of the moving mirror in the step-scanning mode every time a predetermined time elapses, starting at the beginning of the periodic reaction; and

the data processor obtains the temporally changed interference light data according to intensity data at each elapsed time, starting at the beginning of the periodic reaction and further obtains the time-resolved spectrum data, for each minute measurement region.

5. A microscope according to claim 1,

further comprising a measurement-area moving unit for moving the measurement area, the measurement-area moving unit comprising:

a stage on which the sample is placed;

a stage driver for moving the stage horizontally; and

a stage controller for controlling the movement of the stage performed by the stage driver,

wherein the measurement area in the sample is moved by the movement of the stage, where the sample is placed.

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