United States Patent

Mori et al.

[15] 3,697,180

[45] Oct. 10, 1972

[54] **APPARATUS FOR AUTOMATICALLY RECORDING THE HEDEPOLARIZATION RATIOS OF RAMAN BANDS**

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[73] Assignee: **Nihon Denshi Kabushiki Kaisha,** Tokyo, Japan

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[21] Appl. No.: **95,700**

[30] **Foreign Application Priority Data**

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Feb. 28, 1970 Japan 45/17383

[52] **U.S. Cl.** **356/75,** 356/114, 356/116
[51] **Int. Cl.**..........................**G01j 3/44,** G01n 21/40
[58] **Field of Search**.........356/75, 103, 104, 114–119

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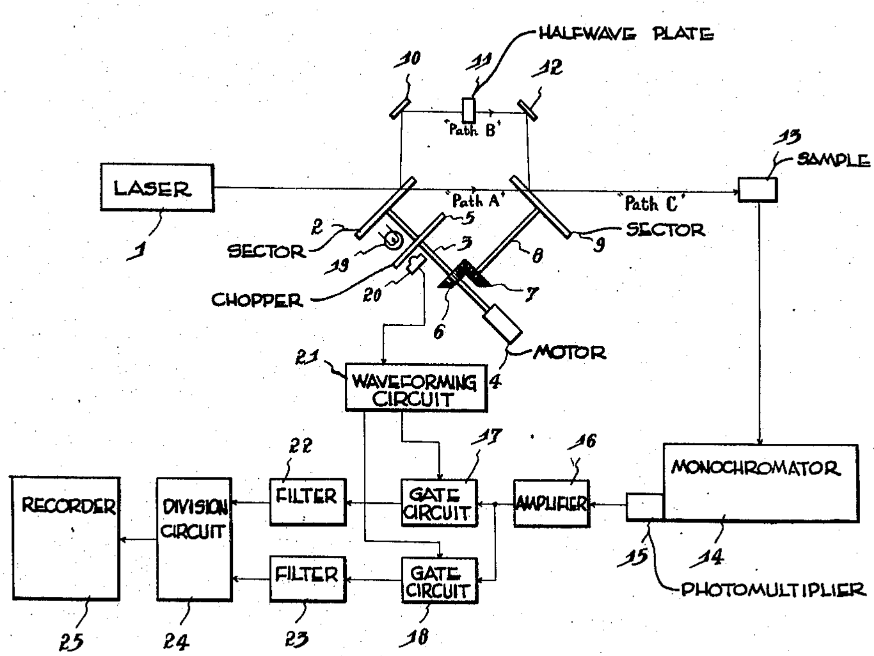
Primary Examiner—Ronald L. Wibert
Assistant Examiner—F. L. Evans
Attorney—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

Two rays of light polarized parallel and perpendicular with respect to a plane are produced from a single ray of light generated by a laser. By alternately illuminating a sample with the said two rays of light, two Raman scattering light rays having different intensities are produced and in turn applied to a monochromator where they are dispersed according to wave length. After dispersion, the rays are detected by a photomultiplier and the resultant signals applied to a division circuit where the depolarization ratio is automatically calculated. This process is repeated for subsequent sets of signals, thereby effecting a continuous operational sequence.

4 Claims, 11 Drawing Figures



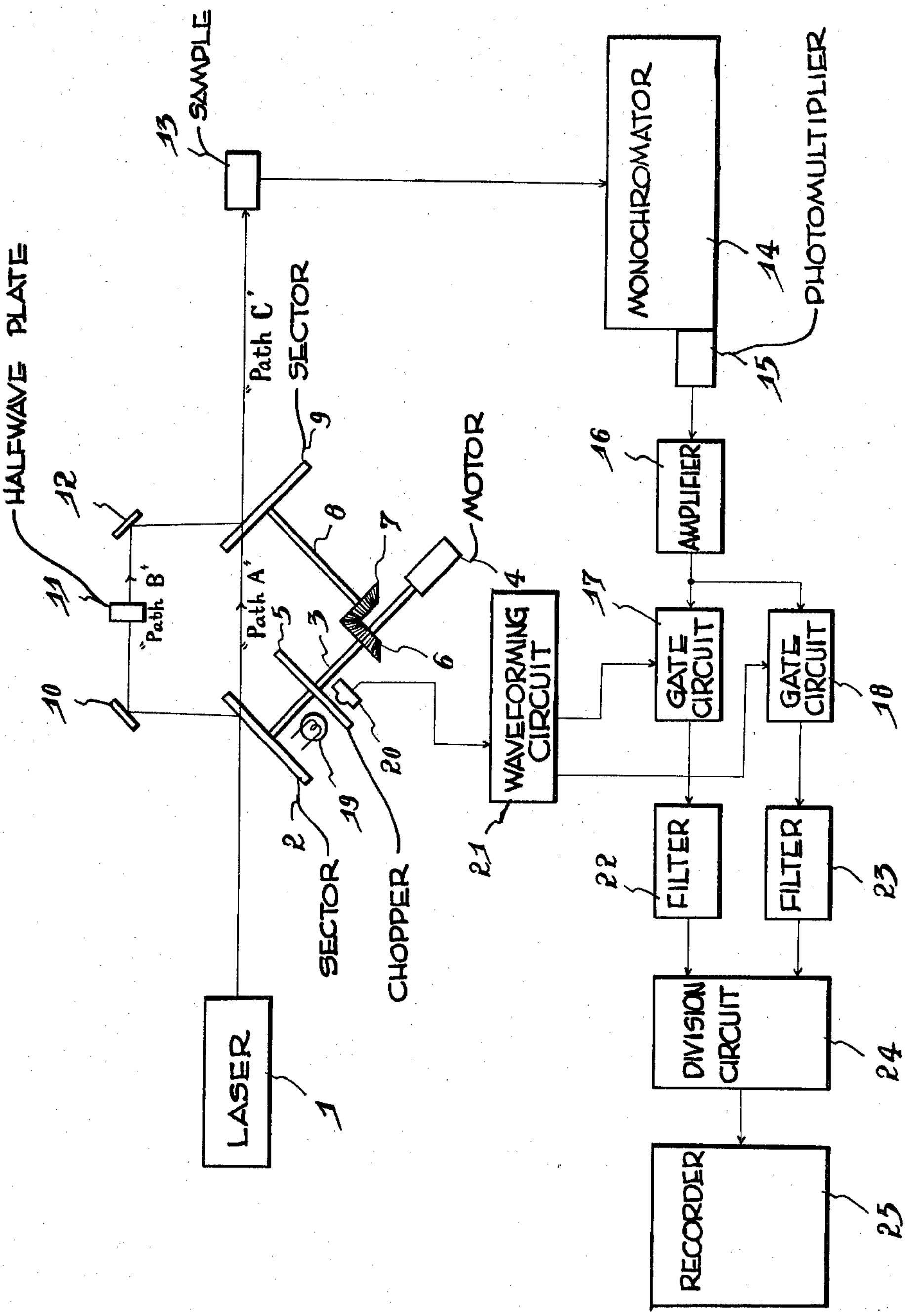
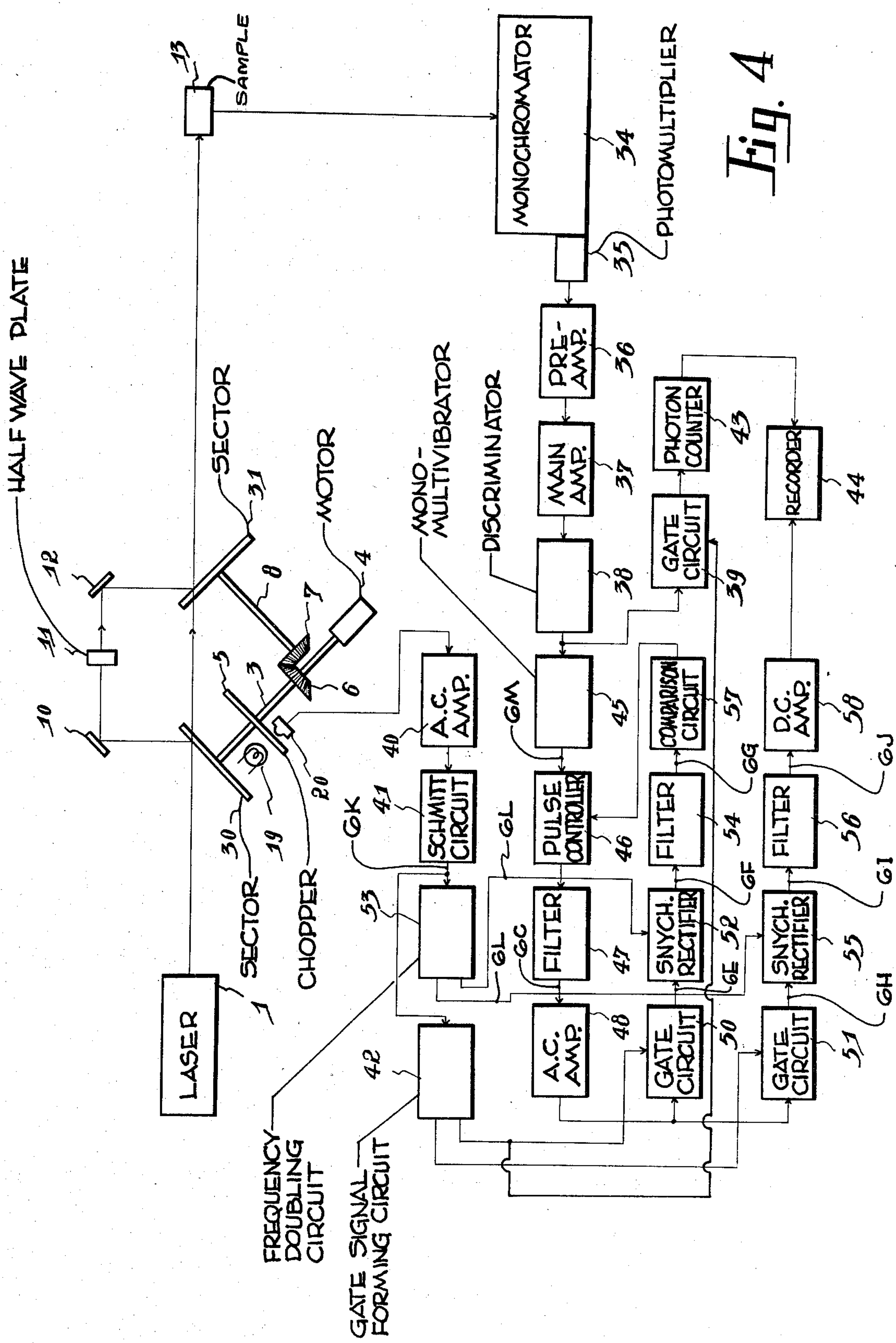

LASER
SECTOR
CHOPPER
MOTOR
SECTOR
HALFWAVE PLATE
SAMPLE
"Path A"
"Path B"
"Path C"
MONOCHROMATOR
PHOTOMULTIPLIER
AMPLIFIER
WAVEFORMING CIRCUIT
GATE CIRCUIT
GATE CIRCUIT
FILTER
FILTER
DIVISION CIRCUIT
RECORDER

Fig. 1


HALF WAVE PLATE
SECTOR
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LASER
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CHOPPER
MONO-MULTIVIBRATOR
DISCRIMINATOR
PRE-AMP.
MAIN AMP.
PHOTON COUNTER
GATE CIRCUIT
RECORDER
A.C. AMP.
SCHMITT CIRCUIT
PULSE CONTROLLER
COMPARISON CIRCUIT
D.C. AMP.
FILTER
FILTER
FILTER
SNYCH. RECTIFIER
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A.C. AMP.
GATE CIRCUIT
GATE CIRCUIT
FREQUENCY DOUBLING CIRCUIT
GATE SIGNAL FORMING CIRCUIT

Fig. 4

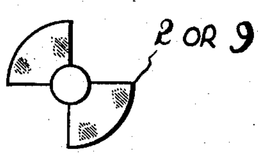


Fig. 2

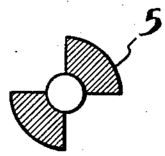


Fig. 3

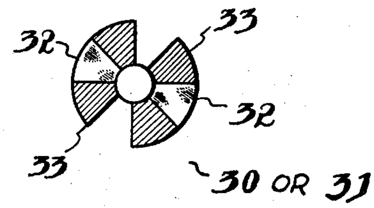


Fig. 5

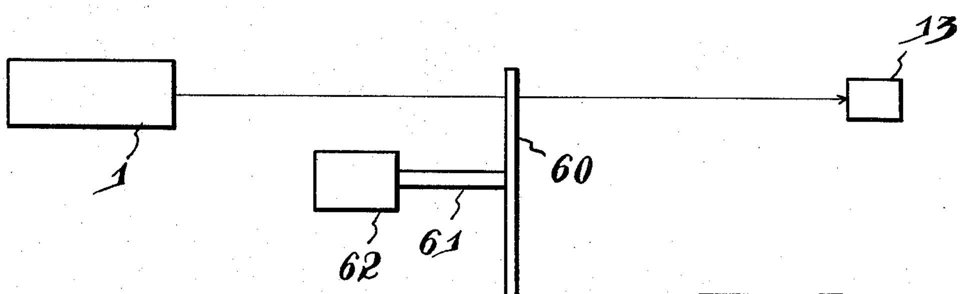


Fig. 7

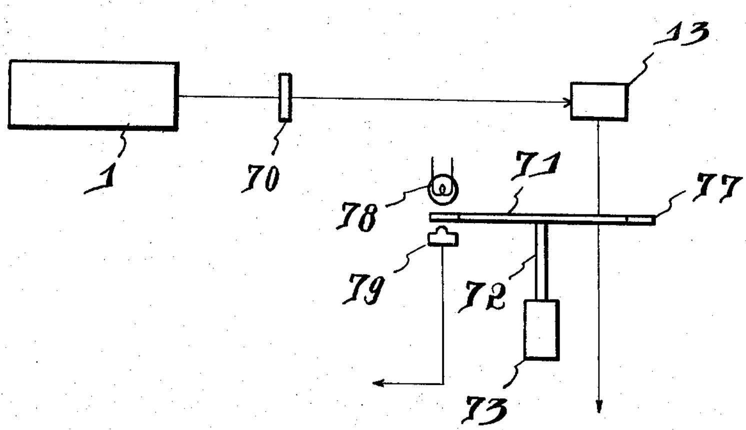


Fig. 9

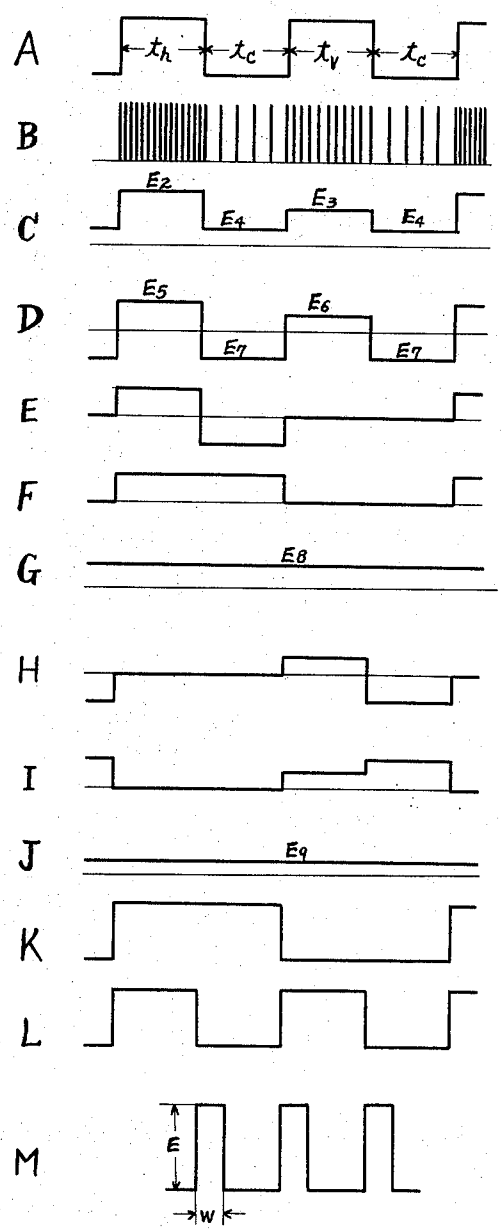


Fig. 6

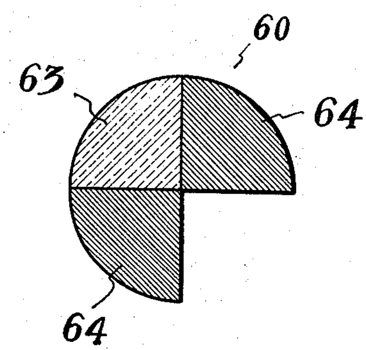


Fig. 8

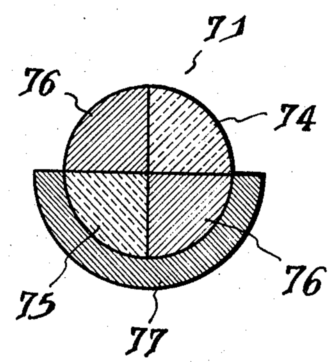
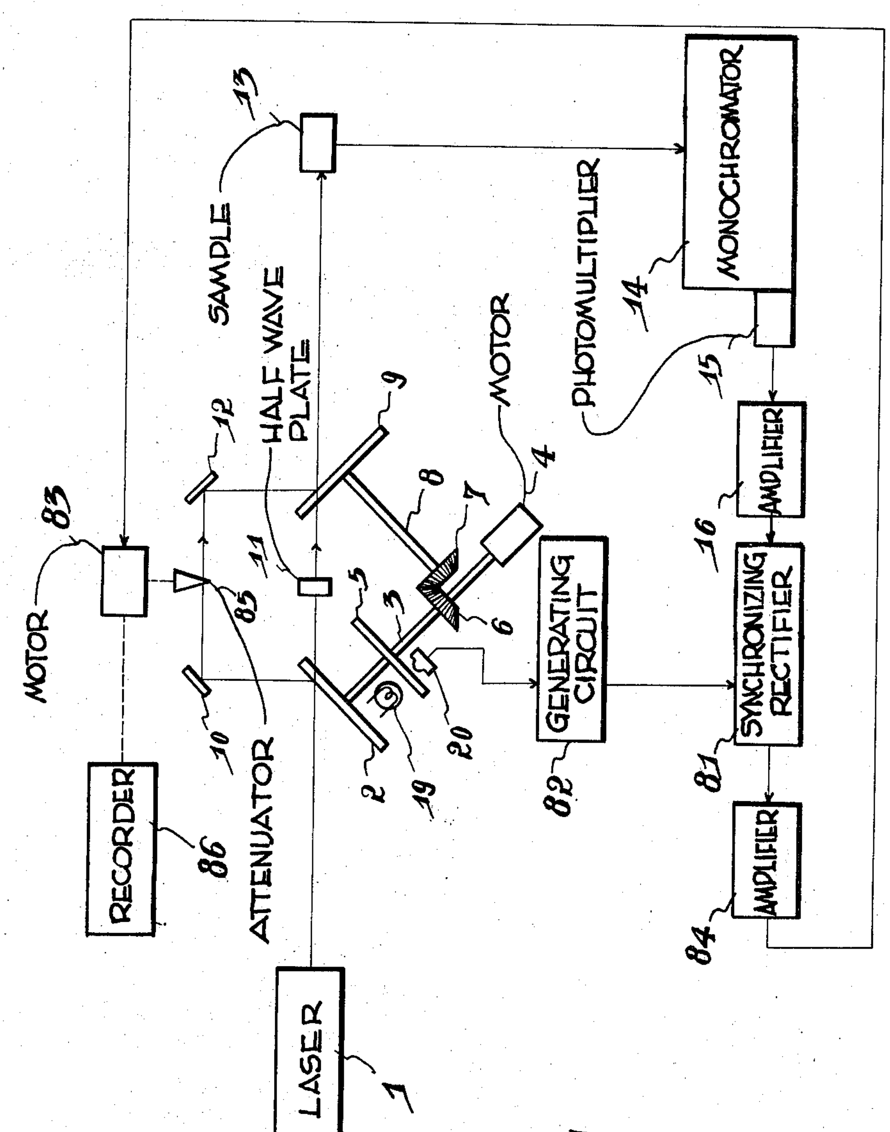


Fig. 10


LASER
1
ATTENUATOR
85
MOTOR
83
RECORDER
86
10
12
HALF WAVE PLATE
11
SAMPLE
13
MONOCHROMATOR
14
PHOTOMULTIPLIER
15
AMPLIFIER
16
SYNCHRONIZING RECTIFIER
81
GENERATING CIRCUIT
82
AMPLIFIER
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MOTOR
4
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19
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Fig. 11

APPARATUS FOR AUTOMATICALLY RECORDING THE HEDEPOLARIZATION RATIOS OF RAMAN BANDS

This invention relates to a method and apparatus for measuring Raman scattering light. More particularly, it relates to a method and apparatus for automatically recording the depolarization ratios of Raman bands.

It is well recognized that the depolarization ratios of Raman bands is very useful in the assignment of the Raman bands.

The depolarization ratio $\rho(\lambda)$ is expressed as follows:

$$\rho(\lambda)=R\,u\,(\lambda)/R\,h\,(\lambda) \quad (1)$$

where $Ru\ (\lambda)$ represents the intensity of the rays of Raman light scattered from a sample as a result of illuminating the sample with a ray of incident light polarized perpendicular to a plane and $Rh\ (\lambda)$ represents the intensity of the rays of Raman light scattered from the sample by illuminating the sample with a ray of incident light polarized parallel to the said plane.

In the present mode of depolarization measurements, a Raman spectrum is first observed by illuminating the sample with an incident ray of light polarized parallel to a plane and then again observed by illuminating the sample with an incident ray of light polarized perpendicular to the said plane. The depolarization ratios are then calculated by comparing two intensities of the same line in the two spectra. This method, to say the least, is quite troublesome, not to mention the margin of error involved due to the fluctuation of the incident light intensity, plus, of course, the human element.

According to this invention, there is provided a method and apparatus for automatically recording the depolarization ratios of the Raman bands. It is an advantage of this invention to provide a method and apparatus for measuring the depolarization ratios rapidly and yet with precision.

In one embodiment of this invention, the sample is illuminated alternately by two rays of incident light respectively polarized parallel and perpendicular to a plane. As a result, two rays of Raman light based on the two rays of incident light are scattered from the sample. The two rays of Raman light are then alternately applied to a monochromator where they are dispersed according to wavelength and detected by a detecting means such as a photomultiplier. That is to say, two electrical signals based on the two different rays of incident light are alternately detected by the detecting means. The signals are then amplified and their ratio is automatically calculated by a division circuit and recorded by a recorder. This procedure is continuously repeated so that the ratio of each set of signals is continuously and automatically recorded by the recorder.

In this invention, the depolarization ratios are obtained by a single scanning of the monochromator, thereby shortening the ratio measuring time. Further, since the sample is illuminated alternately, the two Raman spectra are observed under identical conditions, thus ensuring precise measurement of the depolarization ratios.

Various other objects and advantages of this invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings in which:

FIG. 1 shows one embodiment of the invention in which the light path between the light source and the sample is bifurcated.

FIG. 2 shows a sector used in the embodiment shown in FIG. 1.

FIG. 3 shows a chopper used in the embodiment shown in FIG. 1.

FIG. 4 shows another embodiment of this invention.

FIG. 5 shows a sector used in the embodiment shown in FIG. 4.

FIG. 6 shows the wave forms produced by the various electrical units constituting the embodiment shown in FIG. 4.

FIG. 7 shows again a further embodiment for obtaining the two incident rays of light.

FIG. 8 shows the sector used in the embodiment shown in FIG. 7.

FIG. 9 shows yet another embodiment of this invention in which the sector is inserted in the optical path between the sample and the monochromator.

FIG. 10 shows the sector used in the embodiment shown in FIG. 9.

FIG. 11 shows one more embodiment of this invention.

Now referring to FIG. 1, a coherent ray of light polarized parallel to a reference plane, preferably the horizontal plane, is produced by a laser **1**. The optical path of the coherent ray of light is changed by a sector **2** which takes the form of a fan-shaped reflector as shown in FIG. 2. The said sector is mounted on a shaft **3** rotated by a motor **4**. Also mounted on the said shaft is a chopper **5** and a gear **6**, the said gear **6** being meshed to gear **7**, on a shaft **8** of which a second sector **9**, identical in form to the sector **2**, is mounted. Accordingly, the rotation of the sector **9** is synchronized with the rotation of the sector **2**.

The light deflected by the sector **2** is reflected by a mirror **10** so as to follow "Path B," the said light being polarized perpendicular to the plane by a half-wave plate **11** and directed to "Path C" by a mirror **12** and the sector **9**.

On the other hand, the light emanating from the laser **1** which is not reflected by the sector **2**, that is to say, the light passing through the non-bladed section of the sector **2**, forms a "Path A" which joins up with "Path C" since the sector **9** is synchronized with the sector **2**. As a result, two light rays, one polarized parallel to the plane and the other polarized perpendicular to the plane illuminate the sample **13** alternately, and in so doing, excite the said sample causing a scattering of Raman light rays. The light rays scattered from the sample are then directed to a scanning monochromator **14** where they are dispersed according to wave length. Once dispersed, the rays are converted into electrical signals by a photomultiplier **15** and amplified by an amplifier **16**. The amplified signals are then fed into gate circuits **17** and **18**. At the same time, light emanating from a light source **19** is detected by a phototransistor **20** and applied to the respective gate circuits via a waveforming circuit **21** as gate signals.

Further, the chopper **5**, shown in FIG. 3, located between the light source **19** and the phototransistor **20**, is synchronized so as to pass light when the sample **13** is illuminated by incident light polarized parallel to the plane and to intercept light when the sample **13** is illuminated by incident light polarized perpendicular to the plane. As a result, the gate circuit **17** is opened when the sample is illuminated by incident light polarized parallel to the plane, enabling signals based on Raman light rays generated by parallel incident light to pass through the said gate circuit and into filter **22** where they are smoothed.

Similarly, the gate circuit **18** is opened when the sample is illuminated by incident light polarized perpendicular to the plane, this time enabling signals based on Raman light rays generated by perpendicular incident light to pass through the said gate circuit and into filter **23** where they are smoothed. The output signals from filters **22** and **23** are then fed into a division circuit **24** where the intensities of the output signals from filter **23** are divided by the intensities of the output signals from filter **22**. The resultant quotients, viz, the depolarizarion ratios, are finally recorded by the recorder **25**.

FIG. **4** shows another embodiment of this invention in which the same optical system as described in the aforedescribed embodiment is used for obtaining the two incident light rays polarized parallel and perpendicular to the plane. In this case, however, the sectors **30** and **31** are different as shown in FIG. **5**. Sections **32** of the sectors, for example, take the form of fan-shaped mirrors and sections **33** serve to absorb the light emanating from the laser **1**. FIG. **6**A shows the train of light signals illuminated onto the sample **13**. Here, the period *th* represents the period in which the incident light polarized parallel to the plane illuminated the sample **13**, period *tu* represents the period in which the incident light polarized perpendicular to the plane illuminates the said sample and period *tc* represents the period in which the sample is not illuminated at all. As in the former embodiment, Raman light rays scattered from the sample are dispersed according to wavelength by a monochromator **34**.

According to the embodiment set forth in FIG. **4**, one circuit produces and records the Raman spectrum. Another circuit (interconnected) produces and records the depolarization ratio.

Once dispersed, the rays are converted into pulse signals, having frequencies proportional to the intensities of the said rays, by a photomultiplier **35**. The pulse signals are then amplified by pre-and main-amplifiers **36** and **37**. Low amplitude noise, such as dark current, in the said pulse signals is removed by discriminator **38**, the output of which is fed into a gate circuit **39** into which gate signals are also fed. The gate signals are based on the light generated by lamp **19**. During the period *th* and the subsequent period *tc*, the light generated by the said lamp is detected by a phototransistor **20** and converted into an electrical signal. Again, during the period *tu* and the subsequent period *tc*, the light generated by lamp **19** is intercepted by a chopper **5**. The signals detected by the phototransistor **20** are amplified by an AC amplifier **40** and wave formed by a Schmitt circuit **41**. The output of the Schmitt circuit **41** is then fed into a gate signal forming circuit **42** in which the phases and the level of the signals are regulated. Thence, the pulsed signals enter the gate circuit **39** which is opened during the period *th* and the subsequent period *tc*. The intensity of the Raman signals passed through the said gate circuit is counted by a photoncounter **43** and the Raman spectrum is recorded by **2**-pen recorder **44**.

The discriminator **38**, in addition to feeding output pulses into the gate circuit **39**, also feeds pulses into a monomultivibrator **45**. Once in the monomultivibrator the input pulses are wave formed to similar pulses as shown in FIG. **6**M, where W is the pulse width and E is the pulse height. The monomultivibrator output signal waveform is shown in FIG. **6**B. The intensities $R'h$ (λ) and $R'u$ (λ), namely, the output pulse frequencies of the monomultivibrator during the periods *th* and *tu* are expressed as follows:

$$R'\mathrm{h}\,(\lambda) = Rh\,(\lambda) + R\mathrm{n} \qquad (2)$$

$$R'\mathrm{u}\,(\lambda) = Ru\,(\lambda) + R\mathrm{n}\ \mathrm{TM}\ (3)$$

where R*n* is the intensity of the signal attributable to dark current or thermal noise.

The monomultivibrator pulses output is fed into a pulse controller **46** where the pulse widths and heights are controlled. The controlled pulses are then fed into a filter **47** and smoothed. The voltage E_1 of the smoothed signal is expressed as follows:

$$E_1 = f \cdot W \cdot E \qquad (4)$$

where *f* is a pulse frequency.

Referring to formulas (**2**), (**3**) and (**4**), the voltages E_2, E_3 and E_4 of the smoothed signals at *th*, *tu* and *tc* respectively are expressed as follows:

$$E_2 = {}_{R}'\,(\lambda) \cdot \mathrm{W} \cdot \mathrm{E} \qquad (5)$$

$$E_3 = R'(\lambda) \cdot \mathrm{W} \cdot \mathrm{E}$$

$$E_4 = \mathrm{R}n \cdot \mathrm{W} \cdot \mathrm{E} \qquad (7)$$

The wave form of the filter output signals is shown in FIG. **6**C.

The said output signals are amplified by an AC amplifier **48** where the DC component E*dc* is removed by a coupling condenser, so as to produce voltages E_5, E_6 and E_7, as shown in FIG. **6**D. The said voltages are expressed algebraically as follows:

$$E_5 = A\,(E_2 - \mathrm{E}dc) = A.R'\mathrm{h}\,(\mathrm{h}) \cdot W \cdot \mathrm{E} - \mathrm{A} \cdot \mathrm{E}dc \qquad (8)$$

$$E_6 = A\,(E_3 - \mathrm{E}dc) = A \cdot R \cdot \mathrm{h}\,(\mathrm{h}) \cdot W \cdot E - \mathrm{A} \cdot \mathrm{E}dc \qquad (9)$$

$$E_7 = A\,(E_4 - \mathrm{E}dc) = A \cdot Rn \cdot \mathrm{W} \cdot \mathrm{E} - A \cdot \mathrm{E}dc \qquad (10)$$

where A is the amplification degree of the AC amplifier **48**.

With the DC component removed, the amplifier output signals are fed into gate circuits **50** and **51** to which gate signals are applied from the wave forming circuit **42**. The *th* and following *tc* signals pass through the gate circuit **50**. FIG. **6**E shows the output signal waveform of the gate circuit **50**. The output of the said gate circuit is fed into a synchronizing rectifier **52** to which a synchronizing signal, which is double the output signal frequency of the Schmitt circuit **41**, is applied from circuit **53** (refer to FIGS. **6**K and **6**L).

Once in the synchronizing rectifier **52**, the *th* and *tc* input signals are rectified to form positive and negative signals respectively in accordance with the incoming synchronizing signals from circuit **53**. FIG. **6**F shows the output signal of the synchronizing rectifier **52** and FIG. **6**G shows the rectified output after being smoothed by filter **54**. The output voltage E_8 of the said filter is expressed as follows:

$$E_8 = \frac{1}{4}\{E_5 - E_7\}$$
$$= \frac{1}{4}\{A'R'h(h)\cdot W'E - A'Edc - ARn\cdot W'E + A'Edc\}$$
$$= \frac{1}{4}A'W'E\cdot\{R'h(h) - Rn\}$$
$$= \frac{1}{4}A'W'E'Rh(h) \quad (11)$$

On the other hand, the tu and tc components in the output signal of the AC amplifier **48** pass through the gate circuit **51**, the output of which is shown in FIG. 6H, and are then fed into a synchronizing rectifier **55**. The synchronizing signals as shown in FIG. **6L** are also fed into the said synchronizing rectifier from the circuit **53**. As a result, the *tu* and *tc* input signals are rectified to form positive and negative signals respectively. FIG. **6I** shows the output signal of the synchronizing rectifier **55**, and FIG. **6J** shows the rectified output signal after being smoothed by filter **56**. The output voltage E_9 of the said filter is expressed as follows:

$$E_9 = \frac{1}{4}\{E_6 - E_7\}$$
$$= \frac{1}{4}A'W'E\{Ru(h) - Rn\}$$
$$= \frac{1}{4}A'W'E'Ru(h) \quad (12)$$

And the depolarization ratio $p(d)$ is expressed as follows:

$$p(h) = \frac{Ru(h)}{Rh(h)}$$
$$= \frac{\frac{1}{4}'A'W'E'E_9}{\frac{1}{4}'A'W'E'E_8} = \frac{E_9}{E_8} \quad (16)$$

By maintaining E_8 at a constant voltage K,p (ρ) can be expressed as follows:

$$\lambda(h) = E_9/K \quad (17)$$

Thus, E_9 is linearly proportional to the depolarization ratio $\lambda(h)$.

A comparison circuit **57** is used for maintaining the voltage E_8 constant. This is to say the signal of the filter **54** is fed into the comparison circuit **57** and compared with a reference voltage. The resultant differential voltage is then fed back to a pulse controller **46** so that the pulse width and height of the pulse passed through the pulse controller are controlled in order to maintain a constant filter output voltage. As a result, the output voltage of the filter **56** is also controlled at the same rate as the output voltage of the filter **54** by the pulse controller **46** and a voltage proportional to the depolarization ratio is obtained automatically from the filter **56**. The output signal of the filter **56** is fed into the two-pen recorder **44** via a DC amplifier **58** where the depolarization ratios are recorded in accordance with the wavelength scanned by the monochromator.

In the above embodiment, the differential voltage is fed back to the pulse controller **46** in order to control the filter output voltages. It is also possible, however, to feed back the differential voltage to the AC amplifier **48** and to control the amplification degree A of the said amplifier in order to keep the output voltage of the filter **54** constant.

FIGS. **7** and **8** show another embodiment for obtaining the two incident rays of light polarized parallel and perpendicular to the plane. In this embodiment, a sector **60**, mounted on a shaft **61** rotated by a motor **62** is inserted between the laser **1** and the sample **13**. Section **63** forming part of sector **60** comprises a half-wave plate and sections **64** serve as light intercepters. As a result, the light polarized parallel to the plane passes through the sector **60** and the light passing through section **63** is polarized perpendicular to the plane by the half-wave plate. In this way, the two incident rays of light polarized parallel and perpendicular to the plane illuminate the sample **13** alternately.

It is possible to measure the depolarization ratios by means of two Raman light rays, one polarized parallel to the plane and the other polarized perpendicular to the plane, by illuminating the sample with circularly polarized light. Referring to FIG. **9**, laser light produced by a laser **1** passes through a quarter wave plate **70** and is circularly polarized. The said polarized light is then made to illuminate sample **13**, resulting in Raman light rays being scattered from the sample. The said rays are directed to a monochromator (not shown) via a sector **71**, (see FIG. **10**), which is mounted on a shaft **72** of a motor **73**. In FIG. **10**, sections **74** and **75** represent polarizers in which the Raman light rays polarized parallel and perpendicular to the plane respectively pass. Sections **76** serve to intercept the passage of light. Thus, the two Raman light rays enter the monochromator alternately. The depolarization ratios are measured by the electrical units used in the prior described embodiments. The gate signal is produced by chopper **77**, mounted fixedly on the periphery of the sector and thereby rotating in unison with the said sector, a light source **78** and a phototransistor **79**.

FIG. **11** shows one more embodiment of this invention. In the figure, two light rays polarized parallel and perpendicular to the plane are produced by the optical system used in the embodiment shown in FIG. **1** and illuminate the sample **13** alternately. The light rays scattered from the sample are then directed to the monochromator **14** where they are dispersed according to wavelength. Once dispersed, the rays are converted into electrical signals by the photomultiplier **15** and amplified by the amplifier **16**. The amplified signals are then fed into a synchronizing rectifier **81**, to which a synchronizing signal is applied from a synchronizing signal generating circuit **82**, so that a differential signal of the intensities of the two Raman light rays resulting from the two differently polarized incident rays of light is produced. The differential signal is fed into a motor **83** via an amplifier **84**. The motor moves an attenuator **85** into the optical path between the two mirrors **10** and **12** so as to attenuate the intensity of the light polarized parallel to the plane. When the differential signal is zero, the relationship between the two Raman light rays is expressed as follows:

$$Rh(h)\,k = Ru(h)$$

$$K = Ru(h)/Rh(h)$$

where K is the attenuation coefficient of the incident light polarized parallel to the plane. Therefore, when the differential signal is zero, the attenuation coefficient K is equal to the depolarization ratio $\rho(h)$. The said coefficient, viz, the depolarization ratio, is recorded by a recorder **86** connected with the said motor **83** so that the movement of the attenuator **85** is recorded.

Having thus described the invention with the detail and particularity as required by the Patent Laws, what is desired protected by Letters Patent is set forth in the following claims.

We claim:

1. An apparatus for automatically recording the Raman Spectrum and the depolarization ratios of Raman bands of a sample comprising:

A. a monochromatic light source;

B. means for obtaining two incident rays of light polarized respectively parallel and perpendicular to a reference plane, said means being located in the optical path between said light source and said sample;

C. means for alternately illuminating said sample with said two incident rays of light;

D. a monochromator for dispersing the resultant scattered Raman light rays;

E. means for creating electrical signals indicative of the intensity of the dispersed Raman light rays;

F. detecting means for detecting the intensity of either one of the electrical signals resulting from the two differently polarized incident rays of light;

G. an analyzing circuit for providing a signal indicative of the ratio of the intermittent electrical signals resulting from the two differently polarized rays of light; and,

H. means for recording the output signals of said detecting means and said analyzing circuit simultaneously.

2. An apparatus according to claim **1** wherein said light source comprises a laser providing a plane polarized monochromatic output.

3. An apparatus for automatically recording the Raman Spectrum and the depolarization ratios of Raman bands of a sample comprising:

A. a monochromatic light source;

B. means for obtaining two incident rays of light polarized respectively parallel and perpendicular to a reference plane, said means being located in the optical path between said light source and said sample;

C. means for alternately illuminating said sample with said two incident rays of light;

D. a monochromator for dispersing the resultant scattered Raman light rays;

E. means for creating an electrical signal indicative of the intensity of the dispersed Raman light rays;

F. detecting means for detecting the intensity of either one of the electrical signals resulting from the two differently polarized incident rays of light;

G. an analyzing circuit for providing a signal indicative of the ratio of the intermittent electrical signals supplied thereto comprising:

1. circuit means for comparing the signal voltage of the Raman light resulting from the parallel polarized incident rays of light to a reference voltage;
2. a control circuit and a circuit means for feeding back the differential voltage observed in the comparing circuit to control the intensity of both electrical signals maintaining the signal based on the parallel polarized incident rays of light constant;
3. circuit means for producing a signal being the difference between the signal voltage of the Raman light resulting from the perpendicular polarized incident rays of light, said signal being indicative of the depolarization ratios; and,

H. means for recording the depolarization ratios and the output signal of the detecting means simultaneously.

4. An apparatus for automatically recording the Raman Spectrum and the depolarization ratios of Raman bands of a sample comprising

A. a monochromatic light source;

B. means for obtaining two incident rays of light polarized respectively parallel and perpendicular to a reference plane, said means being located in the optical path between said light source and said sample,

C. means for alternately illuminating said sample with said two incident rays of light;

D. a monochromator for dispersing the resultant scattered Raman light rays;

E. means for creating an electrical signal indicative of the intensity of the dispersed Raman light rays;

F. detecting means for detecting the intensity of either one of the electrical signals resulting from the two differently polarized incident rays of light;

G. means for producing a differential signal of said electrical signals;

H. means for attenuating the intensity of the incident light polarized parallel to the plane according to said differential signal so as to equalize the intensities of the two Raman light rays; and,

I. means for recording the attenuation coefficient of the incident light polarized parallel to the plane and the output signal of said detecting means simultaneously.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,697,180 Dated October 10, 1972

Inventor(s) Hajime Mori and Mamoru Irizuki

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Title, "HEDEPOLARIZATION" should read --DEPOLARIZATION--

Col. 4, l. 11, formula (3) should read --$R'u(\lambda) = Ru(\lambda) + Rn$--

Col. 4, l. 42, formula (8) should read

--$E_5 = A(E_2 - Edc) = A \bullet R'h(\lambda) \bullet W \bullet E - A \bullet Edc$ --

Col. 4. l. 43, formula (9) should read

--$E_6 = A(E_3 - Edc) = A \bullet R'h(\lambda) \bullet W \bullet E - A \bullet Edc$ --

Col. 5, l. 2, the formula should read

--$= \frac{1}{4} \left\{ A \bullet R'h(\lambda) \bullet W \bullet E - A \bullet Edc - A \bullet Rn \bullet W \bullet E + A \bullet Edc \right\}$--

Col. 5, l. 3, the formula should read

--$= \frac{1}{4} \left\{ A \bullet W \bullet E \bullet R'h(\lambda) - Rn \right\}$ --

Col. 5, l. 4, formula (11) should read

--$= \frac{1}{4} A \bullet W \bullet E \bullet Rh(\lambda)$--

FORM PO-1050 (10-69)

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,697,180 Dated October 10, 1972

Inventor(s) Hajime Mori and Mamoru Irizuki -2- (continued)

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 5, l. 24, the formula should read

$$-- = \frac{1}{4} A \cdot W \cdot E \left\{ Ru\ (\lambda) - R_n \right\} --$$

Col. 5, l. 25, formula (12) should read

$$-- = \frac{1}{4} A \cdot W \cdot E \cdot Ru\ (\lambda) --$$

Col. 5, l. 26, "p (d)" should read $--\rho(\lambda)--$

Col. 5, l. 29, the formula should read

$$--\rho(\lambda) = \frac{Ru\ (\lambda)}{Rh\ (\lambda)} --$$

Col. 5. l. 32, formula (16) should read

$$-- = \frac{\frac{1}{4} \cdot A \cdot W \cdot E \cdot E_9}{\frac{1}{4} \cdot A \cdot W \cdot E \cdot E_8} = \frac{E_9}{E_8}$$

Col. 5, l. 36, "p (ρ)" should read $--\rho(\lambda)--$

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,697,180 Dated October 10, 1972

- 3 -

Inventor(s) Hajime Mori and Mamoru Irizuki (continued)

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 5, l. 39, formula (17) should read -- $\rho(\lambda) = \frac{E_9}{K}$ --

Col. 5, l. 41, "λ(h)" should read -- $\rho(\lambda)$ --

Col. 6, l. 58, the formula should read -- $Rh(\lambda)\,K = Ru(\lambda)$ --

Col. 6, l. 61, the formula should read

-- $K = \frac{R_u(\lambda)}{Rh(\lambda)}$ --

Col. 6, l. 66, "ρ(h)" should read -- $\rho(\lambda)$ --

Signed and sealed this 6th day of March 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents