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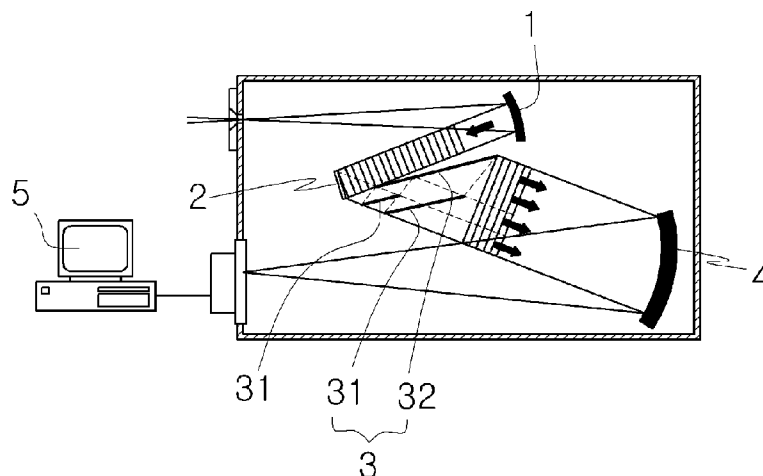
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(54) **Title:** DIFFRACTION GRATING SPECTROMETER

[Fig. 2]



(57) **Abstract:** Disclosed is a diffraction grating spectrometer. The diffraction grating spectrometer obtains the high spectral resolution by using diffraction gratings having a smaller number of grating lines and low grid density. In the diffraction grating spectrometer, a beam diffracted from a small-size diffraction grating is expanded through the intensity division and wave front reconstruction by using an intensity division/wave front reconstruction unit to obtain the spectral resolution realized by a large-size diffraction grating, so that the size of the diffraction grating spectrometer is reduced.



Description

Title of Invention: DIFFRACTION GRATING SPECTROMETER

Technical Field

- [1] The present invention relates to a diffraction grating spectrometer. More particularly, the present invention relates to a diffraction grating spectrometer capable of obtaining the high spectral resolution by using diffraction gratings having a smaller number of grating lines and low grid density.
- [2] In particular, the present invention relates to a diffraction grating spectrometer, in which a beam diffracted from a small-size diffraction grating is expanded through the intensity division and wave front reconstruction by using an intensity division/wave front reconstruction unit to obtain the spectral resolution realized by a large-size diffraction grating, so that the size of the diffraction grating spectrometer can be reduced.

Background Art

- [3] A spectrometer is a device for measuring the spectrum of light emitted from or absorbed in a material and includes an interference spectrometer, a prism spectrometer and a grating spectrometer.
- [4] The grating spectrometer uses diffraction gratings that disperse light having various wavelengths. The diffraction gratings have been used for the Raman scattering research to analyze the molecular vibration mode, the spectrum measurement for fluorescent light generated from a biological specimen or a chemical specimen, and the optical spectrum analysis for a photonic device. Recently, the diffraction gratings are also used for manipulating ultra-short laser pulses.
- [5] One example of the spectrometer is shown in FIG. 1. As shown in FIG. 1, according to the conventional spectrometer, a light irradiated from a light source is reflected from a mirror 100, and the reflected light is diffracted by a diffraction grating 200 and then introduced into a detection unit 400 after it has been reflected by a mirror 300, so that the light can be detected.
- [6] The performance of the conventional spectrometer can be determined depending on the spectral resolution. In addition, the spectral resolution is determined depending on the number of grating lines on which the incident beam is irradiated. In detail, the diffraction grating must have a large size to increase the number of the grating lines in order to improve the spectral resolution.
- [7] In order to increase the spectral resolution, there have been suggested a method for increasing the number of the grating lines by enlarging the size of the diffraction grating and a method for increasing the grid density. However, the method for in-

creasing the grid density requires the high-precision technology and the manufacturing cost is increased in a geometrical progression as the size of the diffraction grating is enlarged. For this reason, the method for enlarging the size of the diffraction grating has been adopted to improve the spectral resolution.

- [8] However, according to the method for enlarging the size of the diffraction grating, as shown in FIG. 1, a great space is required for the diffraction grating, so that the size of the spectrometer becomes enlarged.

Disclosure of Invention

Technical Problem

- [9] The present invention has been made to solve the above problems occurring in the prior art, and an object of the present invention is to provide a diffraction grating spectrometer capable of improving the spectral resolution by using diffraction gratings having a small size, in which a beam diffracted from a diffraction grating having a small diffraction area is subject to the intensity division and the wave front reconstruction through an intensity division/wave front reconstruction unit having the multi-step structure, so that the beam can be expanded, thereby improving the spectral resolution.

Solution to Problem

- [10] In order to accomplish the above object, the present invention provides a diffraction grating spectrometer for outputting a beam irradiated from a light source to an analysis/detection unit by diffracting the light using a diffraction grating. The diffraction grating spectrometer includes an intensity division/wave front reconstruction unit including a semi-transparent mirror, which divides an intensity of the beam diffracted from the diffraction grating to reflect a part of the beam and to transmit a remaining beam, and a total reflection mirror, which expands a wave front of the beam by aligning a wave front of the beam reflected from the semi-transparent mirror on a same phase with a wave front of the beam transmitting through the semi-transparent mirror and reconstructing the wave fronts of the beams such that opposite sides of the wave fronts of the beams make contact with each other.

Advantageous Effects of Invention

- [11] According to the present invention, the light diffracted from the diffraction grating is expanded by the intensity division/wave front reconstruction unit having the singular structure or the multi-step structure, so the spectral resolution realized by the diffraction grating having the large size can be obtained even if the diffraction grating has the small size, thereby reducing the size of the spectrometer.

Brief Description of Drawings

- [12] FIG. 1 is a schematic view showing the structure of a diffraction grating spectrometer

according to the related art;

[13] FIG. 2 is a schematic view showing the structure of a diffraction grating spectrometer according to the embodiment of the present invention;

[14] FIG. 3 is a graph showing the principle of a spectrometer using a semi-transparent mirror;

[15] FIG. 4 is a graph showing a path of light according to the number of mirrors;

[16] FIG. 5 is a graph showing a phase mismatch according to the arrangement state of mirrors and diffraction gratings; and

[17] FIG. 6 is a graph showing a spectral line according to the arrangement state of mirrors and diffraction gratings.

Mode for the Invention

[18] Hereinafter, exemplary embodiments of the present invention will be described in detail. The accompanying drawings are illustrative purposes only to easily explain the technical features, contents and ranges of the present invention and the present invention is not limited thereto. Various modifications and changes may be possible within the scope of the present invention.

[19] As shown in FIG. 2, the present invention provides a diffraction grating spectrometer, in which the high spectral resolution realized by a large-size diffraction grating can be obtained by using a small-size diffraction grating, so that the size of the diffraction grating spectrometer can be reduced. The diffraction grating spectrometer includes a diffraction grating 2 and an intensity division/wave front reconstruction unit 3 for expanding a beam diffracted from the diffraction grating 2.

[20] The diffraction grating 2 diffracts the incident beam and outputs the incident beam to an analysis/detection unit 5. Although the diffraction grating 2 is similar to the diffraction grating used for the conventional spectrometer, the size of the diffraction grating 2 can be reduced as compared with that of the diffraction grating used for the conventional spectrometer. This is because the spectral resolution the same as that of the related art can be achieved by expanding or multi-expanding the beam using the intensity division/wave front reconstruction unit 3.

[21] The intensity division/wave front reconstruction unit 3 includes a semi-transparent mirror 31 which divides the intensity of the beam diffracted from the diffraction grating to reflect a part of the beam and to transmit the remaining beam, and a total reflection mirror 32, which expands the wave front of the beam by reconstructing the wave front of the beam reflected from the semi-transparent mirror 31 such that the wave front of the beam reflected from the semi-transparent mirror 31 may not overlap with the wave front of the beam transmitting through the semi-transparent mirror 31.

[22] In detail, as shown in FIG. 4 a and b, the intensity division/wave front reconstruction

unit 3 reflects the reflection beam reflected from the semi-transparent mirror 31 by using the total reflection mirror 32 such that the transmission beam and the reflection beam may travel in parallel to each other, and reconstructs the wave front of the beam such that the wave front of the transmission beam may not overlap with the wave front of the reflection beam, thereby expanding the beam.

- [23] The intensity division/wave front reconstruction unit 3 has the multi-step structure arranged in series, so the beam incident into each step of the intensity division/wave front reconstruction unit 3 is subject to the intensity division or wave front reconstruction, so that the beam can be output while being gradually expanded. For instance, the beam can be expanded about 2^n times, in which 'n' represents the number of steps of the intensity division/wave front reconstruction unit 3.
- [24] In addition, the semi-transparent mirror 31 and the total reflection mirror 32 constituting the intensity division/wave front reconstruction unit 3 can be prepared as individual units separated from each other in such a manner that the number of the semi-transparent mirror 31 and the total reflection mirror 32 may correspond to the number of the intensity division/wave front reconstruction units. In this case, preferably, the semi-transparent mirror units and the total reflection mirror units are configured to have widths gradually increased in such a manner that all incident beams can be subject to the intensity division or total reflection.
- [25] For instance, if the width of the incident beam is 1, the width of the semi-transparent mirror unit and the total reflection mirror unit of the first intensity division/wave front reconstruction unit is 1 or slightly larger than 1. In this case, the beam output through the first intensity division/wave front reconstruction unit is expanded to have the width of 2, so the width of the semi-transparent mirror unit and the total reflection mirror unit of the second intensity division/wave front reconstruction unit 3 must be 2 or slightly larger than 2. That is, the size of the semi-transparent mirror unit and the total reflection mirror unit may be gradually increased as the number of the intensity division/wave front reconstruction units is increased.
- [26] In addition, as shown in FIG. 4 c, according to another embodiment of the semi-transparent mirror 31 and the total reflection mirror 32 constituting the intensity division/wave front reconstruction unit 3, a plurality of intensity division/wave front reconstruction units may share one total reflection mirror 32 having a large area.
- [27] In this case, the semi-transparent mirrors 31 are configured to have widths gradually increased such that all of incident beams can be subject to the intensity division.
- [28] In addition, an angle between the diffraction grating 2 and the semi-transparent mirror 31 can be adjusted such that the intensity division and the wave front reconstruction can be achieved according to the incident angle of the beam. Such an angle adjustment can be performed by using various fine adjustment devices generally

known in the art. In this case, the angles of the semi-transparent mirror 31 and the total reflection mirror 32 may be adjusted while fixing the diffraction grating, or the total reflection mirror 32 and the diffraction grating may be adjusted while fixing the angles of the semi-transparent mirror 31.

[29] As described above, although it is possible to analyze and detect the light by directly irradiating the light of the light source to the diffraction grating 2, a plurality of mirrors can be installed to facilitate the analysis for the light. For instance, a first mirror 1 can be installed at one side of the diffraction grating 2 to reflect the beam irradiated from the light source toward the diffraction grating 2 and a second mirror 4 can be installed to reflect the beam output through the intensity division/wave front reconstruction unit 3 such that the beam can be introduced into the analysis/detection unit 5.

[30] Hereinafter, the construction and operation of the present invention will be described in detail.

[31] First, the process for dividing the light by reflecting and transmitting the light through the intensity division/wave front reconstruction unit 3 of the diffraction grating spectrometer will be described.

[32] As shown in FIG. 3, the plane wave above and below the diffraction grating 2 can be expressed as follows.

[33] (1)

$$\phi(\vec{x}) = \phi_i(\vec{x}; \vec{k}_i) = A(\vec{k}_i) \exp[-i\vec{k}_i \cdot \vec{x}] \quad \text{for } z < 0$$

[34] (2)

$$\phi(\vec{x}) = \sum_m \phi_m(\vec{x}; \vec{k}_m) = \sum_m A(\vec{k}_m) \exp[-i\vec{k}_m \cdot \vec{x}] \quad \text{for } z > 0$$

[35] In the above equations, $\vec{k}_i$ is a wave vector of the incident beam and $\vec{k}_m$ is a wave vector of the m diffraction order beam. In addition, the size is as follows

$$\vec{k}_i^2 = \vec{k}_m^2 = \vec{k}^2. \text{ If the translation operator } \vec{T}_{\vec{a}} \text{ is applied to each beam, } \phi_i(\vec{x}; \vec{k}_i) \text{ is converted into}$$

$$\exp[i\vec{k}_i \cdot \vec{a}] \phi_i(\vec{x}; \vec{k}_i) \text{ and } \phi_m(\vec{x}; \vec{k}_m)$$

$$\text{is converted into } \exp[i\vec{k}_m \cdot \vec{a}] \phi_m(\vec{x}; \vec{k}_m),$$

wherein $\vec{a}$ is a movement vector.

[36] As shown in FIG. 3, two mirrors M1 and M2 (sky-blue color) are installed on a surface of the diffraction grating 2 so that the diffracted beam is reflected twice. Thus, the reflected beam is spatially moved by $|\vec{a}| = 2\alpha$ from A to A' (marked with a pink

arrow). The condition for making the phase of the beam before movement identical to the phase of the beam after movement can be found from the following equation.

[37] (3)

[38]
$$\hat{T}_{\vec{a}} \phi_m(\vec{x}; \vec{k}_m) = \exp[i\vec{k}_m \cdot \vec{a}] \phi_m(\vec{x}; \vec{k}_m) = \phi_m(\vec{x}; \vec{k}_m)$$

$$\vec{k}_m \cdot \vec{a} = 2\pi n \quad \text{or} \quad 2d \cos(\theta + \theta_m(\lambda)) = n\lambda \quad (n = \text{integer})$$

[39] In the above equation, $\theta_m(\lambda)$ is a diffraction angle at the m diffraction order, d is a

distance between mirrors and θ is an inclination angle of mirrors. In addition to the above equation, each beam must satisfy the diffraction grating equation of

$b(\sin \theta_i + \sin \theta_m(\lambda)) = m\lambda$, wherein b is the grating period and θ_i is the incident angle. If the equation of the trigonometric

function $\sin(\theta + 90) = \cos \theta$ is utilized, equation (3) can be expressed as $2d \sin(90 + \theta + \theta_m(\lambda)) = n\lambda$. When comparing with the diffraction grating equation, $\theta = -90^\circ$ and $\theta_i = 0^\circ$ are

resulted, wherein $2dm = nb$.

[40] Since n is the integer, the above result signifies that the beam must be moved by multiple times of the grating period in all diffraction orders. This result coincides with the result expected by intuition.

[41] In order to apply the above result, an optical system has been constructed as shown in FIG. 2. A distance between the semi-transparent mirror 31 and the total reflection mirror 32 constituting the intensity division/wave front reconstruction unit 3 is set to $d = nb/2$, and the angle between the semi-transparent mirror 31 and the diffraction grating 2 is set to 90. Since the semi-transparent mirror 31 reflects the light by a half (50%), both the original diffraction beam and the reflected beam are present. Since these two beams have the same intensity and phase, the irradiation range may be widened by two times.

[42] Therefore, as shown in FIG. 4 c, if the diffraction grating spectrometer is configured to have two intensity division/wave front reconstruction unit 3, one total reflection mirror M2 having the large area and two semi-transparent mirrors M1 and M3, the spectral resolution, which is identical to the spectral resolution obtained by the conventional spectrometer having the diffraction grating with the size four times larger than the size of the diffraction grating of the conventional diffraction grating spectrometer according to the present invention, can be obtained. The above procedure may be continuously repeated.

[43] The above description has been made based on the light vertically incident onto the diffraction grating and the following description will be made based on the typical incident light.

[44] If the incident beam is not vertically irradiated onto the diffraction grating, equation (3) may not be applicable for all wavelengths. Thus, the equation available in a narrow region in the vicinity of the specific wavelength λ_0 must be found. To this end, both sides of equation (3) are differentiated to obtain the following equation.

[45] (4)

$$[46] \quad -2d \sin(\theta + \theta_m(\lambda)) \left(\frac{d\theta_m}{d\lambda} \right) = n \quad \text{at } \lambda = \lambda_0$$

[47] The grating dispersion is $d\theta_m / d\lambda = m / b \cos \theta_m$, which leads to the following equation.

[48] (5)

$$[49] \quad -\frac{nb}{2dm} = \frac{\sin(\theta + \theta_m(\lambda))}{\cos \theta_m(\lambda)}$$

[50] In addition, the following equation can be obtained by comparing equation (3) with equation (5).

[51] (6)

$$[52] \quad \frac{b}{\lambda m} \cos \theta_m(\lambda) = -\tan(\theta + \theta_m(\lambda))$$

[53] Here, θ can be obtained by solving equation (6).

[54] In addition, n can be obtained based on d , θ_m and equation (5).

[55] At this time, $n \times 2$ represents the phase mismatch between the original diffraction beam and the parallel-moved beam.

[56] The wavelength region capable of improving the spectral resolution can be obtained based on the phase mismatch plots a function of the wavelength. For instance, FIG. 5 a shows the case where the diffraction grating having the grid density of 830 lines/mm is vertical to a pair of the semi-transparent mirror and the total reflection mirror, and FIG. 5 b shows the case where the diffraction grating is inclined at an angle of 94 with respect to a pair of the semi-transparent mirror and the total reflection mirror.

[57] In this case, $\lambda_0 = 773\text{nm}$, and the incident angle θ_0 is 5.5, wherein $m = 1$, and $d = 3.5\text{mm}$.

[58] Thus, the pair of the semi-transparent mirror and the total reflection mirror is further rotated clockwise by an angle of 4° .

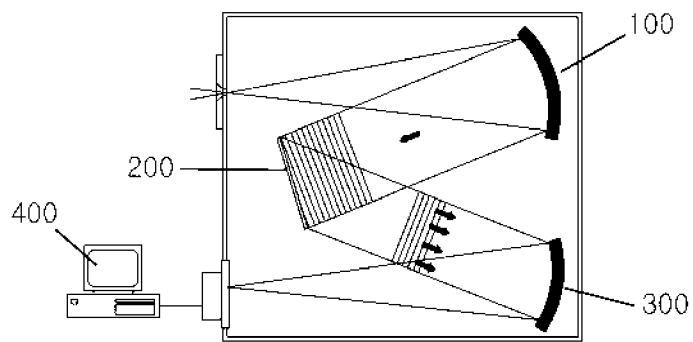
- [59] In the vicinity of the central wavelength ($\lambda_c = 773\text{nm}$), the value of the phase mismatch at the region having a relatively large spectral area ($\Delta\lambda = 36\text{nm}$) is less than 0.25×2 , so the spectral resolution can be improved.
- [60] FIG. 6 is a graph showing a spectral line, in which FIG. 6 a shows the spectral line of the light measured by using only the diffraction grating, FIG. 6 b shows the spectral line when the diffraction grating is arranged vertically to the pair of the semi-transparent mirror and the total reflection mirror of the intensity division/wave front reconstruction unit, and FIG. 6 c shows the spectral line when the diffraction grating is inclined at an angle of 94° with respect to the pair of the semi-transparent mirror and the total reflection mirror.
- [61] As shown in FIG. 6 c, the spectral line is evenly narrowed in the given wavelength region. If the pair of the semi-transparent mirror and the total reflection mirror of the intensity division/wave front reconstruction unit is vertically arranged without being inclined, the phase mismatch may be significantly changed depending on the wavelength variation as shown in FIG. 5 a. Thus, the spectral line may not be uniform, but severely deformed as shown in FIG. 6. b. According to the above theory and experimental result, the spectral resolution can be improved by the intensity division/wave front reconstruction unit including at least one pair of the semi-transparent mirror and the total reflection mirror although the incident angle of the light is not vertical to the diffraction grating.
- [62]
- [63]

Claims

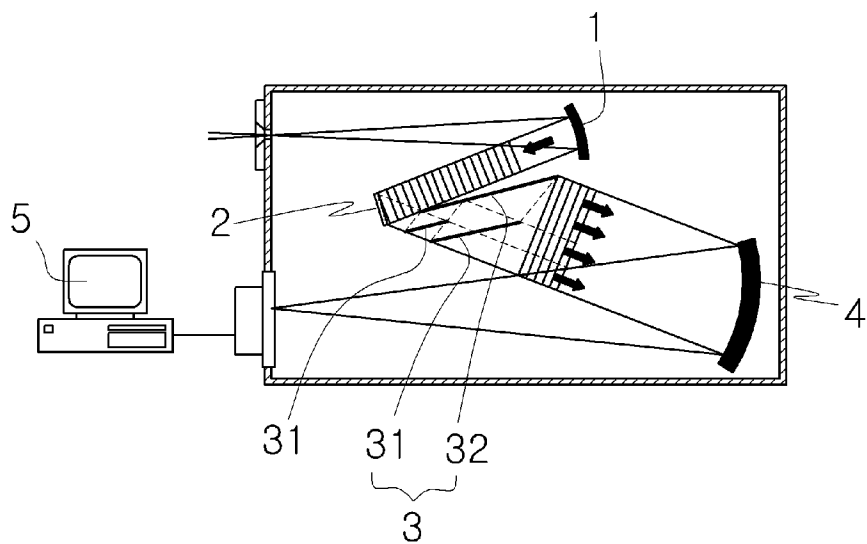
- [Claim 1] A diffraction grating spectrometer for outputting a beam irradiated from a light source to an analysis/detection unit by diffracting the light using a diffraction grating, the diffraction grating spectrometer comprising:
an intensity division/wave front reconstruction unit (3) including a semi-transparent mirror (31), which divides an intensity of the beam diffracted from the diffraction grating (2) to reflect a part of the beam and to transmit a remaining beam, and a total reflection mirror (32), which expands a wave front of the beam by aligning a wave front of the beam reflected from the semi-transparent mirror on a same phase with a wave front of the beam transmitting through the semi-transparent mirror and reconstructing the wave fronts of the beams such that opposite sides of the wave fronts of the beams make contact with each other.
- [Claim 2] The diffraction grating spectrometer of claim 1, wherein the intensity division/wave front reconstruction unit (3) has a multi-step structure arranged in series, so the beam incident into each step of the intensity division/wave front reconstruction unit (3) is subject to intensity division and wave front reconstruction, so that the beam is output while being gradually expanded.
- [Claim 3] The diffraction grating spectrometer of claim 2, wherein the semi-transparent mirror and the total reflection mirror of the intensity division/wave front reconstruction unit (3) having the multi-step structure are prepared as individual units separated from each other and the semi-transparent mirror units and the total reflection mirror units are configured to have widths gradually increased in such a manner that all incident beams are subject to the intensity division or total reflection.
- [Claim 4] The diffraction grating spectrometer of claim 2, wherein the intensity division/wave front reconstruction unit (3) having the multi-step structure includes a plurality of semi-transparent mirrors separately aligned in each step of the multi-step structure and one total reflection mirror having a large area, and the semi-transparent mirrors have widths gradually increased so that all incident beams are subject to the intensity division or total reflection.
- [Claim 5] The diffraction grating spectrometer of claim 1, wherein an angle

between the diffraction grating (2) and the semi-transparent mirror (31) is adjustable according to an incident angle of the beam such that the beam is subject to the intensity division or total reflection.

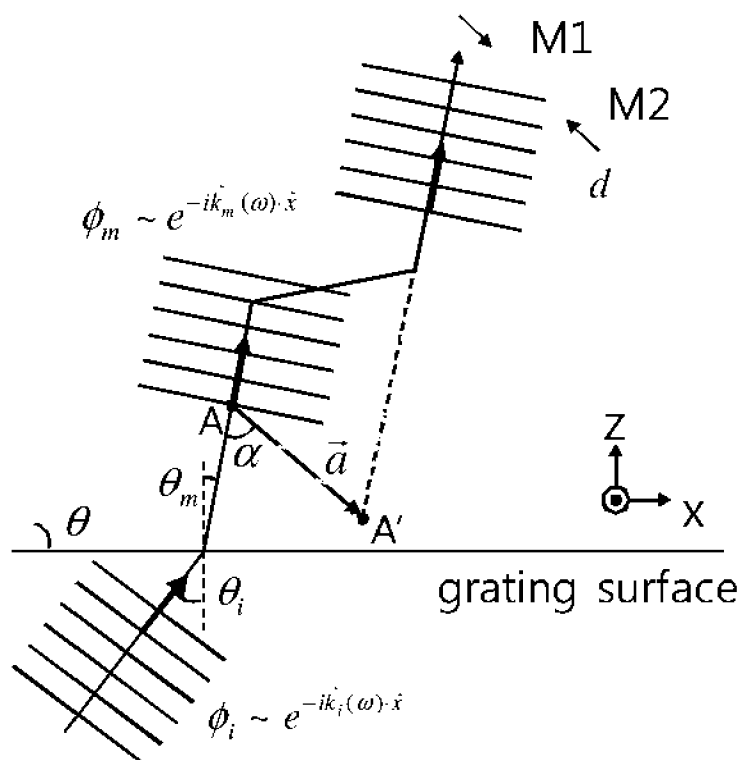
[Fig. 1]



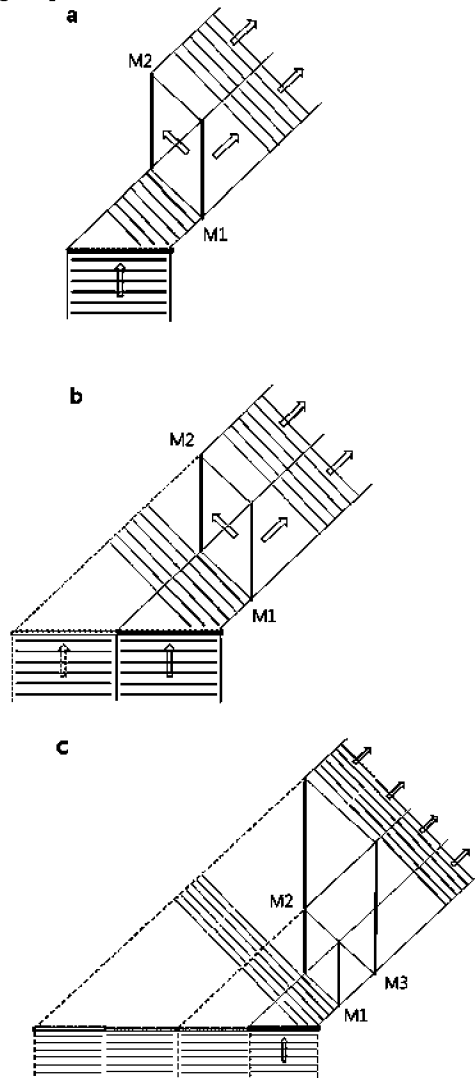
[Fig. 2]



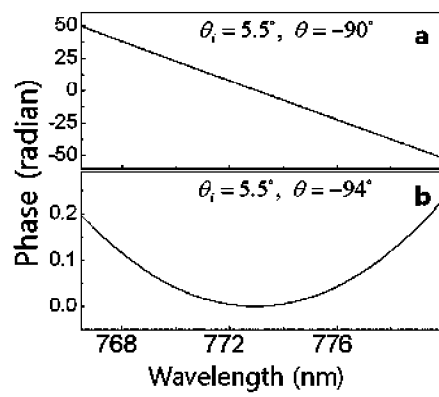
[Fig. 3]



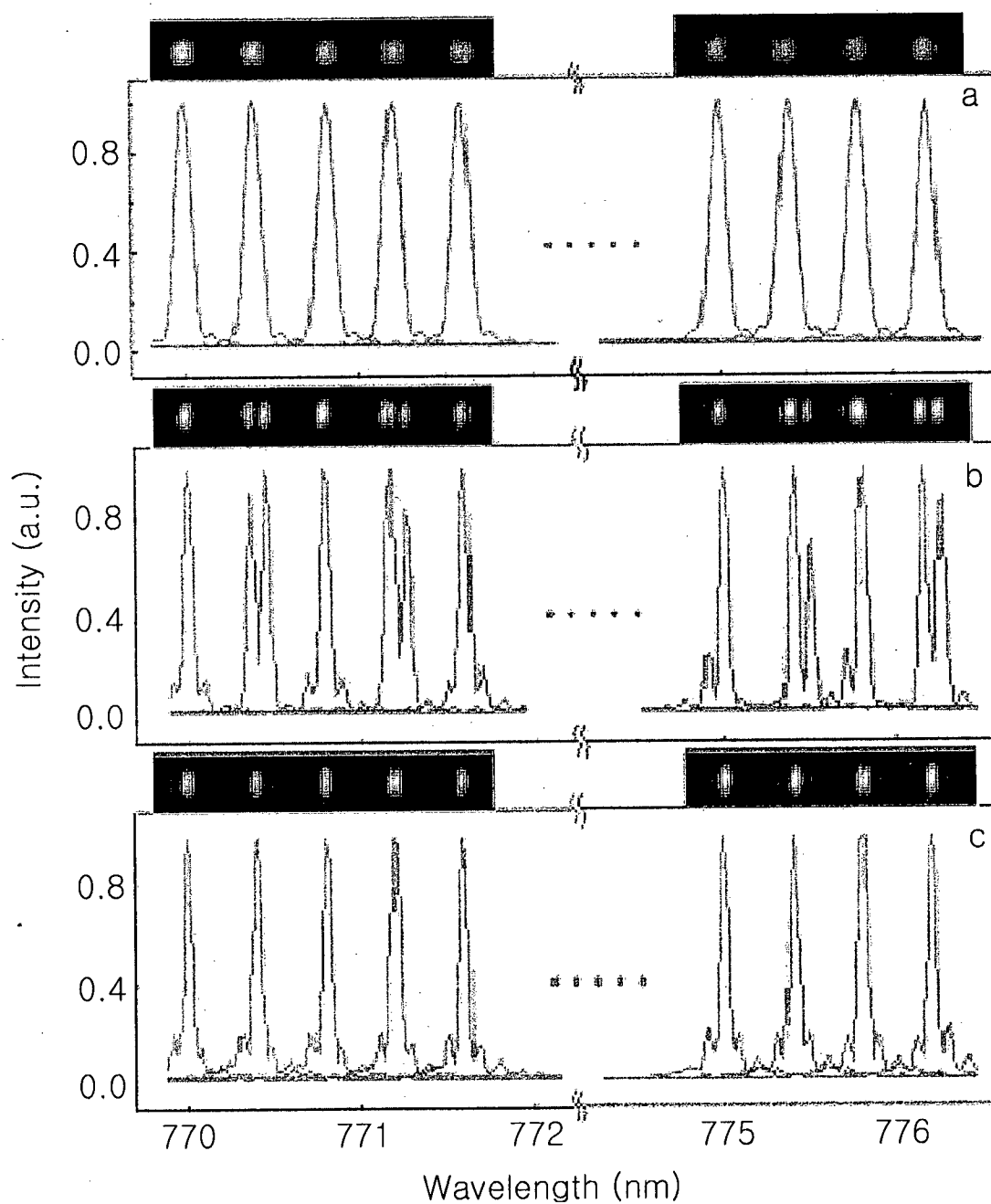
[Fig. 4]



[Fig. 5]



[Fig.6]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2011/008111**A. CLASSIFICATION OF SUBJECT MATTER****G01J 3/18(2006.01)i, G01J 3/02(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01J 3/18; G02B 5/18; G11B 7/1353; G01J 3/36; G01J 1/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: "DIFFRACTION," "GRATING," "SPECTROMETER," "MIRROR," "REFLECTION,"
AND "SEMI-TRANSPARENT"**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2004-0003907 A (LG ELECTRONICS INC.) 13 January 2004 See the abstract; figures 1-6 ; claims 1-3	1-5
A	JP 10-282318 A (NIKON CORP.) 23 October 1998 See the abstract; figures 1-5 ; claims 1-4	1-5
A	JP 06-011392 A (TOSHIBA CORP.) 21 January 1994 See the abstract; figures 1-5 ; claims 1-3	1-5
A	JP 08-509293 A (Kaiser Optical Systems, Inc.) 01 October 1996 See the abstract; figures 1-7 ; claims 1-17	1-5
A	JP 09-145477 A (TOKYO INSTR:K.K.) 06 June 1997 See the abstract; figures 1-8 ; claims 1-7	1-5

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

24 MAY 2012 (24.05.2012)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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