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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,218,326**
(22) 1997/10/16
(43) 1999/04/16

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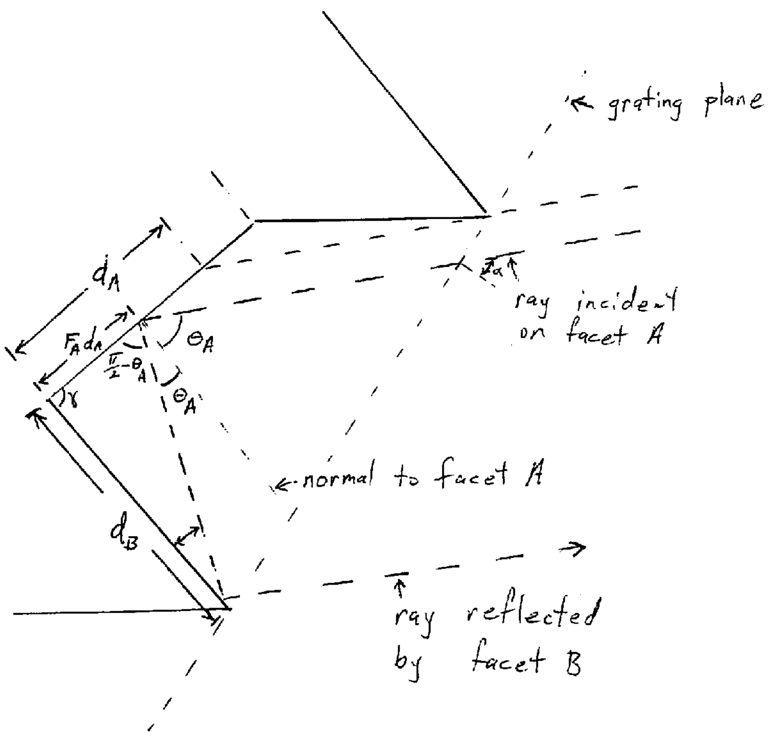
(51) Int.Cl.[6] G02B 5/18

(54) **RESEAU DE DIFFRACTION REFLECHISSANT DOTE DE RAINURES AYANT DEUX FACETTES REFLECHISSANTES**

(54) **REFLECTIVE DIFFRACTION GRATING WITH GROOVES COMPRISING TWO REFLECTIVE FACETS**



(57) Réseau de diffraction réfléchissant formé par un réseau de rainures, chacune étant constituée de deux facettes réfléchissantes et d'une surface montante. Les deux facettes réfléchissantes d'une seule rainure sont orientées de façon qu'une partie des rayons lumineux frappant la rainure soit réfléchie une fois par chaque facette. La surface montante relie une des facettes réfléchissantes d'une rainure à une des facettes réfléchissantes d'une rainure contiguë et n'est pas conçue pour réfléchir la lumière atteignant la rainure.

(57) A reflective-type diffraction grating is formed by an array of grooves, each groove comprising two reflective facets and a riser. The two reflective facets of a single groove are oriented so that some of the light rays incident on the groove reflect once off each facet. The riser joins one of the reflective facets within one groove to one of the reflective facets in an adjacent groove and is not designed to reflect light incident on the groove. In one embodiment that is particularly suited to the Littrow mount or the Eagle mount, the reflective facets are

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Dans une version particulièrement appropriée à une fixation Littrow ou à une fixation Eagle, les facettes réfléchissantes sont orientées à angles droits afin que les rainures rétroréfléchissent les rayons lumineux qui les frappent. Dans une version particulièrement conçue pour un démultiplexeur optique intégré, l'interface entre deux milieux diélectriques sert de facettes réfléchissantes et la lumière incidente est propagée à travers le milieu affichant l'index de réfraction le plus élevé, de sorte que les facettes peuvent réfléchir la lumière principalement au moyen de la réflexion interne totale.

oriented at right angles so that the grooves will retroflect the incidence light rays. In one embodiment that is particularly suited for integrated optical demultiplexer, the interface between two dielectric media is used for the reflective facets and the incident light propagates through the medium with the higher index of refraction so that the reflective facets may reflect light predominantly by means of total internal reflection.

ABSTRACT

A reflective-type diffraction grating is formed by an array of grooves, each groove comprising two reflective facets and a riser. The two reflective facets of a single groove are oriented so that some of the light rays incident on the groove reflect once off each facet. The riser joins one of the reflective facets within one groove to one of the reflective facets in an adjacent groove and is not designed to reflect light incident on the groove. In one embodiment that is particularly suited to the Littrow mount or the Eagle mount, the reflective facets are oriented at right angles so that the grooves will retroreflect the incidence light rays. In one embodiment that is particularly suited for integrated optical demultiplexer, the interface between two dielectric media is used for the reflective facets and the incident light propagates through the medium with the higher index of refraction so that the reflective facets may reflect light predominantly by means of total internal reflection.

REFLECTIVE DIFFRACTION GRATING WITH GROOVES COMPRISING TWO REFLECTIVE FACETS

This invention relates to a reflecting diffraction grating.

BACKGROUND OF THE INVENTION

Reflecting diffraction gratings have commonly been employed as the optical element primarily responsible for the separation of light into components of different wavelength.

Examples of relevant prior art are disclosed in the following U.S. patent:

4,838,645 6/1989 Mächler, et al. 350/162.23

and in the following other publications:

1) M.C. Hutley, "Diffraction Gratings," Academic Press, New York, 1982.

2) E. Hecht and A. Zajac, "Optics," Addison-Welsy, Melano Park, California, 1979.

3) R.A. Livingston and R.R. Krchnavek, "Planar diffraction grating for board-level WDM application," International Conference on Massively Parallel Processing Using Optical Interconnects (MPPOI), Proceedings 1996, IEEE, Los Alamitos, CA, pp. 77-84, 1996.

4) K.A. McGreer, IEEE Photon. Technol. Lett., vol. 7, no. 4, pp. 397-399, 1995.

5) P.C. Clemens, et al., IEEE Photon. Technol. Lett., vol., 6, no. 9, pp. 1109-1111, 1994.

6) C. Cremer, et al., IEEE Photon Technol. Lett., vol., 4, no. 1, pp. 108-110, 1992.

7) J. Soole, et al., Electronics Letters, vol. 27, no.2, pp.132-134, 1991.

The theory, manufacture techniques and applications of gratings has been reviewed by Hutley [1 above]. Planar gratings are designed so that an incident monochromatic plane wave is diffracted into an emerging plane wave with an angle of diffraction that depends on the optical wavelength. Concave gratings are designed so that diverging monochromatic light from a point source is diffracted into a converging wave that is focused to a point, the location of the point depends on the optical wavelength.

If the incident light propagating towards the grating passes through a homogeneous, three dimensional region, then the grating is said to be a bulk optic grating. The homogeneous, three dimensional region may be vacuum, air, or a dielectric material.

If the incident light propagating towards the grating passes through an optical slab waveguide, then the grating is said to be an integrated optical diffraction grating. An optical slab waveguide is composed of a dielectric slab that is bounded by material of higher refractive index such that light is guided within the dielectric slab.

The grating efficiency refers to the optical power that is diffracted into a particular diffraction order divided by the incident optical power of a monochromatic source.

An arrangement in which the angle of incidence α nearly equals the angle of diffraction β (i.e., condition the angular deviation α-β is near zero in value) has been referred to as the "autocollimation condition" or a "retro-reflecting arrangement." When a grating satisfies the autocollimation condition the grating arrangement is referred to as the "Littrow mount" in the case of planar gratings and the "Eagle mount" in the case of concave gratings. Gratings that satisfy the autocollimation condition have greater efficiency than similar gratings that do not satisfy the autocollimation condition [see 1 above Pp.211-212].

A grating referred to as a "blazed grating" in the prior art utilizes a groove shape that is comprised of a series of facets separated by risers. Each facet is designed to be planar reflecting surface oriented to provide specular reflection into a particular diffraction order. For a facet at an angle of ϕ relative to the surface of the grating, specular reflection from the facet is provided at angle $\beta=2\phi-\alpha$ and diffraction efficiency will be maximum near angle β. Blazed gratings have greater efficiency than similar gratings that are not blazed. Each riser is usually oriented with its surface nearly parallel to the direction of propagation of the incident light. Light may inadvertently reflect off the riser, but the riser is not oriented to take advantage of this reflected light.

In the prior art, metallic coatings have been applied to the facets to enhance the facet reflectivity.

An alternative technique for maximizing facet reflectivity is to utilize total internal reflection. Total internal reflection can occur at a surface separating a high refractive index optical medium from a low refractive index medium. When an optical plane wave is incident on the surface from the high index side at an angle greater than the critical angle, the light will be undergo total internal reflection [see 2 above].

When the incident light propagates through an optical slab waveguide the light may be regarded as begin composed of a combination of plane waves, each propagating in a different direction. When most of these plane wave components are incident on the surface at angles greater than the critical angle, then the guided light will be reflected predominantly by total internal reflection.

The above U.S. Pat. No. 4,838,645 describes a grating with grooves, where each groove is comprised of a single reflective facet which, when used with an angular deviation $|\alpha-\beta|$ greater than 90°, reflects light by total internal reflection. This latter invention required an angular deviation that prohibits its use in Littrow mount or in Eagle mount.

A grating similar to that of above U.S. Pat. No. 4,838,645 is described in 3 and 4 above.

Integrated optical diffraction gratings have potential application as optical demultiplexers in a wavelength division multiplexed (WDM) telecommunication systems. Such a grating could economically separate signals that are being carried by different wavelengths of light. In this application the optical wavelengths that will most likely be relevant are 1530 - 1570 nm. Integrated concave echelle gratings with Rowland circle construction and Eagle mount have been demonstrated for this application in 6, 7 and 8 above. The design used in these latter studies require metalization of the facets to maximize the facet reflectivity.

SUMMARY OF THE INVENTION:

It is one object of the present invention to provide an improved reflective diffraction grating.

A reflective-type diffraction grating is formed by an array of grooves, each groove comprising two reflective facets and a riser.

In Figure 2A, the two reflective facets are adjacent to each other and are labeled "facet A" and "facet B" and the riser is a curved surface. In Figure 2B, the riser is a flat surface. In Figure 2C, the two reflective facets are separated by a surface referred to as the facet spacer. Most of the light rays incident on a groove of the grating will initially impinge upon one of the two reflective facets of the groove.

The essential difference between this invention and the prior art is that the interference pattern of the reflected light will be dominated by the interference pattern from light rays that each have reflected off two reflective facets. In the prior art, the riser is sometimes referred to as a facet; however, less than half the light rays reflect off both the facet and the riser, so the interference pattern is dominated by the interference pattern of light rays that each have reflected off one facet; furthermore, in the prior art, the orientation of the riser is not designed to allow light rays that have reflected off both the facet and the riser to interfere in a purposeful way. The invention will improve the performance of the grating when the reflectivity of the facets is substantially increased due to the fact that the light incident on each of the two facets typically has a larger angle of incidence than the angle of incidence of the light incident on a comparable grating with a single reflective facet.

In the prior art shown in Figure 1A, the schematic shows four grooves of the grating, each groove consisting of a facet designed to reflect light and a riser that is not designed to reflect light. Light may inadvertently reflect off the riser, but the riser is not oriented to take advantage of this reflected light. The angle of the facet ϕ is designed so that when the incident light is at angle α with respect to the grating plane, then the diffraction efficiency is maximized for diffraction at angle β. Such a grating is referred to as a blazed grating or an echelle grating.

In the prior art shown in Figure 1B, the illustration depicts six grooves of the grating. The interface between a medium of high index of refraction and low index of reflection form the reflective facets. The light incident upon the grating, propagates though the medium of high index of refraction immediately prior to impinging upon the grating.

In the prior art, less than half the light rays reflect off both the facet and the riser, so the interference pattern is dominated by the interference pattern of light rays that each have reflected off one facet. Furthermore, in the prior art, the orientation of the riser is not designed to allow light rays that have reflected off both the facet and the riser to interfere in a purposeful way.

In this invention, the interference pattern of the reflected light is dominated by the interference pattern from light rays that each have reflected off two reflective facets.

Let F_A be the quantity defined by:

$$F_A = (d_B/d_A)(\cos(\gamma-\theta_A)/\cos(\theta_A)). \qquad \text{eq.1}$$

where, as illustrated in Figure 2B, d_A is the length along facet A that is illuminated by incident light rays, d_B is the length along facet B that is illuminated by incident light rays, θ_A is the angle of incidence with respect to the facet normal of the light incident on facet A, and γ is the angle between the reflective facets. Provided that F_A is not greater than unity, F_A may be interpreted as the number of light rays that first reflect off facet A and second reflect of facet B divided by the number a light rays that are incident on facet A.

Let F_B be the quantity defined by:

$$F_B = (d_A/d_B)(\cos(\gamma-\theta_B)/\cos(\theta_B)). \qquad \text{eq.2}$$

where θ_B is the angle of incidence with respect to the facet normal of the light incident on facet B. Provided that F_B is not greater than unity, F_B may be interpreted as the number of light rays that first reflect off facet B and second reflect of facet A divided by the number a light rays that are incident on facet B.

For this invention the values of d_A/d_B, θ_A, θ_B, and γ should satisfy the constraints that F_A and F_B each be greater than 0.5. Under these constraints, more than half the light rays incident on one facet of the groove with be reflected once by each facet. Generally it is expected that γ will be in the range from 45° to 135°.

For maximum diffraction efficiency at a particular optical wavelength with retrodiffraction, $F_A=F_B=1$, which is the case when $\theta_A=45°$, $d_B/d_A = 1$, and γ =90°. These parameters may be optimum for some applications; however, other parameters may be optimum for other applications. For example, the range of wavelengths with suitable diffraction efficiency may be broadened by making γ slightly larger or smaller than 90°. Alternatively two diffraction orders can be made to have the equal diffraction efficiency by making γ substantially larger or smaller than 90°.

The fraction of the incident light rays that initially impinges on the riser is given by $F_R=d_2/(d_1+d_2)$ where the distances d_1 and d_2 are illustrated in Figure 2A. If, for example, the riser is flat and parallel to the orientation of the incident light rays then F_R is equal to zero. This invention may use risers that are not flat or that are not oriented parallel to the incident light rays; however, their shape and orientation of the riser must be such that F_R is less than 0.5.

The fraction of the incident light rays that initially impinges on the facet spacer is given by $F_S=d_S/(d_1+d_2)$ where the distances d_S , d_1 and d_2 are illustrated in Figure 2C. If, for example, the reflective facets are immediately adjacent, then F_S is equal to zero. This invention requires that the facet spacers be sufficiently short that F_S is less than 0.5.

With F_A, and F_B each greater than 0.5 and with F_R and F_S each less than 0.5, the interference pattern of the reflected light will be dominated by the interference pattern from light that has reflected from two reflective facets.

The reflective facets should deviate from a surface that is flat and smooth by less than one wavelength of the incident light and preferably less than one tenth of one wavelength of the incident light.

A metallic surface or alternatively an interface between two dielectric materials are suitable materials for the reflective facets.

The invention improves the performance of the grating when the optical properties of the facets is substantially improved due to the fact that the light incident on each of the two facets typically has a larger angle of incidence than the angle of incidence of the light incident on a comparable grating with a single reflective facet.

In one embodiment that is particularly suited for integrated optical demultiplexer, the interface between two dielectric media is used for the reflective facets and the incident light propagates through the medium with the higher index of refraction so that the reflective facets may reflect light predominantly by means of total internal reflection. In the latter embodiment, the two facets are similar to the two reflecting surfaces of a corner prism in that they utilize two instances of total internal reflection to achieve retroreflection. The primary advantage of this invention when used in this embodiment is that the reflectivity of the grooves is enhanced even when the grating is used under the autocollimation condition.

<u>BRIEF DESCRIPTION OF THE DRAWINGS</u>

A number of embodiments of the invention will now be described in conjunction with the accompanying drawings in which:

Figure 1A is a schematic illustration of a prior art plane diffraction grating.

Figure 1B is a schematic illustration of a prior art blazed concave grating for which the facets reflect predominantly by total internal reflection.

Figure 2A is a schematic illustration of one groove from a grating according to this invention.

Figure 2B is a schematic illustration of the groove of Figure 2A showing a ray that first reflects off facet A and then reflects off facet B.

Figure 2C is a schematic illustration of one groove from a grating according to this invention. In this groove the reflective facets are separated by the facet spacer.

Figure 3 is a schematic illustration of a first embodiment according to the present invention of the type in which the facets have a metallic finish.

Figure 4A is a cross-sectional view of a second embodiment according to the present invention in which the facets utilize total internal reflection to achieve high reflectivity and the grating is optimized for Littrow mount.

Figure 4B is an isometric view of the embodiment of Figure 4A.

Figure 4C is a cross-sectional view similar to that of Figure 4A of a third embodiment with the addition of a glass half-cylinder affixed to the prism to prevent refraction at the entrance surface when the incident angle of light differs from 45°.

Figure 5A is a cross-sectional view of a fourth embodiment of this invention.

Figure 5B is an isometric view of the fourth embodiment of Figure 5A.

Figure 5C is a cross-sectional view showing a detail of a groove of the grating of Figure 5A. Line segment ABCD is a riser, line segment DE is facet A, and line segment EF is facet B.

Figure 6 is a cross-sectional view of a fifth embodiment in which a concave grating is composed of grooves ruled onto a curved blank.

Figure 7 is a cross-sectional view of an sixth embodiment in which an integrated optical concave diffraction grating is formed by etching a trench into an optical slab waveguide and the grating is complemented by the fabrication of ridge waveguides for the light entering and exiting the device.

Figure 7A is a closer view of the grating of Figure 7.

Figure 8 is a cross-sectional view of a seventh embodiment in which an integrated optical plane diffraction grating is formed by etching a trench into an optical slab waveguide and the grating is complemented by the fabrication of an integrated concave mirror and ridge waveguides for the light entering and exiting the device.

DETAILED DESCRIPTION:

Turning now to Figure 3 there is shown a grating formed in a metallic surface. Thus a reflective-type diffraction grating is formed by an array of grooves, each groove comprising two reflective facets A and B and a riser. Incident light reflects off both facets of each groove.

The grating may be manufactured by ruling the grooves in a metallic material or by replication of a suitable master. Light incident on the grating propagates through air or vacuum prior to impinging on the grating. The two reflective facets of a single groove are oriented at right angles so that the grooves will cause the light rays incident on the groove to reflect once off each facet and consequently the incidence light is retroreflected by the groove. This is particularly suited to the Littrow mount if the grooves are manufactured on a planar surface and is particularly suited to the Eagle mount, if the grooves are manufactured on a concave blank. An advantage of the invention in this embodiment may be that the polarization dependent loss may be reduced.

Turning now to the embodiments shown in Figures 4A, 4B and 4C in which a planar bulk optic grating is fabricated on the surface of a prism, the grating is ruled on the surface of an optical prism. The base of the prism is a right triangle with two 45° angles. Herein the grating plane is the rectangular surface of the prism that has an edge common with the hypotenuse of the triangular base as it existed prior to grating fabrication. The entrance surface is one of the two the rectangular surfaces of the prism that is not on the grating plane and it is the surface of the prism that the incident light will enter.

The grooves consist of one facet A on the grating plane, an adjacent facet B produced by the ruling process perpendicular to the grating plane, and a riser R joining the adjacent facet B to the next groove in the series of grooves. Ideally, the riser R is perpendicular to the entrance surface.

The groove spacing may be constant. Alternatively the grating may be chirped (i.e., the groove spacing may vary) to focus the diffracted light

The light rays first encounter a groove of the grating either at facet A or facet B. In the former case, first facet A will reflect the light towards facet B and then facet B will reflect the light towards the entrance surface. In the latter case, the order of the reflections is reversed, but the end result is the same. In both cases, the light rays are incident on each facet at an angle of 45° relative to the facet normal. If the incident light rays are nearly perpendicular to the entrance surface and the grating is used in Littrow mount, then total internal reflection will occur at each facet provided that the index of refraction of the prism is greater than 1/sin(45°).

The air space behind the grating may be sealed with a cover that is not is in contact with grating and contacts the prism only around the perimeter. The cover prevents contamination of the grating by the condensation of water or other causes, and provided the cover does not make contact with the grating, total internal reflection still occurs.

A glass half-cylinder, Figure 4C, is fixed to the prism to prevent refraction at the entrance surface when the incident angle of light differs from 45°.

Turning now to the embodiment shown in Figures 5A, 5B and 5C, there is shown a planar bulk optic grating fabricated on an optically transparent sheet affixed to a prism. The grating is formed by etching a series of long trenches into the top surface of the sheet and affixing the sheet to an optical prism such that the bottom surface of the sheet is nearest the prism. Quartz is a suitable material for the sheet and glass or quartz is a suitable material for the prism.

Ideally, the trenches have side walls defined between points B and C and between points E and F that are perpendicular to the grating plane so that facet B is perpendicular to facet A. The known process of reactive ion etching is a suitable process for etching trenches with vertical side walls. In this embodiment, the riser R consists of the bottom of the etched trench between points A and B, one side wall of the etched trench between points B and C, and the part between points C and D of the top surface of the sheet that is not etched. The distances between the points BC, DE, and EF are equal to each other.

If the incident light rays are nearly perpendicular to the entrance surface and the grating is used in Littrow mount, then total internal reflection will occur at each facet provided that the index of refraction of the optically transparent sheet is greater than 1/sin(45°).

Turning now to Figure 6 there is shown a concave bulk optic grating which is ruled on a concave surface of an optical element referred to herein as the grating blank. The concave surface may, for example, be the surface of a sphere, cylinder, toroid, ellipsoid, or any other surface previously used to produce bulk optic concave gratings.

Grooves are ruled into the grating blank. Each groove is comprised of two reflective facets and a riser

The spacing of the grooves may be (as shown) non-uniform to provide proper focusing. For example, the projection of the grooves onto a chord may be equally spaced as required by a Rowland circle grating.

If the Eagle mount is used and the incident light rays are incident upon each facet at an angle of 45°, then total internal reflection will occur at each facet provided that the index of refraction of the grating blank is greater than 1/sin(45°).

If the Eagle mount is not used total internal reflection at each facet will still occur provided that $|\sin(\theta_A)|>1/n$ and $|\sin(\theta_B)|>1/n$, where θ_A is the angle of the ray incidence on facet A, θ_B is the angle of the ray incidence on facet B, and n is the index of refraction of the optical medium.

Turning now to Figures 7 and 7A, there is shown an integrated optical concave grating formed by etching a trench into an optical slab waveguide. Reactive ion etching (RIE) is a known method of forming a trench in a slab waveguide such that the side walls of the trench are nearly perpendicular to the plane of the slab waveguide. One side of the trench comprises a series of grooves that comprise the grating. This grating has a geometry that is similar to the embodiment of Figure 6 and is the integrated version of the grating of the embodiment of Figure 6.

The reflective properties of each facet will be determined by how each plane wave component of the guided light wave reflects off the facet. Total internal reflection will occur at each facet for each plane wave component that encounters the facet at an angle greater than the critical angle for total internal reflection. Light will reflect off both facets predominantly by total internal reflection provided $|\sin(\theta_A)|>1/N$ and $|\sin(\theta_B)|>1/N$, where θ_A is the angle of the ray incidence on facet A, θ_B is the angle of the ray incidence on facet B, and N is the effective index of the slab waveguide.

The grating is particularly convenient when a single integrated optical component includes both the concave grating and ridge waveguides. In the prior art, integrated optical components including both a concave grating and an ridge waveguide have been fabricated; however, the design of the integrated concave grating differs from the design of the concave grating described in this invention. [see 5-7 above] The ridge waveguides may be used to guide the incident light from an optical fiber to a focal point of the grating. The optical ridge waveguides may also be used to guide diffracted light from the focal curve of the grating to the edge of the integrated optical component.

An integrated grating may be fabricated as shown in Figure 7 with the exception that the grating lies along a straight line rather than a concave curve and that the grating is chirped to provide the focusing of the diffracted light.

Turning now to Figure 8, there is a grating formed by etching a trench into an optical slab waveguide and a concave reflector formed by etching trench into the same optical slab waveguide. A series of equally spaced grooves that lie along a straight line comprise one side of one trench which comprises the grating. Two facets and a riser comprise each groove of the grating. The reflective properties of each facet will be the same as described for the embodiment of Figure 7.

Collimated light is provided by the concave reflector. The reflector can be designed to collimate light that emerges from a ridge waveguide that is also integrated in the slab waveguide. The same reflector may be used to focus the diffracted light. Ridge waveguides may be utilized in this embodiment in a manner that is similar to that of the embodiment of Figure 7.

Since complete description of optical properties requires a detailed application of the electromagnetic theory of light, it is intended that the description of optical properties of the invention contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made within the spirit and scope of the claims without departing from such spirit and scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

I CLAIM:

1. A method of forming a diffraction pattern from incident light comprising:

providing a reflective-type diffraction grating having an array of surface elements formed in a support medium and a plurality of risers, each separating one surface element from a next adjacent surface element;

arranging the surface elements and the risers such that reflection of the light occurs primarily from the surface elements and such that the incident light is reflected by the array of surface elements separated by the risers to form a diffraction pattern;

forming each surface element so as to include two reflective substantially planar facets;

arranging the facets at an angle relative to each other;

and directing the incident light in a direction relative to the facets and arranging the angle between the facets such that the diffraction pattern is formed primarily from light which is reflected from each facet onto the other facet.

2. The method according to Claim 1 wherein the diffraction pattern is formed primarily from light which is reflected once only in each facet.

3. The method according to Claim 2 wherein the facets and the riser of each surface element are arranged relative to the direction of propagation of incident light such that the majority of that portion of the incident light which impinges on that surface element is reflected once only in each facet of that surface element.

4. The method according to Claim 1 wherein F_A and F_B each are greater than 0.5 where F_A is given by

$$F_A = (d_B/d_A)(\cos(\gamma-\theta_A)/\cos(\theta_A)) \qquad \text{eq.1}$$

where d_A is the length along facet A that is illuminated by incident light, d_B is the length along facet B that is illuminated by incident light, θ_A is the angle of incidence with respect to the facet normal of the light incident on facet A, and γ is angle between the reflective facets where F_B is given by

$$F_B = (d_A/d_B)(\cos(\gamma-\theta_B)/\cos(\theta_B)), \qquad \text{eq.2}$$

where θ_B is the angle of incidence with respect to the facet normal of the light incident on facet B.

5. The method according to Claim 1 wherein the light that is incident on the reflective facets is confined to propagate within an optical slab waveguide, and the interface between the optical slab waveguide and air is used for the reflective facets, and the facets are arranged so as to reflect most of the plane wave components of the light by means of total internal reflection.

6. The method according to Claim 5 wherein the plurality of grooves forms an Eagle mount concave diffraction grating.

7. The method according to Claim 1 wherein the interface between two media is used for the reflective facets and the incident light propagates through the medium with the higher index of refraction so that the reflective facets may reflect light predominantly by means of total internal reflection.

8. The method according to Claim 7 wherein the first facet of each groove is defined by one side of a trench formed into a predominantly flat surface and a second facet is defined by a portion of said predominantly flat surface.

9. The method according to Claim 8 wherein the predominantly flat surface comprises one side of a sheet of optically transparent material and the opposite side of the sheet is affixed to an optically transparent prism.

10. The method according to Claim 8 wherein the trenches are formed by reactive ion etching.

11. The method according to Claim 1 wherein the facets are arranged such that the angle between them is of the order of ninety degrees.

12. The method according to Claim 4 wherein γ is of the order of ninety degrees and both θ_A and θ_B are both of the order of forty five degrees.

13. The method according to Claim 1 wherein the riser is arranged so as to be approximately parallel to the incident light.

14. The method according to Claim 1 wherein the facets deviate from a surface that is flat and smooth by less than one wavelength of the incident light and preferably less than one tenth of one wavelength of the incident light.

15. The method according to Claim 1 wherein the facets are immediately adjacent.

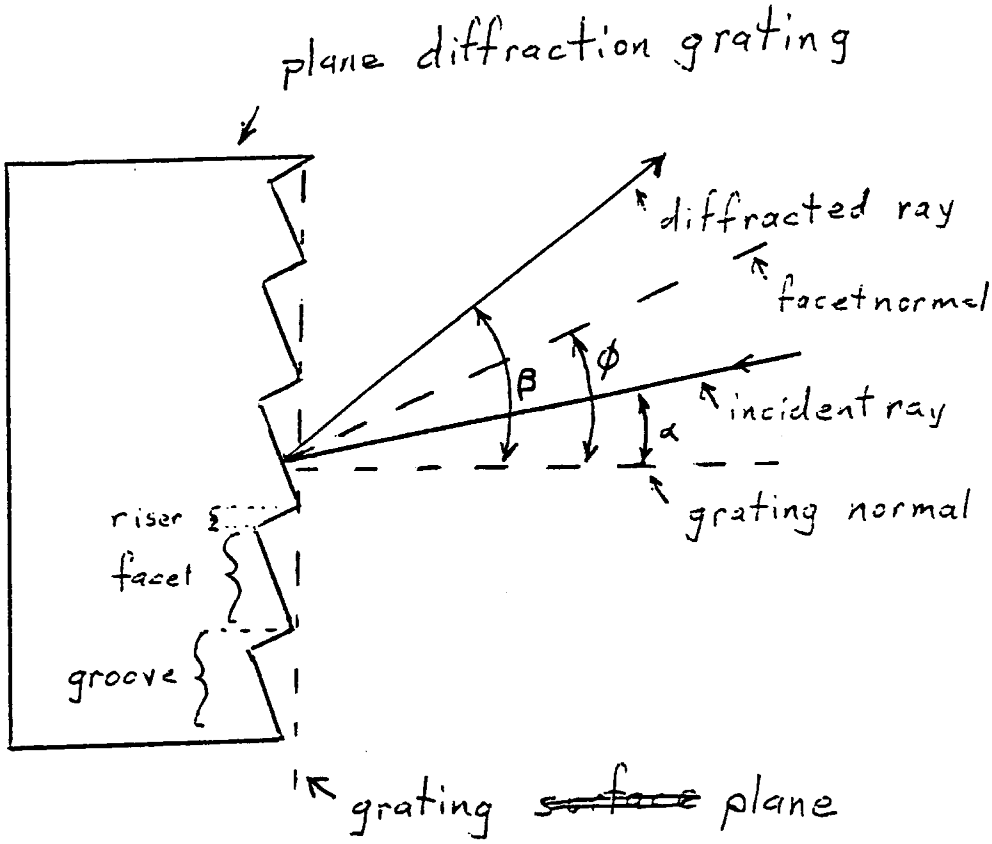

Fig. 1 A PRIOR ART

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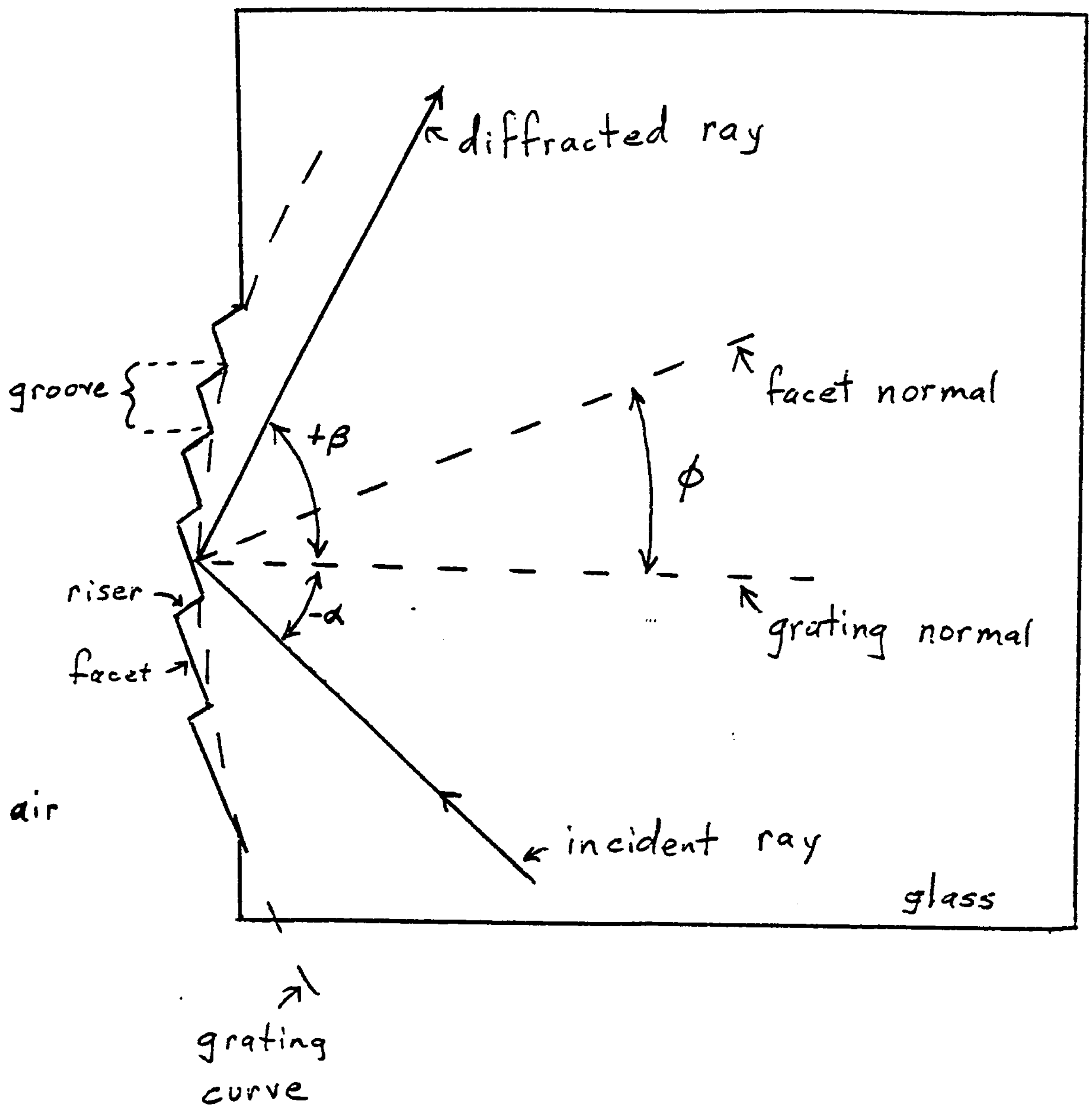

Fig. #1B PRIOR ART

INVENTOR:
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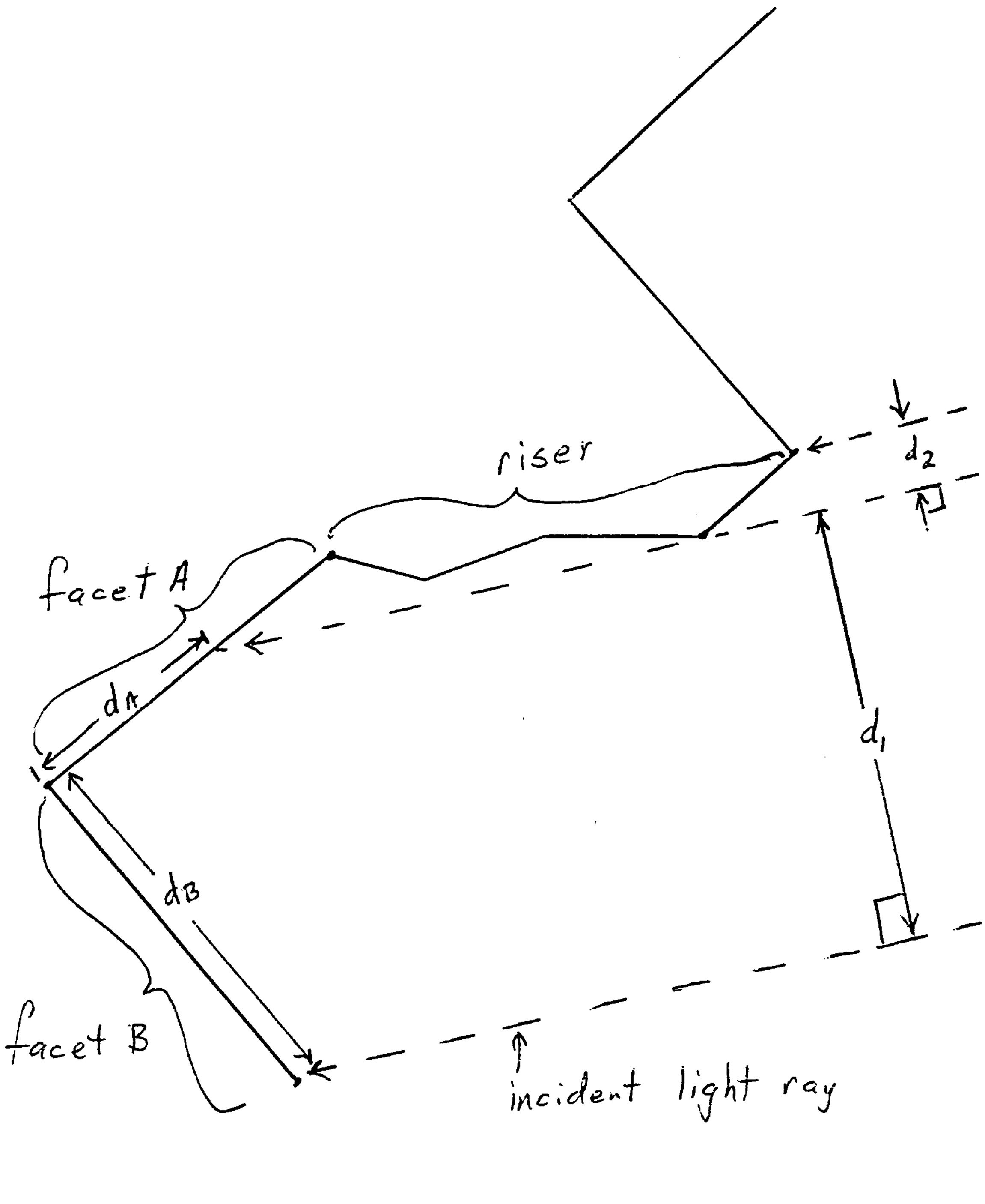

fig. 2A

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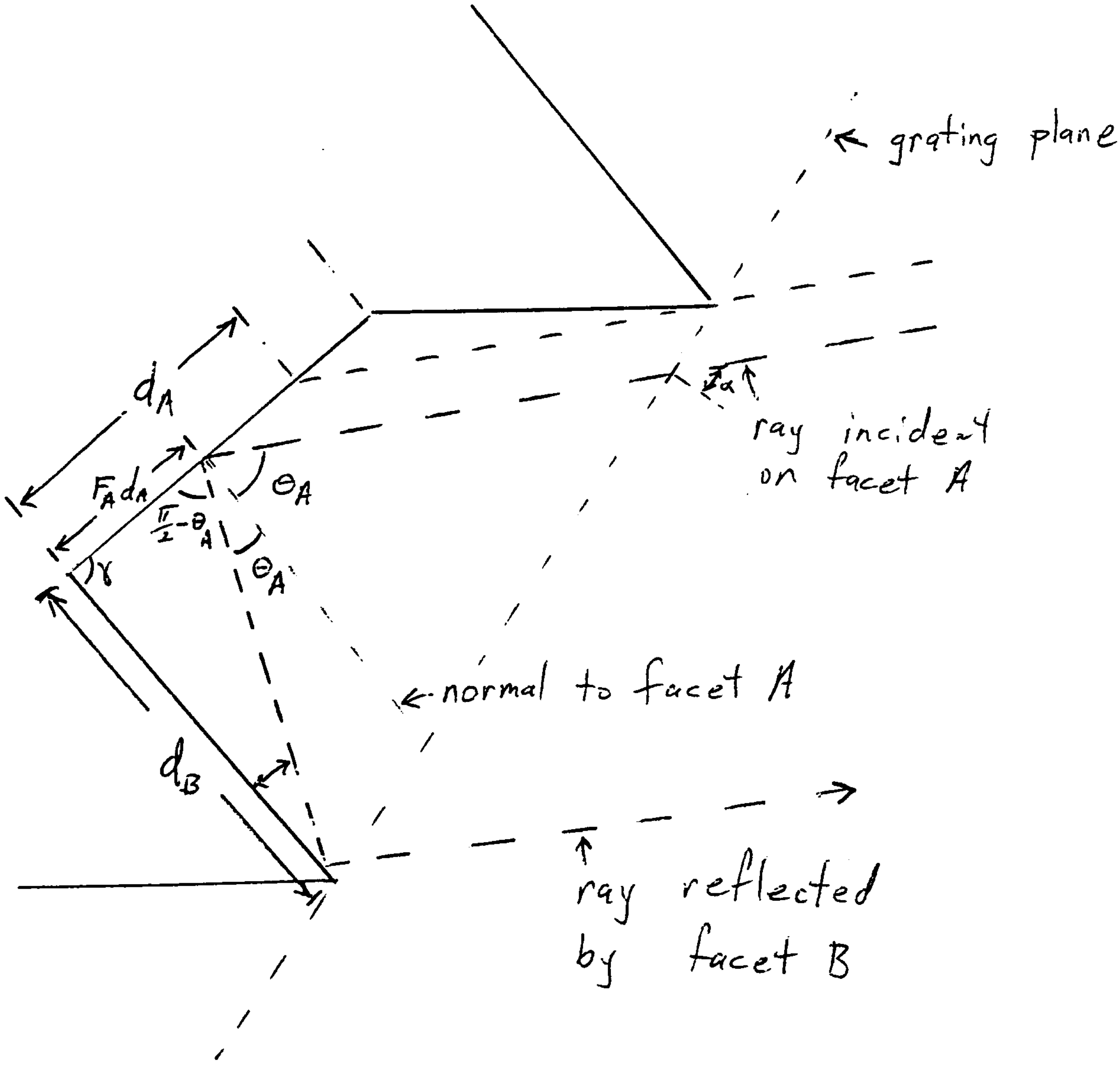

fig. 2B

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PER:
ADE & COMPANY

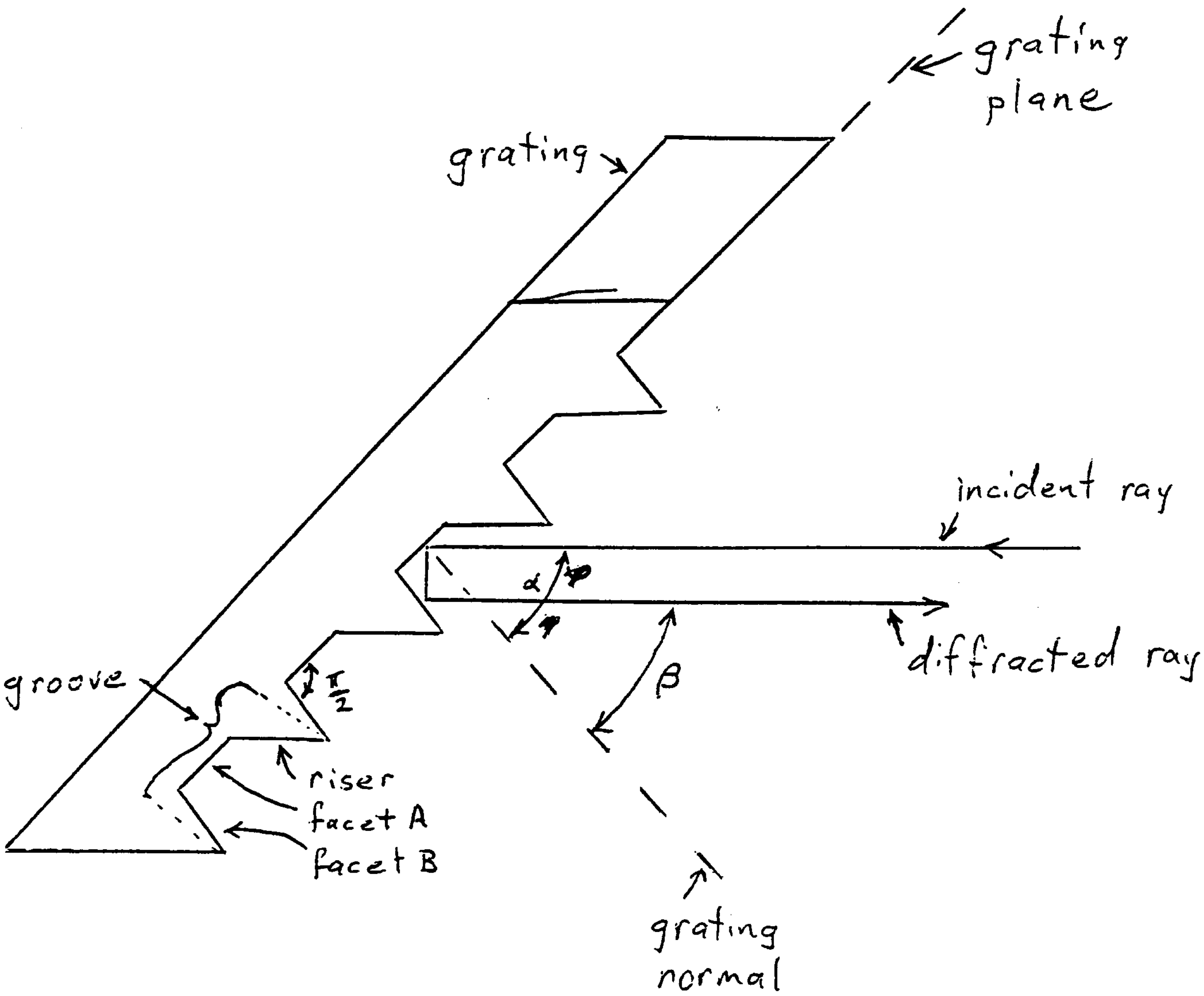

Fig. 3

INVENTOR:
KENNETH A. MCGREER
PER:
ADE & COMPANY

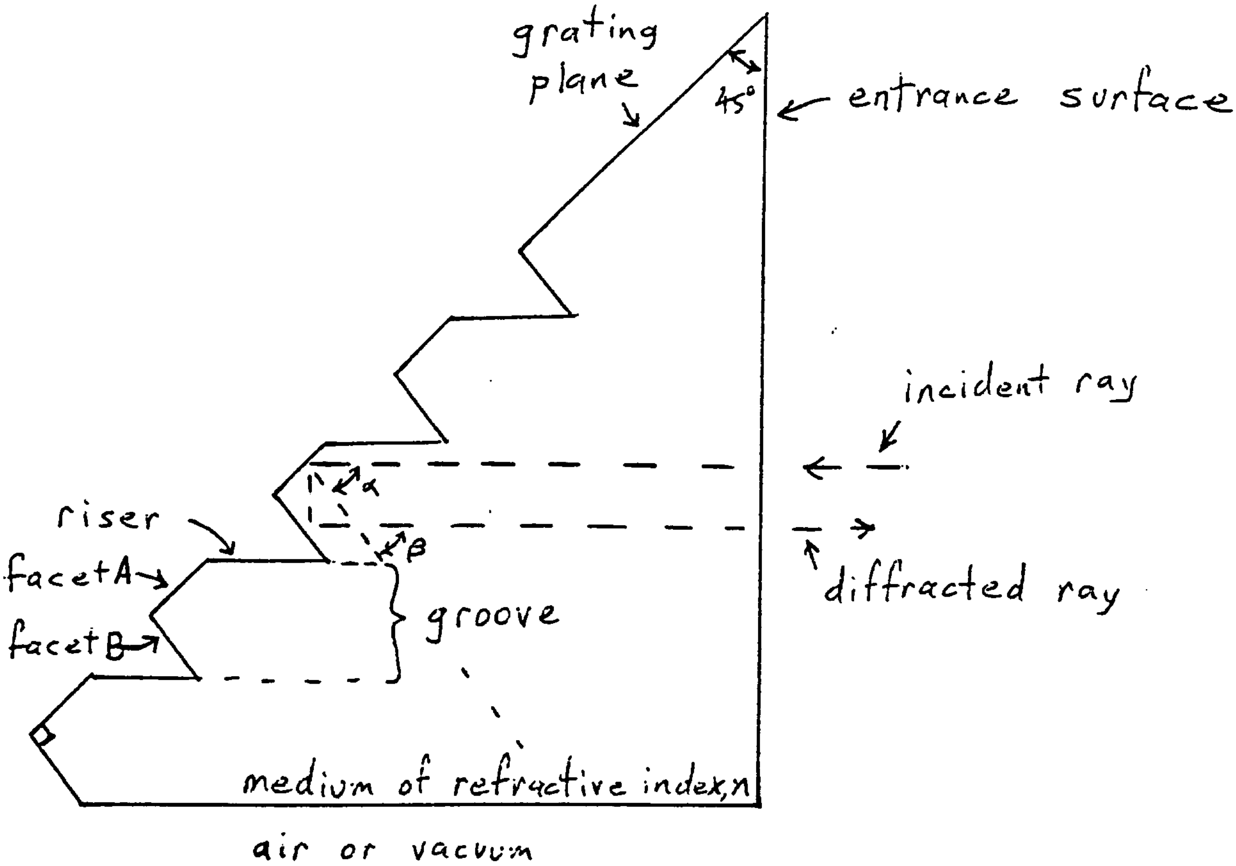

FIG. 4A

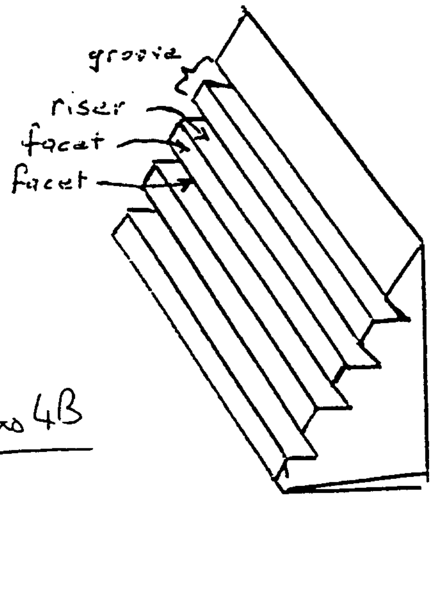

FIG. 4B

INVENTOR:
KENNETH A. MCGREER
PER:
ADE & COMPANY

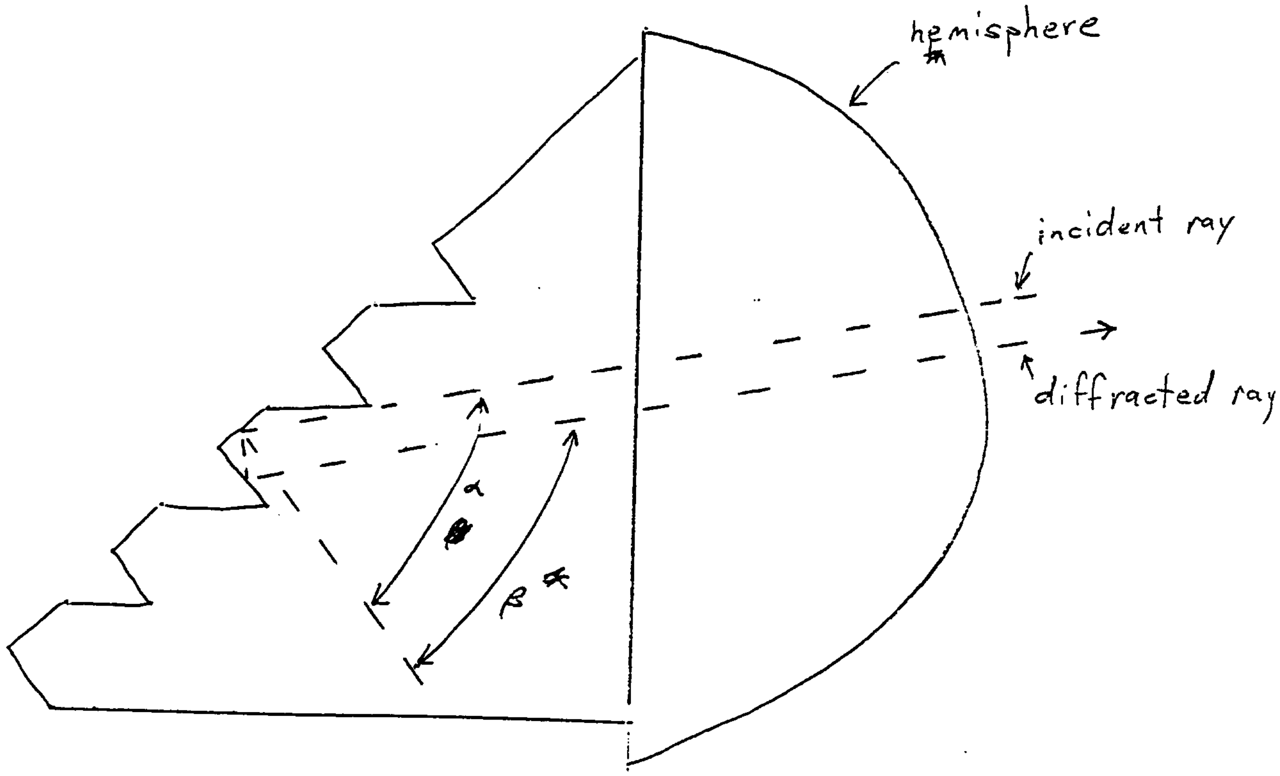

FIG. 4C

INVENTOR:
KENNETH A. MCGREER
PER:
ADE & COMPANY

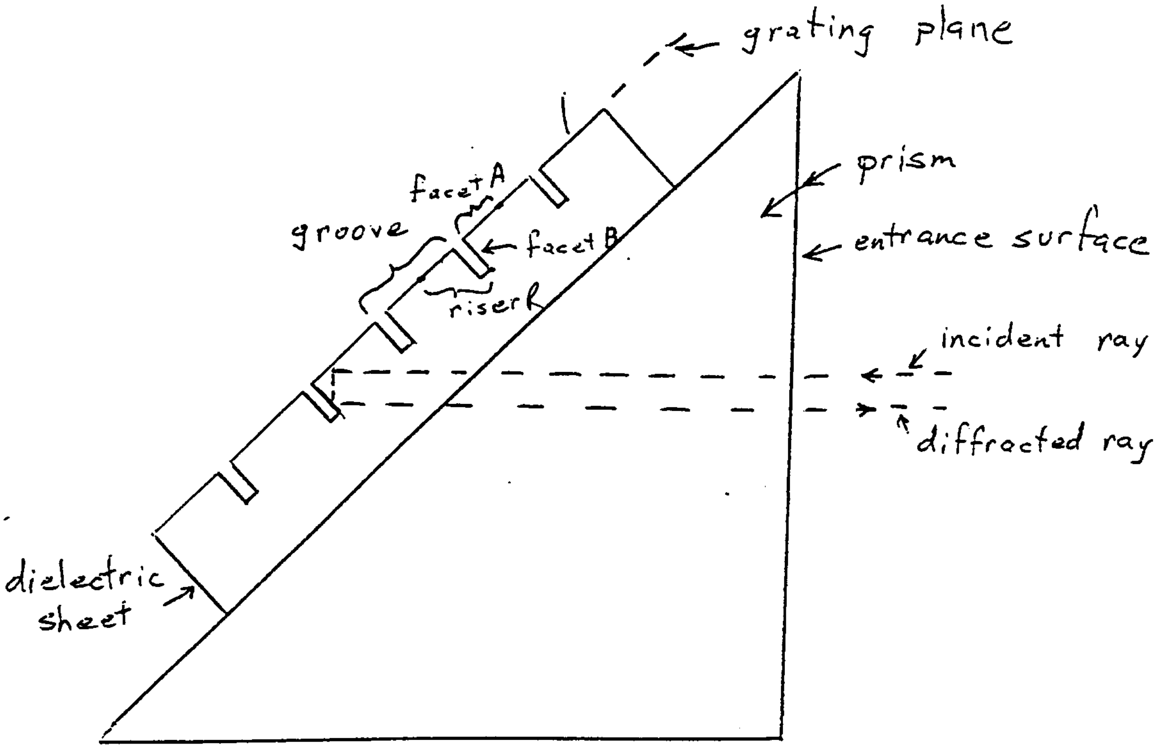

FIG. 5A

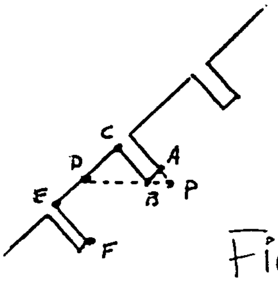

FIG. 5B

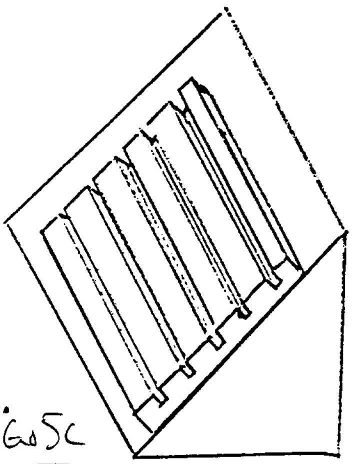

FIG. 5C

INVENTOR:
KENNETH A. MCGREER

PER:
ADE & COMPANY

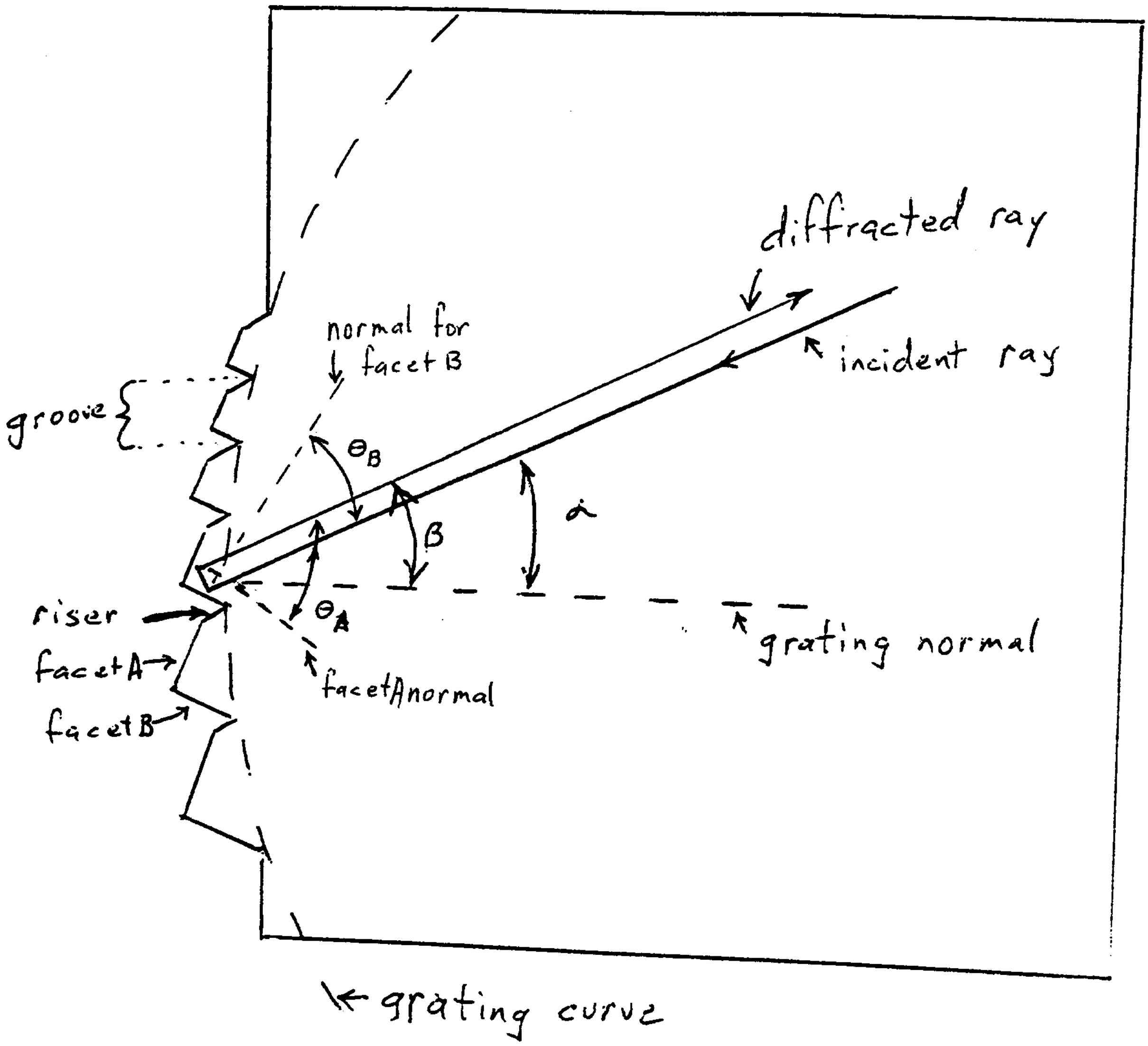

FIG. 6

INVENTOR:
KENNETH A. MCGREER
PER:
ADE & COMPANY

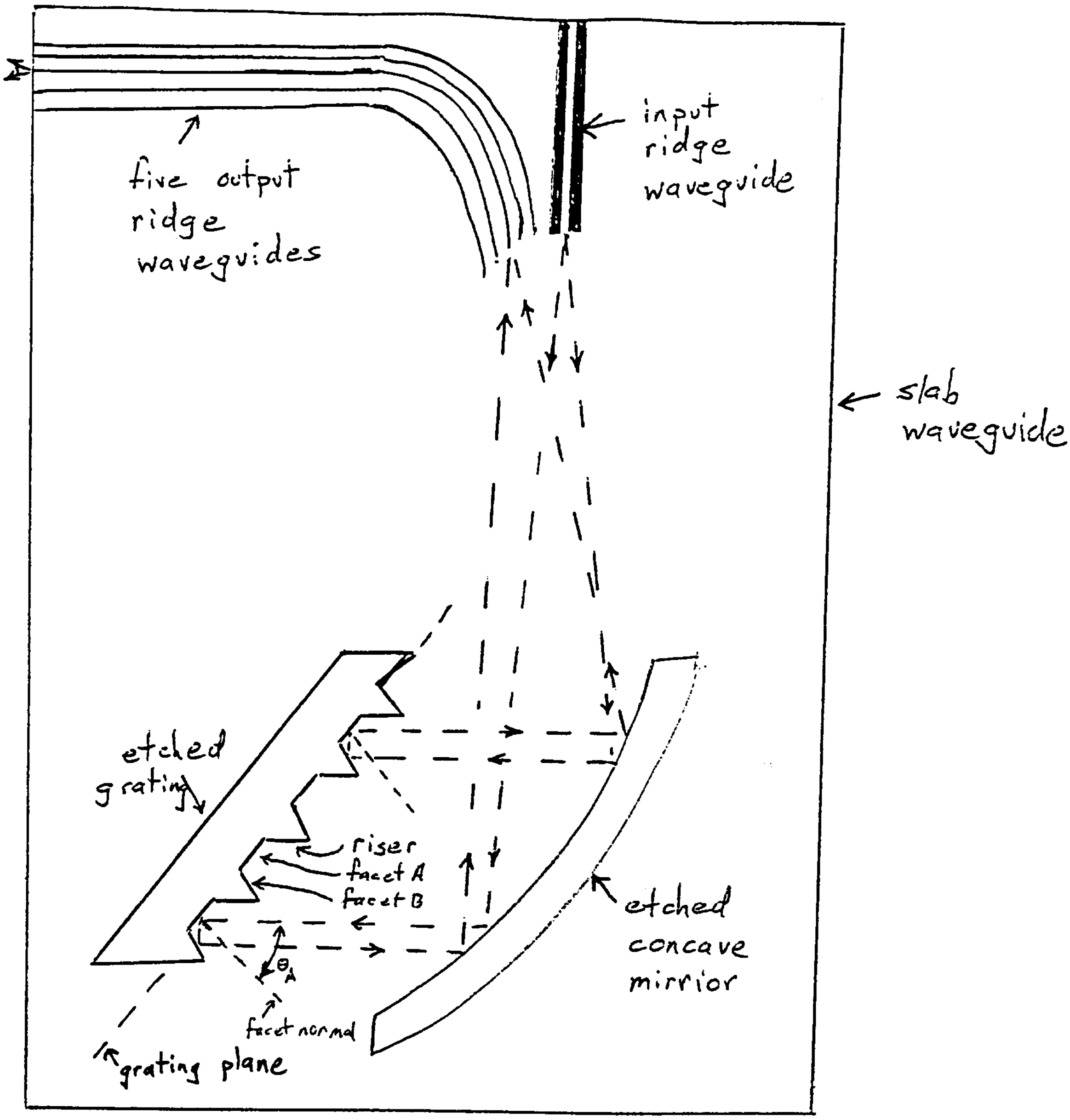

FIG. 7

INVENTOR:
KENNETH A. MCGREER
PER:
ADE & COMPANY

FIG. 8

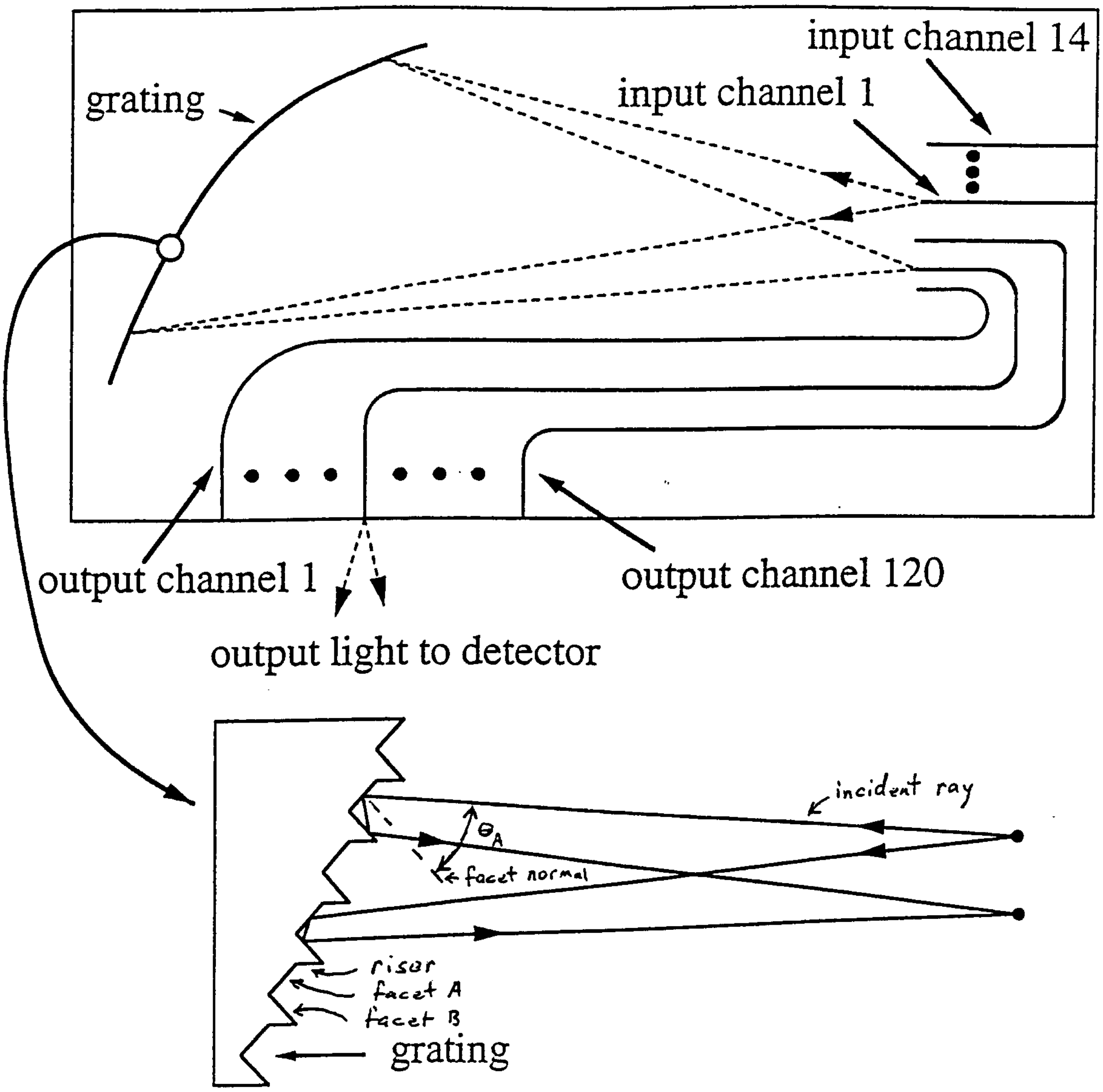

FIG. 8A

INVENTOR:
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PER:
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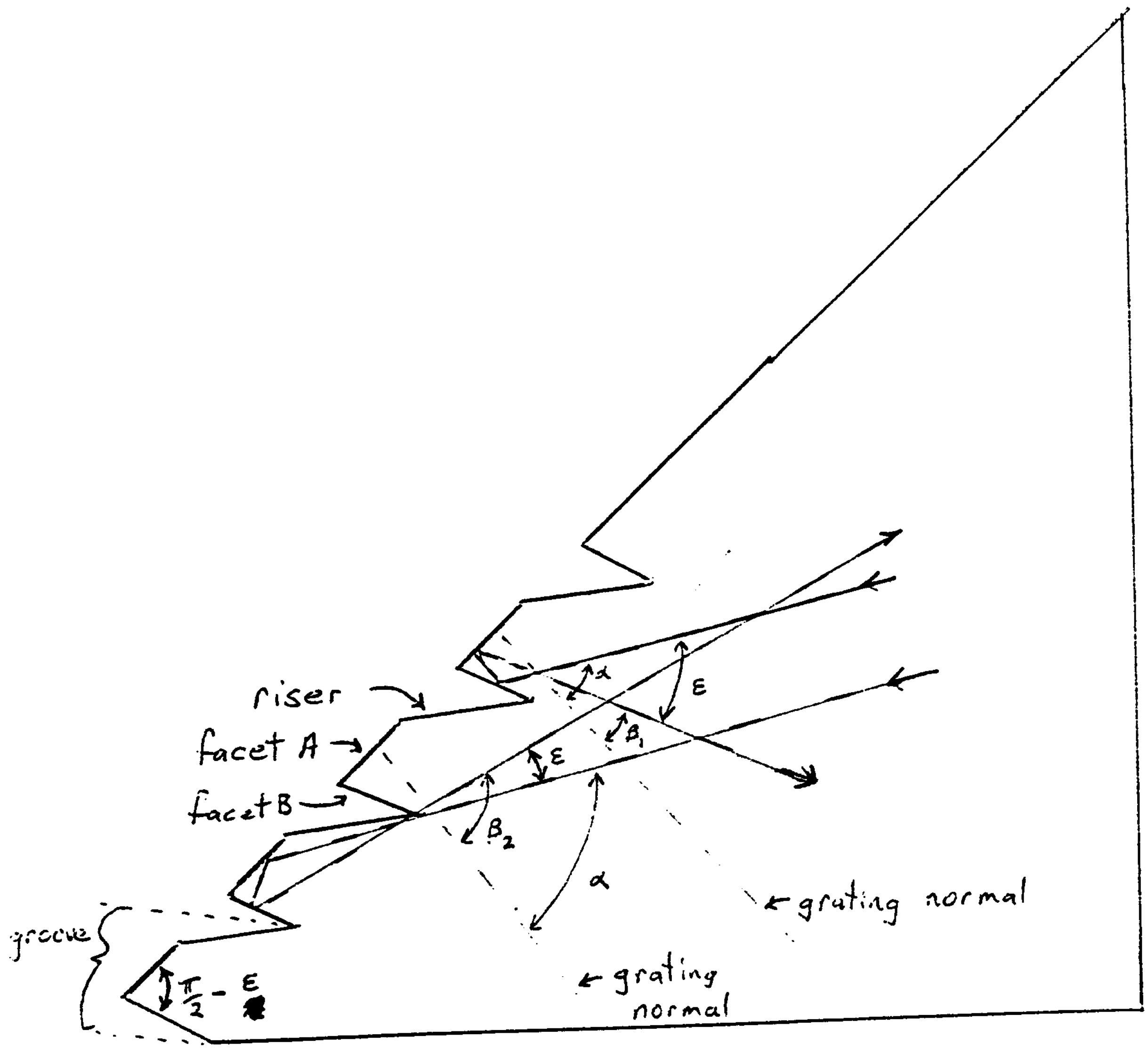


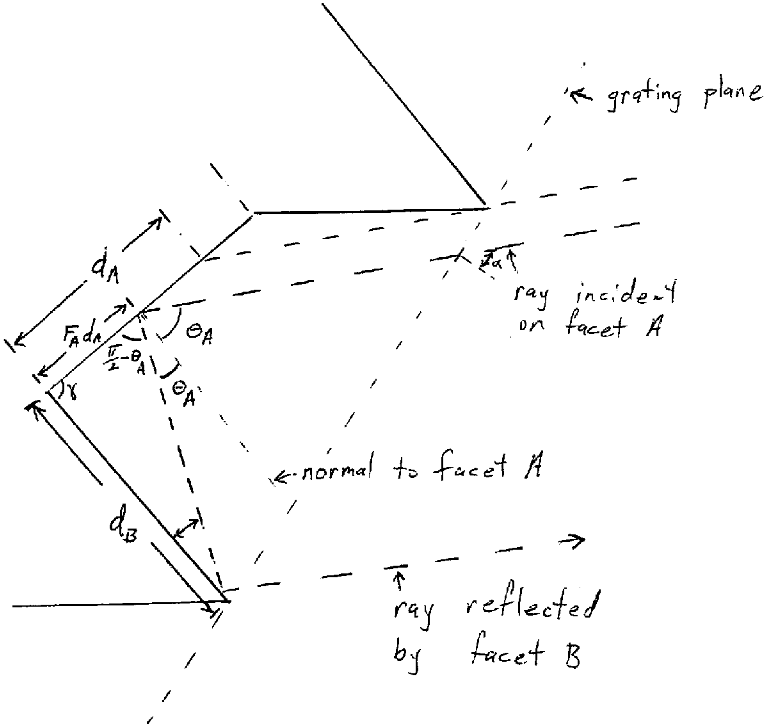
FIG. 9

INVENTOR:

KENNETH A. MCGREER

PER:

ADE & COMPANY


grating plane
ray incident on facet A
normal to facet A
ray reflected by facet B
d_A
$F_A d_A$
θ_A
$\frac{\pi}{2}-\theta_A$
γ
d_B