United States Patent [19]

Takahashi et al.

[11] **3,814,946**

[45] **June 4, 1974**

[54] **METHOD OF DETECTING DEFECTS IN TRANSPARENT AND SEMITRANSPARENT BODIES**

[75] Inventors: **Shiro Takahashi; Takeshi Asao,** both of Kitakyushu, Japan

[73] Assignee: **Asahi Glass Co. Ltd.,** Tokyo, Japan

[22] Filed: **Dec. 4, 1972**

[21] Appl. No.: **312,103**

[52] **U.S. Cl.** **250/572,** 356/200

[51] **Int. Cl.. G01n 21/30,** G01n 21/16, G01n 21/32

[58] **Field of Search** .... 250/219 DF, 223 B; 356/239, 200

[56] **References Cited**

UNITED STATES PATENTS

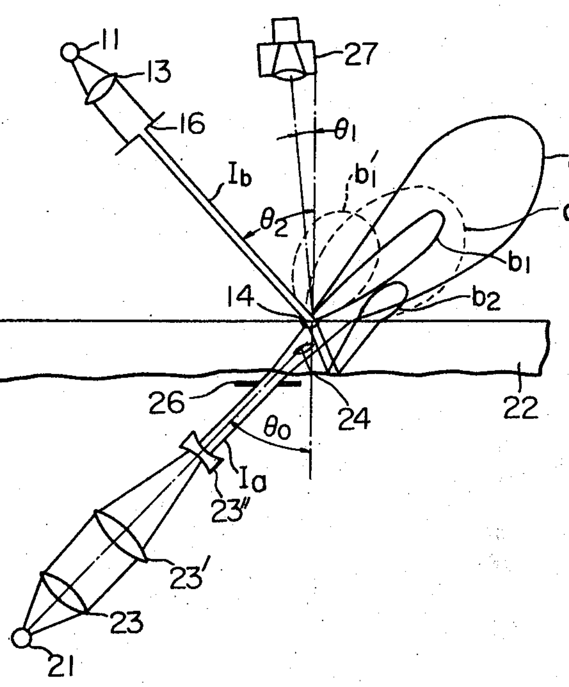
3,030,516	4/1962	Seavey	250/223 B
3,085,160	4/1963	Dahms	250/223 B
3,302,786	2/1967	Conrad	250/223 B
3,338,130	8/1967	Gafford	250/219 DF
3,361,025	1/1968	Gafford	250/219 DF
3,386,579	6/1968	Schulze et al.	250/223 B
3,415,433	12/1968	Shaw, Jr.	250/219 DF
3,475,615	10/1969	Samuel	250/219 DF
3,478,218	11/1969	Wuellner et al.	250/219 DF
3,493,769	2/1970	Revesz et al.	250/219 DF
3,533,704	10/1970	Krenmayr	250/223 B

Primary Examiner—Archie R. Borchelt
Assistant Examiner—T. N. Grigsby
Attorney, Agent, or Firm—Oblon, Fisher, Spivak, McClelland & Maier

[57] **ABSTRACT**

A method and apparatus for detecting defects in a transparent or semitransparent plate having a figured surface and an oppositely disposed smooth surface. A first light source is disposed on one side of the plate while a second light source is disposed on the opposite side so that the first light source and the second light source form, in conjunction with a photodetector, first and second optical systems respectively. The first optical system detects an internal defect in the plate by means of light which has passed through the plate and has been scattered by internal defects. The second optical system detects defects present in the smooth surface of the member by detecting light which has been reflected from the plate and scattered by surface defects.

2 Claims, 9 Drawing Figures



PATENTED JUN 4 1974 3,814,946

SHEET 1 OF 5

Fig. 1A

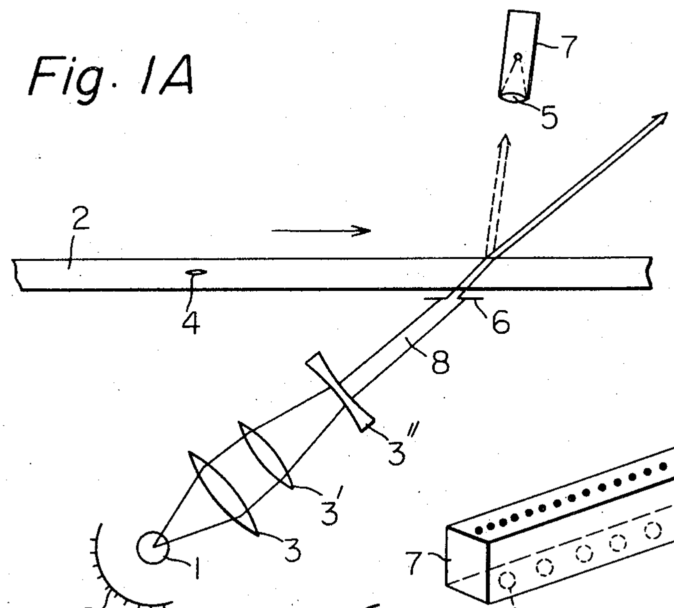


Fig. 1B

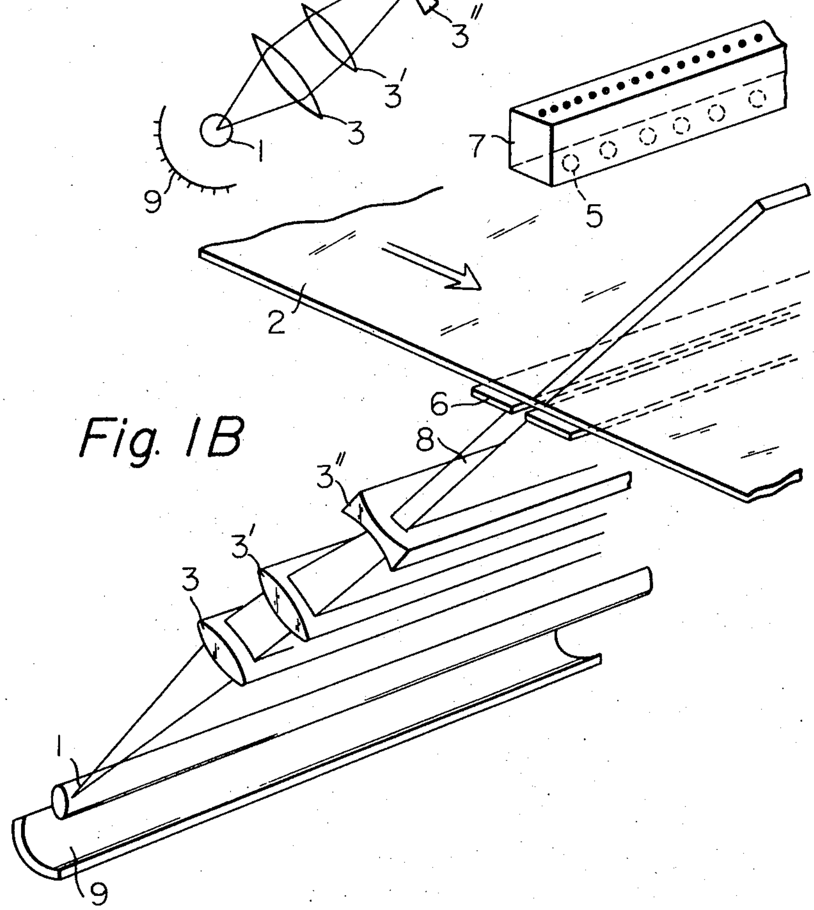


Fig. 2

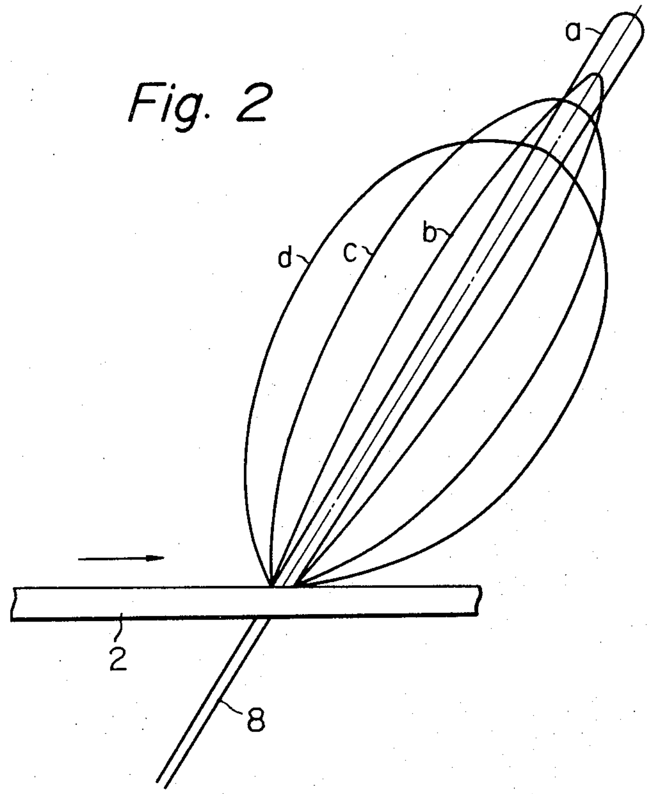


Fig. 3

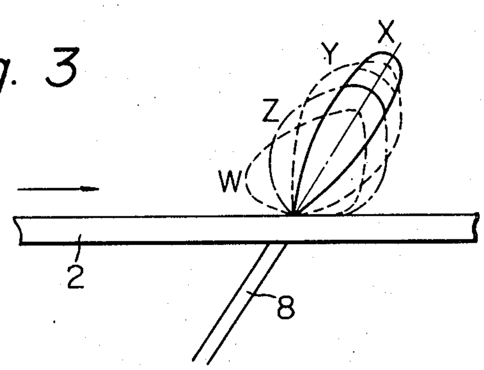


Fig. 4

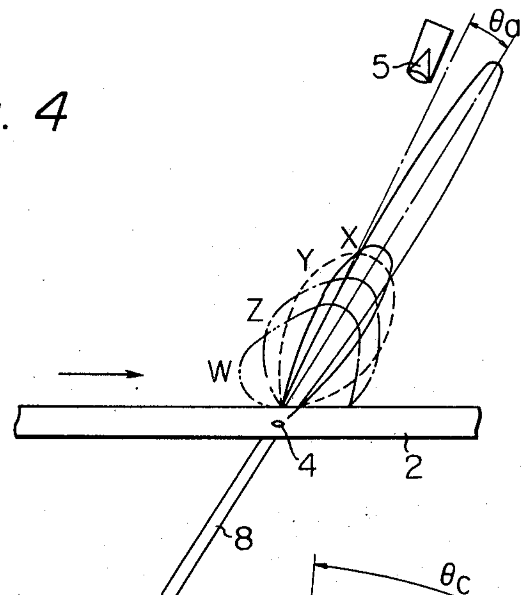
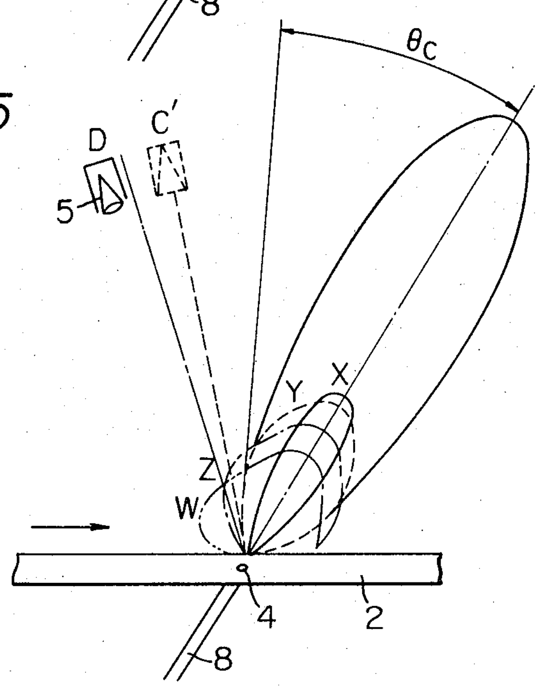


Fig. 5



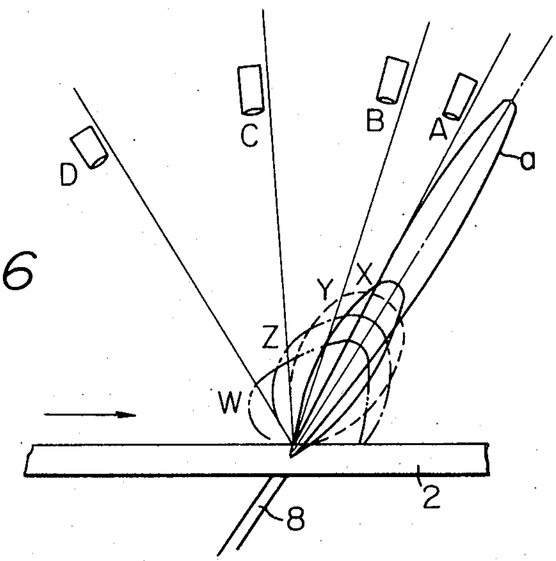


Fig. 6

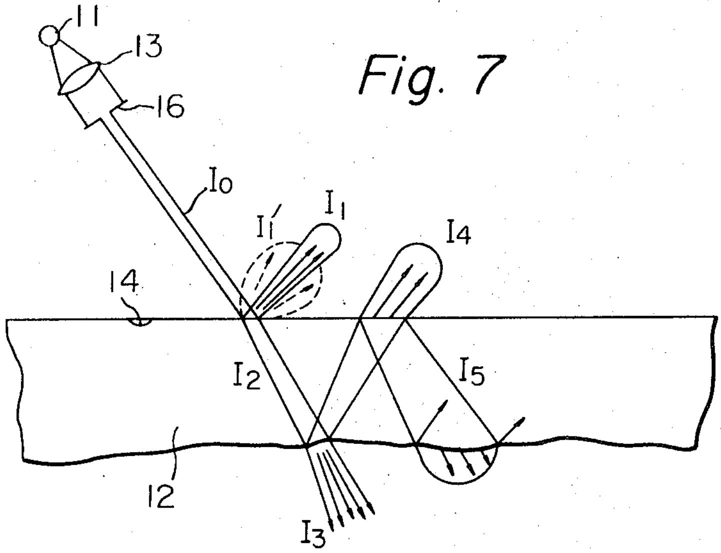
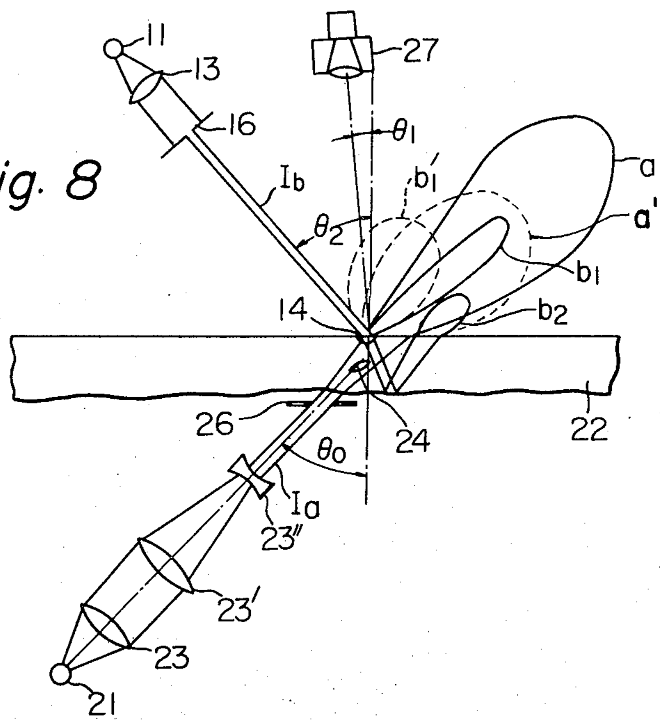


Fig. 7

Fig. 8



METHOD OF DETECTING DEFECTS IN TRANSPARENT AND SEMITRANSPARENT BODIES

FIELD OF THE INVENTION

The present invention relates to a method and system for automatically detecting optical defects in transparent or semitransparent bodies.

DESCRIPTION OF THE PRIOR ART

The most commonly known method of automatically detecting defects in a transparent plate comprises the steps of directing a light beam onto various portions of the transparent plate, measuring the amounts of light which have passed through the respective portions of the plate, converting the amounts of light thus measured into the corresponding electrical signals respectively by means of a photoelectric converter, and comparing the electrical signal obtained from the portion of the plate having a defect (hereinafter referred to as the "abnormal portion of the plate") with that obtained from the portion of the plate having no defect (hereinafter referred to as the "normal portion of the plate" to determine the presence or absence of such a defect. In such a method, if we represent the amount of light having passed through a normal portion of the plate by I_0 and that of light having passed through an abnormal portion of the plate by I_1, then the deviation ΔI in the amount of light received at a photodetector equals $I_1 - I_0$. If ΔI is large enough as compared with I_0, this method can detect a defect with practically high precision. However, if ΔI is small as compared with I_0 to the extent that the ratio of ΔI to an extremely small variation (noise) in I_0 which inevitably exists, that is, the signal-to-noise ratio, becomes very small, it is difficult to provide a sufficiently high degree of precision in detection. If it is attempted to constitute an automatic defect detector in accordance with such a method, it will be necessary to make the detecting range of each photodetector small to decrease the magnitude of I_0 relative to ΔI so that the signal-to-noise ratio is improved, or to suppress substantially the undesirable variation in ΔI itself, but, in consequence, the apparatus will become complicated and costly. Therefore, from industrial and economical viewpoints, such a technique cannot easily be applied to a micro-defect detecting apparatus.

A further difficult problem is encountered when it is attempted to rely upon the above said prior art in constituting a defect detecting apparatus which can be used for semitransparent plates having one patterned or figured surface and an opposite smooth surface as well as transparent plates. More particularly, in the case of a plate having various patterns or figures on its surface, such as ground glass, or figured glass, undesirable irregularities in the amount of light passed through are caused due to such surface patterns or figures, and such irregularities might be sensed by the photodetector while it is receiving the light even from the normal portion of the plate, so that the photodetector will be unable to distinguish the variation in the amount of light passed through due to said irregularities from the variation in the amount of light passed through due to a surface defect in the smooth surface of the plate which is intended to be detected.

In accordance with the present invention, a light source is disposed on one side of a plate to be checked and a photodetector is disposed outside the area of distribution of the light having been passed through and scattered from the normal portion of the plate so that the photodetector catches only the light scattered from the normal portion of the plate.

Also, a second light source is disposed on the opposite side of the plate with respect to said first light source. Said photodetector is disposed so that it receives the light which has been emitted from the second light source and reflected from the surface of the plate but does not receive the direct light from the second light source. The light from the second light source is used to detect defects present in the smooth surface of the plate which cannot be detected by means of the light from the first light source.

The present invention will be described in more detailed in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* shows a diagrammatic view of a first optical defect detecting system utilizing "passed-through" light.

FIG. 1*b* shows an enlarged perspective view of the detector section of the defect detecting system.

FIG. 2 shows the distribution characteristic of the light which has been passed through the portion of a transparent plate having no defect,

FIG. 3 shows the distribution characteristic of the light which has been passed through the portion of the transparent plate having a defect,

FIG. 4 is a view diagrammatically showing the placement of a photodetector in the system of FIG. 1*a* for the detection of defects in an ordinary plate glass,

FIG. 5 is a view diagrammatically showing the placement of photodetector in the system of FIG. 1*a* of the detection of defects in a figured plate glass,

FIG. 6 is a view diagrammatically showing the placement of a plurality of photodetectors in the system of FIG. 1*a* for the detection of various kinds of defects.

FIG. 7 is a view showing the passed-through light and the reflected light resulting from an incident light beam onto a smooth surface of a figured glass,

FIG. 8 shows a diagrammatic view of the embodiment of the invention.

DESCRIPTION OF THE EMBODIMENTS

In FIG. 1, there is shown an optical system for defecting various kinds of defects present in a transparent plate utilizing passed-through light. In the drawing, a source of light beam **1** is positioned, for example, below a transparent plate **2**, such as a glass plate, which is being continuously formed in a ribbon-like shape or which has been prepared by cutting a large glass sheet into sections. The light emitted backwardly from the light source **1** is focused by a concaved silvered plate **9** disposed on the rear side thereof and, together with the light emitted forwardly, directed through lenses **3**, **3'** and **3''**, whereby it is shaped into collimated light rays **8**. A slit **6** is disposed in the path of the collimated rays **8** so that a light beam impinges upon the glass plate **2** at a predetermined incident angle. Substantial portion of the light beam passes through the glass plate **2** and is directed in the direction indicated with an arrow in the drawing. Reference numeral **7** designates a photodetector disposed so that it does not catch the direct light but catches the portion of the light that has been scattered by a defect **4** present in the glass plate **2.** The photodetector may usually be composed of a condensing lens **5** and a photoconverter such as a photocell, a phototransistor or a photomultiplier. The condensing lens may preferably be disposed so as to focus the image present at the intersection of the incident light beam and the glass plate **2** onto the sensitive surface of the photoconverter. The collimated rays **8** from the light source **1** are usually reduced to about 1 –10 mm in diameter and directed onto the glass plate **2.** If it is desired to detect a defect in a glass plate moving in a predetermined direction, such collimated light rays **8** may be directed in a band-like form onto the glass plate **2** perpendicularly thereto, and a number of photodetectors **7** may be disposed in an equally spaced relationship perpendicularly to the direction of movement of the glass plate.

FIG. **1***b* shows an arrangement wherein a band-like light source is disposed in parallel to the glass plate, and lenses, photodetectors and a slit are also disposed in parallel relationship correspondingly.

FIG. **2** shows one example of the distribution of the amount or intensity of the passed-through light obtained when a glass plate having no defect passes in the region of the band-like light. Particularly, in the case of a polished glass plate, the area of distribution of the passed-through light is very narrow, and, in the case of an ordinary glass plate, the area of distribution of the light is somewhat broader, but, in either case, the distribution characteristic resembles that indicated by *a* in FIG. **2.** In the case of a figured glass, it resembles those indicated by *b*, *c* and *d*, respectively, in accordance with the patterns provided on the surface thereof.

FIG. **3** shows one example of the distribution of the amount or intensity of the passed-through light obtained when a glass plate having various kinds of defects passes through the region of the light band. More particularly, FIG. **3** shows the light intensity distribution characteristic generated by connecting the points having the same and predetermined value representing the amount or intensity of the light scattered in all directions from the crossing point of the incident light beam and the glass plate during the period from the time of the entry into the light band of the defect of the plate to the time of its leaving from said light band. FIG. **3** also shows the intensity distribution characteristic of the light scattered in all directions during the passage through the light band of one pattern of a figured plate glass which has a series of periodic patterns, in the similar manner to FIG. **2.** For example, in the case of an ordinary plate glass having a small surface defect, the intensity distribution characteristic of the passed-through light may be represented by X. In the case of a plate glass having a small bubble as a defect, the intensity distribution characteristic of the passed-through light may be represented by Y. If the plate glass has a relatively large defect, such as a relatively large bubble or a spherical bubble, the intensity distribution characteristic of the passed-through light may be represented by Z. On the other hand, if the plate glass has an opaque defect, such as a particle of refractory material or insoluble material, a devitrified spot, or a crack, it may be represented by W.

FIG. **4** shows that a photodetector **5** can be disposed just outside the region of angle θa representing the area of distribution of the light passed through the normal portion of a polished plate glass, for example.

By disposing the photodetector **5** at such a position, the scattered lights corresponding to the distribution characteristics X, Y, Z and W may be caught by the photodetector **5,** and it becomes possible to constitute a detector which is capable of detecting all defects covering from those presenting a narrow distribution of scattered light to those presenting a broad distribution of scattered light.

FIG. **5** shows that a photodetector can be disposed at D so as to accept any defects which are nonsignificant from practical viewpoint, such as a small surface unevenness (which corresponds to the distribution characteristic X) or a small bubble in the plate (which corresponds to distribution characteristic Y), but so as not to accept any opaque defects (which corresponds to the distribution characteristic W).

In the case of a figured glass presenting a distribution characteristic of scattered light corresponding to that represented by *c*, it is unnecessary to detect unevenness, and a small bubble, since they matter little for the reason that they are masked by the pattern itself of the figured glass. However, if the bubble in the figured glass is relatively large, a photodetector may be disposed at *c* and its sensitivity may be adjusted appropriately so that it produces a defect signal when a bubble is large, but does not produce such a defect signal when the size of the defect is within the allowable limit.

Referring to FIG. **6,** it is shown that an ordinary plate glass presents the distribution characteristic *a* of the light scattered from a normal portion of the plate as well as the distribution characteristic X, Y, Z or W of the light scattered from an abnormal portion of the plate is checked. A plurality of photodetectors A, B, C and D are disposed to detect the defects corresponding respectively to the distribution characteristics X, Y, Z and W and these photodetectors may be adjusted respectively so that the kinds and degree of defects of the plates can be checked collectively.

As one example of such a collective checking, the maximum values of the outputs of the photodetectors A, B, C and D may be amplified by amplifier means (not shown) with predetermined amplification factors respectively, and these amplified output may be combined together to produce a final outputs signal representing collectively the degree of the defect of the plate, or as the case may be, such a final output signal may be compared with a prestored signal representing a standard pattern of defects. Of course, any other known means may be employed to process the outputs of the photodetectors A, B, C and D.

Although the above description has been made in the case of a glass, the method described above is equally applicable to any other transparent and semitransparent bodies, such as films, plates or films of resin.

In operation of the system shown in FIG. **1***b*, the glass plate may be moved relative to the fixed optical system, or alternatively, the light source and photodetectors may be moved to scan the stationary glass plate.

FIG. **7** shows that the intensity distribution characteristic of the light reflected from the surface of a plate varies depending upon the nature of that surface.

In FIG. **7,** the light beam directed onto a figured glass having its upper smooth surface by means of a light source **11** through a lens **13** and a slit **16** is represented by I_0. The light beam is divided into a reflected light I_1 and a forwardly-advancing light I_2, which light I_2 reaches the lower surface of the glass plate while it is being partially absorbed by the plate, whereupon one portion of said light I_2 is emitted as a passed-through light I_3 and the other portion thereof is reflected upwards to produce a second reflected light I_4 and a second forwardly-advancing light I_5. The light will thus undergo repeated refraction and reflection. It has been found that I_1 has a specific distribution characteristic depending upon the nature of the surface of the glass plate and the area of distribution of I_1 is usually narrow in the case of a smooth surface having no defect, but, when there is a defect **14** at the reflection point of the incident light I_0 on the upper surface of a figured glass **12**, the area of distribution of the reflected light I_1' is broader in width than that of said reflected light I_1 resulting from the normal portion of the smooth surface of the plate, although it varies in accordance with the kind of the defect.

Thus, it is possible to constitute a surface defect detecting system having a high signal-to-noise ratio, by disponsing a photodetector at a position outside the region of scattering of the light reflected from the normal portion of the surface but within the region of scattering of the light reflected from the abnormal portion of the surface.

As mentioned above, in the case of a figured glass, it has been impossible to distinguish between the variation in he amount of light resulting from the pattern in one surface of the glass and the variation in the amount of light resulting from a defect in the other smooth surface of the glass.

Such defect can be abniated by the defect detecting system according to the invention which is constituted by combining the defect detector utilizing reflected light shown in FIG. **7** with the aforementioned defect detector utilizing passed-through light shown in FIG. **1***a*. A light source **11** and a photodetector **27** are disposed above a figured glass **22** to form an optical system, and an optical system comprising a second light source **21**, lenses **23**, **23'** and **23''**, and a slit **26** is provided on the opposite side thereof with respect to the first light source **11**.

In FIG. **8**, the distribution characteristic of the light from the light source **21** that has been passed through the normal portion of the plate and scattered therefrom is represented by a, and the distribution characteristics of the reflected light resulting from the light beam of the source **11** that has been projected onto the normal portion of the plate are represented by b_1 and b_2, respectively. A^1 represents the distribution characteristic of the light from the light source **21** that has been passed through the abnormal portion of the plate. In this case, if the degree of unevenness of the upper surface of the figured glass **22** is as low as is negligibles as compared with that of the lower surface on which the pattern is formed, then, due to such a surface defect **14**, the passed-through light from the light source **21** is not scattered to such an extent as to effectively detect that sort of surface defect **14**.

On the other hand, the incident light beam Ib is scattered by such a surface defect **14** to provide such a distribution characteristic of light as is indicated by b_1. In this case, because the lower surface of the figured glass **22** is a patterned surface and the upper surface thereof has a much higher degree of smoothness than that of the lower surface, the area of light distribution of b_1 is much narrower in width than that of a. The area of light distribution of b_2 is not broader than that of a.

Therefore, even if the angle θ_2 at which the light source **11** is disposed is considerably smaller than the angle θ_0 at which the light source **21** is disposed, the photodetector never catches the light b_1 and b_2 reflected from the upper surface of the plate having no defect.

The second optical system comprising the light source **11** and the photodetector **27** can detect with a high precision defects which cannot be detected by means of the first light source.

Although the above description of the embodiments has been made in conjunction with the detection of defects in a plate-like member, the method according to the invention is equally applicable to any other shape of member such as bottle, so long as a photodetector can be disposed so as to catch the light scattered from a defect in the member.

What we claim is:

1. A method of detecting defects in a flat substantially transparent member having a figured surface on one side thereof and a smooth surface on an opposite side thereof comprising the steps of:

directing a first collimated light beam onto said figured surface of said member in a spaced relationship to said figured surface so that said first collimated light beam passes through said member;

directing a second collimated light beam onto said smooth surface of said member in a spaced relationship to said smooth surface so that said second collimated light beam reflects off said smooth surface of said member;

positioning a photodetector means in a region of said smooth surface side of said member outside a region of said first and second collimated light beam passing through a non-defective portion and reflecting off a non-defective surface, respectively, of said member, and inside a region of said first and second collimated light beams passing through a defective portion and reflecting off a defective surface, respectively, of said member; and

measuring a total amount of light received by said photodetector whereby both defects in said smooth surface of said member and internal defects in said member are detected.

2. An apparatus for detecting defects in a flat substantially transparent member having a figured surface on one side thereof and a smooth surface on an opposite side thereof comprising:

a first source of light disposed in a first side region of said member in a spaced relationship to the figured surface of said member, said first light source directing a first collimated beam onto said figured surface of said member and through said member;

a second source of light disposed in an opposite side region of said member in a spaced relationship to said smooth surface of said member, said second light source directing a second collimated beam onto said smooth surface of said member, said second collimated beam reflecting from said smooth surface; and a

photodetector means disposed on said opposite side of said member in a spaced relationship thereto at a position outside a region of light from said first source having passed through a non-defective portion of said member and light from said second source having been reflected from said smooth surface of said member having no defects, and inside a region where light from said first source having passed through a defective portion of said member and light from said second source having been reflected from surface defects in said smooth surface

of said member are significant;

whereby light received by said photodetector means is indicative of internal and smooth surface defects of said member.

* * * * *