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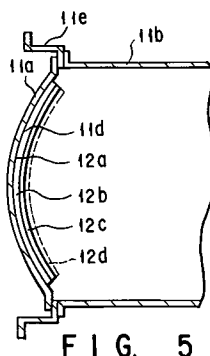
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DE FR GB(71) Applicant: **KABUSHIKI KAISHA TOSHIBA**
72, Horikawa-cho
Saiwai-ku
Kawasaki-shi
Kanagawa-ken 210 (JP)(72) Inventor: **YAMAGISHI, Shirofumi**
Toshiba Creare No. 203
1384-2, Wakakusa 1-chome
Ohtawara-shi
Tochigi-ken 324 (JP)(74) Representative: **Henkel, Feiler, Hänzel &**
Partner
Möhlstrasse 37
D-81675 München (DE)(54) **X-RAY IMAGE INTENSIFIER.**

(57) This invention discloses an X-ray image intensifier including a vacuum container having a metallic X-ray input window (11a), and an input plane formed on the inner surface of the X-ray input window. In the container, convergence electrodes, an anode and an output plane are sequentially disposed along the path of electrons emitted from the input plane. The X-ray input window has a hardened undulating layer (11d) on the surface thereof on the input side and the input plane has a phosphor layer (12b) formed on the hardened undulating layer, and a photoelectric surface (12d) formed on the phosphor layer.

**FIG. 5****EP 0 644 572 A1**

Technical field

The present invention relates to an X-ray image intensifier.

5 Background Art

Recently, an X-ray image intensifier has been widely applied to medical diagnosis, non-destructive examinations and the like, in which an X-ray image obtained by a low-energy X-ray having an X-ray tube voltage of 30 KV (a tube current of 1 mA) or less, or by a high-energy X-ray having an X-ray tube voltage of 10 30 KV (a tube current of 1 mA) or more is converted to a visible light image.

As shown in FIGS. 1 and 2, a conventional X-ray image intensifier is basically constituted of an input screen 12, a focusing electrode 13, an anode 14, and an output screen 15, all arranged in a vacuum envelope 11 (hereinafter referred to as an "envelope") in the order mentioned from an X-ray source A. The envelope 11 has an input window 11a made of metal, on which an X-ray is incident, a body 11b made of 15 glass for supporting the focusing electrode, and an output portion 11c made of optical glass serving as the output screen 15 or as a support for the output screen 15.

The input screen 12 provided at a predetermined distance from the input window 11a, functions as an cathode. The input screen 12 is consisted of a curved substrate 12a, for example, an aluminum metal substrate, which is a convex formed so as to project toward the X-ray source A; a phosphor layer 12b for 20 converting an X-ray to a visible light, formed on the concave of the metal substrate 12a; a transparent conductive film 12c formed on the phosphor layer 12b; and a photocathode 12d for converting the visible light from the phosphor layer 12b to electrons, formed on the transparent conductive film 12c. The transparent conductive film 12c is generally made of indium oxide, ITO (a compound made of indium oxide and titanium oxide) or the like. The transparent conductive film 12c is used for preventing the reaction 25 between an alkali halide such as sodium iodide activated cesium iodide constituting the phosphor layer 12 and a material constituting the photocathode 12d and for providing continuous conductivity on the surface of the phosphor layer.

On the other hand, an anode 14 is disposed in the opposed side to the input screen 12, namely, in the side in which the output screen 15 disposed (the outer face herein is constituted by a structure such that 30 the optical glass substrate supporting output phosphors serves as part of the envelope). The anode 14 is supported by the side in which an envelope output portion 11c is formed. Between the anode 14 and the input screen 12 used as the cathode, a first focusing electrode 13a is provided along the inner wall of the envelope body 11b. Between the focusing electrode 13a and the output screen 15, a pipe-shape second focusing electrode 13b is provided. The first and the second focusing electrodes 13a and 13b constitute an 35 electrostatic electron lens system.

In the X-ray image intensifier thus constituted, an X-ray B radiated from the X-ray source A is transmitted through an object C, reaching the input window 11a. The X-ray image reflected on the input window 11a is converted to an electron image formed on the input face, as will be described later. The electron image is accelerated and focused through the electrostatic electron lens system constituted of the 40 first focusing electrode 13a and the second focusing electrode 13b. A tube voltage, which is applied between the input screen 12 as the cathode and the anode 14, e.g., 30 KV of a tube voltage, is divided into two voltages and these voltages are applied to the electrodes, 13a, 13b, respectively. Thereafter, the electron image is converted back into a visible light on the output screen 15. In this way, a visible image can be intensified, for example, 1000 times or more, in proportional to the intensity of the visible light 45 entered the input screen 12.

As shown in an enlarged view of FIG. 2, the input screen of the above-mentioned conventional X-ray image intensifier has a problem in that the X-ray is more scattered, lowering image contrast since the input window 11a and the input screen 12 are separated at a predetermined distance each other. Hereinbelow, this problem will be explained by way of example of an X-ray image intensifier having an effective input- 50 screen diameter of 4 inches, with reference to FIG. 3.

To obtain data shown in FIG. 3, 50KV of a tube voltage and 1 mA of a tube current were applied to the X-ray tube. A contrast (%) and a contrast ratio of the X-ray image intensifier are plotted on a vertical axis and a diameter (mm) of a lead circular plate is plotted on the horizontal axis. The contrast herein is indicated in percentage of brightness in the effective input visual field when a lead plate having a 55 predetermined diameter is positioned at the center of the effective input visual field, based on the brightness in the effective input visual field of the X-ray image intensifier when no lead plate is positioned. The contrast ratio is numerically calculated from the contrast values (%).

A curve c of FIG. 3 shows the characteristics of the X-ray image intensifier having the conventional structure shown in FIG. 2. As is apparent from the curve c, as the diameter of the lead circular plate used in measuring contrast becomes smaller than 40 mm, the image contrast significantly reduces. This fact implies that the contrast of a small object image is significantly inferior to that of a large object. From the industrial point of view, this fact leads to a drawback in that it is difficult to find defects of fine portions.

FIG. 4 shows the contrast data obtained from an experiment conducted in the same manner as above except that a tube voltage of the X-ray tube is changed to 30 KV, using the same X-ray intensifier. According to the straight line e of FIG. 4, in the same fashion as in the curve c of FIG. 3, as the diameter (mm) of the lead circular plate becomes smaller than 40 mm, the contrast significantly reduces. However, the degree of the image contrast reduction in this case is larger than in the case of FIG. 3.

On the other hand, Jpn. UM Appln. KOKOKU Publication No. 34-20832 and some other publications disclose an X-ray image intensifier comprising an input screen directly formed on the inner surface of an aluminum input-window. Nonetheless, such an X-ray image intensifier comprising an input screen directly formed on an inner surface of an input window made of aluminum has not yet been put into practical use. If an X-ray image intensifier comprising the input window made of such a thin material is fabricated and then evacuated, the input window will be distorted by the pressure difference between the inside and the outside of the tube. As a consequence, the input screen will be distorted. Hence, a desired photocathode cannot be obtained and the output image is distorted.

Disclosure of Invention

The object of the present invention is to provide an X-ray image intensifier which overcomes the aforementioned drawbacks, maintains high brightness of an image, and provides high image contrast.

According to the present invention, there is provided an X-ray image intensifier which comprises a vacuum envelope having a metal X-ray input window; an input screen formed on the inner surface of the X-ray input window; a focusing electrode, an anode, and an output screen arranged in the vacuum envelope along the traveling direction of electrons generated from the input screen, wherein the X-ray input window has a surface-hardened layer with a rough surface on its side on which the input face is formed, and the input face includes a phosphor layer formed on the surface-hardened layer and a photocathode formed on the phosphor layer.

In the X-ray image intensifier of the present invention, a material possibly used as the metal X-ray input window, is a substance, for example, aluminum or an aluminum alloy, which has a high X-ray transmissivity, good workability, and sufficient strength enough to tolerate the pressure difference between the outside and the inside of the X-ray image intensifier, due to the surface hardening.

The rough, surface-hardened layer of the metal X-ray input window can be formed by applying the surface-hardening to a metal plate constituting the metal X-ray input window. The treatment for forming the rough, surface-hardened layer can be performed as follows:

Hard spherical particles such as glass beads having a particle diameter of 50 to 200 μm are impinged onto the metal plate at a pressure of 1 to 4 kg/cm^2 for a processing time of 1 to 5 minutes, thereby completing the surface hardening. As a result, the surface of the metal plate becomes rough, providing a surface-hardened layer with a rough surface.

The X-ray image intensifier of the present invention is effective particularly in the case where a low-energy X-ray having a X-ray tube voltage of 30 KV (1 mA in a tube current) or less is used.

Brief description of Drawings

FIG. 1 is a schematic view of a conventional X-ray image intensifier used for explaining an X-ray photography;

FIG. 2 is a sectional view of part of the conventional X-ray image intensifier shown in FIG. 1;

FIG. 3 is a graph showing image contrast characteristics obtained under the application of a high-energy X-ray in the embodiment of the X-ray image intensifier according to the present invention and a conventional X-ray image intensifier;

FIG. 4 is a graph showing contrast characteristics obtained under the application of a low-energy X-ray in an embodiment of the X-ray image intensifier according to the present invention and a conventional X-ray image intensifier;

FIG. 5 is an partially enlarged sectional view of a main portion of the X-ray image intensifier according to an embodiment of the present invention;

FIG. 6 is a partially enlarged sectional view of the portion shown in FIG. 5; and

FIG. 7 is a graph showing the relationship between the surface roughness of an Al plate obtained by the surface hardening and the hardness of the surface-hardened layer.

Best Mode of Carrying Out the Invention

The X-ray image intensifier of the present invention has the same constitution as that of the conventional X-ray image intensifier shown in FIG. 1, except that an input screen is formed directly on the inner surface of an input window and the surface-hardening is applied onto the inner surface of the input window.

To be more specific, as shown in FIG. 1, the X-ray image intensifier of the present invention is basically constituted of the input screen 12, the electrode 13, the anode 14, the output screen 15, all disposed in the vacuum envelope 11 in the order mentioned from the X-ray source A. The envelope 11 is further constituted of the metal input window 11a, to which an X-ray is radiated, the glass body 11b supporting the focusing electrode, and the glass output portion 11c serving as the output screen 15 or a support for the output screen 15.

As shown in FIG. 5, the surface-hardened layer 11d having a rough surface obtained by the surface hardening is formed on the inner surface of the input window 11a. An aluminum alloy, in particular, an ASTM 5000 series Al-Mg alloy is used as the material of the input window 11a. Such an aluminum alloy plate is press-molded into a dish shape and the aforementioned surface-hardening is applied thereto, thereby obtaining the input window 11a.

The input screen 12 is formed directly onto the rough-surface of the surface-hardened layer 11d. The input screen 12 is constituted of the optically reflective substance layer 12a formed on the rough-surface of the surface-hardened layer 11d; the phosphor layer 12b for converting an X-ray to a visible light, formed on the layer 12a; the transparent conductive film 12c formed on the phosphor layer 12b; and the photocathode 12d for converting the visible light from the phosphor layer 12b into electrons, formed on the transparent conductive film 12c. The transparent conductive film 12c is generally made of indium oxide, ITO (a compound made of indium oxide and titanium oxide) or the like. The transparent conductive film 12c is used for preventing the reaction between an alkali halide such as sodium iodide activated cesium iodide constituting the phosphor layer 12 and a material forming photocathode 12d, and for providing continuous conductivity on the surface of the phosphor layer.

On the other hand, an anode 14 is disposed in the opposed side to the input screen 12, namely, in the side in which the output screen 15 is disposed (the output screen is constituted by the structure such that an optical glass substrate supporting output phosphors serves as part of the envelope). The anode 14 is supported by the side in which an envelope output portion 11c is placed. Between the anode 14 and the input screen 12 serving as the cathode, a first focusing electrode 13a is provided along the inner wall of the envelope body 11b. Between the focusing electrode 13a and the output screen 15, a pipe-shape second focusing electrode 13b is provided. The first and the second focusing electrodes 13a and 13b constitute an electrostatic electron lens system in the same fashion as in the structure of the X-ray image intensifier shown in FIG. 1.

As described above, according to the X-ray image intensifier of the present invention, the rough, surface-hardened layer 11d is formed on the inner surface of the input window 11a, and the input screen 12 is formed directly on the rough, surface-hardened layer. The Vickers hardness of the rough, surface-hardened layer 11d is preferably in a range of 120 to 250 as described above. If the Vickers hardness is less than 120, since the layer 11d is not strong enough to tolerate the pressure difference between the inside and the outside of the X-ray image intensifier, the X-ray input window will be distorted. In contrast, if the Vickers hardness exceeds 250, the moldability of the layer lid will unfavorably deteriorate.

The surface roughness of the rough, surface-hardened layer 11d is preferably in a range of 1 to 10 μm . If the roughness is less than 2 μm , the hardness of the rough, surface-hardened layer 11d is too low to tolerate the pressure difference between the inside and the outside of the X-ray image intensifier, with the result that the X-ray input window 11a will be distorted. In contrast, if the roughness exceeds 10 μm , phosphors to be formed on the layer 11d exhibit weak adhesiveness and has disadvantages in its film quality.

The present inventors have conducted an experiment in the following manner with a view to find the relationship between the surface roughness of the surface-hardened Al alloy, the hardness of the treated surface, the adhesiveness of phosphors to the treated surface, and the phosphor-film quality.

The aforementioned Al-Mg alloy plate of 0.5 mm in thickness was molded into the shape of the input window, and then subjected to the surface-hardening by use of glass beads of 100 μm in diameter. Al-alloy input-window samples having a wide variety of surfaces roughness were obtained by varying the pressure

and the processing time.

The Vickers harnesses of the treated surfaces of the Al input-window samples were measured. The results are shown in FIG. 7. From the graph of FIG. 7, it is found that the surface of the input window must have the roughness of 2 μm or more in order to attain the Vickers hardness of 120 or more at which the input window exhibits tolerance to the pressure difference between the inside and the outside of the X-ray image intensifier.

Next, phosphor layers were formed on the treated surfaces of the Al alloy input window samples by the vapor-deposition. The adhesiveness and the film quality of the phosphor layers were checked. The results are shown in the following Table 1.

Table 1

Roughness of the treated surface (μm)	$x < 2$	$2 < x < 5$	$x = 5$	$5 < x < 10$	$10 < x$
Hardness	X	Δ	$\bigcirc$	$\odot$	$\odot$
Adhesiveness	$\bigcirc$	$\bigcirc$	$\odot$	$\bigcirc$	Δ
Phosphor film quality	$\odot$	$\odot$	$\odot$	Δ	X
$\odot$: very good $\bigcirc$: good Δ : slightly good X : not good					

Table 1 demonstrates that the surface roughness of the Al-alloy input window plate is preferably 5 or more to obtain sufficient hardness thereof; that the surface roughness of the Al-alloy input window is preferably 10 μm or less to obtain sufficient adhesiveness of phosphors; and that the surface roughness of the Al-alloy input window is preferably 2 to 10 μm to obtain sufficient quality of the phosphor film.

As far as only adhesiveness and the film quality of phosphors are concerned, the Al-alloy plate having the surface roughness of 5 μm is the most preferable, whereas, the hardness thereof is not the most preferable. However, even if the surface roughness is 5 μm , it is possible to obtain the most preferable hardness depending on the manner of the surface-hardening.

More specifically, to obtain the most preferable hardness, the Al-Mg alloy plate (ASTM 5000 series) is molded into the shape identical to the input window, and then subjected to the rough-surface treatment with high pressure, thereby obtaining the surface roughness of 10 μm or more. Second, the Al-plate is subjected to the surface-hardening with low pressure to smooth the projections and recesses which have been formed, thereby attaining the surface roughness of about 5 μm . In this way, it is possible to impart the Vickers hardness of approximately 250 μm to the surface even if the surface roughness thereof is 5 μm .

As described in the foregoing, according to the X-ray image intensifier of the present invention, since the rough, surface-hardened layer is formed on the inner surface of the X-ray input window, the X-ray input window is less distorted by the pressure difference, caused by evacuation, between the inside and the outside of the X-ray image intensifier. Due to the presence of an reflective substance layer formed on the rough surface-hardened layer, light generated from the input screen travels toward the photocathode, bringing a high contrast output-image.

In the case where Al or an Al alloy is used as a material of the X-ray input window, an X-ray image intensifier having an X-ray input window excellent in moldability can be obtained with advantage in cost.

Further, it is possible to obtain an output image of a small object with higher contrast when the X-ray image intensifier of the present invention employs a low-energy X-ray source.

Hereinbelow, Examples of the present invention will be described.

(Example 1)

The X-ray image intensifier according to this example is characterized in that it has an input screen of a specific structure. To be more specific, the surface-hardening is applied to the concave of the X-ray input window 11a, which is made of an aluminum alloy (or aluminum) of 0.5 mm in thickness. Due to surface-hardening, the surface becomes rough having projections of several microns tall and pits of several microns deep; and simultaneously the surface becomes hard. In this way, a rough surface-hardened layer 11d is formed on the concave of the X-ray input window 11a thus treated.

On the rough surface of the rough, surface-hardened layer 11d, an aluminum thin film 12a of approximately 2000 Å, namely, a reflective substance layer is formed. The aluminum thin film is formed by the vapor-deposition under reduced pressure of approximately 2×10^{-5} Pa. On the reflective substance layer 12a, a phosphor layer 12b of 400 μm in thickness is formed by the vapor-deposition. The phosphor layer 12b is manufactured by the two steps; the first layer is formed of CsI/Na phosphors in a thickness of approximately 380 μm under a pressure of 4.5×10^{-1} Pa at a substrate temperature of 180 °C, and then, a second layer is formed of CsI/Na phosphors by the vapor-deposition in a thickness of approximately 200 microns under a pressure of 10^{-3} Pa.

The X-ray input window 11a including the phosphor layer 12b is welded to the envelop body 11c via a ring 11e made of metal, e.g. steel. The envelope body 11c connected to the X-ray input window 11a is then connected to the envelope output portion 11c. Thereafter, the photocathode 12d is formed on the phosphor layer 12b, directly or via the transparent conductive layer 12c.

In the X-ray image intensifier constituted as above, when the X-ray B from the X-ray source A is transmitted through the object C and entered into the input window 11a, light is generated, for example, at a point a in the phosphor layer 12b as shown in FIG. 6. The generated light is divided into two, light b which travels toward the output screen and light c which heads for the input window 11a. The light c heading for the input window when reaches the rough surface 12f of the rough, surface-hardened layer which is a surface of the input window 11a, causes irregular reflection. In general, the resultant irregular reflection light d is a cause of reducing brightness. However, due to the presence of the aluminum thin film 12a, namely, the reflective substance layer formed on the rough, surface-hardened layer 11d, the light c is reflected by the aluminum thin film 12a and then travels toward the output screen 15 instead of entering the rough, surface-hardened layer 11d, thereby preventing the decrease of brightness.

Hereinbelow, the data of the image contrast characteristics obtained by the X-ray image intensifier of this embodiment and the X-ray image intensifier of the conventional structure are compared to each other by way of example of the effective input screen diameter of 4 inches with reference to FIG. 3.

In FIG. 3, as described above, a contrast (%) and a contrast ratio are plotted on the vertical axis and a diameter of a lead circular plate is plotted on the horizontal axis. The experiment of FIG. 3 is conducted using the X-ray image intensifier having an effective input screen diameter of 4 inches at a tube voltage of 50 KV and a tube current of 1 mA.

In the case where the input window of this embodiment is used, lines a and b of FIG. 3 are obtained. More specifically, the line a is obtained in the case of aluminum input window. The line b is obtained in the case of beryllium input window, whose size is the same as that made of aluminum. The line c exhibits the image contrast which is obtained by a conventional X-ray image intensifier shown in FIG. 1.

According to the results shown in FIG. 3, the image contrast obtained by the conventional X-ray image intensifier drastically decrease as the diameter (mm) of the lead circular plate becomes smaller than 40 mm. In contrast, the contrast obtained by the X-ray image intensifier of this example linearly increases in proportional to and depending on the diameter (mm) of the lead circular plate, as shown in the lines a and b. This fact means that it is very easy to detect a smaller object, in particular, in the case where a light and shade are discriminated by coloring.

As described in the foregoing, the present invention made it possible to realize the X-ray image intensifier having an input window serving as an input screen, which has been considered difficult to attain.

Example 2

In this example, the image contrast characteristics were determined by applying a low-energy X-ray to the X-ray image intensifier (a material of the input window is an Al-Mg alloy) which is identical X-ray image intensifier to that used in the Example 1. In FIG. 4, as described above, a contrast (%) and a contrast ratio are plotted on the vertical axis, and the diameter of the lead circular plate on the horizontal axis. An experiment is carried out at a X-ray tube voltage of 30 KV and a tube current of 1 mA.

In FIG. 4, line d shows the change in the contrast obtained by the X-ray image intensifier of this Example. Line e shows the same data as above obtained in the case of the conventional X-ray image intensifier shown in FIG. 1.

As shown in FIG. 4, compared to the case where a high-energy X-ray (an X-ray tube voltage of 50 KV, a tube current of 1 mA) is applied, the image contrast obtained by the conventional X-ray image intensifier significantly decreases as the lead circular plate becomes smaller than 40 mm, whereas the contrast of the X-ray image intensifier of this example increases linearly in proportional to and depending on the diameter of the lead circular plate as shown in line d. Hence, in the X-ray image intensifier of the present invention, it is demonstrated that a smaller object can be examined with a high level of accuracy.

As explained in the foregoing, the present invention accomplished an X-ray image intensifier having a structure, which has been difficult to attain, such that an input screen is formed directly on the inner surface of an input window, and realized an X-ray image intensifier which can provide higher image contrast.

For reference, even in the case where an Al-Mg-Si series alloy (ASTM 6000 series) is employed instead
5 of the Al-Mg alloy used in the above Examples, similar effects can be expected.

Claims

- 10 1. An X-ray image intensifier comprising a vacuum envelope having a metal X-ray input window; an input screen formed on an inner surface of said X-ray input window; and a focusing electrode, an anode, and an output screen arranged in turn in said vacuum envelope along traveling direction of electrons generated from said input screen, wherein said X-ray input window has a rough, surface-hardened layer on a side on which said input screen is formed, and said input screen includes a phosphor layer formed on the rough, surface-hardened layer and a photocathode formed on the phosphor layer.
- 15 2. The X-ray image intensifier according to claim 1, wherein a material of said metal X-ray input window is aluminum or an aluminum alloy.
- 20 3. The X-ray image intensifier according to claim 1, wherein the surface roughness of said rough, surface-hardened layer is 2 to 10 μm .
4. The X-ray image intensifier according to claim 1, wherein the Vickers hardness of said rough, surface-hardened layer is 120 to 250.
- 25 5. The X-ray image intensifier according to claim 1, wherein said rough, surface-hardened layer can be obtained by impinging hard spherical particles onto a surface of a shaped material of said input window after an input window material is pressed into a shape of said input window.
- 30 6. The X-ray image intensifier according to claim 1, wherein said input screen further comprises a reflective substance layer formed on said rough, surface-hardened layer.
7. The X-ray image intensifier according to claim 6, wherein said reflective substance layer is a metal thin film.

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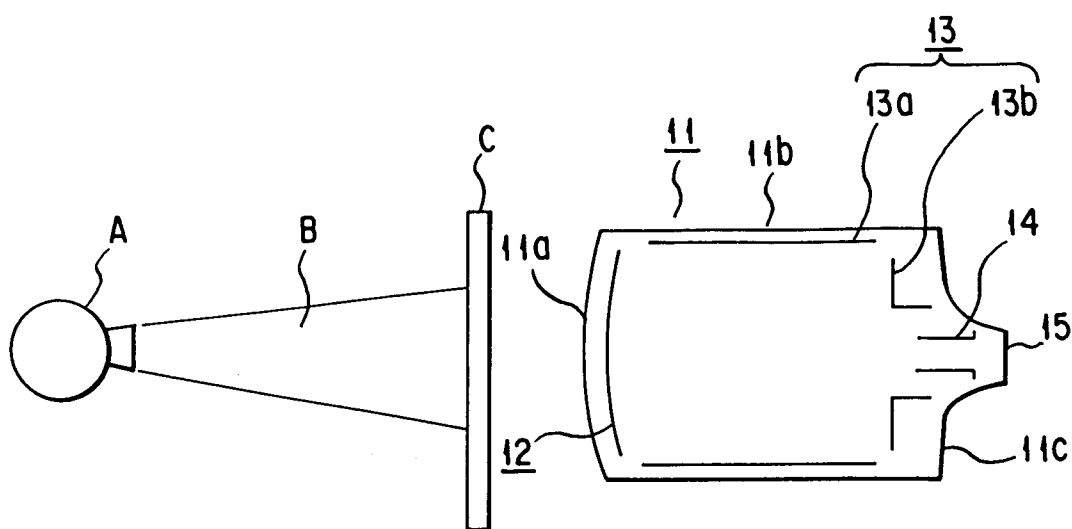


FIG. 1

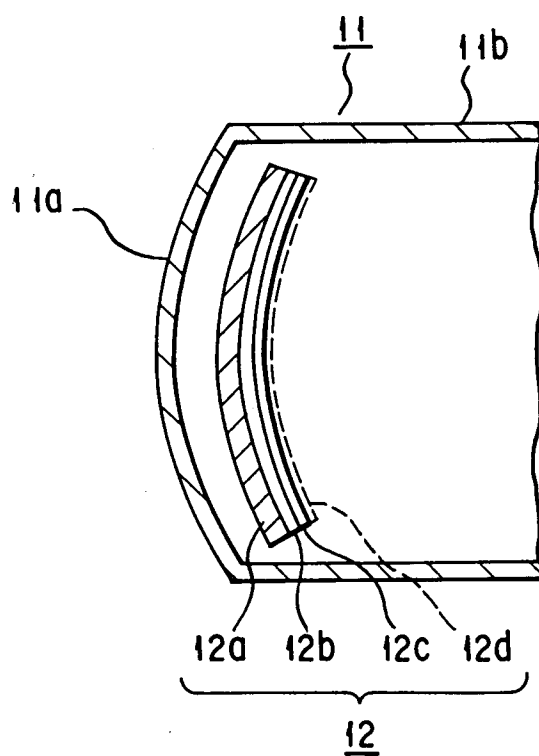


FIG. 2

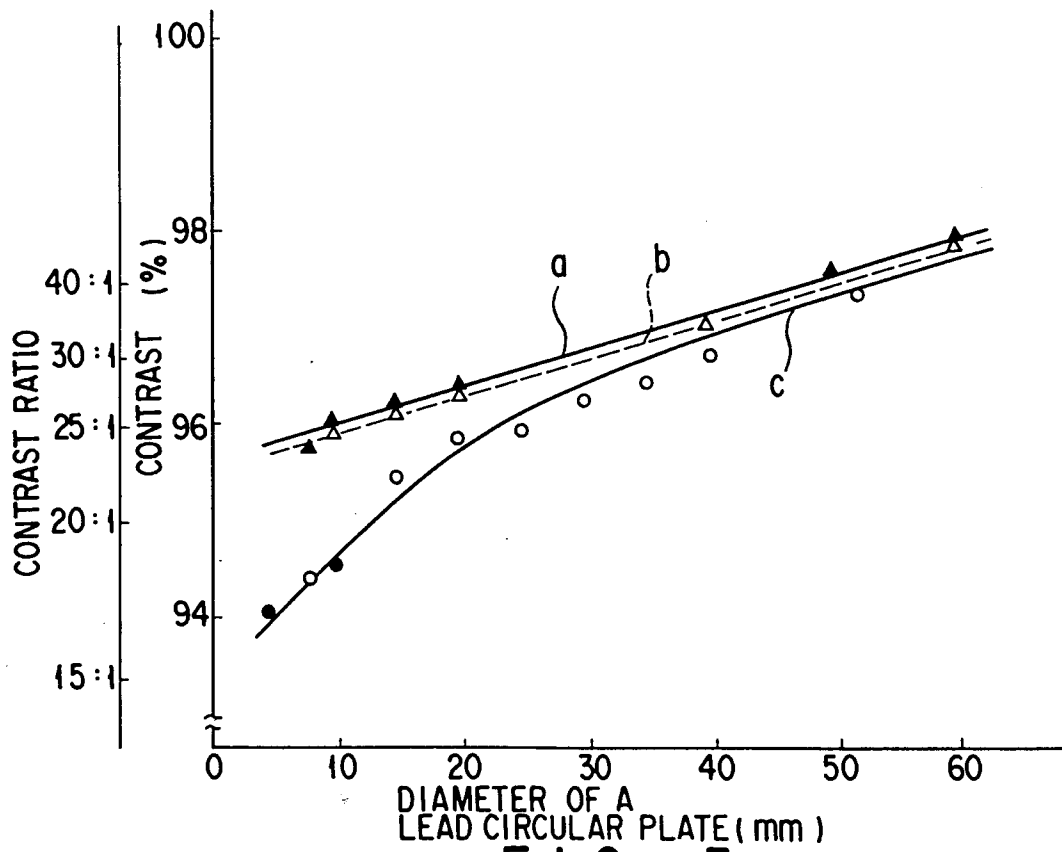


FIG. 3

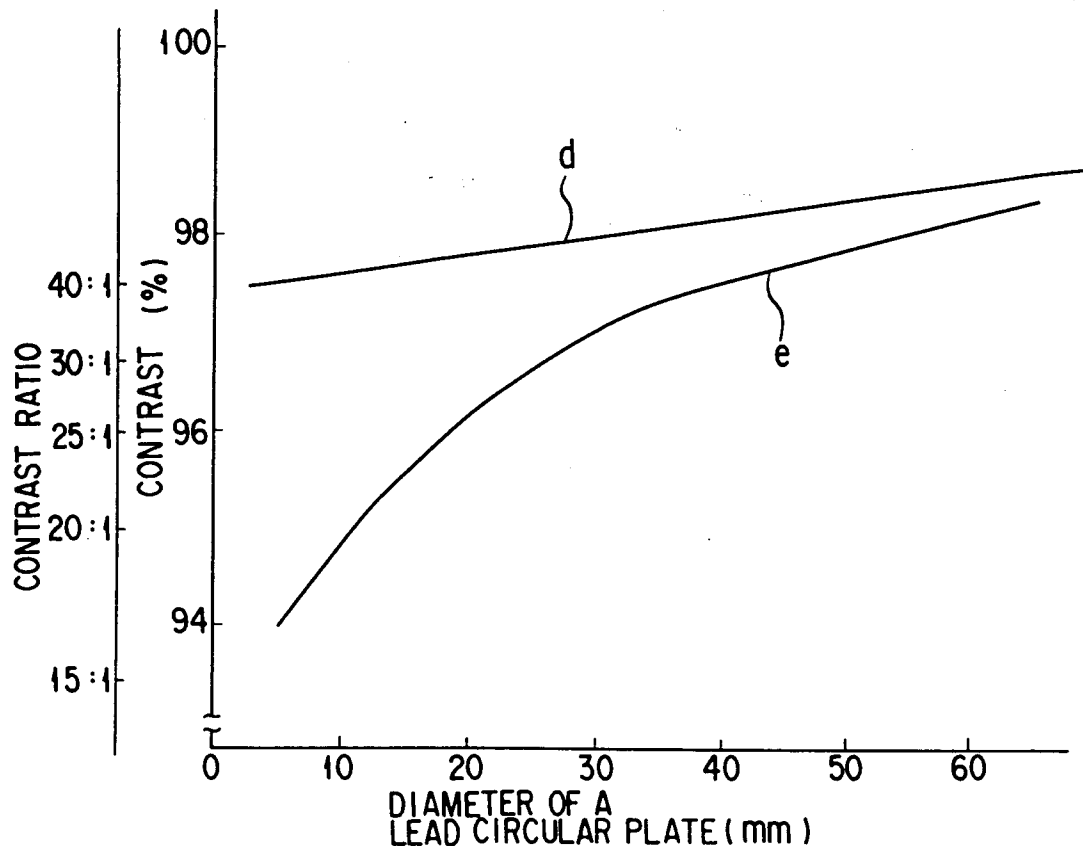
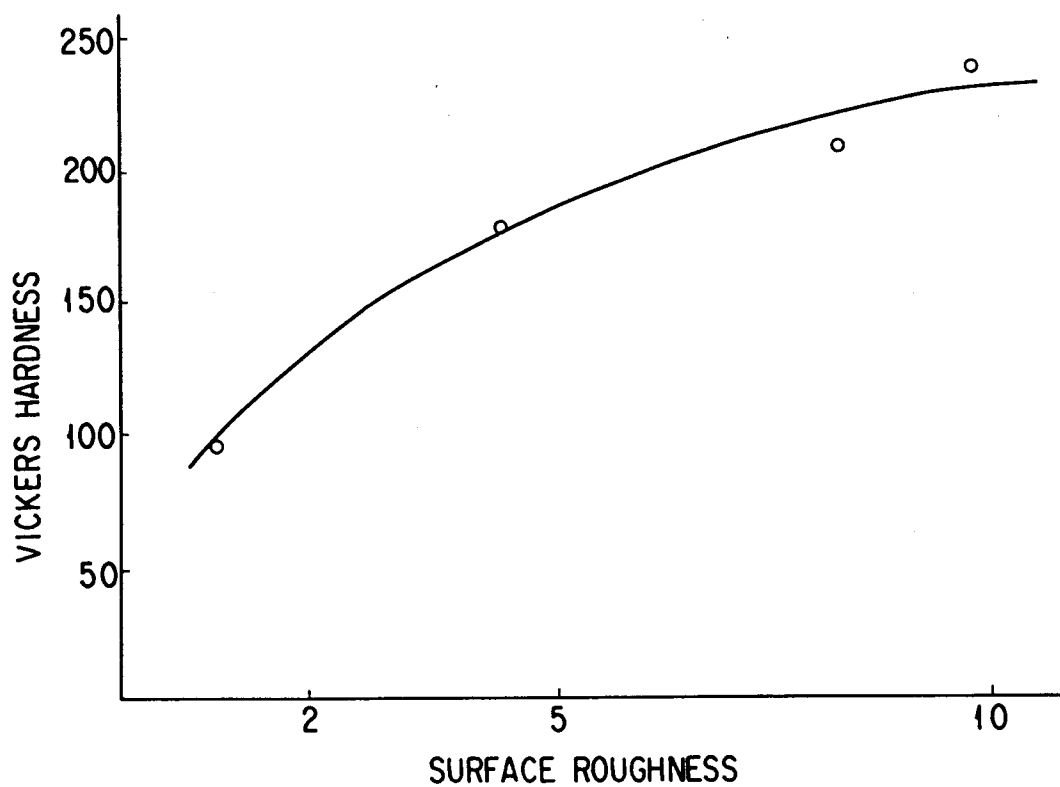
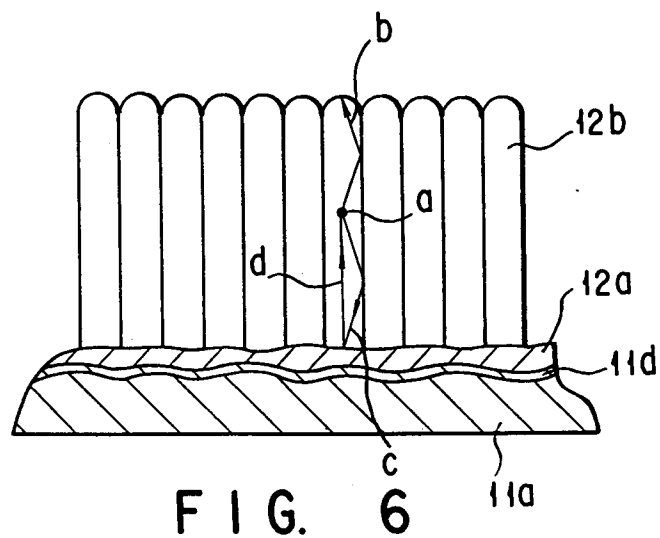
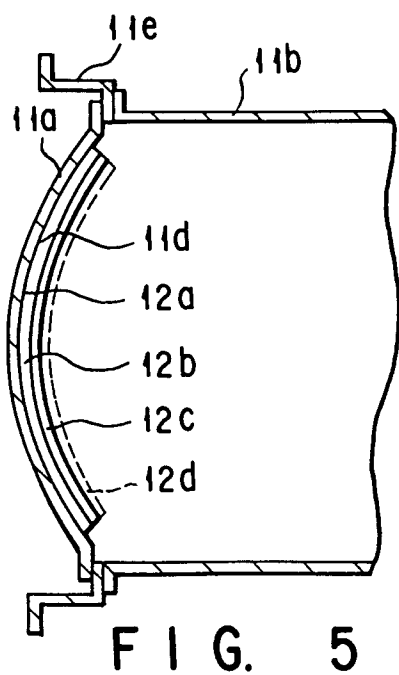


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP94/00430

A. CLASSIFICATION OF SUBJECT MATTER		
Int. Cl ⁵ H01J31/50		
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)		
Int. Cl ⁵ H01J31/50, 31/49, 29/38		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Jitsuyo Shinan Koho 1926 - 1993		
Kokai Jitsuyo Shinan Koho 1971 - 1993		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, A, 55-150535 (Shimadzu Corp.), November 22, 1980 (22. 11. 80), Figs. 2 to 5, (Family: none)	1, 2
A	JP, A, 59-75544 (Toshiba Corp.), April 28, 1984 (28. 04. 84), Line 4, upper right column to line 2, lower left column, page 2, (Family: none)	1, 2
☐ 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		Date of mailing of the international search report
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