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[54] **COMPOSITE INPUT SCREEN FOR X-RAY IMAGING DEVICES**

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[52] **U.S. Cl.** .... **250/483,** 250/486, 252/301.4 S

[51] **Int. Cl.** **H01j 1/62**

[58] **Field of Search** .... 250/460, 483, 486; 252/301.4 S

[56] **References Cited**

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[57] **ABSTRACT**

A composite screen is made from a mixture of CsI:Tl and Gd_2O_2S:Tb phosphors. The composite is formed by slowly removing a mixture of the phosphors from a hot zone so that molten CsI:Tl progressively cools and hardens to bind the Gd_2O_2S:Tl particles together. When completed, the composite material is sliced to form a plurality of screens.

9 Claims, 2 Drawing Figures

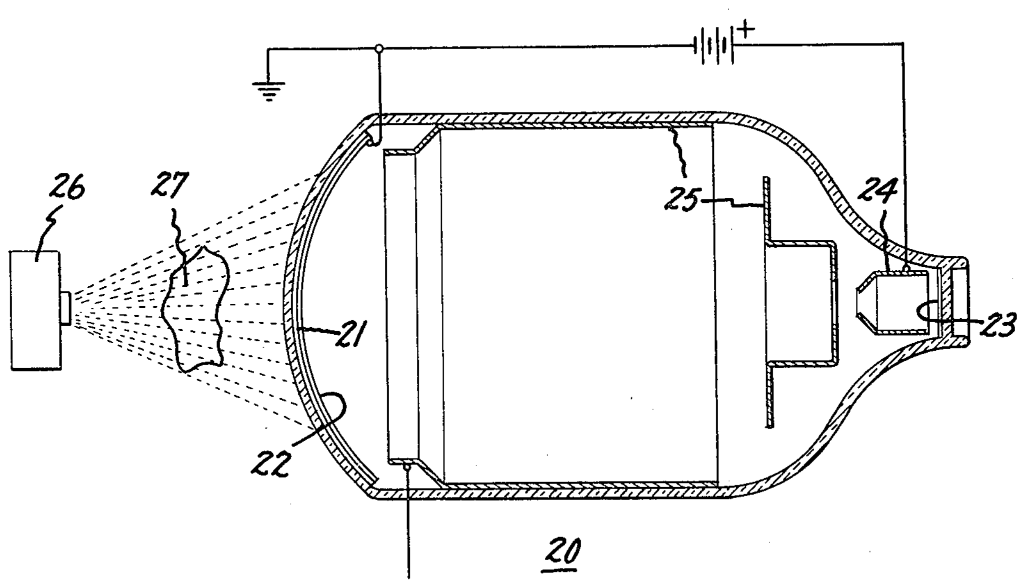


Fig. 1.

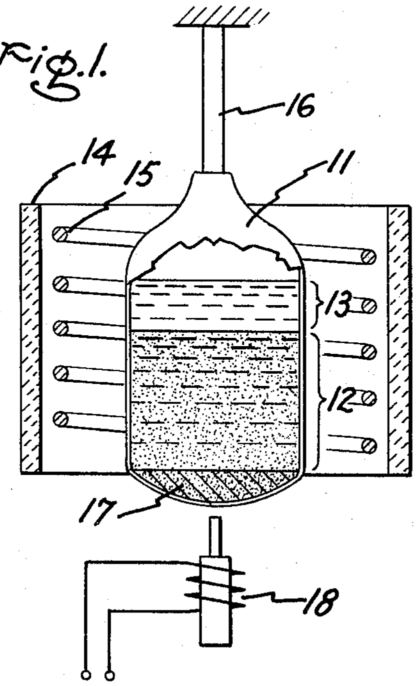
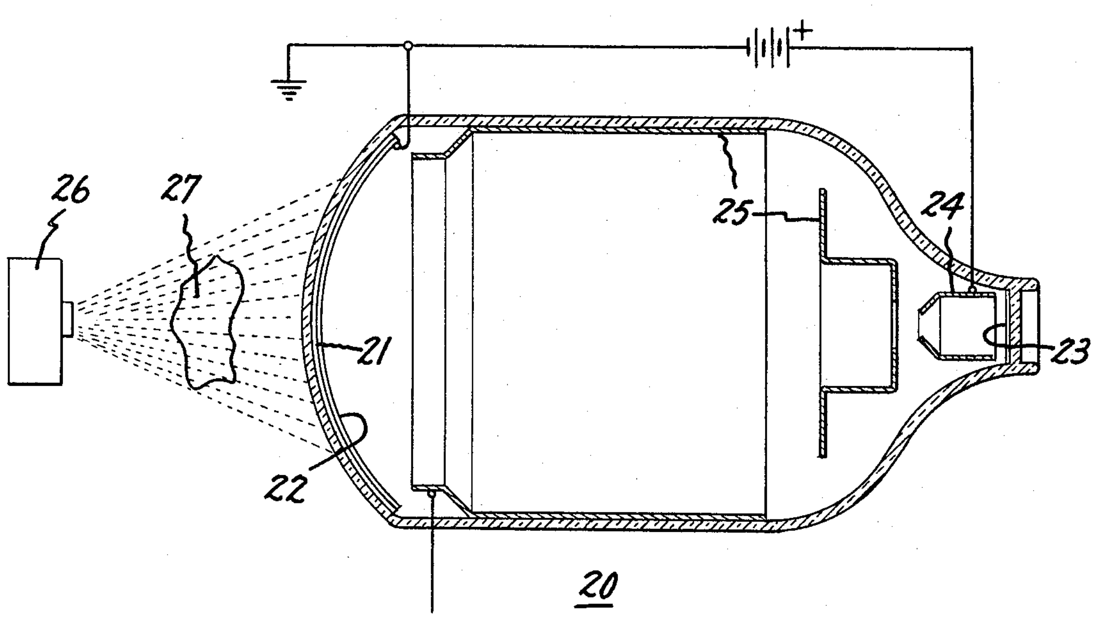


Fig. 2.



COMPOSITE INPUT SCREEN FOR X-RAY IMAGING DEVICES

This invention relates to x-ray imaging devices and, in particular, to an improved input screen for x-ray imaging devices.

A typical fluoroscopic x-ray examination utilizes an x-ray source, an x-ray image intensifier and a choice of viewing or recording devices such as direct viewing optics, camera for still or cine photography, or a television camera tube. The x-ray image intensifier converts the x-ray image, essentially a shadow cast by a subject positioned between the source and the image intensifier, to a visible image capable of being viewed or recorded.

The x-ray image intensifier comprises an evacuated glass envelope containing an input phosphor screen for absorbing the incident x-ray photons and converting these into light photons. In intimate contact with the input screen is a photoemissive surface for absorbing the light photons and converting them into photoelectrons. A series of electrodes focuses and accelerates the electrons so that they impinge on an output phosphor screen, which converts the electron image back to a visible light image. The image on the output phosphor screen is much brighter than that formed by the input phosphor screen. This increase in brightness is due partly to the acceleration of the electrons and partly to the reduced size of the output screen as compared to the input screen, typically 10:1 for a 6 inch input screen.

Input phosphor screens available in the prior art have comprised, for example, ZnCdS:Ag or Gd_2O_2S:Tb powder in a resin binder, or evaporated films of CsI:Na or CsI:Tl. Taking one phosphor powder as an example, Gd_2O_2S:Tb, known to be an efficient x-ray phosphor, must be mixed in powder form with a resin, such as Dow Corning R-61-049 junction coating resin, to make a screen. The screen thus comprises both active material, the x-ray phosphor, and inactive material, the resin, which contributes nothing to the conversion of the x-ray image to a visible image. Further, approximately 58 percent by volume of the screen is the inactive resin, i.e., the density and hence the x-ray absorption of the screen is much lower than that of bulk Gd_2O_2S:Tb, for a given thickness.

For doped films of CsI, the density of the films is approximately that of a doped, single crystal of CsI.

For a given thickness, at x-ray energies greater than 50 keV, the x-ray absorption of a Gd_2S_2O:Tb crystal is higher than that of a CsI crystal or a ZnCdS crystal. Although one can make evaporated CsI screens readily with a density approximately that of a single crystal, it has not been possible to make screens from Gd_2O_2S:Tb with a density close to that of a single crystal and a thickness of several mils. However, the efficiency of the evaporated CsI film in converting x-ray photons to light photons is not as high as for Gd_2S_2O:Tb.

Increasing the thickness of either screen, while providing more active material, is off-set by a decrease in the resolution obtainable. Conversely, decreasing the thickness of the screen, while increasing resolution, reduces the amount of active material, thereby absorbing less x-rays.

Increased x-ray absorption and x-ray to light conversion efficiency is desirable due to the discrete nature of the x-ray information. Information contained in the x-ray photons incident upon the input screen is lost unless the photons are absorbed and converted into light photons. Simply increasing the brightness of the output light image, e.g. by accelerating the electrons to higher energies, does not increase the available information. If the x-ray absorption of screen made from high conversion efficiency x-ray phosphors were increased, then more information can be gleaned from the same x-ray does. Conversely, the dosage could be decreased with no loss of information as compared to other input screens of the prior art.

In view of the foregoing, it is therefore an object of the present invention to provide a phosphor screen with higher x-ray absorption for a given thickness than has been obtainable in the prior art.

Another object of the present invention is to provide a brighter input screen, for a given thickness.

A further object of the present invention is to provide a higher resolution input screen for a given thickness for x-ray imaging devices.

Another object of the present invention is to provide an improved x-ray input screen enabling lower x-ray dosage of human subjects.

The foregoing objects are achieved in the present invention wherein a composite of CsI:Tl and Gd_2O_2S:Tb powder is grown from a mixture of the two materials by heating a sealed evacuated tube containing the mixture above the melting point of the CsI:Tl (621° C) and slowly lowering the container from the hot to a cooler zone so that the CsI:Tl crystallizes slowly and progressively from one end to the other to form the solid composite. The solid composite is then sliced into wafers, where each wafer forms a screen. The CsI:Tl, which is also an efficient x-ray phosphor, acts as a binder for the Gd_2O_2S:Tb particles, thereby providing an active binder.

The notation ":Tb" or ":Tl", as known in the art, indicates that the preceding material is doped with terbium or thallium, respectively. For Gd_2O_2S:Tb, the phosphor contains from 3×10^{-4} to 1×10^{-2} mole fraction Tb_2O_2S. For CsI:Tl, the phosphor contains from 5×10^{-4} to 5×10^{-3} mole fraction TlI.

A more complete understanding of the present invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates the apparatus used in growing a composite in accordance with the present invention.

FIG. 2 illustrates the input screen in accordance with the present invention in use in an x-ray image intensifier.

Input screens in accordance with the present invention comprise a dense ceramic like composite material, Gd_2O_2S:Tb-CsI:Tl. In these, the CsI:Tl x-ray phosphor acts as a binder for the powdered Gd_2O_2S:Tb x-ray phosphor. The screen is mounted on the input side of a suitable evacuated glass envelope containing the remaining parts of the image intensifying device. The Gd_2O_2S:Tb and CsI:Tl compounds, while known separately in the art as efficient x-ray phosphors, have not been utilized together. Thus, for example, Gd_2O_2S:Tb must be mixed with a silicone resin binder to provide a mechanically strong input screen. However, in so doing, the screen is less dense than desired for absorbing the incident x-rays. Thus screens of the prior art are less x-ray absorbing than would be otherwise desirable for obtaining maximum information from the x-ray beam. In accordance with the present invention, input screens with higher x-ray absorption for a given thickness are obtainable than from either phosphors in resin or evaporated phosphors. Alternatively, thinner screens with the same x-ray absorption for a given thickness may be produced than are obtainable from the prior art, thus increasing their resolution. Further, since CsI:Tl is a phosphor while the resin is not, brighter screens are obtainable for the same thickness and x-ray dosage than from either phosphors in resin or evaporated phosphors.

FIG. 1 illustrates suitable apparatus for making screens in accordance with the present invention. Generally, the apparatus comprises a furnace from which a container of the phosphors may be slowly removed. Further, provision must be made for agitating the mixture periodically as it cools to prevent the formation of bubbles or voids in the final composite.

Specifically, screens in accordance with the present invention are made by mixing together the CsI:Tl and Gd_2O_2S:Tb powders and placing them in a suitable container, such as a clear fused quartz tube. The tube is then outgassed and sealed under vacuum. The container, illustrated in FIG. 1 as container **11**, is then inserted in furnace **14** and heated to a temperature in excess of the melting point of the CsI:Tl phosphor, that is, in excess of 621° C. For example, 700° C has been found to be a convenient temperature. The proportion of the phosphors in mixture **12** is such that, upon melting of the CsI:Tl, excess CsI:Tl forms a pool **13** at the top of the container.

Container **11** is preferably fixed to a support by connecting means **16** and heated by moveable furnace **14** having heating coils **15**. Moveable furnace **14** may be moved by any suitable means, such as a platform jack. During the progressive cooling of container **11**, furnace **14** is slowly raised so that more and more of container **11** protrudes from furnace **14**. As the melt cools, the CsI solidifies and bonds together the particles of Gd_2O_2S:Tb to form a ceramic like, composite material **17**. At the end of the cooling cycle, furnace **14** is shut off and lowered out of the way.

Furnace **14** is moved at a sufficiently slow rate, e.g. 0.1 to 1.0 centimeters per hour, to assure that the melt solidifies from one end to form a compact solid free of internal voids. Internal voids may form due to the large decrease in volume the CsI undergoes upon solidification. Due to the high viscosity of the liquid containing the suspended particles of Gd_2O_2S:Tb, voids may become trapped in the composite during solidification. To prevent this, some means of agitation must be provided, such as by solenoid **18**. Solenoid **18** is actuated to tap container **11** and agitate the contents thereof. The frequency of the agitation depends upon the growth rate of composite **17**. At a growth rate of 0.5 centimeters per hour, agitation once per second is adequate.

As previously noted, pool **13** is formed at the top of liquid **12**. This pool acts as a reservoir from which sufficient CsI is withdrawn to replace the volume lost through shrinkage upon solidification. Thus, despite the high viscosity of the liquid portion containing the suspended Gd_2O_2S:Tb particles, voids are prevented through the combination of agitation and pool **13**.

A sufficient excess of CsI is obtained from a typical ratio by weight of 2.5:1, CsI:Tl to Gd_2O_2S:Tb, respectively. While less CsI:Tl may be utilized, for example, a ratio of 2:1, the care required in assuring an adequate supply of phosphor binder makes it inconvenient and inadvisable to work near the minimum ratio of compounds. In other words, by providing an excess of the phosphor binder, a convenient indicator is obtained of whether or not an adquate amount of phosphor binder has been provided. Once pool **13** is obtained, adding further CsI:Tl phosphor binder is unnecessary.

After passing through furnace **14**, container **11** is broken and the composite removed. The composite does not adhere to the clear fused quartz tube and is easily removed. After removal, the composite is cut into thin wafers, for example, 3 to 10 mils thick, to provide a plurality of screens from a single growth. The solidified excess CsI:Tl is removed and can be re-used. The wafers from the composite are cut in a flat plane by any suitable mechanism known in the art and sagged into the desired spherical shpe by heating to slightly less than the melting point of the CsI:Tl, e.g. 615° C. Alternatively, the wafers can be cut spherically or cut thicker than desired and ground to the desired spherical shape. Suitable mechanisms for performing the cutting and shaping of the wafers are known in the art.

FIG. 2 illustrates a screen in accordance with the present invention. Wafer **21**, formed as described above, is placed at the input face of tube **20** and cemented to it to act as a mechanically strong substate. Formed in contact therewith is a photoemissive screen **22** for converting the faint optical image into an electron image. The electrons emitted by photoelectrode **22** are accelerated to output phosphor screen **23** where the electron image is converted into a brighter optical image. Suitable accelerating and focusing electrodes **24** and **25**, respectively, are provided as known in the art to accelerate and focus the electrons. Due to the increase in energy of the electrons, the brightness of the visible image formed is intensified.

In operation, x-rays from a suitable source, designated as source **26**, irradiate a subject **27** so that the shadow formed by the varying degrees of x-ray opacity of subject **27** falls upon input screen **21**. The image is converted and intensified as described above and may be viewed on screen **23** directly or a television camera tube may be used so that the image is displayed on a TV monitor. Alternatively, still or motion pictures may be taken of the output screen image.

There is thus provided by the present invention an improved input screen for x-ray imaging devices wherein one can obtain an output visible image containing a higher information content, a brighter image, a higher resolution image or, by decreasing the dosage, a longer exposure of the subject so that the subject can be studied for a longer period of time without exceeding recommended x-ray dosages. In addition, the screen in accordance with the present invention is mechanically strong and can be easily made in quantity.

Having thus described the invention it will be apparent to those of skill in the art that various modifications can be made within the spirit and scope of the present invention. For example, while container **11** has been described as fixed and furnace **14** moveable, the same relative motion can be obtained with a fixed furnace by moving container **11** together with the agitation mechanism **16**. Further, other dopants may be utilized in the cesium iodide, such as sodium for example.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. An improved screen for x-ray imaging devices comprising:

a wafer comprising a high density, high conversion efficiency phosphor powder bonded together with doped CsI;

said doped CsI forming approximately 60–80 percent by volume.

2. An improved screen as set forth in claim 1 wherein said doped CsI comprised CsI:Tl.

3. An improved screen as set forth in claim 1 wherein said high density, high conversion efficiency phosphor comprises Gd_2S_2O:Tb.

4. An improved screen as set forth in claim 1 wherein said screen is from 3 to 10 mils thick.

5. The method of making an improved input screen for x-ray imaging devices comprising the steps of:

mixing together in a container Gd_2O_2S:Tb and doped CsI in the ratio of about 1:2.5 by weight;

sealing said container under vacuum;

heating said container to at least 621° C to melt said doped CsI;

slowing withdrawing said container from the heat to form a composite of Gd_2O_2S:Tb — CsI;

removing the composite from said container; and

forming a plurality of wafers from said composite, wherein each wafer comprises a complete input screen.

6. The method as set forth in claim 5 wherein said container is heated to approximately 700° C.

7. The method as set forth in claim 5 wherein said composite is formed by withdrawing the container at 0.1 to 1.0 centimeters per hour.

8. The method as set forth in claim 5 wherein said wafers are formed by slicing said crystal and grinding the slices to a curved surface configuration to form an input screen for an x-ray imaging device.

9. The method as set forth in claim 5 wherein said doped CdI comprises CsI:Tl.

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