

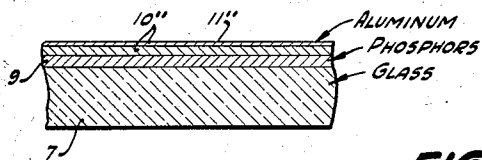
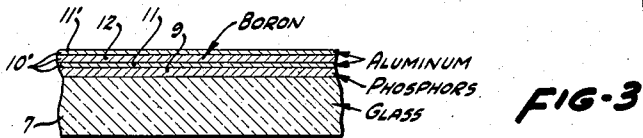
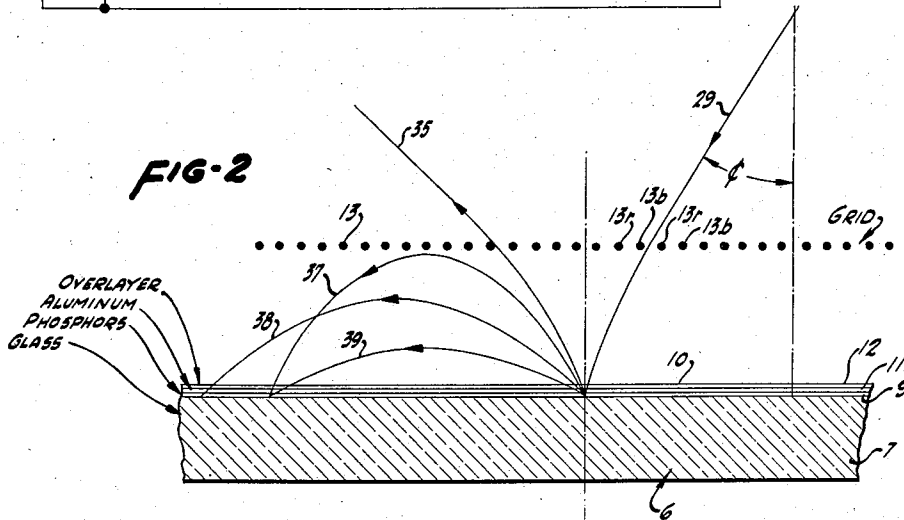
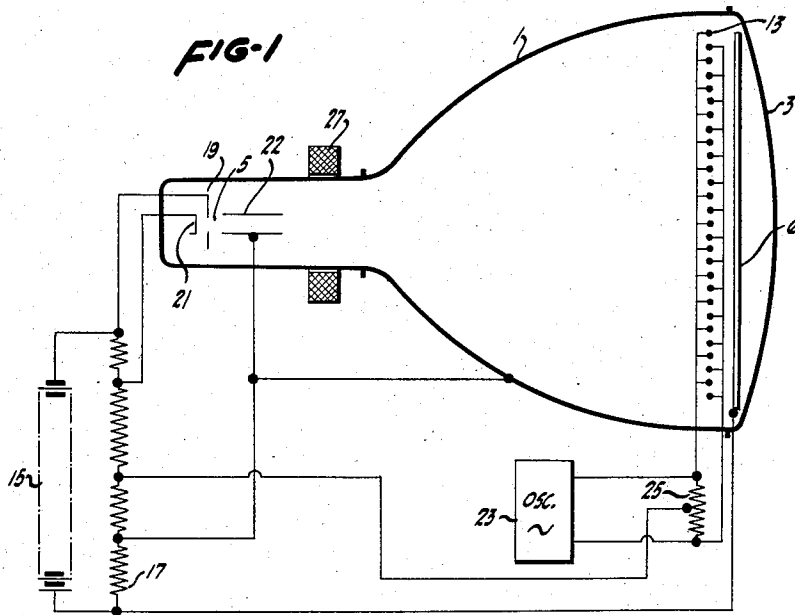
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COLOR TELEVISION DISPLAY SCREEN

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1

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COLOR TELEVISION DISPLAY SCREEN

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8 Claims. (Cl. 315—1)

This invention relates to display screens for cathode-ray tubes, particularly to screens for use in tubes intended for displaying television images in their natural colors.

This application is a continuation-in-part of my application Serial No. 495,560, filed March 21, 1955, now abandoned.

The screens employed in display tubes used in color television comprise, in general, a transparent base with a coating thereon of a number of different phosphors, usually three, which are emissive of light of different component colors which additively produce white. The colors emitted by the phosphors are generally red, blue, and green, and for convenience the phosphors will be referred to the red, blue and green phosphors, although they will usually appear white or nearly so when viewed by reflected light.

In such tubes the different color phosphors are disposed in a repeating pattern of color cells, which in one dimension at least, approximate in size the dimension of a single elementary area or picture point of the image to be reproduced, each color cell containing phosphors of all the primary colors used. In the other dimension the color cells may run together to form strips extending across the entire width of the display screen, the pattern on the screen therefore either being aggregates of dots or of strips. Means are provided for so directing the electron beam which excites the phosphors to the particular phosphor desired so as to excite its primary color to the proper proportion to make the particular picture element occur at the proper hue. Usually, but not always, the means for controlling which phosphor or phosphors will be excited at a specific instant involve either a shadow mask which occults the beam except with respect to a specific phosphor, or a lens- or focus-grid which, in connection with other electrode structure within the tube, establishes electric fields which act as electron lenses to focus the beam on the desired phosphor.

The phosphors most generally used are salts of metals of fairly high atomic number, the most common base in these salts being zinc, with an atomic number, Z , of 30. Of the other phosphors, which might conceivably be employed, calcium ($Z=20$) has the lowest atomic number, and even where a calcium-base phosphor employed for one color, it would almost certainly be associated with materials of much higher atomic number base for the phosphors of other colors. Thus cadmium ($Z=48$) has been employed in some tubes. The great preponderance of the phosphors used are those having a zinc base, one characteristic screen using zinc phosphate, $Zn_3(PO_4)_2$ for the red phosphor, zinc silicate, (Zn_2SiO_4) for the green phosphor and zinc sulphide (ZnS) for the blue.

When an electron beam impacts a phosphor layer it is multiply scattered before its kinetic energy is entirely dissipated in ionizing the phosphors, with the resultant production of useful light, the term "ionizing" as here used including both the removal of an orbital electron from an atom and raising one to an excited state within the atom. As a result of the scattering the electrons form-

2

ing the beam are deflected from their original courses by angles which are initially distributed substantially in accordance with the normal probability curve, the mean angle of deflection or scattering being proportional to the atomic number of the atoms responsible for the scattering action, half of the electrons being scattered to less, and half to greater angles than the mean scattering angle.

As the electrons penetrate more deeply, they are subjected to further multiple scattering events, and at the same time lose energy through ionizing the orbital electrons of the atoms through which they pass. The number of orbital electrons encountered in traversing a path through a layer of a given mass per square centimeter is approximately independent of the atomic numbers of the elements constituting the layer, since the atomic weights are roughly proportional to the atomic numbers in materials of fairly low Z . The scattering angle is determined primarily by the concentrated charges on the nuclei of these atoms and the average scattering angle is proportional approximately to the atomic numbers of the scattering nuclei. Both scattering angle and loss of energy by ionization of the penetrated material are inversely proportional to the energy of the electrons, in electron volts. The number of scattering events and the total angles through which the electrons are scattered therefor both increase with depth of penetration.

Some of the electrons of the beam are deflected through angles wide enough to cause them to emerge through the screen surface while still retaining a considerable portion of their initial energy, and these are referred to as "back-scattered" electrons. Such back-scattered electrons include a very small proportion of so-called "reflected" electrons which emerge from the screen with substantially their entire input energy, and have probably been subjected to only a single deflection, probably by a close encounter with a nucleus. A great majority will emerge because of a large number of cumulative scattering deflections, and with much less than their initial energy, although with much more energy than that of true secondary-emission electrons of only a few electron volts. The number of back-scattered electrons of both singly and multiply scattered categories is substantially proportional to the Z of the scattering material. Their distributions in angle and in energy are statistical functions, but except in thin films, or in the surface layers of thick films, their distribution is no longer Gaussian.

In tubes for the presentation of television images in monochrome back-scattered electrons are of little moment, since they are not subjected to electrical fields which would return them to the screen and they therefore are ordinarily collected on the walls of the tube. Where, however, the electrons are subjected to focusing fields tending to return them toward the screen from which they were emitted they arrive there, in general, with the full energy which they had upon emission and at angles of incidence equal to their angles of emission. As a result the spot of impact of the primary beam is surrounded by a halo, the size and brilliancy of which depends upon the maximum energy and the angles at which they were emitted. Since the azimuth of their angles of emission are random and the halo follows the spot in its deflection across the viewing screen, the emitted electrons may fall back upon phosphors emissive of any of the colors employed in the tube construction and since, in color tubes, the colors emitted will usually be the three primaries which additively produce white, the over-all effect is a dilution or desaturation of all of the colors exhibited, a general raising of the background level of illumination and a loss of contrast and detail.

The primary object of the present invention is to provide means of suppressing the halo thus formed, and so permit the presentation of color television images in

stronger, more saturated colors and with better definition. Other objects are to provide a display screen which can be manufactured by known processes and without involving health hazards; to provide display screens for cathode-ray tubes which will display a beam spot of minimum size; and to provide a display screen which, in the several modifications in which it can be made and which will be described hereinafter, can be adapted for use in color tubes of the type wherein halo effects are likely to be observed.

Broadly, the screen of the present invention comprises, in addition to the usual transparent base and its coating of phosphors having the high atomic number constituents described above, a plurality of layers of materials of atomic number materially less than the effective value of the atomic number of the phosphors. One of the layers is of metal and is so disposed as to reflect light emitted from the phosphors back through the base to increase the apparent illumination of the screen, this layer being of the minimum thickness which will give it continuity. Another layer is preferably of material all constituents of which are of lower atomic number than the metal of the layer first described and further layers may be employed if desired. The combined thickness of all layers used is such that the great preponderance of electrons which are scattered in the phosphor layers to angles which would result in their emergence from the screen and the formation of a halo will lose substantially all of their energy in passing through the superposed layers before again striking the phosphors of the screen; in most tubes this combined thickness is that corresponding to somewhere between one-sixth and one-third of the range of the incident beam in the materials of which the layers are composed.

Other features of the invention will become apparent in the course of the detailed description of the invention which follows, and which is illustrated in the accompanying drawings wherein:

Fig. 1 is a schematic drawing of a cathode-ray tube of the type wherein the present invention finds a particular value;

Fig. 2 is a fragmentary cross-sectional diagram of a screen in accordance with the present invention, shown on a greatly exaggerated scale, and illustrating its relationship to a focusing electrode;

Fig. 3 is a diagram showing a modified screen construction; and

Fig. 4 is a similar diagram showing a further modification of screen construction.

The tube of Fig. 1 is shown symbolically to illustrate the conditions giving rise to the particular problem which the present invention is designed to alleviate. Characteristically, a tube of this character will comprise an evacuated envelope 1, which is generally of funnel-shape and can be either metal or glass. For present purposes it will be assumed that this envelope is of metal; if of glass it will be provided with a conductive lining. The large end of the funnel is provided with a transparent window 3 through which the television images are displayed. In the neck of the funnel is an electron gun 5. For the present purposes only one such gun is shown, although in certain forms of the tube for which the present invention is adapted a plurality of guns may be used.

Within the window 3 is the display screen 6 upon which the television images are projected. The screen comprises a transparent base 7, which may, in certain instances, be the window itself. Deposited upon the surface of the screen which faces the electron gun is a layer 9 of phosphors which are deposited (for a color tube) in a repeating pattern of color cells which in one dimension at least are of the order of magnitude of a single "picture point" or elemental area of the image to be reproduced. These cells may be of like size in the other dimension, or they may be of strips extending

entirely across the screen area. In the present instance it will be assumed that they are of this latter form. Each color cell includes sub-areas of the individual phosphors which, upon electrical impact, emit light of the various primary colors used in the system for which the tube is designed, usually red, green, and blue.

Deposited on the layer of phosphors 9 is a backing 10 comprising at least two and possibly three layers of different materials of atomic number lower than that of the basic element in the phosphors of the screen. The details of such structures are shown in Figs. 2, 3 and 4, the backing shown in Fig. 2 comprising a layer 11 of a light metal, preferably aluminum, in contact with the phosphors of the screen and a layer 12, superposed thereon, of a material of lower effective atomic number, the layer 12 being materially thicker than the layer 11. The arrangements of the layers and their materials, as shown in Figs. 2, 3 and 4, as well as the materials available for the various layers will be discussed hereinafter.

Mounted adjacent to this screen is a lens-grid or focus-grid structure 13, which, since a strip-type phosphor screen has been assumed, comprises a multiplicity of elongated linear electrodes, the interspaces between which form the apertures of the multiplicity of electron lenses each of which is electron-optically aligned with a corresponding color cell on the screen. With a single gun tube, of the type shown, the electrodes forming the grid are divided into two sets which are mutually insulated and interleaved.

In the operation of the tube shown, the various elements within the tube are operated at definite relative potentials. This is symbolized in the drawing by conventionally shown potential source 15, connected across a voltage divider 17 which has various taps connected to these elements. The most negative point on the divider connects to a control grid 19 of the electron gun. The gun cathode 21 is connected to a slightly more positive point on the divider, the voltage with respect to the cathode usually being somewhere in the neighborhood of 100 volts or less. Taking the other elements of the tube in order of increasing positive potential, the lens grid 13 may be operated somewhere in the neighborhood of 5 kv. positive to the cathode, the gun anode 22 and the envelope of the tube somewhere in the neighborhood of 200-400 volts positive to the focus grid, and the film 11 about 18 kv. positive to the cathode or 13 kv. positive to the grid 13. It is to be understood that these figures are given for the purpose of illustration only, and that tubes may be designed to operate at relative voltages quite different from those here suggested. Furthermore, it will be realized that the lens-grid structure here shown is one of the simplest, and that, in addition to the single grid here described, a lens-grid can include one or more additional grids, which may be either nearer to or farther from the screen than that forming the apertures of the electron lenses. In the present case the electron lenses are formed by the electric fields between the film 11 and the grid wires 13.

With the particular form of lens here described, and with the relative voltages mentioned applied to the electrodes, a beam of cathode-rays from gun 5, directed through any of the apertures in the lens-grid structure, will be focused on the center of the corresponding color cell. So focused, its cross-sectional width, normal to the electrodes of the grid, will be small in comparison to the width of the aperture and the beam will fall on a particular phosphor; i. e., that which occupies the mid-position in the array of strips of different phosphors forming the cell. For various reasons which are not pertinent to the present invention the central phosphor strip will usually be that emitting green.

In order to change the color displayed by the tube, a potential difference is applied between the two sets of electrodes, 13_a and 13_b, of the grid. This potential difference may be applied from a "color oscillator" 23,

connected across a resistor 25, the center tap of which connects to the voltage divider 17 so that the latter supplies the mean potential of the grid. The oscillating voltage thus applied deflects the electrons passing through the interspace between the electrodes to one side or the other, so that the beam is focused on either the red- or blue-emitting phosphor as the case may be, depending upon the phase of the voltage supplied by the oscillator 23.

In operation the tube is also provided with a conventional scanning yoke 27 which deflects the beam over the surface of the display screen in a raster which defines the picture area. There will usually also be provided means, not shown, for interrupting or blanking the beam as its focal point is deflected across the junction between the different phosphors as a result of the shifting position of the focal point effected by the oscillator 23.

It is conventional, in tubes of the general character here considered to provide the phosphor coating with a backing layer of aluminum, this layer being made as thin as possible while maintaining continuity so that the layer will provide a conducting mirror surface over the entire area of the phosphor screen, and will also have sufficient density to stop any negative ions which may be formed in the tube from reaching the phosphors. The layer 12, however, is not a conventional element in structures of this character. Its nature and the reasons for and effects of its use can best be appreciated by first considering the effects produced in tubes of conventional construction, which effects are diagrammatically illustrated, superimposed upon the diagram of Fig. 2.

As shown in Fig. 2, in the operation of the tube a beam of electrons is directed toward the screen surface along a path whose center line is indicated by the line 29 in the figure, which makes some angle, ϕ , with the normal to the surface of the screen. Passing through the wires of the grid 13, the electrons of the beam follow a parabolic course under the influence of the accelerating field between the grid and the screen, and strike the screen at an angle slightly less, in general, than the angle ϕ . Striking the surface of the screen they pass through the aluminum layer 11, enter the phosphor coating and are scattered thereby, some scattering having previously taken place in traversing the aluminum film 11. The angles θ through which electrons are scattered in passing through the thin aluminum films usually employed are distributed statistically approximately in accordance with the Gaussian probability curve represented by the equation:

$$P(\theta)d\theta = Ae^{-\frac{bV\theta^2}{Z^2}}d\theta \quad (1)$$

where A and b are constants, V is the energy of the electrons of the beam in electron volts, and Z is the average of the atomic numbers in the molecules of the scattering material.

After passing through the aluminum layer and entering the phosphors the majority of the electrons of the beam expend their entire energy within the phosphor layer, either in ionizing it and producing useful light or in heating it. As they do this, they lose more and more of their velocity, in passing close to a nucleus they therefore are subject to its influence for longer times and are, on the average, deflected through wider angles. A proportion of them will be deflected through cumulative angles wide enough to cause back-scattering so that they emerge from the screen to cause halo.

The distribution of back-scattered electrons in angle does not vary greatly with change in Z of the scattering material. The number, proportionally, of electrons so back-scattered varies almost directly as Z. Considering an electron beam striking the screen normal to its surface, it is obvious that in order to emerge they must be deflected from their original course by an angle in excess of 90 degrees. The density of the back-scattered electrons per differential angle varies from substantially zero

at 90 degrees to a maximum at about 104 degrees. From this point it falls off gradually to about 20 percent of the maximum at 120 degrees and then falls off nearly linearly to approach zero again at 180 degrees. In terms of energy of the emergent electrons, it reaches a peak at nearly the angle of maximum intensity, the peak occurring between 103 and 113 degrees, falling off again nearly linearly toward zero at 180 degrees. The range of the electrons of an incident beam which has been subjected to an acceleration by a potential of V kilovolts can be expressed quite accurately by the equation:

$$R=2.1V^2 \quad (2)$$

where R is expressed in micrograms per square centimeter of material. This equation holds fairly accurately for materials of relatively low effective Z, since for such materials the density varies nearly in direct proportion to the atomic number and hence the probability of an electron encountering and ionizing an orbital electron in a layer of given mass per unit area is substantially a constant.

The range given is, however, along the actual path of the electron. Since the electrons are subjected to deflection by the nuclei (and to some slight extent by the orbital electrons) while traversing their range, their paths will be more or less tortuous. In passing through a film of a thickness corresponding to a given fraction of a range of R the energy remaining is not, in general, proportional to the square of the remaining fraction of the range, but instead the loss of energy is nearly in proportion to the thickness of the film in terms of its fraction of the total original range, at least for electrons of high initial velocity and fractional ranges which do not approach unity. The range R is therefore a useful measure of relative thickness of the layer 11.

In conventional tubes, as constructed for either monochrome or color television images, the thickness of the aluminum layer, where used, has been minimized in order to minimize the loss of energy of the electrons penetrating it, this loss being more than made up by reflection of light emitted toward the layer from the phosphors and reflected back from it toward a viewer. The best measurements made to date indicate that in a tube designed for beam potentials of 13 to 14 kv. the thickness of the layers used has been in the neighborhood of $\frac{1}{4}$ R. In order to obtain sufficient brilliancy color tubes have usually employed higher beam potentials, in which case the thickness of the layer has not been materially increased, making its thickness somewhere in the range of $\frac{1}{17}$ R to $\frac{1}{20}$ R for 18 to 20 kv. tubes. There may be some slight increase in the thickness of the layers used in higher voltage tubes to enable the layers to withstand the bombardment of energetic ions for longer periods, but in general the higher the normal operating voltage of the tube the smaller will be the proportion of the electron range represented by the thickness of an aluminizing film.

In accordance with the present invention, as stated above, there is superposed upon the layer 11 a layer 12 of a material having an effective Z materially lower than that of aluminum, $Z=13$. Preferably the material used is one chosen from the first period of the periodic table, beryllium ($Z=4$) boron ($Z=5$) and carbon ($Z=6$) being the materials preferred, although compounds of these materials or others, provided their effective Z values are lower than that of aluminum, may be employed. Boron trioxide, a compound of two materials in the first period, has an effective Z as a back-scattering agent of $7\frac{1}{4}$ and can be used, or boron carbide, $Z=5.2$, although boron is preferred. Various other compounds of low average atomic number are available and will give good results.

The layers 11 and 12 preferably have a combined thickness of between $\frac{1}{4}$ and $\frac{1}{3}$ R, preferably between $\frac{1}{6}$ and $\frac{1}{5}$ R. Of this total range the aluminum should form as small a percentage as possible while still retain-

ing a conducting and light reflecting surface. As has been pointed out, the beam loses energy substantially in proportion to the depth to which it is penetrated. The probability of scattering at a given depth of penetration is approximately inversely proportional to its remaining energy in electron volts and directly proportional to Z . With a coating of lower effective Z than the average of the phosphors and of a thickness of $\frac{1}{8} R$ to $\frac{1}{5} R$, it is therefore quite apparent that most of the back-scattering must take place in the phosphor layer, both because of its lower Z and of the higher energy of the electrons traversing the overlying layers. It is also apparent that, once having reached the phosphor layer, the electrons must be back-scattered far enough to leave the phosphors if they are to re-enter the layer 11 and escape to form a halo. Any electrons which do not leave the phosphors will be effective to produce useful light; their range in the phosphors is small in comparison with the dimensions of the beam and such scattering does not contribute greatly to increase of spot size.

It has also been stated that the greatest density of back-scattered electrons occurs at an angle of about 104 degrees and that the peak in energy of such electrons occurs between 103 degrees and 113 degrees to the angle of incidence. A combined thickness of the layers 11 and 12 of $\frac{1}{5} R$ is just about sufficient to stop all electrons leaving the phosphors at peak energy and density of emission, assuming no further scattering occurs in the layers 11 and 12 and that the sole effect of these layers is to absorb electron energy. This assumption is, of course, not valid; further scattering, with consequent increase in path length, occurs in the protective layers and therefore thinner layers, down to about $\frac{1}{8} R$, are quite effective.

Because, however, some of the scattering occurs among the electrons returning through the protective layers 11 and 12 after having once escaped therefrom will be in a direction toward the phosphors, neither a layer of $\frac{1}{5} R$ nor $\frac{1}{8} R$ will completely prevent electrons from re-entering the phosphors. Not even a layer of the theoretical thickness of $\frac{1}{3} R$ (which would require that all electrons reaching the phosphors would have to traverse straight paths totalling the complete electron range to reach them again) will wholly prevent some emission of light spaced from the initial point of impact of the beam, since some very small proportion of the beam will be back-scattered in the outer portion of the layer 12 and thus retain enough energy to penetrate it upon their return. Furthermore, some electrons escaping from the layer 12 and re-entering it will be scattered so as to reach the phosphors by shorter paths than their angles of incidence would indicate, and therefore excite some slight halo.

The halos thus excited are, however, very faint as compared to those formed with screens having only a layer 11 of normal thickness. Intensity of illumination of the halo depends on both the number of electrons and their energy and both are greatly decreased by the presence of the layer 12.

The preferred materials for the layer 12 are those of lowest atomic number, preferably of those in the first period of the periodic table or compounds thereof, although any material having a lower atomic number than that of aluminum will provide an improvement over an aluminum layer of the same proportional thickness in terms of electron range. Compounds of these materials whose effective atomic numbers are low in comparison with that of aluminum can also be used, provided, of course, that they are stable under the conditions which they must meet in the outgassing and other treatment of the tube. Under present procedures lithium ($Z=3$) does not meet this latter requirement, although otherwise it would be the material of choice. Beryllium ($Z=4$) is an excellent material for the purpose. Even though beryllium will itself form a conductive and reflecting layer it has been found that it adheres much better when

deposited upon an underlying layer 11 of aluminum. Beryllium, however, has the disadvantage that its fumes are extremely toxic and that special precautions are necessary in manufacture when it is used.

Boron, boron carbide, carbon, and boron oxide, are desirable, in that order, all having been used successfully, the densest of these, boron oxide, having an effective atomic number only a little over half of that of aluminum.

The layer 12 can be applied to screens previously aluminized with the layer 11 in a variety of ways. Any of those materials that have been mentioned can be evaporated on to the screen in vacuo, in the same general manner as aluminum. Carbon layers may be applied in the form of soot or by applying a layer of carbonaceous liquid and then carbonizing it; e. g., a lacquer having a cellulose base may be sprayed on or floated on and carbonized, provided the base is not a nitrocellulose, which will disintegrate completely under heat, leaving no residue.

Coatings of boron, boron carbide or boron oxide can be formed by mixing the materials in the form of an amorphous powder with a volatile vehicle, such as acetone, possibly with a very small amount of nitrocellulose lacquer, and applying it with a spray gun; in baking out the tube the vehicle appears to volatilize completely, leaving an adherent coating of the powder.

The fact that certain of the materials mentioned are non-conductors under ordinary circumstances is of no moment, since, as has already been implied, these materials are ionized and made conducting by the high-voltage beam. The layer 11 therefore still forms a satisfactory conductive coating which can be charged to a potential highly positive with respect to the grid 13 to form electron lenses. In case it should, for any reason, be necessary or desirable to have conduction immediately on the side of the screen facing the electron gun the construction illustrated in the fragmentary cross-section of Fig. 3 can be used, wherein the protective coating, here designated as 10', is formed of three layers instead of two; first, a very thin layer 11' of aluminum, next a thicker layer 12 of boron or one of the other materials that have been mentioned, and finally another layer 11'' of aluminum. With this construction both layers 11 and 11' can be even thinner than those normally employed, since failure to achieve complete continuity in either is not ordinarily fatal to satisfactory performance, one layer supplementing the other when connected by the ionized layer between.

Still another possible construction is illustrated in Fig. 4. In this case the layer 12' is formed of a transparent or translucent material of low effective Z . One available material for this purpose is sodium silicate, having an approximate formula $\text{Na}_2\text{O}; 3.45 \text{ SiO}_2$, making the average Z 9.4. Better materials are lithium fluoride, LiF , and lithium carbonate, Li_2CO_3 , each with an effective atomic number of 6. Either of these materials will form a glassy layer, on which the film of aluminum, 11'', can be deposited. Its thickness can be, as in the case of the layer described in connection with Fig. 1, the minimum required for reflectivity and continuity.

Where this construction is used, reliance is placed upon the fact that the electrons passing through the aluminum layer directly from the electron gun traverse it at maximum energy and are therefore least affected by scattering deflections. Where the aluminum layer is placed nearest the phosphors scattering is more likely to occur in it but the electrons scattered have a greater probability of being stopped by the overlying layer of lower Z material. Which arrangement will give the best results is dependent upon various factors which cannot be predicted except with complete knowledge of the parameters of the design and which is adopted for commercial production depends upon both performance and difficulty or ease of manufacture. Although it is preferable, wherever the arrangement of Fig. 4 is used that

the layer 12'' be transparent, the effective proportion of the light reflected from the metal layer through the layer 12'' is only slightly reduced if it is merely translucent, as, for example, in a layer formed of powdered lithium carbonate, sprayed on as has been described for the application of boron powder. The layer is very thin, the material is very white, and although not as much specular reflection will occur as where the aluminum is deposited upon a glassy or fully transparent backing, where a merely translucent layer is used the additional scattering of light (as distinguished from electron scattering) that occurs in it is relatively unimportant.

Throughout this specification the values given for the effective atomic numbers of compounds have been the average values of the atoms entering into the compounds. In Equation 1 representing the initial scattering in the first thin film, Z appears as the square, it might appear that the root-mean-square value would be the more accurate expression. Furthermore, Equation 2 would suggest that the loss of energy of a beam in passing through a layer of given thickness would follow a parabolic instead of a linear law. This would be true if the electrons were not deflected, and followed straight paths; that this is not the case explains the empirical result that the average loss of energy is approximately directly proportional to the thickness of the layer. With the materials and compounds of very low atomic numbers which are preferably used for the layers 12 or 12'' the difference between the mean values and the root-mean-square values of the elements of a compound are not large; since in any event the effort is to obtain a material of as low a Z as possible either criterion would serve as an effective guide.

Various formulas have been published for both scattering and loss of energy in penetrating thick and thin films by electron beams. In general the formulas for scattering consider primarily the fields of the nuclei of the scattering material only. It is evident, however, that an ionizing event in the passage of an electron through a layer would in general impart some transverse velocity to the electron of the beam. Some of the scattering is therefore undoubtedly due to forces between electrons as distinguished from forces between beam electrons and nuclei. Since atomic electrons bound by nuclei of higher atomic number are on the average restrained by greater forces, both scattering by electrons and scattering by nuclei will vary substantially as Z , and therefore it makes little difference which source of scattering is considered as being dominant, particularly since empirical results bear out the fact that the degree of back-scattering varies substantially in direct proportion to the atomic number.

In films which are so thin as to produce scattering angles small enough so that these angles can be equated to their tangents, back-scattering can be ignored and the distribution in angle of the beam electrons follows substantially the Gaussian law. The smaller the angle through which the beam electron is deflected in each scattering event the greater will be the depth of its penetration, in terms of range, before the distribution in angle of the beam electron departs materially from the Gaussian law. The lower the Z of the coatings 11, 11'' or 12, and the thinner the coatings 11', or 12'', the more nearly will the distribution of the electrons as they enter the phosphors correspond with the Gaussian distribution. The closer this ideal is reached the higher will be the percentage of the back-scattering that takes place in the phosphors themselves, the deeper will be their penetration into the phosphor layer before they are back-scattered and the more effective will be the protective layers in suppressing halo effect.

After back-scattering has occurred to such an extent that the tangent of the scattering angle can no longer be equated to the angle itself the computation becomes so complex that it is safer to rely upon empirical results. The theory insofar as it is herein presented, affords a

qualitative explanation of these results and is presented for that purpose only and not as limiting the scope of the invention, all intended limitations being expressed in the claims which follow.

I claim:

1. In a cathode-ray display tube comprising means for directing a beam of electrons to bombard a target area with an energy of V kilo electron volts, a display screen within said area comprising a transparent base, a coating on said base of phosphors the average of the atomic numbers of the atoms of the component molecules whereof is greater than 13 and a backing on said coating comprising a layer of metal in contact with said coating of minimum thickness to establish continuity and a second heavier layer of material of lower average atomic number than 13 covering said metal layer, the combined mass per square centimeter of said coatings being in the range between $0.35 V^2$ and $0.7 V^2$ micrograms per square centimeter.

2. A display screen as defined in claim 1 wherein the material of said metal layer is aluminum and the constituents of said second layer are of atomic number less than 10.

3. In a cathode-ray display tube comprising means for directing a beam of electrons against a target area with a maximum kinetic energy of V kilo electron volts, and in the operation whereof electric fields are established tending to return reflected electrons from said beam which are scattered by materials in said target area toward the structure comprising the scattering materials, a display screen positioned in said target area comprising a transparent base, a coating of phosphors the average of the atomic numbers of the atoms in the molecules whereof is greater than 13 deposited on said base, and a plurality of layers of material all constituents whereof are of lower atomic number than 14 superposed on said coating, one of said layers being metallic and adapted to reflect light emitted from said coating back through said base and the combined thickness of said layers corresponding to a mass per square centimeter of between $0.35 V^2$ and $0.7 V^2$ micrograms.

4. In a cathode-ray display tube comprising means for directing a beam of electrons against a target area with a maximum kinetic energy of V kilo electron volts, and in the operation whereof electric fields are established tending to return reflected electrons from said beam which are scattered by materials in said target area toward the structure comprising the scattering materials, a display screen positioned in said target area comprising a transparent base, a coating of phosphors the average of the atomic numbers of the atoms in the molecules whereof is greater than 13 deposited on said base, and a plurality of layers of material all constituents whereof are of lower atomic number than said element superposed on said coating, the layer in contact with said coating being of aluminum and the second layer superposed thereon being of a material all constituents whereof are of atomic number less than 10, and a mass per square centimeter of between $0.35 V^2$ and $0.7 V^2$ micrograms.

5. A display screen as defined in claim 4 wherein the thickness of said aluminum layer is a minor portion of the thickness of the combined layers.

6. In a cathode-ray display tube comprising means for directing a beam of electrons having a kinetic energy of V kilo electron volts to bombard a target area, a display screen within said area comprising a transparent base, a coating on said base of phosphors the mean of the atomic numbers of the constituent atoms whereof is greater than 13, and a backing on said coating comprising a plurality of layers of material on said base, one of said layers being of aluminum and another of said layers being of a material the average of the atomic numbers of the atoms whereof is less than 13, and the combined mass of said layers being greater than $0.35 V^2$ and less than $0.7 V^2$ micrograms per square centimeter.

7. A display screen as defined in claim 6 wherein said aluminum layer is of less thickness than said last-mentioned layer.

8. In a cathode-ray display tube comprising means for directing a beam of electrons to bombard a target area, a display screen within said area comprising a transparent base, a coating of phosphors on said base, a film of aluminum overlying said coating, and a layer of boron overlying said film.

5

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