Oct. 12, 1965 D. S. BULEZA 3,211,663

ELECTROLUMINESCENT DEVICES AND MATERIALS

Filed June 15, 1962

FIG. 1.

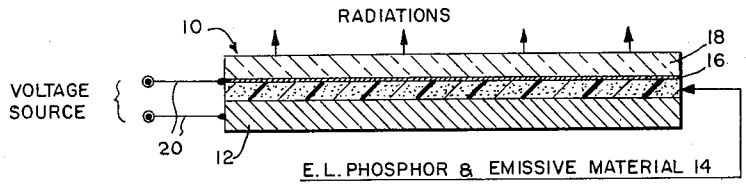


FIG. 2.

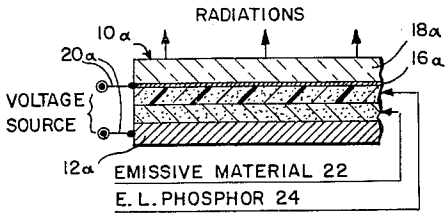


FIG. 3.

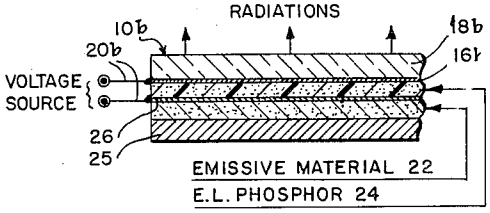


FIG. 4.

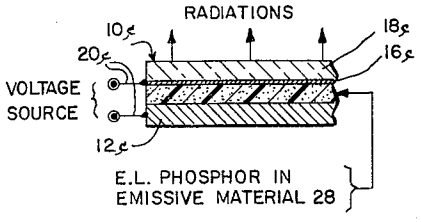


FIG. 5.

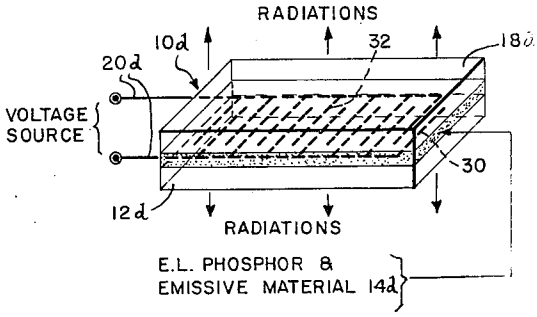


FIG. 6.

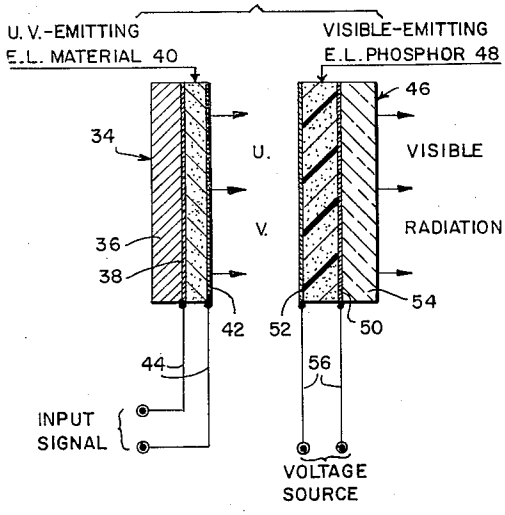
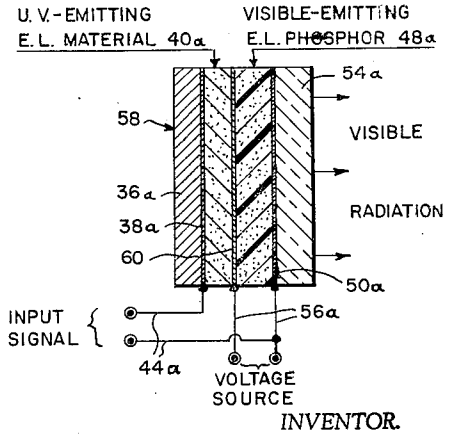


FIG. 7.



INVENTOR.

Daniel S. Buleza

United States Patent Office 3,211,663 Patented Oct. 12, 1965

3,211,663

ELECTROLUMINESCENT DEVICES AND MATERIALS

Daniel S. Buleza, Homestead, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Filed June 15, 1962, Ser. No. 202,770
19 Claims. (Cl. 252—301.1)

This invention relates to electroluminescent devices and, more specifically, to means and methods for enhancing the output of such devices and materials.

When certain phosphors are subjected to an electric field they become excited and emit light. This direct conversion of electrical energy into radiant energy is termed "electroluminescence" and constitutes an entirely new mode of light generation. While the phenomenon of electroluminescence is not yet perfectly understood, it has added a new dimension to the lighting art insofar as it has provided a practical solution to the problem of making area-type light sources in various shapes, sizes and colors. Moreover, since the transformation of electricity into light is accomplished by the phosphor itself such electroluminescent light sources are solid state devices and, thus, inherently have long useful lives and low power requirements. The unique properties of electroluminescent materials have also led to the development of new types of imaging and read-out devices, etc. that heretofore were not possible or practical.

Despite their long life and relative simplicity as regards construction, electroluminescent light sources as presently manufactured do not have sufficiently high outputs or brightness levels to enable them to be used for general lighting and various other applications. Because of this basic deficiency, commercial use of electroluminescent materals and devices has thus far been restricted to such low-volume applications as specialized instruments, indicators and auxiliary light sources such as night lights or the like.

It is accordingly the general object of the present invention to provide a convenient and economical means of enhancing the output of electroluminescent devices and materials.

Another and more specific object is the provision of an electroluminescent device that includes a conventional type electroluminescent phosphor the output whereof is enhanced by another component that constitutes an integral part of the device.

Another object is the provision of electroluminescent materials that display an enhanced output when excited by an electric field.

The aforesaid objects, and other advantages which will occur to those skilled in the art, are obtained according to this invention by combining an electroluminescent phosphor with a preselected emissive material (or materials) which irradiates the phosphor and constitutes an integral part of the device or the phosphor structure. The emission material is such that the phosphor is irradiated with sub-atomic particles (such as electrons), rays in the short wavelength region of the spectrum (ultraviolet or gamma rays for example), or both, while it is simultaneously subjected to an electric field. The resulting multiple excitation of the electroluminescent phosphor and coaction of the exciting agents amplifies or enhances the output of the phosphor. Various embodiments wherein the selected emissive material is incorporated as an integral part of the electroluminescent device or phosphor particles themselves are disclosed. Methods for making such phosphors and modifying the structural and performance characteristics of conventional electroluminescent phosphors are also described.

A better understanding of the invention will be obtained from the accompanying drawing, wherein:

FIGURE 1 is an enlarged cross-sectional view of an electroluminescent device according to one form of the invention wherein the electroluminescent phosphor and selected emissive material are admixed with one another and placed between two electrodes;

FIG. 2 is a fragmentary cross-sectional view of an alternative embodiment wherein the electroluminescent phosphor and the emissive material are arranged in separate layers;

FIG. 3 is a corresponding view of another embodiment wherein the emissive material is included in the form of a separate layer that is interposed between one of the device electrodes and the substrate or base member;

FIG. 4 is a corresponding view of still another form of the invention wherein the electroluminescent phosphor is embedded in a dielectric matrix that includes the emissive material;

FIG. 5 is a perspective view of another device embodiment wherein grid electrodes are employed in combination with a layer that contains admixed electroluminescent phosphor and emissive material;

FIG. 6 is an enlarged cross-sectional view of a device according to this invention wherein the electroluminescent phosphor is simultaneously irradiated by a UV-emitting electroluminescent phosphor that is separately excited by a signal voltage; and,

FIG. 7 is a corresponding view of an alternative embodiment of such a device wherein the UV-emitting and visible-emitting electroluminescent components are combined to form a monolithic structure.

While the present invention may be advantageously employed in various types of devices such as image amplifiers, display and read-out units, etc. that include electroluminescent components or materials, it is particularly adapted for use in electroluminescent lighting devices and accordingly has been so illustrated and will be so described.

The invention

Broadly defined, the present invention encompasses the concept of combining a selected emissive material with an electroluminescent phosphor that is disposed in radiation receptive proximity to the emission material and can thus be simultaneously irradiated and subjected to an electric field. The emission material accordingly comprises an integral part of the electroluminescent device, or phosphor, and, through the resulting coaction of the two exciting agents, amplifies or enhances the output of the electroluminescent phosphor particles.

The term "emissive material" as here used refers to any material that emits radiation or sub-atomic particles capable of enhancing the output of an electroluminescent phosphor when the latter is simultaneously subjected to the influence of an electric field. The emissive material accordingly can consist of suitable photoemissive materials, artificial or natural radioactive materials, and even another electroluminescent phosphor that emits UV or other short wavelength radiation when field excited. Since the emissive material comprises an integral part of the electroluminescent phosphor or device, the invention provides a most convenient and effective arrangement for controlling or improving the performance of such materials and devices by means of a "built-in amplifying" component, so to speak.

The enhancement of electroluminescent emission per se by means of the simultaneous UV irradiation of an electroluminescent phosphor with an external UV source is well known and described by W. A. Thornton and H. F. Ivey in their article entitled "Radiation, Fields and Electroluminescent Phosphors," Westinghouse Engineer; vol. 19;

No. 5; September, 1959; pages 134–138. As there stated, when an electroluminescent phosphor is simultaneously irradiated with ultraviolet (UV) radiations and field excited, either by an A.C. or D.C. potential, the resultant light emission from the phosphor is greater than the sum of the individual light outputs produced when the UV and the electric field are applied separately. That is, true light amplification occurs when both forms of excitation are applied to the phosphor simultaneously. In some cases, amplification factors as high as 100 or more have been achieved by this means. Prior art devices utilizing luminescent screens that are irradiated with UV or X-rays from an external source and simultaneously electrically energized are described in U. S. Patent No. 2,909,692, issued October 20, 1959 to D. A. Cusano, and in U.S. Patent No. 2,933,602, issued April 19, 1960 to J. L. Gillson, Jr.

The present invention differs radically from the foregoing prior art devices in that the radiation source comprises an integral part of the electroluminescent phosphor or device instead of constituting a separate and external component. The electroluminescent phosphor is thus internally irradiated and correspondingly higher excitation levels are attained, even with relatively small amounts of radiation. In addition, the present invention is not limited to emissive materials that emit UV or X-rays but includes materials that emit electrons or other sub-atomic particles as well as gamma rays. Thus, selected radioactive materials may be incorporated directly into the electroluminescent phosphor and thus internally irradiate the phosphor particles with low-energy β or γ rays, for example, that is, with high speed electrons or very short electromagnetic radiation, or both. Materials that emit α rays may also be employed.

Alternatively, a suitable photoemissive material that is responsive to radiation produced by the electroluminescent phosphor when admixed or otherwise placed in irradiation-relationship with the phosphor particles can also be used to simultaneously inject free electrons directly into the electroluminescent phosphor crystals when the latter are subject to an electric field.

Following are illustrative examples of electroluminescent devices which embody the present invention.

Embodiment I

In FIG. 1 there is shown an electroluminescent lamp **10** comprising a pair of spaced electrodes **12** and **16** having a layer **14** therebetween that includes an admixed electroluminescent phosphor and a suitable emissive material. To facilitate the fabrication of the lamp, the phosphor and emissive material are preferably in granular form and embedded in a suitable dielectric matrix, such as polyvinyl-chloride acetate, cyanoethyl cellulose or a fired glass frit that has a sufficiently high dielectric constant and a low firing temperature. Thus, the lamp **10** and the devices subsequently described may be fabricated in accordance with the customary and well-know procedures employed in making conventional so-called "glass-plastic" or "ceramic" type electroluminescent lamps.

The electrode **16** is light transmitting and comprises a thin layer of tin oxide or the like. A protective overcoat **18** of plastic or ceramic material that also transmits light covers the electrode **16** and prevents gaseous contaminants from passing through the face of the lamp into the layer **14**. The electrodes **12** and **16** are connected to a suitable voltage source, either A.C. or D.C., by a pair of conductors **20**.

Any electroluminescent phosphor which is responsive to the emission emanating from the particular emissive material employed can be used. By the same token, various emissive materials may be employed, the only limitation being that they emit particles or radiation that increase the output of the phosphor particles when the latter are simultaneously field-excited. For example, a photoemissive material that has a sufficiently low threshold frequency may be used as the emissive material in combination with an electroluminescent phosphor that has an emission which will cause the photoemissive material to eject electrons. Thus, when the lamp **10** is energized, the electroluminescent phosphor will emit radiations which, in turn, will impinge upon the admixed photoemissive material and cause it to emit free electrons that are injected directly into the electroluminescent phosphor crystals. Since it is theorized that the luminous output of electroluminescent phosphors increases as the number of free electrons in the conduction band increases, the impinging electrons from the photoemissive material will materially increase the supply of electrons in the crystal lattice and excite more luminescent centers. As a specific example, particles of cuprous oxide or zinc may be admixed with blue-emitting electroluminescent zinc sulfide phosphor activated with copper. Oxides of alkaline earth metals, such as barium oxide and strontium oxide, etc., may also be used as the photoemissive material providing they are combined with the phosphor in the layer **14** in such a manner that they do not contaminate the phosphor.

Alternatively, the emissive material can comprise either a natural or artificial radioactive substance that emits electrons, neutrons or other sub-atomic particles that will increase the number of free electrons within the crystal lattice of the phosphor or otherwise promote luminescent transitions within the phosphor crystals and thus increase the luminous output of the lamp **10** when it is energized. A radioactive material that emits γ rays in addition to electrons or β rays may also be used, in which case the electroluminescent phosphor particles will be internally irradiated both with free electrons and electromagnetic radiation in the γ or X-ray region of the spectrum while it is simultaneously subjected to an electric field.

For example, radium D may be used since it emits both β and γ rays and has a half life of 22 years. Other natural radioactive elements such as actinium that emits β rays and has a half life of aproximately 13 years, or mesothorium I that has a half life of 6.7 years and emits β rays may also be employed if desired. In addition, various artificial radioactive elements that have a sufficiently long half life can be used.

Since relatively small numbers of free electrons and amounts of short-wave radiation will produce a marked increase in the activation of the luminescent centers in the phosphor crystals due to the proximity of the materials, only very small amounts of radioactive material are required. The exact amount, of course, will vary depending upon the type of electroluminescent phospher and radioactive material employed. As a specific example, the ratio in parts by weight of electroluminescent phosphor to radioactive material is desirably maintained in the order of about 100 to 1. In any event, the concentration is kept within such limits that no radiation hazard is presented or adequate shielding can readily be provided.

In addition to photoemissive and radioactive materials a UV-emitting electroluminescent material, such as boron nitride for example, can be used as the emissive material and admixed with an electroluminescent phosphor that emits visible radiations. Boron nitride has an emission that extends from about 2950 A. to 6500 A. with the principal emission being in the ultraviolet region below about 3900 A. A detailed discussion of the emission characteristics of boron nitride is given in U.S. Patent No. 2,921,218 issued January 12, 1960 to S. Larach and R. E. Shrader. The combination of the aforesaid electroluminescent UV-emitting material and an electroluminescent phosphor that emits visible radiations will, accordingly, automatically achieve the simultaneous UV-irradiation and field-excitation of the visible-emitting electroluminescent phosphor particles when ever the lamp **10** is energized. As a specific example, equal amounts of the two electroluminescent materials are admixed.

Embodiment II

The electroluminescent phosphor and selected emissive material may also be formed as separate layers that are arranged in radiation receptive proximity to one another, as shown in FIG. 2. In this case, the emissive material is dispersed in a suitable dielectric medium such as a plastic resin or ceramic to form a layer **22** over the base electrode **12***a*. The electroluminescent phosphor particles are similarly embedded in a suitable dielectric matrix to form a second layer **24** that overlies the emissive layer and is, in turn, coated with a light transmitting electrode **16***a*. When the electrodes are connected to a voltage source by the conductors **20***a*, the field is applied to both layers and enhanced visible radiations will be generated and transmited through the protective faceplate **18***a* as in the case of Embodiment I described above.

Embodiment III

Alternatively, only the layer containing the electroluminescent phosphor is included between the electrodes to form the modified lamp embodiment **10***b* shown in FIG. 3. According to this construction, the dielectric-emissive material layer **22** is formed on top of a base member **25**, such as a glass plate, and an electrode **26** that transmits the particules or radiations generated by the emissive material is placed over the aforesaid layer. The electrode **26** may comprise a grid-like array of wires or metal foil, or a very thin layer of aluminum or the like. The dielectric-electroluminescent phosphor layer **24** is formed over the electrode **26** and is, in turn, coated with a light-transmitting electrode **16***b*. When the lamp **10***b* is energized by connecting the electrodes to a voltage source through conductors **20***b*, enhanced radiations will be generated by the simultaneously irradiated electroluminescent phosphor particles and transmitted through the transparent faceplate **18***b*.

In contrast to the embodiments shown in FIGS. 1 and 2, the embodiment illustrated in FIG. 3 precludes the use of a field-responsive UV-emitting material such as boron nitride as the emissive material insofar as the emissive layer **22** is not located between the electrodes and, accordingly, is not subjected to the electric field when the lamp is energized.

Embodiment IV

As shown in FIG. 4, the emissive material may also be incorporated as an integral part of the dielectric matrix in which the electroluminescent phosphor particles are embedded. This may be accomplished by doping the dielectric material with a selected emission material while the dielectric material per se is being fabricated. For example, a predetermined quantity of radium D can be admixed with the raw mix constituents used to prepare the dielectric material, or one of the raw mix constituents may itself be radioactive. For example, in the case of a glass dielectric, a radioactive alkali oxide or the like may be used as one of the materials in preparing the glass batch and resultant frit.

In accordance with this embodiment, the electroluminescent phosphor particles are embedded in the emissive dielectric material to provide a layer **28** that is placed betwen the base electrode **12***c* and the light-transmitting electrode **16***c* of the lamp **10***c*. The electroluminescent phosphor particles are, accordingly, disposed in radiation receptive proximity to the emissive material and are continuously irradiated thereby so that when the lamp is connected to a suitable voltage source through the conductors **20***c* enhanced radiations will be generated by the phosphor particles and transmitted through the electrode **16***c* and the faceplate **18***c*.

Embodiment V

As illustrated in FIG. 5, a lamp **10***d* may also be constructed that will emit radiations from both faces. This is accomplished by utilizing a base plate **12***d* that is light-transmitting and a pair of interlinking grid electrodes **30** and **32** that are embedded in a layer **14***d* that includes both the electroluminescent phosphor and emissive material. This layer can be of the type described above in connection with Embodiments I and IV, for example. When the grid electrodes are connected to a voltage source through the conductors **20***d*, the enhanced radiations produced by the simultaneously irradiated and field-excited electroluminescent phosphor particles will pass through the electrode interstices and both faces of the lamp **10***d* through the face plate **18***d* and the base plate **12***d*.

Embodiment VI

As shown in FIG. 6, the enhancing or amplifying effect produced by the emitting material in accordance with the present invention may also be utilized to modulate the luminous output of an electroluminescent device by means of a signal voltage. As illustrated in this figure, the control or modulating component **34** of such a combination comprises a base plate **36**, an electrode **38**, a dielectric layer **40** containing a UV-emitting electroluminescent material such as boron nitride, and a second electrode **42** that will transmit UV radiation, arranged in overlying relationship with one another in the order named.

The electroluminescent component **46** comprises a visible-emitting electroluminescent phosphor dispersed in a suitable dielectric matrix to form a layer **48** that is included between a pair of electrodes **50** and **52**. The electrode **50** is light-transmitting and covered by a transparent face plate **54**, whereas the electrode **52** is of a type that transmits UV radiation.

The two components **34** and **46** are so disposed that they comprise an integral structure and UV radiations emanating from the component **34** irradiate the light-generating element **46**. Thus, when an input signal voltage is applied to the UV-emitting material through the conductors **44** a UV beam of varying intensity impinges upon component **46**. When the latter is simultaneously energized by means of conductors **56**, the amplified output of the electroluminescent phosphor will vary according to the variation in the intensity of the impinging UV radiation. The signal will thus be reproduced in the form of light generated by the electroluminescent cell **46** that varies in brightness according to amplitude of the signal voltage.

Embodiment VII

Alternatively, the UV-emitting and light-emitting components can be combined to provide a monolithic device **58** of the type shown in FIG. 7. As there shown, such a device comprises a base plate **36***a* that is coated with an electrode **38***a* over which is formed the layer **40***a* comprising a dielectric matrix and embedded UV-emitting electroluminescent material. Over this layer there is provided an electrode **60** that is UV-transmitting and is common to the layer **48***a* which comprises a dielectric material impregnated with the visible-emitting electroluminescent phosphor. The layer **48***a* is, in turn, coated with a light-transmitting electrode **50***a* that is desirably protected by a transparent face plate **54***a*. The visible-emitting layer **48***a* is connected to a voltage source by conductors **56***a* that are attached to the electrodes **50***a* and **60**. The input signal is applied to both the UV and light-emitting layers **40***a* and **48***a*, respectively, by conductors **44***a*, one of which connects with electrode **38***a* and the other with electrode **50***a*. Thus, the signal voltage is superimposed on the voltage being applied to the visible-emitting layer **48***a* through the conductors **56***a* and produces a variation in the intensity of the light output of this layer that is in phase with and added to that produced by the varying UV radiation from the layer **40***a*. The variations in the light intensity are, accordingly, amplified to a correspondingly greater degree.

In order to achieve maximum brightness the electroluminescent phosphor layer in Embodiments II, III and V to VII described above is preferably deposited in the form of a thin film, without a dielectric matrix, in radiation receptive proximity to the emissive material. This arrangement permits the latter to irradiate all of the phosphor particles and high field gradients to be realized within the phosphor layer using reasonably low voltages. The film thickness can be in the order of 2 to 10 microns for example. It can be formed in the manner described in copending U.S. application Serial No. 837,988 (now Patent No. 3,044,902) of W. A. Thornton, Jr., entitled "Method of Forming Films of Electroluminescent Phosphor," assigned to the assignee of the present invention; or in accordance with the teachings of such patents as U.S. Patent Nos. 2,819,420 and 2,917,442.

Electroluminescent materials and method of fabrication

The simultaneous irradiation and field-excitation of electroluminescent phosphor particles can also be accomplished in accordance with the present invention by incorporating the emissive material directly into the crystal structure of the phosphor particles themselves. For example, the raw mix constituents from which the phosphor is made can be doped with a suitable artificial or natural radioactive element that emits radiant energy of the proper intensity and character. As a specific example, a predetermined amount of radium D can be added to the phosphor raw mix constituents and the latter processed and fired in the conventional manner so that the radium D is assimilated by and becomes an integral part of the crystalline structure of the phosphor particles.

Alternatively, radioactive copper, manganese, chlorine or other elements can be used as activators and as coactivators in the electroluminescent phosphor. Since radioactive isotopes have substantially the same chemical properties as the stable form of the element, such additives will be assimilated into the crystal structure of the phosphor in the customary manner.

The phosphor can also be rendered radioactive by firing the raw mix constituents in a gaseous atmosphere that contains the radioactive material. For example, they can be fired in radioactive tritium instead of the usual nitrogen, or in a mixture of nitrogen and tritium, so that the phosphor is doped with a tritium-containing compound. Tritium emits β rays that have only a few percent of the energy of the electrons emitted by strontium 90, for example, and would thus reduce the radiation hazard to a minimum. The gaseous tritium can also be converted into a solid stable form such as titanium hydride or zirconium hydride wherein the hydrogen atoms are replaced with tritium in accordance with the teachings of British Patent No. 869,698. The stable tritium compound is then admixed with the electroluminescent phosphor particles or deposited thereon in a thin transparent layer in the manner described in the aforesaid patent. Or the phosphor particles can be coated with a thin layer of tritium-treated organic compounds selected from the group of the alcohols or paraffin acids that have 12 to 20 carbon atoms, in accordance with the teachings of U.S. Patent No. 2,749,251.

Thus, the electroluminescent phosphor can itself be rendered radioactive or doped with a suitable emissive material during its fabrication by replacing some or several of the raw mix constituents with radioactive materials or compounds having the same chemical properties, or by firing the raw mix constituents in a radioactive gas or a gas that contains the radioactive material and chemically reacts with the raw mix constituents. The emissive material may also be incorporated in the form of a stable compound that is inert with respect to the electroluminescent materials and is coated or otherwise placed in irradiating relationship with the phosphor crystals. The means by which the radioactive material is added to the electroluminescent phosphor is unimportant for the purposes of this invention as long as the phosphor particles are located in radiation receptive proximity to the radioactive material.

The character of conventional electroluminescent phosphor particles can also be modified in accordance with the present invention by irradiating the finished phosphor with high speed sub-atomic particles, such as neutrons, alpha particles or electrons, to render the phosphor artificially radioactive or to change the crystalline structure thereof in such a manner that the output of the phosphor is enhanced. Such irradiation can be accompanied by the application of a strong electric field and/or heat, if desired.

Conclusion

It will be appreciated from the foregoing that the objects of the invention have been achieved insofar as electroluminescent devices and phosphors have been provided which have a "built-in" emissive component that enhances or amplifies the output of the electroluminescent component when the latter is simultaneously energized. In addition, methods for incorporating such emissive components into an electroluminescent phosphor and modifying the character of conventional phosphors, either during or after their preparation, have also been disclosed.

While several embodiments have been illustrated and described, it will be obvious to those skilled in the art that various structural and procedural modifications can be made without departing from the spirit and scope of the invention.

I claim as my invention:

1. In an electroluminescent device, the combination of an electroluminescent phosphor, an emissive material that is disposed in irradiating relationship with said electroluminescent phosphor, and means for simultaneously applying an electric field to said irradiated electroluminescent phosphor.

2. The combination set forth in claim 1 wherein said emissive material is admixed with said electroluminescent phosphor.

3. The combination set forth in claim 1 wherein said emissive material and said electroluminescent phosphor comprise separate layers.

4. The combination of a material that emits radiation in the ultraviolet-gamma region of the spectrum, and an electroluminescent phosphor in radiation-receptive proximity to said material.

5. The combination of a radioactive material, and an electroluminescent phosphor in radiation-receptive proximity to said radioactive material.

6. The combination of a radioactive material that emits primarily beta rays, and an electroluminescent phosphor in receptive proximity to the rays emanating from said radioactive material.

7. A radioactive electroluminescent phosphor.

8. An electroluminescent phosphor having a radioactive material included as an integral part thereof.

9. An electroluminescent phosphor having a radioactive activator.

10. An electroluminescent device comprising, in combination, an electroluminescent phosphor, means for applying a voltage to said phosphor, and means comprising an integral part of said device for simultaneously irradiating said electroluminescent phosphor with radiation in the ultraviolet-gamma region of the spectrum.

11. The combination of a radioactive material that emits primarily beta and gamma rays, and an electroluminescent phosphor in receptive proximity to the radiation emanating from said radioactive material.

12. The combination of a first electroluminescent phosphor that emits radiation having a wavelength shorter than about 3900 A., a second electroluminescent phosphor in radiation-receptive proximity to said first electroluminescent phosphor, and means for applying a voltage to said first and second electroluminescent phosphors.

13. The combination of a first electroluminescent phosphor that emits radiation having a wavelength shorter than about 3900 A., a second electroluminescent phosphor that is disposed in radiation-receptive proximity to said first electroluminescent phosphor and emits radiation in the visible portion of the spectrum, means for applying a voltage to said second electroluminescent phosphor, and means for applying a varying voltage to said first electroluminescent phosphor and thereby controllably enhancing the luminous output of said second electroluminescent phosphor when the latter is simultaneously energized.

14. In combination, a source of electrons, and an electroluminescent phosphor in receptive proximity to electrons emitted by said source.

15. The combination of an electroluminescent phosphor, and a photoemissive material that is in radiation-receptive proximity to said electroluminescent phosphor and, in response to impinging radiation therefrom, injects free electrons into the electroluminescent phosphor particles.

16. A radiation-generating component comprising, in combination, a thin film of electroluminescent phosphor, means for applying a voltage across said phosphor film, and means for simultaneously irradiating said film with electrons, said electron-irradiating means comprising an integral part of said radiation-generating component.

17. An electroluminescent phosphor dispersed in a dielectric matrix that includes an emissive material which irradiates the electroluminescent phosphor particles.

18. An electroluminescent phosphor dispersed in a radioactive dielectric matrix.

19. An electroluminescent device comprising, in combination, an electroluminescent phosphor, means for applying a voltage to said phosphor, and means comprising an integral part of said device for simultaneously irradiating said electroluminescent phosphor with sub-atomic particles.

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REUBEN EPSTEIN, *Examiner.*