

Dec. 26, 1961

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3,015,044

ELECTROLUMINESCENT LAMP

Filed Nov. 19, 1956

Fig. 1

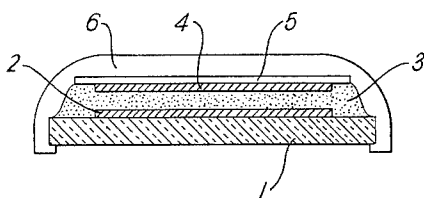
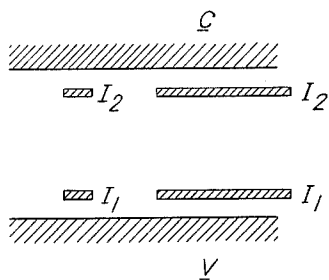


Fig. 2



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ELECTROLUMINESCENT LAMP

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Filed Nov. 19, 1956, Ser. No. 638,190

6 Claims. (Cl. 313-108)

This invention relates to electroluminescent lamps, that is to lamps in which the light is produced by the action of an electric field on a phosphor.

This application is a continuation-in-part of Serial No. 307,282, filed August 30, 1952, now abandoned.

According to the present invention, the efficiency of the lamp is increased by the use of electroluminescent substances, such as phosphors, in which a large proportion of activator is used, or by the use of unactivated substances in which the valence and conduction bands are separated by an energy difference corresponding to that of visible light, or of the radiation desired. Higher fields will generally be required with such substances than with the type using smaller quantities of activating impurities. If there are no intermediate levels between the valence and conduction bands, or no intermediate levels from which electrons can drop back to produce light emission, the material will not be a phosphor in the usual sense.

The invention will be further explained with reference to the accompanying drawing in which FIG. 1 shows one embodiment of my device and FIG. 2 is a schematic energy diagram of a suitable phosphor.

In the ordinary substitutionally-activated phosphor, for example zinc sulphide activated with manganese, small amounts of activator are used so that the activating material will be dispersed into well-separated centers. This provides separated energy levels I_1 , I_2 , between the main levels of the valence band V and conduction band C. If a sufficient field is available, electrons can be excited from the I_1 level to the I_2 level, and will cause emission of light on the electrons' return to I_1 . The centers of the energy levels I_1 are separated in space by the distance between the activator atoms, so electrons cannot ordinarily pass directly from one activator to the next.

However, if the electron is excited all the way to the energy of the conduction band C, it can then travel throughout the crystal, because the conduction band extends through the crystal. Such travel through the crystal introduces losses by scattering, collisions with atoms and ions, and the like, as pointed out in my copending application, Electroluminescent Lamps Serial No. 305,400, now Patent No. 2,755,406, filed August 20, 1952. The energy lost to other atoms or ions than those of the activator material is generally wasted, since light is produced chiefly by excitation of activator atoms which can afterward return to their normal state with the emission of light. Collisions with atoms of the main matrix material of the crystal will usually result in the emission of thermal energy rather than of light.

Increasing the number of activator atoms increases the proportion of the available electrons which will make collisions with activator atoms, and hence if other factors remained constant, would increase the efficiency. However, increase of activator concentration will decrease the mean free path of an electron, and hence, for a given field, will decrease the energy possessed by an electron when it strikes an activator atom. Under such circumstances, fewer electrons may be freed by the field for travel through the crystal, so that the number of electrons available for travel through the crystal may be fewer, except where the freeing of electrons for travel is by thermal agitation.

Increasing the activator content and the field applied

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with the increased activator, can improve the efficiency. The use of fields sufficient to excite an activator atom to an intermediate level without exciting an electron all the way to the conduction band will also increase the efficiency, because it eliminates the losses due to travel of the electron, as pointed out in my copending application hereinbefore mentioned.

The present application is directed toward another method of improving the efficiency. In ordinary phosphors, the concentration of activator atoms is kept low enough to insure that the activating centers are spaced well apart, to prevent reaction between them. If, however, the concentration of activator centers is increased to the point where they do interact, so that an electron can pass from one to another and thus transform the intermediate levels I_1 and I_2 into bands extending a considerable distance through the crystal, then electrons can travel in the activator conduction band corresponding to I_2 , and which will probably merge with the main conduction band C. Similarly, the lower levels I_1 , will spread out through the crystal and probably merge with the valence band V. But the energy gap between the bands will correspond to that between I_1 and I_2 , and so an electron can be raised from the lower band I_1 directly to the upper band I_2 , and will afterward return to level I_1 , with the emission of light. Due to the electron travel in the band I_2 , there may be losses to the lattice atoms other than activator atoms, but since the proportion of activator atoms is high, the efficiency will be high. And if the activator concentration is such that the conduction band C and the activator band I_2 do not merge, the electron may travel directly from one activator atom to another, without losing energy to the atoms of the main lattice material.

Suitable phosphors with high activator concentrations are titanium-activated barium phosphate, tin-activated tri-calcium phosphate, lead-activated magnesium tungstate and many others, including zinc silicate and zinc sulfide, activated with between 3 and 40 mole percent of manganese.

Substances having an energy gap of between about 1 and 3 electron-volts between their valence and conduction bands can be excited directly by the field to emit radiation without any activator, although the field required will generally be quite high, at least in certain points in the crystal, say between 10^6 and 10^7 volts/cm. For the emission of visible light, which requires energy gaps or about two to about three electron volts, suitable substances are cadmium sulphide, cadmium oxide, cadmium silicate, copper chloride, manganese chloride, manganese sulfide, manganese silicate, and zinc selenide, all being substantially free from activating impurities. Tellurides and selenides may be used in place of the sulfides. Indium and other elements between zinc and lead in the periodic table may generally be used in place of the cadmium. Zinc selenide, free from activating impurities, may also be used, but zinc sulphide has an energy difference of about 3.5 electron-volts between its conduction and valence bands and would hence not give visible emission on recombination of an electron in the conduction band with a hole in the valence band. It would require an activator.

The above materials can be used in stoichiometric proportions if in contact with an electrode preferably a metal, for example, tungsten, aluminum or the like, or even if in contact with another semi-conductor, for example, the conductive coatings such as stannous chloride or the like used on glass surfaces to make them conductive. If it is not desired to have a separate contact to the substance for example, if the electroluminescent particles are embedded or suspended in a dielectric material, a thin coating of the conducting material can be placed directly on

the particle's surface, preferably on only a part of the surface.

Under the above conditions, the substance could be excited directly by the field, that is, an electron from the valence band would be excited directly to the conduction band, and eventually return to the valence band with emission of light. If the field were high enough, electrons might be emitted directly into the substance from the electrode by "field emission" therefrom. Such materials would not be phosphors in the usual sense of the word.

However, in many cases, it may be desirable to have some "free" or loosely-bound electrons present in the material itself, so that they can be accelerated. In that case, the particles should have either non-stoichiometric proportions, with a slight excess of one element or the other, preferably of the metallic component or anion, or it can contain some other type of crystal defect, for example acceptor or donor impurities in small amounts. Gallium or chlorine, for example, can be used as such impurities, and are especially effective in cadmium sulfide. The amount of such material can be very small, preferably less than 10^{-5} gram atoms per gram-mole of the main matrix material, such as cadmium sulfide. An amount of 10^{-7} or 10^{-9} will generally be sufficient.

The electroluminescent particles can be embedded in a dielectric material or used directly in a compressed layer. In FIG. 1, such a compressed layer 3 is shown between a transparent conductive coating 2, on a glass plate 1, and a metal coating 4. An insulating piece 5 of mica or the like is shown over the metal layer 4, to protect the edges of electroluminescent layer 3 when the enclosure 6 of plastic material is moulded around it. The layer 3 may be of electroluminescent particles embedded in dielectric if the particles used can be excited at field strengths below those corresponding to dielectric breakdown in the embedding dielectric. In that case the mica piece 5 will generally be unnecessary.

The conductive coating 2 is of stannous chloride, as shown for example in copending application Serial Number, 120,398, filed October 8, 1949, by Eric L. Mager, now Patent No. 2,624,854. The metal layer 1 and the plastic enclosure 2, together with other mechanical and electrical constructional features of the device shown in FIG. 1, can be as described in my copending application, S.N. 305,400, Electroluminescent Lamps, filed in the Patent Office on August 20, 1952, now Patent No. 2,755,406.

In substances having a dielectric constant less than about 4, the substitution of an atom or ion which can lose or gain two more electrons than the atom it replaces, can provide levels of about light-emitting energy spacing from the conduction or valence bands, and the excitation of these levels will produce light on return

to normal. The number of atoms which can be effectively replaced in that manner is generally small, however.

What I claim is:

1. An electroluminescent lamp comprising two electrodes and an electroluminescent substance therebetween, said substance being one having an energy gap of between about two and about three electron-volts between its valence band and its conduction band.

2. An electroluminescent lamp comprising two electrodes and an electroluminescent substance therebetween, said substance being one having an energy gap of between about two and about three electron-volts between its valence band and its conduction band, and having an impurity to produce carriers in said crystal but being free from any activating impurities.

3. An electroluminescent lamp comprising two electrodes and an electroluminescent compound therebetween, said compound being of non-stoichiometric proportions and having an energy gap of between about two and about three electron-volts between its valence band and its conduction band.

4. An electroluminescent lamp comprising two electrodes and an electroluminescent substance therebetween, said substance being selected from the group consisting of the following unactivated materials: cadmium oxide, cadmium silicate, copper chloride, manganese chloride, manganese sulphide, manganese silicate, and zinc selenide.

5. An electroluminescent lamp comprising two electrodes and a stoichiometric unactivated compound therebetween and in contact therewith, said compound having an energy gap of between about two and three electron-volts between its valence band and its conduction band.

6. The lamp of claim 4, in which the electroluminescent substance is in contact with at least one of said electrodes, and is stoichiometric.

References Cited in the file of this patent

UNITED STATES PATENTS

2,222,668	Knoll	Nov. 26, 1940
2,441,559	Burrell	May 18, 1948
2,457,503	Singer	Dec. 28, 1948
2,566,349	Mager	Sept. 4, 1951
2,624,857	Mager	Jan. 6, 1953

OTHER REFERENCES

An Introduction to Luminescence of Solids, Humbolt W. Leverenz, John Wiley and Sons, New York, N.Y., 1950.

The New Phenomenon of Electroluminescence and Its Possibilities for the Investigation of Crystal Lattice, by Prof. G. Destriau, Philosophical Magazine, pp. 700-713, vol. 38, October 1947.