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R57ELS 1

PHOTOCONDUCTORS AND ELECTROLUMINESCENT MATERIALS FOR DISPLAY AND SIMILAR DEVICES

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TITLE

PHOTOCONDUCTORS AND ELECTROLUMINESCENT MATERIALS FOR DISPLAY AND SIMILAR DEVICES

ABSTRACT

Materials and processes for use in a light storage display device were studied and developed and the results of the investigations are presented.

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CONCLUSIONS

Optical, electrical and physical data on photoconductive and electroluminescent materials were made available for a light amplifier design.

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I. INTRODUCTION

Intentionally avoiding basic physical studies this report describes results of experiments, evaluations and developments of materials and processes useful in the design and operation of an information display light amplifier. The basic design and construction of the small display panel, which has been used in our demonstrations was conceived by H. J. Evans[1]. Its reduction to practice was carried out by J. C. Almasi, who will describe its construction details in a later report[2]. However an adequate statement of the requirements of the materials for this specific application can be better understood if we consider the basic principle of this type of light amplifier in the next chapter.

The experiments and measurements described are extended basic studies and applications and it is felt, that the results will be a useful link between the basic physical studies and the design of a marketable device. The results should answer some questions imposed by the design engineer and are therefore presented this way.

Some of the results achieved may be useful more or less for a variety of devices incorporating photoconductors and electroluminescent elements, although the work was directed for the specific type of light amplifier in mind.

---

(1) H.J. Evans, Patent disclosure. Electronics Lab.

(2) J.C. Almasi TIS R 57 ELS 2

The Light Amplifier

To be described is an on-off matrix information storage display device, operating with optical in and optical output signals. Light information is picked up by a photoconductor, i.e. a layer of copper activated cadmium sulfide. The change of the resistivity caused by the light signal controls the light output of a light producing system, i.e. electroluminescent cells.

Means are provided to allow light to shine back to the photoconductor to keep the cell lit even after the light input signal has disappeared. If such a device did not consist of a mosaic of individual and independently operating cells, any light signal on any point of the display device would cause the light to spread over the whole array. Therefore, unit elements are required which can be added without mutual interference to any size panel desired. The number of elements per unit area defines the resolution of the display device.

The unit element size used for the experiments are squares of 1/16". The equivalent circuitry of a single cell is shown in Fig. 1 (a), (b), (c). The resistance of the photoconductor PH in Fig. 1(a) is high if no light signal is present. As the impedance of the electroluminescent cell EL is smaller than that of PH, only a smaller portion of the voltage AC is appearing on EL, thus, producing no noticeable light. In Fig. 1(b) a light signal, indicated by two parallel arrows, changes the resistance in PH and the voltage AC increases on the electroluminescence cell EL thus producing light which can be observed. This light also falls back on to the photoconductor as indicated by the arrows.

In Fig. 1(c) the cell stays lit by the feedback light and no input signal is present. Thus, storage is achieved and erasing can be done at will, for example, by opening the circuit. Some theoretical treatment of light amplifier cells of this type was given for example, by J. Rosenthal.[3]

The cells, as described, are made into a mosaic on a glass wafer. Like a matrix, the wafer carries the housing elements for the photoconductor and the electroluminescent part of each cell. Photosensitive glass, for instance, the Corning Fotoform glass, is a useful material for this wafer.

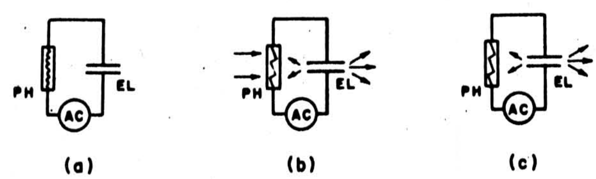


FIGURE 1

The Materials

I. The Photoconductor Section of the Light Amplifier

Basic physics and theory as well as more details about Cd S:Cu photoconductors are presented by various authors.[4][5][6][7][8] Because of its high sensitivity in the visible region of the light spectrum Cd S:Cu photoconductors were used in this application. The slow speed of response of the Cd S is tolerable in the display device described. The photoconductive Cd S:Cu was used in form of powder and prepared in the following way:

(3) J. Rosenthal, Theory and Experiments ... Proc. IRE 43/12, Dec. 1955, page 1882
(4) J.T. Randall and M.H.F. Wilkins, Proc. Roy Soc., 184A, page 347
(5) R.H. Bube, Phys. Rev. 90 (1953), page 70
(6) R.H. Bube, Proc. IRE 43 (1955), page 1836 and bibliography there
(7) A. Rose, Proc. IRE 43 (1955), page 1850 and bibliography there
(8) J.E. Jacobs, Dissertation NW Univ., 1950

1000 pts. by weight of Cd S powder[9]

10 pts. by weight of Cd Cl 2,5H_2O regeant grade[10]

1 pt. by weight of Cu Cl. 2H_2O regeant grade[11]

The powders were ground and distilled water added. After expelling the water, the mixture was fired at 625° C for about 3 minutes in air. This includes the warmup time. Larger quantities than 20 g, as used here, require a longer firing time or higher firing temperature. The firing cycle is interrupted before the photoconductor reaches its peak sensitivity to avoid a loss or decrease of sensitivity during firing or sintering procedures required in deposition steps. The mixture is then ground to a rather fine powder and stored.

This method of preparation proved to be the best and simplest although, for example, Cd S:Cu - vapor depositions were carried out[12] which were discontinued because of the more convenient powder method.

The CdS powder was then sintered to a glass plate[13] provided with conductive coatings forming two electrodes. The gap between the electrodes was 0.05 cm. The length of the Cd S coating along this gap was 0.15 cm, the active area therefore 0.0075 $cm.^2$ The operating voltage of such a cell was 200 V. All experimental data on photoconductors produced here were measured on cells of these dimensions.

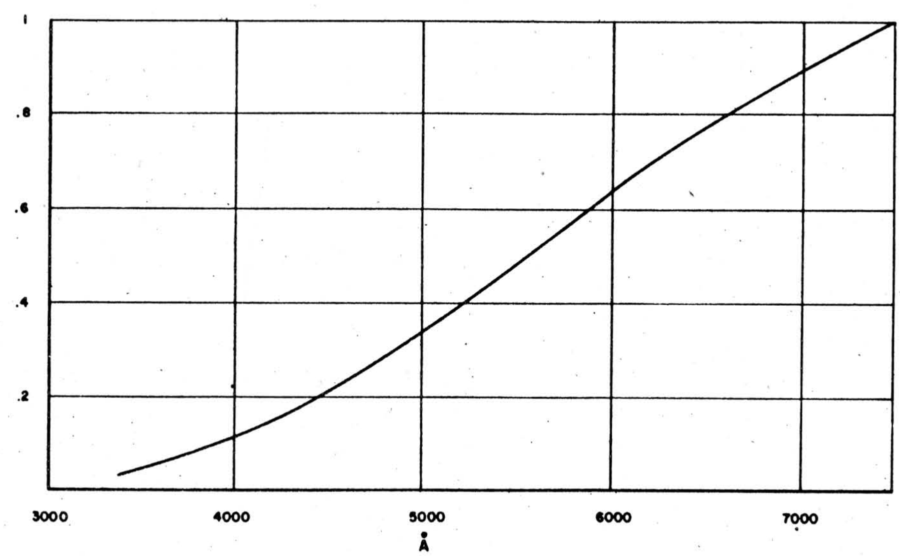
(9) U.S. Radium Corp. Spectrometer shows no copper, however a light impurity of Zn
(10) Baker Chem. Co.
(11) Baker & Adams

(12) See for example.. W - Veith, Z.S.f. angew. Phys. 7/1, 1955, page 1
(13) Two minutes 630°C for microscope slider

Sensitivity Measurements

(1) Spectral Sensitivity -

The light used for the spectral sensitivity measurements on the photoconductors investigated was a calibrated tungsten light source, the spectral distribution of which is shown in Fig. 2. The light source was placed in front of a light spectrometer and the photoconductor sample was located to the viewing section of the spectrometer.



CALIBRATED TUNGSTEN LIGHT SOURSE USED FOR PHOTO CONDUCTOR MEASUREMENTS

FIGURE 2

The curves taken are corrected for equal energy and shown in Fig. 3.

Curve (1) shows the spectral sensitivity of a Cd Se:Cu photoconductor

(2) a Cd Se:Ag

(3) our own Cd S:Cu

(4) the sensitivity of the human eye

(5) Cd S:Ag

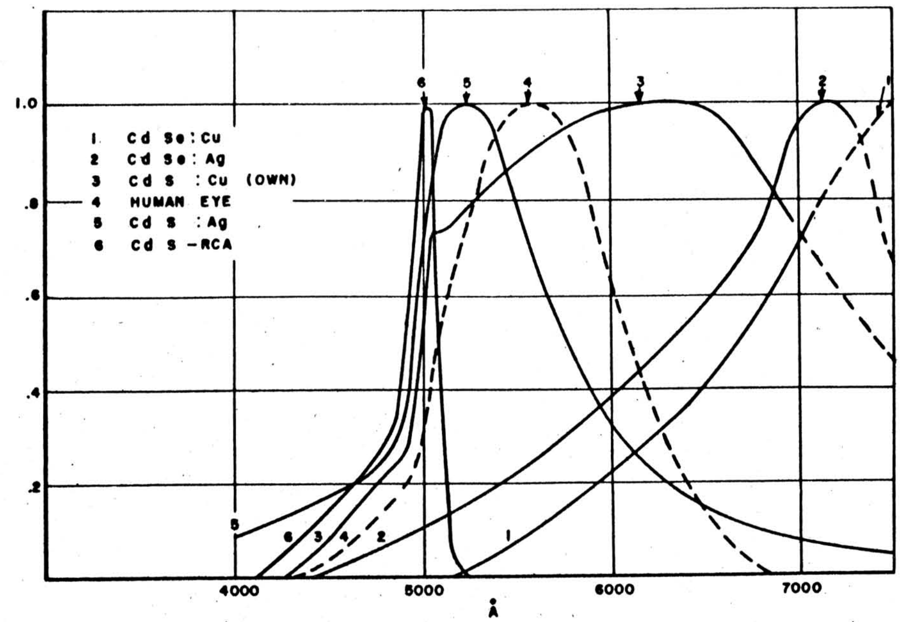
(6) Cd S - RCA

The diagram shows that the Cd S:Cu produced here covers the whole visible spectrum well and still extends towards the I.R. The peak sensitivity is in the red although, from green to red the sensitivity rises only 25% from 75% to 100%. The curves do not show the absolute electrical sensitivities but are only relative.

Our Cd S:Cu photoconductor showed the highest sensitivity of all investigated; it was therefore used for this design. The further described electrical measurements concern our own Cd S:Cu only, unless it is otherwise noted.

(2) Sensitivity at DC Operating Voltage Constant or "DC" Light

A constant intensity light source of a spectral distribution reasonably matching the spectral response of the photoconductor and samples of the above mentioned dimensions was used to measure the "DC" sensitivity. Under this term the sensitivity of the photoconductor is measured with a DC power supply, a constant or "DC" light is used, and a long enough exposure time for the light as well as for the dark period is allowed, to ensure that the conductivity values have reached their saturation in both light and dark conditions.



SPECTRAL RESPONSE OF DIFFERENT PHOTOCONDUCTORS

FIGURE 3

The conductivity values were read at 200 V DC and converted into mhos per square. The ratio of the light to the dark conductivity is considered as the sensitivity. Table I shows the readings for three samples. The variation shown here is typical of the reproducibility which one may expect.

TABLE I

	Dark $\frac{1}{R}$	10 ft. candles $\frac{1}{R}$	Sensitivity
#1	3.85×10^{-12}	8.3×10^{-7}	2.3×10^{5}
#2	1.1×10^{-12}	1.1×10^{-7}	$1. \times 10^{5}$
#3	$1. \times 10^{-12}$	4.15×10^{-7}	4.15×10^{5}

The highest sensitivity measured on a single sample was 2.10^{6}. All readings were taken at room temperature in dry air.

(3) Sensitivity vs Ambient Temperature

A constant light source as described was also used to measure the ambient temperature effects on 2 Cd S:Cu samples. Fig. 4 gives the average results of the two samples. The operating voltage was again 200 V DC. The decrease of the dark resistance is the main contribution to the loss of sensitivity with increasing temperature. The simultaneous increase of light resistance is somewhat surprising and should be further investigated.

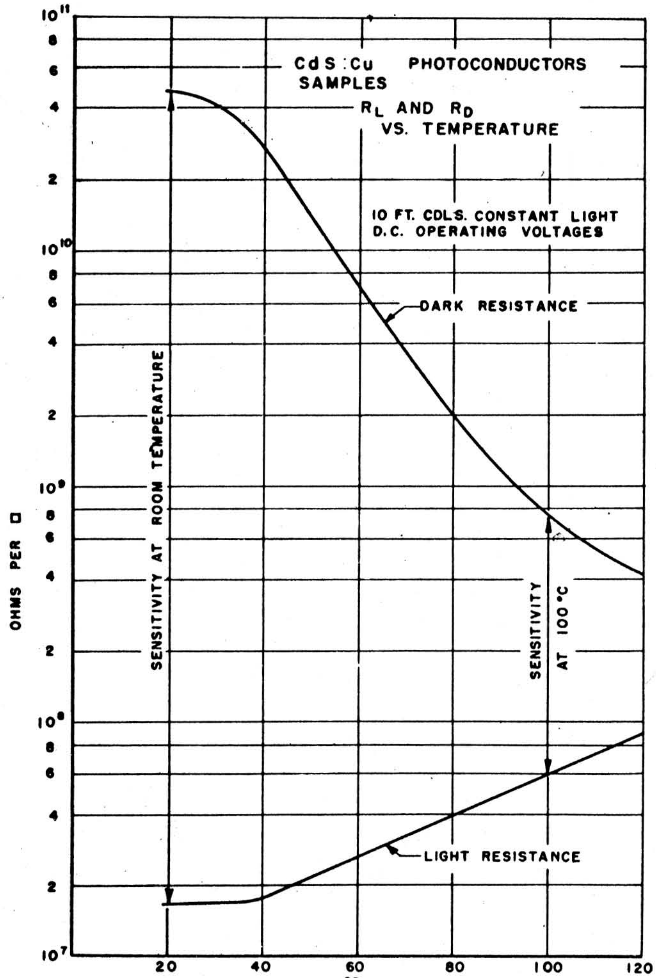


FIGURE 4

According to these results, there is a positive and a negative temperature coefficient of the resistivity on one and the same material, depending whether there is incident light on it or not. The sensitivity of the photoconductor appears to be reduced by a factor of 25 if the temperature is increased 1°C in the range between 40 and 100°C. At about 170°C the photoconductive properties of these Cd S:Cu samples disappear. These data are important for device designs as to their operating temperatures or ambient conditions.

(4) Sensitivity at AC operating Voltage and "DC" Light Impedance Problems -

In many of the Cd S:Cu photoconductor samples investigated the resistance per square in dark was measured in the order of 10^{11}. Because of the high ohmic resistance of some types of photoconductor cells, it should be briefly reminded that circuitry impedances might hamper the performance, if AC is used as an operating voltage. The situation becomes worse with increasing frequency and the circuitry impedance masks the photoconductive effect.

Although obvious, this fact should be mentioned and illustrated in Fig. 5.

(5) Sensitivity vs "DC" Light Level at DC Operating Voltage

The next set of measurements describes the behaviour of DC voltage operated Cd S:Cu samples at reduced light levels. The light, again, was of the same spectral distribution as described before and was constant on its respective level during the measurements. Fig. 6 shows how the resistivity of the samples change with the light level. The values are average values of measurements taken on 4 samples. The dark resistance depending on the ambient temperature establishes the lower limit of the light levels. If photo effects should be observed and used at low light levels, it is necessary to operate the photoconductor at reduced temperatures and, of course, in dry atmosphere; sealed and cooled containers of high transparency at the location of the photoconductor, seem to be unavoidable if low light levels should be measured and responses used for amplifications.

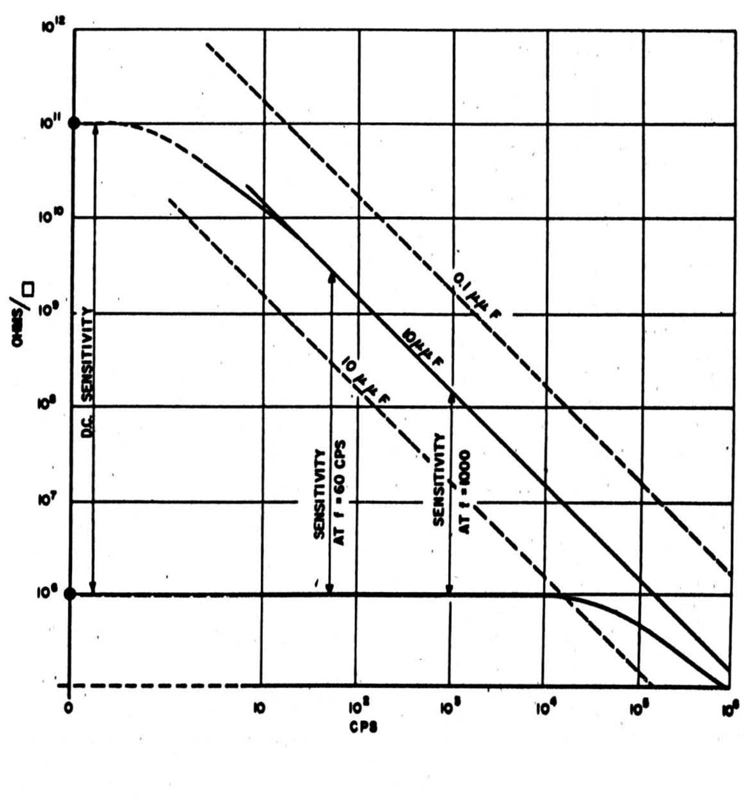
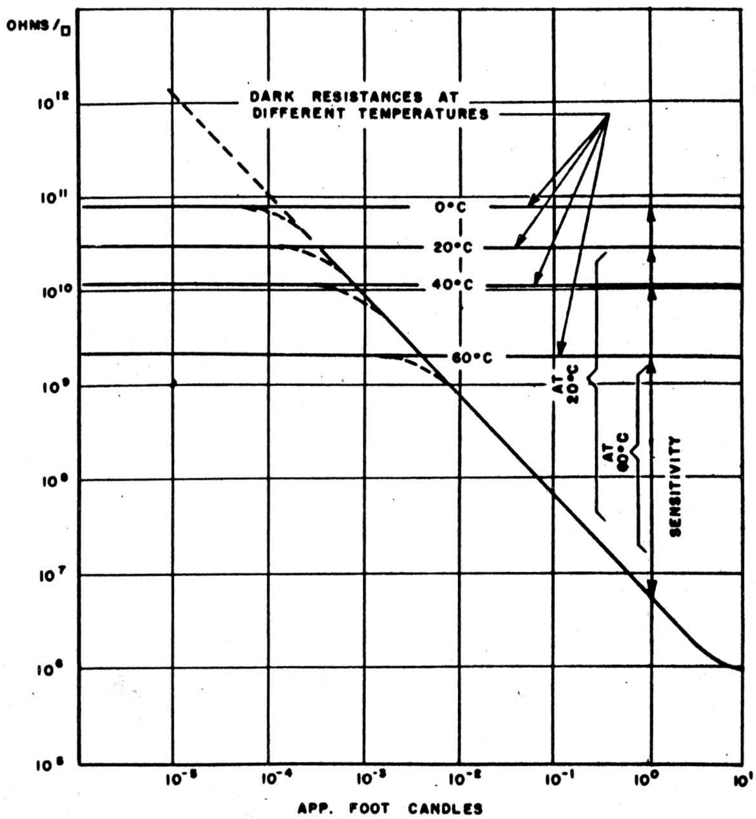
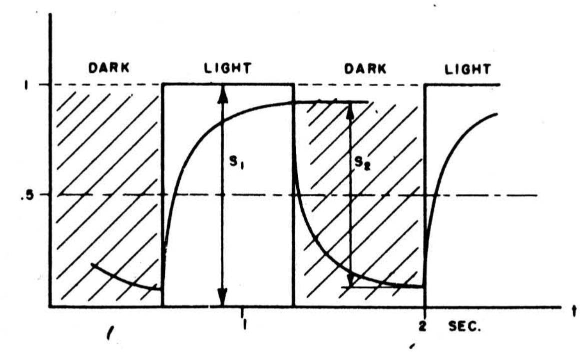


FIGURE 5



$R_{PHOT.}$ VS. LIGHT LEVELS OF 4 CdS: Cu PHOTOCOND. SAMPLES

FIGURE 6

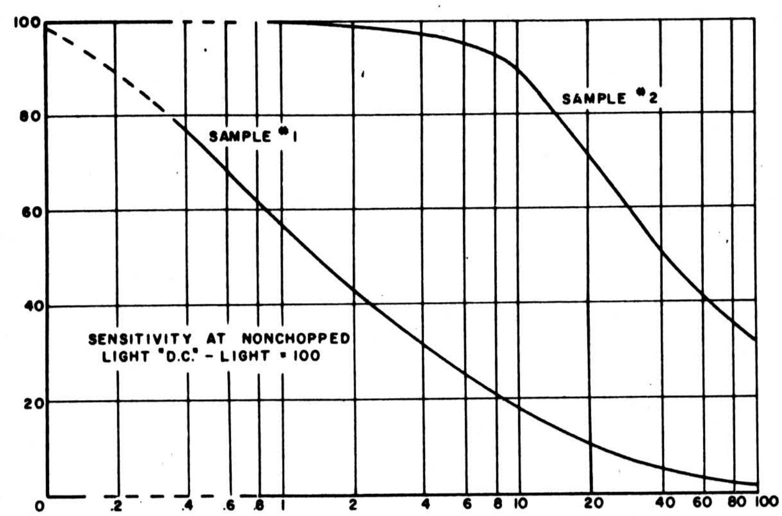


RELATIVE PHOTOSENSITIVITY OF CdS VS. CHOPPED LIGHT

FIGURE 7

(6) Sensitivity at Chopped or "AC" Light at DC Operating Voltages

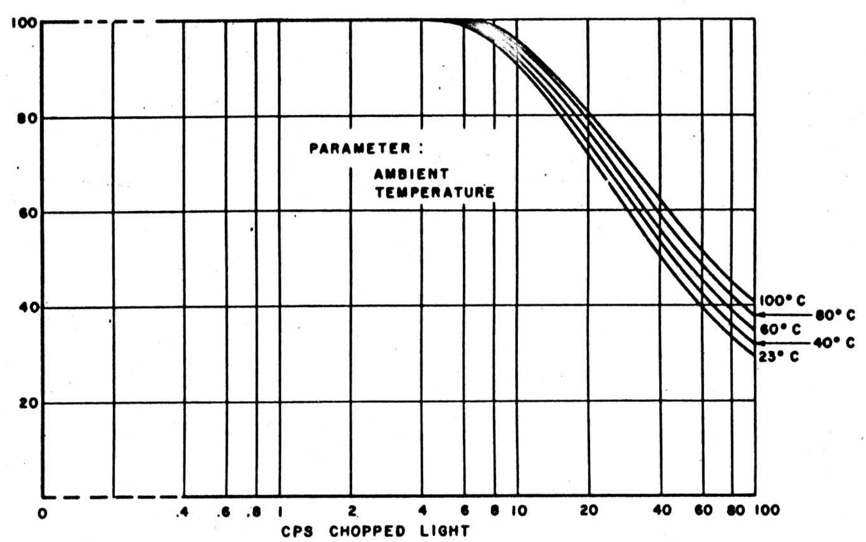
As in most applications, intermittent light is used to excite the photoconductor. The rise and decay times of the cells used for previous sensitivity measurements were studied. One set of measurements used chopped light as shown in Fig. 7. In these measurements a light source having the same wave length distribution as described before and an intensity of 10 apparent foot candles was chopped mechanically by a rotating disc provided with slots, to produce light square waves. The time of "light on" was equal to the time of "light off". The photoconductor samples were again the .05 x .15 cm standard samples and operated with 200 V DC.



PHOTOCONDUCTOR CdS :Cu SENSITIVITY VS. FREQUENCY OF SQUARE WAVE CHOPPED LIGHT

FIGURE 8

On a resistive load which was small compared to the total resistance of the circuit, the signal voltage was picked up for the scope and recorded. An indicator as to whether the light on the sample was on or off and proving the square shape of the "light wave" on the sample was recorded also on the same diagram. As shown in Fig. 7 the amplitude or conductivity level of the photoconductor exposed to unchopped light and darkness is assumed to be unity. In these two conductivity values, showing up as two horizontal lines in a certain distance from each other, the exposure times were chosen long enough to allow the photoconductor to reach saturation levels in dark as well as in light. If light chopping is now performed, there is with increase of the chopping frequency, less and less time available and the photoconductor sample reaches neither its lowest dark conductivity level nor its full light conductivity. This effect shows up as an amplitude reduction.



RELATIVE SENSITIVITY OF CdS : Cu VS. FREQ. OF SQUARE WAVE CHOPPED LIGHT

FIGURE 9

In Fig. 7 a chopping frequency of .7 cps reduced its sensitivity from the saturation sensitivity $S_1 = 1$ to $S_2 = .83$. The decay time required to reach and $\frac{1}{e}$ value of a starting point was measured to be close to 100 ms. At this type of photoconductors and the light used, hardly any difference between rise and decay time of the photoconductor could be found because the experiment was not designed for this purpose.

The rise and decay times depend to a great extent, in addition to the cell geometry, on sometimes even slight variations of heat treatments and introduced impurities. Fig. 8 shows an evaluation of a series of measurements as just described; it illustrates the sensitivity of the photoconductors investigated versus chopping frequency of the light. The two curves show differently treated Cd S:Cu samples and demonstrate strikingly possible differences in the response. At a light chopping frequency of 100 cps, sample #1 shows only 2% of its saturation sensitivity while sample #2 still shows 32%.

Cells of the type #2 were used for the investigations described in this report. This type of cell appears useful in the detection of light pulses of audio frequency.

(7) Sensitivity at "AC" Light, DC - Voltages at Elevated Temperatures

A set of tests were run in which Cd S:Cu samples were heated up to 100°C to study its sensitivity vs light chopping frequencies. The <u>absolute</u> values of the conductivities of the samples behaved as expected and shown in Fig. 4. The absolute values of their sensitivity decreased with increasing temperature.

Fig. 9, however, shows the <u>relative</u> sensitivity of the sample vs frequency of the chopped light with temperature as the parameter.

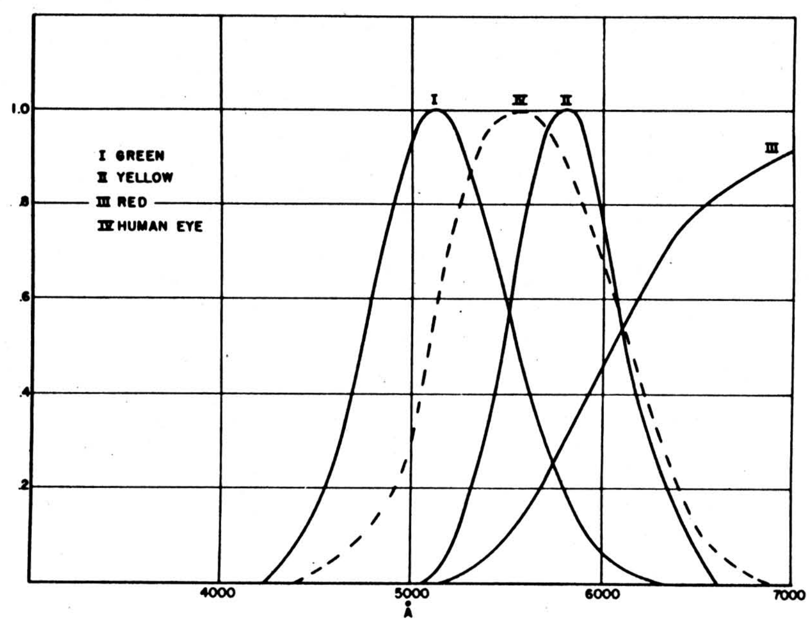
The measurement setup was the same as described in the preceding section. The curves demonstrate that the relative sensitivity increases with increasing temperature.

It looks as if decay and rise times decrease with increase of temperature, because the value of 30% at 100 cps light frequency gradually moved up to 40% with a temperature increase. The same effect may be achieved by infra-red irradiation. This effect may be caused by raising the dark conductivity and thus eliminating the slower portions in the decay processes. These results would indicate that electro-optical devices containing Cd S:Cu photoconductors designed to be used at audio frequencies, such as circuitry elements, should be operated at elevated temperatures or irradiated by I.R. if the relative sensitivity is important and a loss of absolute sensitivity can be tolerated. Experiments to study the behavior of Cd S:Cu samples with respect to its absolute sensitivity or increase of speed of response by exposing the samples to a UV light or to microwave irradiation did not show any useful effect.

II. THE ELECTROLUMINESCENT SECTION OF THE LIGHT AMPLIFIER.

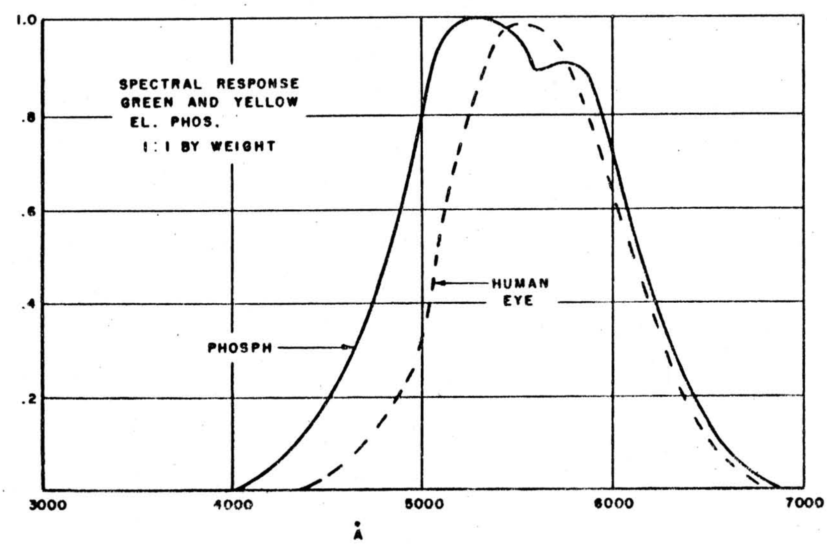
The light producing system of the light amplifier is a mosaic of electroluminescent cells. The investigations described below concern data needed for the design and optimum performance of the cells and the allowable compromises in design.

The electroluminescence phosphor used was received from G.E. Lamp Development Laboratory in Cleveland. Green, yellow and red electroluminescence phosphors were studied. Fig. 10 shows the spectral distribution of the electroluminescence light emitted by these three phosphors. The measurements were taken at 60 cps AC. The ratio of the light output from the green to the



EL. PHOSPHORS AND HUMAN EYE

FIGURE 10



WHITE PHOSPHOR

FIGURE 11

yellow to the red phosphor is about 1 : 0.78 : 0.12 in terms of energy. The value of 0.12 for the red phosphor might be considerably higher. This assumption is based on the fact that the available detection system did not cover a wide enough spectrum as to measure accurately towards the red region.

At 60 cps the green phosphor peaks at 5150 Å, the yellow at 5900 Å and the peak of the red is above 7200 Å. The half-value width of the intensity is 800 Å for the green phosphor, 450 Å for the yellow and is estimated as more than 2500 Å for the red phosphor. The dashed line shows the sensitivity of the human eye. In case of a color display device, more phosphors of desired spectral distribution should be developed or produced by mixing existing phosphors. Red and even infra-red phosphors appear important for future devices.

Fig. 11 shows an electroluminescent phosphor which appears white, which is a mixture of green and yellow phosphors in a ratio of 1 : 1 by weight. The two peaks corresponding to the peaks of the individual phosphor still can be seen. The dashed line shows again the sensitivity of the human eye. The white phosphor and the green phosphor are different enough in their colors to be distinguished and a considerable amount of ambient light can be allowed for manipulations during the observation. As the electroluminescent phosphors used in the amplifier in mind is considered to be a developed to a very high degree, practically no effort was devoted to the improvement of the phosphor material itself.

Considerable investigations, however, were concerned with the matrix or embedding material with cell designs and with the optimum performance of the electroluminescence cell in the specific light amplifier application and also with electrodes.

Matrix Materials

The brightness of the light of an electroluminescent cell is known to depend on the applied voltage to the 4 to 7^{th} power, on the square root of the frequency, and on its thickness up to a value d_{max} which is the depth out of which light can penetrate to the outside and contribute to the brightness. The applied voltage is considered as the field intensity at the phosphor particles or, in the first approximation, it can be read as volts per centimeter thickness of the cell.

A field intensity of 100,000 V/cm can produce (depending on the embedding material) an excellent brightness; 50,000 V/cm produce very good brightness levels; and 30,000 V/cm are sufficient in most applications.

Electroluminescent light still has a relatively poor reputation as to its brightness. This reputation originates mainly from its illumination application where, of course, only the terms of lumens per watt are decisive. The efficiency, however, is of very little importance in applications other than room illumination, but even the efficiency of the electroluminescence light can be well compared with the efficiency of an incandescent lamp of early designs and also some designs still in use. This means there is not any serious problem of insufficient brightness in the design of this device: brightness of 1000 ft. Lambert[14] has been demonstrated.

Under more practical conditions, brightness of 50 foot Lambert could be obtained on samples produced during these investigations which is of course, not the ultimate. Brightness, therefore, still can be traded for other important device features such as life.

---

(14) See, for example, McKeag and Steward, GE England, paper presented by H. Froelich on the San Francisco meeting of the Electrochem. Society in April 29 - May 3, 1956.

A brightness of 5 foot Lamberts begins to be practical and 10 - 15 foot lamberts are sufficient for the display device. Contrast effects and/or different colors between ambient light and displayed light or different information to be distinguished allow relatively low brightness.

Absolute values measured here are given in the following paragraphs where embedding materials are individually described.

Basic studies on the electroluminescence effect[15][16] of Zn S:Cu and similar phosphors in particular and their behavior in a matrix material of different dielectric constants are reported by several authors[17][18][19][20][21] They are not repeated here.

Among the embedding material here investigated are:[22]

Organic - (a) Araldite, (b) Glyptal (printing, spraying), and (c) Aroclor and inorganic - (d) Silicates, and (e) Glass frits.

For each of these materials the brightness was measured vs. voltage applied and thickness. Each of the materials mentioned can be used as matrix material; however, the development of long-life cells points to the inorganic materials. Each material has its advantages and disadvantages.

---

(15) G. Destriau, Phil Mag 38, 700 (1947)
(16) Payne, Mayer and Jerome, Illum. Eng. 45,688 (1950)
(17) W.W. Piper and F.E. Williams, Phys. Rev., 87 #1, 151-152, VII 1952
(18) S. Roberts, Journ. Opt. Soc. 42 #11, p. 850-854, 1952
(19) R.E. Halsted and L.R. Koller, Phys. Rev., 93 #2, 349-350, I 1954
(20) F.E. Williams, Phys. Rev. 98 #2, 547-548 IV 1955
(21) Katz T.I.S. 54-E-299
(22) Other materials will be discussed by J.C. Almasi

(a) Araldite 502

This organic resin hardens by addition of a catalyst to a transparent solid material. The excellent machineability is doubtless its outstanding advantage.

The dielectric constant is about 5. Its disadvantages are inherent in the fact that Araldite is a thermoplastic material, which softens above 120°. As a consequence, it cannot be used if heat treatments of any other components of the device are required after the araldite layer is applied. Phosphor to Araldite 3:1 by weight is the saturation point for binding to a solid mixture.

(b) Glyptal

If the electroluminescence layers is sprayed or printed, a mixture of glyptal spray mix and phosphor is very useful. It is however, hard to spray homogenous layers below .003" thickness. Being an organic material it shows the trend to darken during operation, especially at field intensities above 40,000 V/cm. Thus, life might be a question.

(c) Aroclor

For laboratory experiments, Aroclor seems to be useful as a matrix material. It does not, however, dry. Quick measurements are easy to carry out.

(d) Sodium Silicate

If the thermal expansion coefficient of the supporting material allows the application of sodium or potassium silicate, this is a very useful material. Sodium silicate can be easily applied, by brush and it may be ground after hardening. Definite disadvantages are the weathering properties. Thus, these cells have to be used in a conditioned atmosphere or in a vacuo. The thermal coefficient, however, limits the applications.

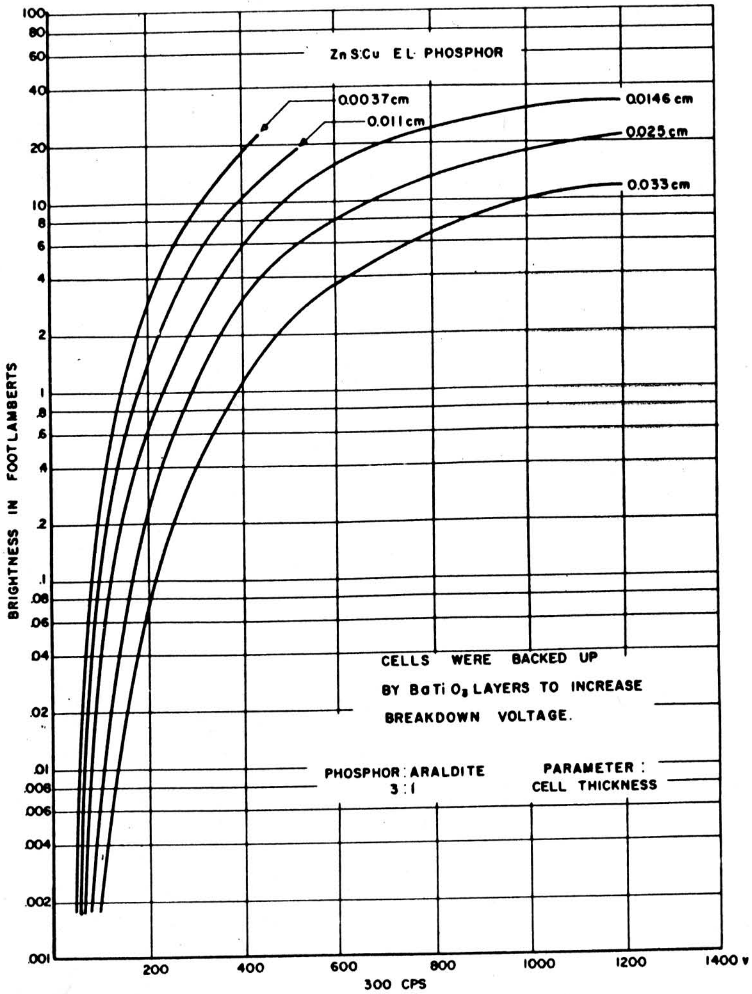
(e) Glass Frit

The most promising matrix material seems to be glass frit and a fused electroluminescent cell. Developmental work is still going on along this line and cells were produced by letting a phosphor - glass frit mixture settle out of an emulsion on to the cell support and then fusing the cell in a heat treatment.

The materials mentioned were experimentally investigated for their physical properties, brightness qualities, and applicabilities for the display device. It would, by far, exceed the scope of this paper to show all the results obtained.

Therefore, only a phosphor:araldite mixture 3:1 is presented as a typical example. Fig. 12 shows a routine set of curves taken at brightness vs. operating AC voltage measurements. The thickness of the phosphor - araldite layer is the parameter. The curves do not show any unexpected effects. As the field intensity on the phosphor and not the applied voltage is decisive for the light output, it is understandable that thinner layers emit more light than thicker ones at a given operating voltage. This, of course, cannot be carried to the extreme so that the thinnest layer shows infinite brightness.

In order to find a reasonable range of dimensions for the design of the electroluminescent cell, all these sets of curves were redrawn as brightness vs. thickness curves with a constant field used as parameter. Such an example of a new set is shown in Fig. 13. It can be seen that the brightness for a constant field intensity increases linearly up to a certain thickness and then to a definite saturation.



BRIGHTNESS VS. APPLIED VOLTAGE

FIGURE 12

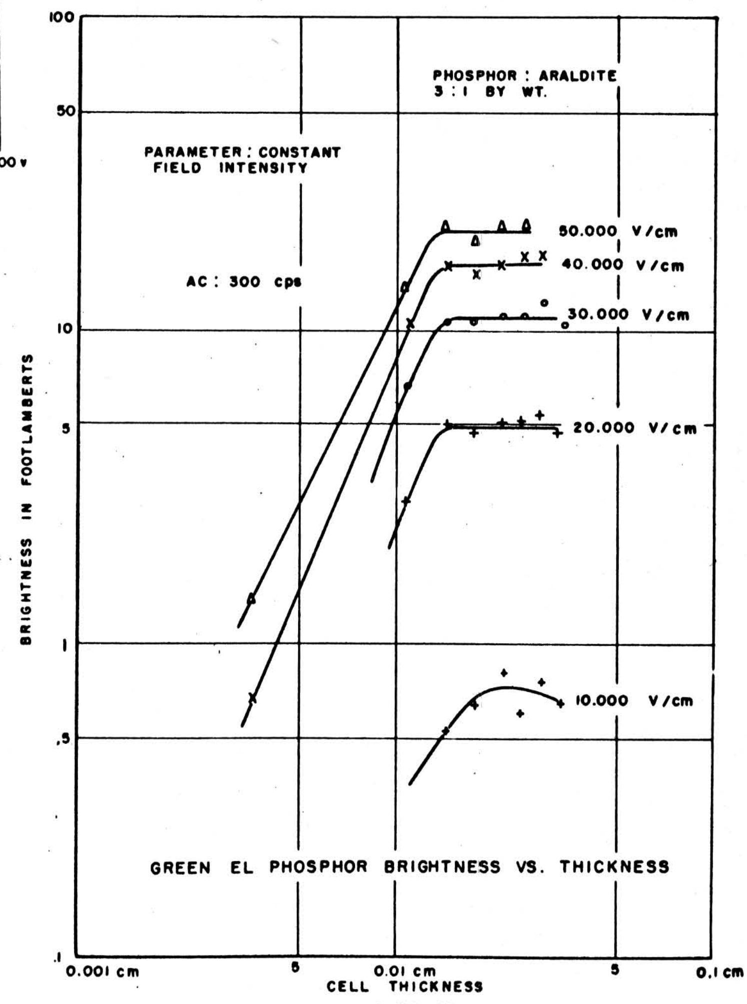


FIGURE 13

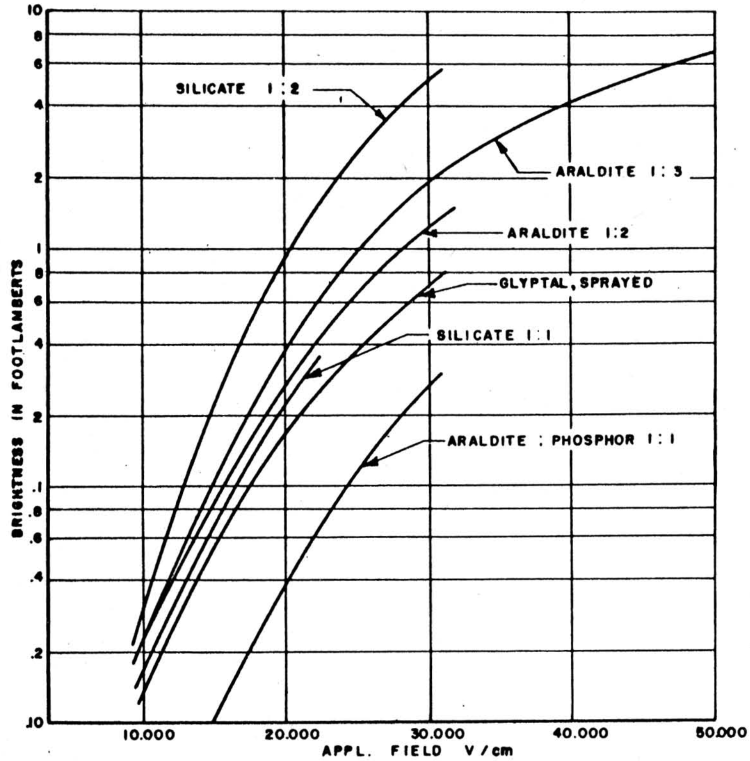
In a way, it is surprising that all curves begin to saturate at practically the same thickness, which means that an increase of field intensity does not make light shine through from deeper portions of the electroluminescence dielectric mixture. According to the results, there seems to be a well-defined depth out of which the light shines through so that it can be seen and measured.

Fig. 14 shows the brightness of electroluminescent cells of equal thickness (0.0075 cm) versus the applied field for different embedding materials. That ratio of phosphor to matrix material influences the brightness. Different brightnesses of several matrix materials, however of same ratios is due to the difference of the dielectric constant of the matrices. According to Fig. 14, further development work on silicates and glass cells seems promising because of the higher light output compared to the other materials. Glass cells also have good chances for a long cell life.

Cell Designs

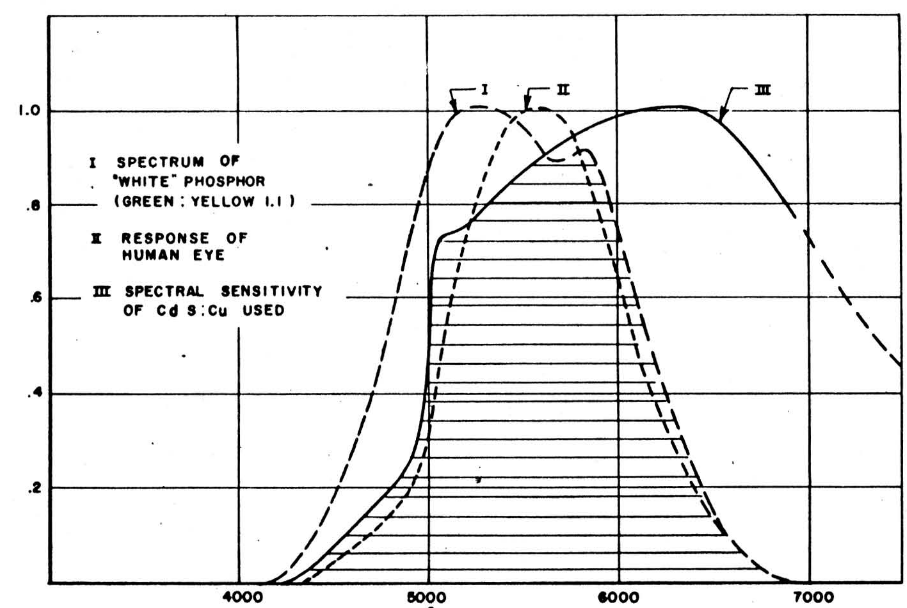
The regular electroluminescence cell is usually a flat capacitor, the dielectric of which consists of embedded electroluminescent phosphor. One or both conductive capacitor electrodes are transparent. Another design allows the observation of the phosphor directly and not through a transparent electrode.

In many designs, it is important to use low voltages (100 volts or less) to operate cells. In order to achieve optimum brightness, the cell thickness has to be reduced to gain field intensity. According to Fig. 13 a layer thickness of .0037 cm at 40.000 V/cm requires 150 V to produce only .65 foot lamberts. Ten times the brightness would require a further reduction of the



ELECTROLUMINESCENT BRIGHTNESS VS. APPLIED FIELD FOR DIFF. MATRIX MATERIALS OF CONSTANT THICKNESS = 0.0075 cm.

FIGURE 14



RECOMMENDED MATERIAL FOR LIGHT - STORAGE - AMPLIFIER

FIGURE 15

thickness and an increase of the field.

Breakdown voltages limit this process. Therefore, it was suggested[23] that a very thin layer of phosphor could be backed-up by a relatively thick layer of $BaTiO_3$. The high dielectric constant of the backing material still builds up the applied field on the phosphor, and avoids ohmic or electrolytic breakdown through the cell. Cells were made emitting light from both sides and having an opaque of high dielectric material between the two phosphor layers.[24]

Another type of cell was investigated which might be useful once the impedance problem becomes critical.[25] One electrode of the capacitor-like cell was replaced by a pin or ballpoint and the field around it used to excite the electroluminescent phosphor. An array of individually supplied pin points could represent cellular structure of an information display of high impedance input. The pin points may be in a certain distance or may touch the electroluminescent phosphor.

Selection of Materials

Fig. 15 shows the spectral properties of the material recommended and used in samples. Curve I shows the spectrum of the white light, emitted from a 1 : 1 mixture of green and yellow electroluminescent phosphor.

Curve II represents, for comparison purposes, the sensitivity of the human eye. It can be seen in the diagram why the light appears white.

(23) J.F. Elliott, R. E. Halsted, Patent Disclosure
(24) E. Fischer - Colbrie Patent Discl. El. Lab
(25) E. Fischer - Colbrie - Patent Discl. El. Lab.

Curve III shows again the spectral sensitivity of the Cd S:Cu photoconductor used. The white light of the phosphor and the spectral response of the Cd S:Cu photoconductor used shows the largest overlapping area. Neither the green nor the yellow phosphor alone matches the sensitivity curve in the extent the white does. As there is hardly any efficiency loss introduced by mixing the yellow phosphor to the green, this mixture is recommended at least for the light which is fed back to the photoconductor from the electroluminescent cell.

Further improvements or developments of red phosphor, to be added to this mixture, will probably further improve the present conditions if their efficiency is sufficiently high.

The optical information signal can be matched in its spectrum better than the feedback signal. An example for a good match is tungsten light and a filter to cut off the uneffective infra-red.*

The color of the light of the display area facing the observer may still be produced by the green electroluminescent phosphor. The color has definite advantages, especially if regular tungsten light is used as ambient light.

The amount of ambient light permissible can be rather high and can be of the same magnitude as the light produced in the information display panel, as long color contrasts exist between the two light sources, as provided in the design. The amount of ambient light may be limited by the transparency of the electroluminescent part of the display panel towards the photosensitive part of it, if an overlapping of the spectral sensitivity

*For example, Corning transmission filter 3965 of the photoconductor and the spectral distribution of the ambient light exists. Such an overlapping would not exist in the present design, if the ambient light is of blue color. Choosing the ambient light this way would even avoid the necessity of screening off the photosensitive part and maintenance and repairs can be easily carried out.

A reasonable contrast to the blue color would be the light of the yellow electroluminescent phosphor, which then seems to be well recommendable, if the contrast to the green electroluminescent phosphor, presently used would not suffice to the blue ambient light.

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