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SPECIAL PHOSPHOR SCREENS FOR IMAGE TUBES

by

D. A. Cusano

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ABSTRACT

Two means of improving the performance of luminescent elements used in image tubes are discussed. Translucent vapor-reacted zinc sulfide layers have been produced with resolutions, measured optically, of up to 115 line pairs/mm. At the same time, such layers have exhibited cathodoluminescent efficiencies from 13 to 17 lumens/watt. Although the efficiency-resolution product turns out to be the same as for P-20 powder screens, these films should be useful where resolution is more important than efficiency, such as, for example, in multistage image tubes.

Vapor-reacted zinc sulfide layers which exhibit enhancement of luminescence under applied voltage and during electron bombardment offer up to an order of magnitude of improvement in efficiency-resolution. These CEL (i. e., cathodoelectroluminescent) screens are brighter than P-20 screens in the range from below 10^{-5} to 10^{-2} micro-amperes/cm^2--by more than 10 times at the lower end of this range. A disadvantage of CEL screens for some image tube applications are the long rise times when compared to those for P-20 or other simple cathodoluminescent phosphors. The long decay times of CEL screens need not be a similar disadvantage.

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SPECIAL PHOSPHOR SCREENS FOR IMAGE TUBES*

D. A. Cusano

INTRODUCTION

Simple or cascaded image converter tubes contain three important components: (1) the photoemissive surfaces, (2) the electron-optics and associated power supply, and (3) the phosphor screens. The majority of past development effort has been devoted to (1) and (2) and carried out under military sponsorship. Until fairly recently, phosphor technology has always been borrowed from the cathode ray tube and fluorescent lamp fields. Pace could easily be kept with the various electronic improvements and innovations in image tubes. This situation is no longer so. Attention should now be given to substantial modification or actual replacement of present fine-particle screens if resolution is not to remain limited by the phosphor. This is particularly important for multistage tubes. Attention should also be directed from ordinary cathodoluminescence to other luminescent effects such as cathodoelectroluminescence (CEL)(1) where, for example, the over-all gain or storage capabilities of image tubes can be improved.

Over the past decade there has been a continuing interest in continuous layer phosphors made by vapor reaction.(2) Most of the effort has been directed to development of high-contrast, high-resolution transparent screens for special cathode ray tubes. The remaining effort has been largely devoted to the study of thin film electroluminescence and related electro-optical effects. This report will deal largely with the results of a research contract (DA-44-009-ENG-4151) arranged to extend technology in vapor-reacted films specifically to the problem of phosphors for image tubes.

This contract was divided into two distinguishable portions from the standpoint of experiment, materials involved, and phenomena. The first part was concerned with the improvement which might be made

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in efficiency-resolution characteristics of image tubes by replacing present granular screens with vapor-reacted zinc sulfide or zinc oxide layers that are thin, but translucent or volume-scattering. The general objective was to achieve much higher resolution than has been heretofore obtained, or is possible, with conventional powder screens--at the same time to reach an efficiency as near as possible to that of the efficient P-20 viewing screen. The second half of the contract was devoted to studying vapor-reacted zinc sulfide layers which exhibit cathodoelectroluminescence (CEL) and thus show an enhancement of luminescence when voltage is applied during electron bombardment. In this case, improvement in efficiency-resolution was also sought. However, it was to come in this case from an increased electron to light conversion efficiency--since electrons bombarding a CEL phosphor control its electroluminescence(1) rather than solely producing cathodoluminescence.

PREVIOUS THIN FILM "EVAPORATION" STUDIES

With the exception of vapor reaction work, most of the effort to prepare continuous layers of phosphors has centered around evaporation in a bell jar. It has always been a great temptation to put a phosphor--no matter how complex it may be regarding impurity and chemical structure--into a suitable heater and vacuum vaporize it onto a substrate held at room temperature or slightly above. In the case of ZnF_2:Mn, such straightforward evaporation indeed produces a transparent deposit which has a chemical composition, optical characteristics, and a luminescent efficiency quite close to those of the original powder. (3) In general, however, one or more of the following things happens. (1) The activator center "breaks up" and is "lost" by selective and nonuniform evaporation of the phosphor impurities; (2) the host crystal dissociates upon heating and results in a deposit with a considerable departure from stoichiometry; (3) the condensate deposits in an amorphous or different crystalline form from that of the original phosphor, and (4) the low substrate temperature prohibits the adequate diffusion of condensed impurities for the reconstruction of activator centers. These difficulties have entailed considerable departure from vacuum evaporation techniques and led to methods now termed one-step, two-step, modified two-step, etc., (4) such methods involving various modifications and heat treatments, both in and out of the bell jar, to restore the condensed deposit to that of the original phosphor--or in some cases, an equally interesting one. (An example of the latter is that of reacting the condensed deposit with the substrate itself.) Activity in the various laboratories has mostly concerned the P-1, or Zn_2SiO_4:Mn, phosphor. The powder counterpart is a green emitting material with a maximum efficiency for laboratory samples of about 35 lumens/watt at 15-kv excitation. (5) Commercial screens come closer to 25 lumens/watt.

The Allen B. Dumont Laboratories recently terminated a contract, No. DA-44-009-ENG-3714, on the evaluation of "evaporated" deposits of the P-1 phosphor for image tubes. From the point of view of maximizing an efficiency-resolution product, it was hoped that control of the texture of the phosphor layer would allow sufficient scattering out of the emitted light with adequate preservation of resolution. However, the silicate deposits are fabricated by high-temperature reaction between deposited oxide components and between these and quartz or glass substrates. The task of controlling phosphor texture by this type of preparation has not been a simple one, although some samples of undetermined resolution have been made which have a luminescent efficiency of about 7.4 lumens/watt.

VAPOR-REACTED SULFIDE AND OXIDE PHOSPHORS

In many thin film phosphor applications, transparent scattering-free deposits have been desired, the cathodoluminescent efficiency not always being the foremost consideration. In the case of image tubes, however, it was recognized that improvement in resolution could only be significant in over-all performance if the efficiency of the deposited phosphor was not too far below that of the fine-grained P-20 phosphor (Zn, CdS:Ag, Cl). The P-20 powder phosphor has the highest known laboratory efficiency of about 80 lumens/watt(5) at 15 kv, and good image tube samples run as high as 45 lumens/watt.

The vapor reaction method, (2) as contrasted to the various procedures mentioned above, has been employed with particular success in the preparation of transparent films of zinc-cadmium sulfides. Five-inch transparent P-11 screened tubes are already in production and being used for low noise, high resolution CR applications. * These polished nonscattering films offered very high resolution--up to 500 line pairs/mm. However, in a truly nonscattering condition, the same phosphors are down an order of magnitude in luminous efficiency from present P-20 screens--a large part of this poor performance due to

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*General Electric Co., Cathode Ray Tube Dept., Syracuse, New York.

internal light trapping. No change or a net loss in efficiency-resolution would be had by using these screens in image tubes. In addition, it would be quite difficult to make use of very high resolution with the conventional optics used in many applications. For these reasons, the present work involved, alternatively, the approach of making the brightest screens possible, making use of and often increasing the light scattering or translucent nature of the films rather than polishing them to a smooth finish. (The high refractive index of zinc sulfide is not a disadvantage for scattering films as it is for transparent, non-scattering deposits.) A useful resolution goal of about three times that of P-20 screens (i.e., ~120 line pairs/mm) was sought.

Figure 1 depicts schematically the arrangement used in preparing the phosphors studied on this contract. In essence, the vapor reaction method(2) is chemically similar to one which is frequently used for growing single crystals. The growth occurs on a hot (> 400°C) surface from reaction between the vapors or gases which contain the elemental constituents of the phosphor as well as the impurities to be incorporated therein. *

The preparations investigated included zinc sulfide and oxide samples with emission bands in the blue, green, and yellow region of the spectrum. The main activator examined was copper. It was incorporated by utilizing either a pre- or post-deposit of copper (sometimes both), the latter requiring an additional heating cycle beyond that of the sulfide deposition itself. All the other activators and the coactivator chlorine were incorporated from the vapor, the most usual way.(2) About 40 or more films were made--only a few alike in the conditions of preparation.

The coating thickness was taken to two or three microns to make full use of 10- to 20-kv electron bombardment. A few samples were made thin to determine the effect on resolution, particularly. Many samples were prepared on thin precoats of various evaporated materials to nucleate growth in different ways. Various glass substrates were examined to explore their effect on luminescence efficiency

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*Insofar as there is considerable evidence that II-VI compounds dissociate at high evaporation temperatures, the "hot wall bell jar evaporation" method for forming II-VI phosphor films(6) may also involve reaction of dissociated constituents. If HCl is added during evaporation, then the salts of the elemental constituents could similarly be involved in reaction.

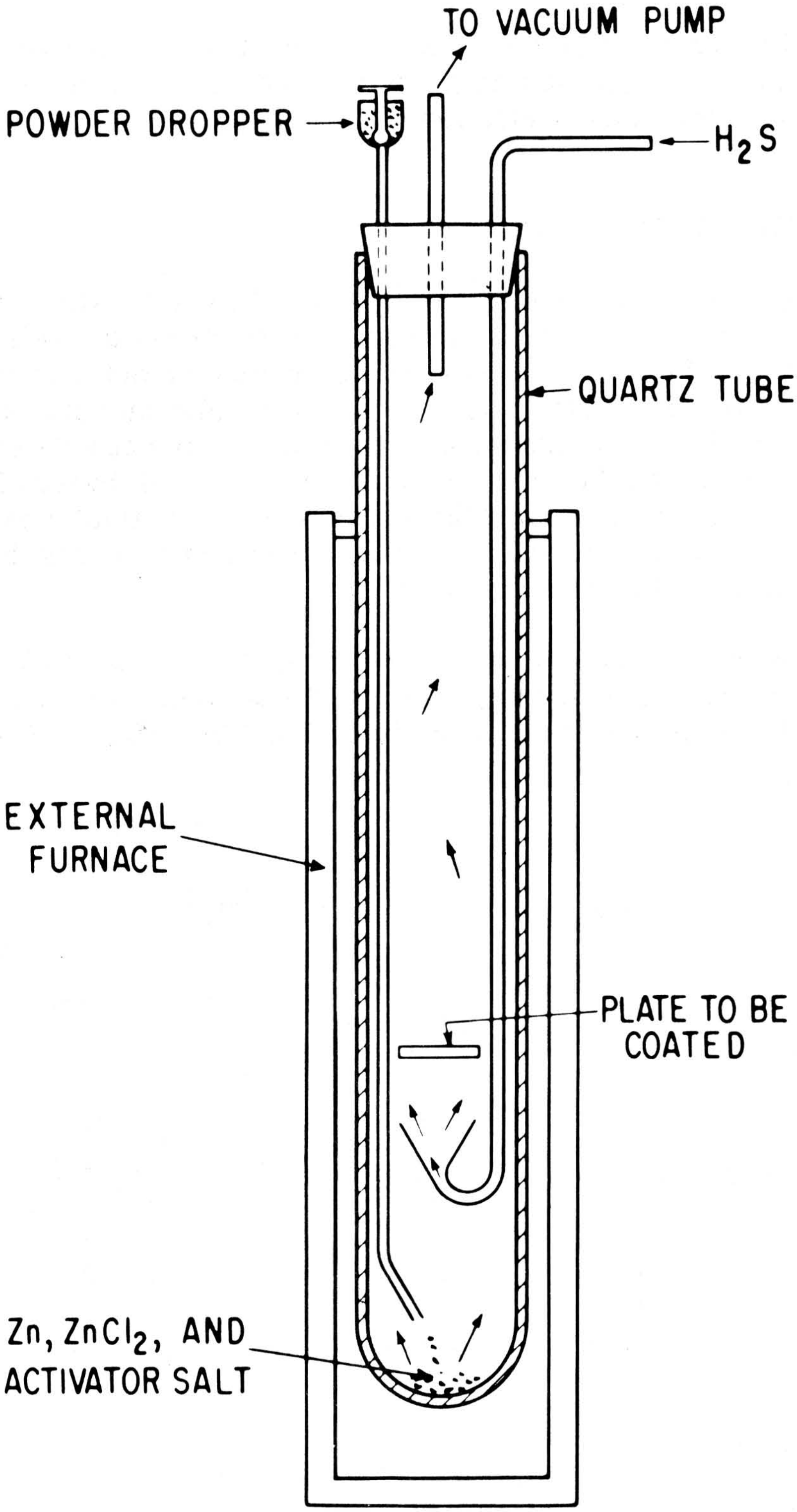

Fig. 1 Vapor reaction coating arrangement for ZnS phosphor layers.

and deposit texture. For the most part, coating temperature was held about as high as the particular glass could take. There was very little evidence that luminescent efficiency did not decrease with temperature reduction.

RESOLUTION MEASUREMENTS

Resolution was measured by optical means, since many zinc sulfide and oxide phosphors luminesce to ultraviolet as well as cathode ray excitation. In essence, this optical measurement provided a simple and rapid means of determining a value of resolution corresponding to a lower limit of what is expected for excitation by cathode rays. [In the near ultraviolet (3650 A), zinc sulfide has a high index of refraction, about 2.7.(7) Therefore, lateral scattering of ultraviolet at the phosphor surface would, if anything, give poorer apparent resolution than that obtainable under electron excitation.]

The optical equipment is shown in Fig. 2. A 3650 A image of a resolution chart transparency was projected onto the scattering phosphor sample to be examined, usually on the film side. A Corning 5840

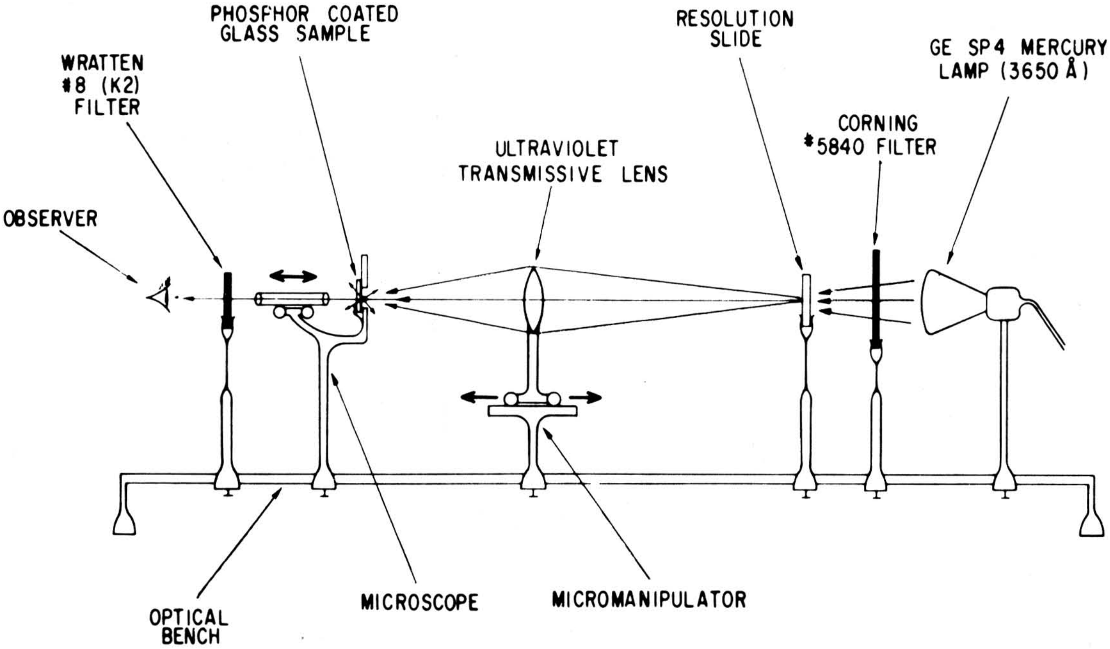

Fig. 2 Arrangement for measuring optical resolution of phosphors.

filter was used in front of the SP4 mercury lamp to further reduce the intensity of the weak 4046 A line in this lamp, beyond that already accomplished by the dark glass envelope. A good quality lens was employed which had adequate transmission to ultraviolet. Brightness was no problem. The resolution pattern, in luminescent light, was viewed with a microscope through the glass side, as it would be in actual image tube use. To avoid any possibility of observing blue radiation from the ultraviolet lamp, a Wratten 8 (K2) filter was employed as shown, between the observer and the microscope.

Resolution measurements were obtained for more than two dozen samples as grown. Values for many sulfide layers reached 84 line pairs/mm, twice as high as P-20 values. Thinner samples gave more than 96 line pairs/mm, while several samples gave low values of 56 to 63 line pairs/mm. Very high values of 140 to 154 were obtained with a ZnO:Zn screen, indicating for one thing that the resolution capability of the measuring system was at least that good.

Unpolished vapor-reacted sulfide phosphors as grown scatter only at the air-phosphor surface. Some of the light which reaches the observer involves long paths through the transparent interior, with the result that the spot size is considerably enlarged. This appeared to be the reason for the low resolution of some samples. The ZnO:Zn screen, which had by far the best resolution, contained an appreciable volume-scattering nature. This was evidenced by the fact that it could not be polished to transparency as could most sulfide layers.

Two techniques were studied to make sulfide layers possess volume as well as surface scattering character. The first, already mentioned, involved precoating the glass substrates with a thin layer of material which nucleates the subsequent sulfide growths so that these deposits consist of disoriented, microcrystallite structure. The second, and more successful, was that of etching the deposits with acid just long enough to cause selective attack at grain boundaries and along microcrystallite surfaces. The air-phosphor interfaces so produced were effective light scattering sites. Resolution before and after etching is shown for several samples in Table I. In two instances, the resolution improved considerably, rising to about 115 line pairs/mm, or nearly three times that of standard P-20 screens. In four other cases the improvement was not as large.

TABLE I

Sample No.	Phosphor	Resolution (line pairs/mm) Before HCl etch	 After HCl etch
S-485	ZnS:Cu, Cl	63(70)	77
S-487	ZnS:Cu, Cl	70(77)	77
S-492	ZnS:Cu, Cl	70(70)	115
S-500	ZnS:As, Cl	70(63)	115
S-501	ZnS:As, Cl	70(70)	77
S-502	ZnS:Cu, Cl	84(77)	77

( ) Measurements made by a second observer.

EFFICIENCY MEASUREMENTS

In order to maintain proper screen potential and approximately double the light reaching the observer, nearly all image tube phosphor screens were backed by a thin reflecting metallic coating usually of aluminum. The aluminum, if deposited directly on these rough surfaces, is gray in appearance and poor in reflection when viewed through the phosphor. This depended in degree on the particular scattering nature of each sample. To avoid this difficulty, aluminum was first evaporated to 0.1 micron on a self-supporting lacquer film, the free surface of this then pressed onto the phosphor, and the lacquer film burned off subsequently in an air bake.

Some two dozen phosphor samples were examined under electron bombardment in a demountable cathode ray tube. The spectral distributions were found to be relatively independent of bombarding voltage and were obtained at 15 kv and 0.1 $\mu a/cm^2$. The spectra are plotted in Figs. 3 and 4. From the area under the product of visibility curve and these spectral distributions, the lumen equivalents, or lumens per output watt, were calculated for each sample. The results obtained are listed in the fourth column, Table II. The suffix E and U in the sample label indicates, respectively, whether the sample had or had not been etched in HCl solution.

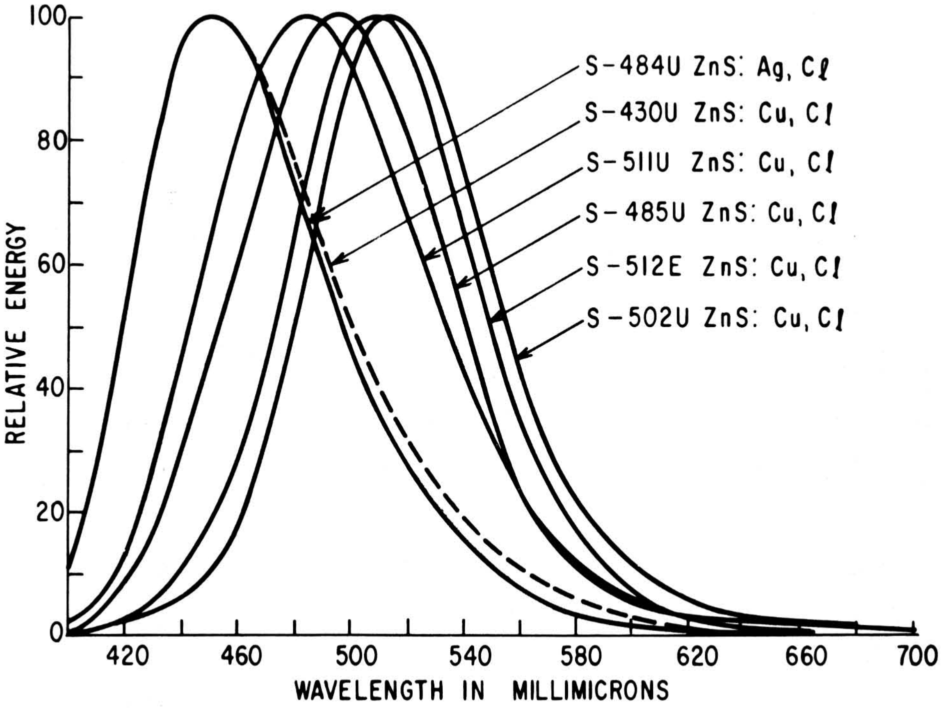

Fig. 3 Spectral distributions of ZnS:Ag, Cl and several ZnS:Cu, Cl vapor-reacted phosphors under cathode ray excitation.

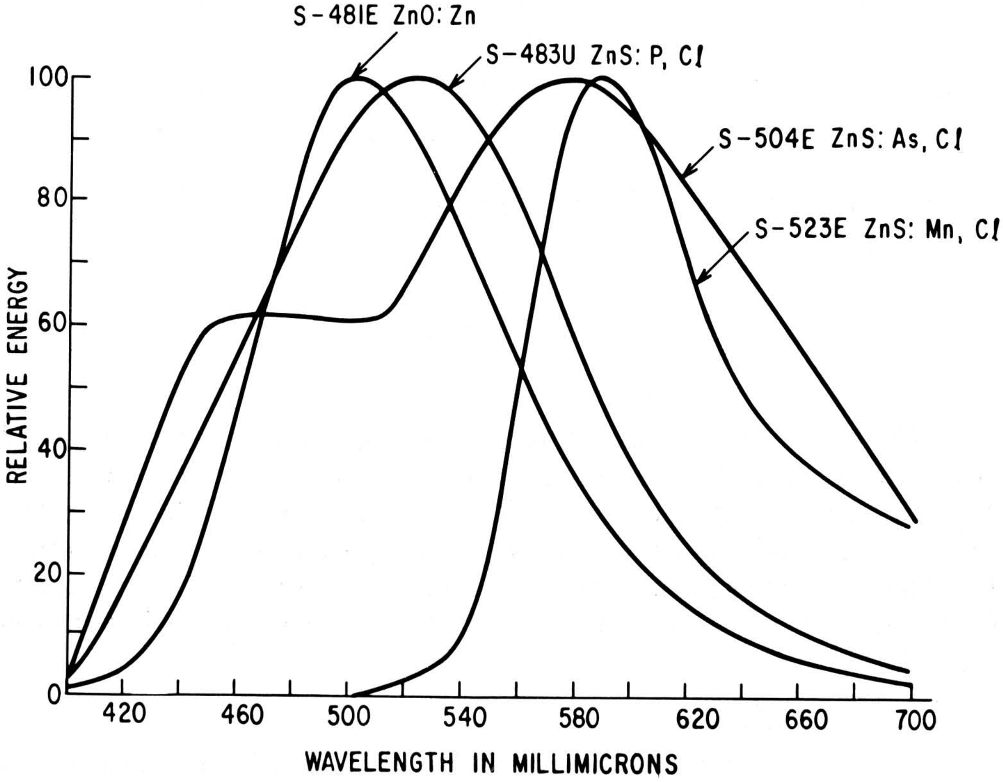

Fig. 4 Spectral distributions of ZnS:P, Cl, ZnS:As, Cl, ZnS:Mn, Cl, and ZnO:Zn vapor-reacted phosphors under cathode ray excitation.

TABLE II

Sample No.	Phosphor	Substrate	Lumen Equivalent (lumens/watt)	Peak Wavelength (A)
S-430 U	$ZnS:Cu, Cl$	Lime glass	150	4540
S-511 U	$ZnS:Cu, Cl$	Pyrex	272	4850
S-485 U	$ZnS:Cu, Cl$	Lime glass	295	5050
S-512 E	$ZnS:Cu, Cl$ (etched in HCl)	Pyrex	368	5100
S-502 U	$ZnS:Cu, Cl$	Lime glass	425	5130
S-504 E	$ZnS:As, Cl$ (etched in HCl)	Pyrex	309	5750 + 4550
S-481 E	$ZnO:Zn$ (etched in HCl)	Pyrex	358	5000
S-483 E	$ZnS:P, Cl$ (etched in HCl)	Pyrex	354	5220
S-523 E	$ZnS:Mn, Cl$ (etched in HCl)	Pyrex	276	5900
P-20*	$Zn, CdS:Ag, Cl$	(Powder phosphor)	515	5500
P-20†	$Zn, CdS:Ag, Cl$	(Powder phosphor)	500	5500
P-1†	$Zn_2SiO_4:Mn$	(Powder phosphor)	475	5250

*This report

†Data from Bril and Klasens.

Cathodoluminescent brightness was measured with a SEI exposure meter for two values of current density, 0.01 and 1 $\mu a/cm^2$, and three bombarding voltages, 10, 15, and 20 kv. The aluminum backing maintained the phosphor at anode potential during bombardment. The maximum brightness values obtained, whether at 10, 15, or 20 kv, were converted directly to lumens per watt efficiencies via the formula below:

$$\text{(Efficiency in lum/w)} = \frac{\text{(Brightness in ft-L)}\ (1.07 \times 10^{-3}\ \text{lum/cm}^2\text{-ft-L})}{\text{(Beam potential in volts)}\ \text{(Beam current density in amp/cm}^2)} \qquad (1)$$

and are tabulated in Table III, fourth column. In general, higher efficiencies were found for higher voltage operation.

The lumens/watt efficiencies, in turn, were converted to energy efficiencies using the lumen equivalents of Table II, fourth column, in the expression below:

$$(\text{Energy efficiency}) = \frac{(\text{Efficiency in lum/w})}{(\text{Lumen equivalent in lum/w})} \qquad (2)$$

These results are plotted in Table III, column five, again for 10, 15, or 20 kv whichever value was highest. These energy efficiencies are an indication of phosphor performance quite independent of emission color.

TABLE III

Sample No.	Phosphor	Peak Wavelength (A)	Maximum Lumens/watt Efficiency	Maximum Energy Efficiency (%)
S-430 U	ZnS:Cu, Cl	4540	4.5	3.0
			(4.8)	(3.2)
S-511 U	ZnS:Cu, Cl	4850	13.4	4.9
			(10.7)	(3.9)
S-485 U	ZnS:Cu, Cl	5050	11.4	3.9
			(11.8)	(4.0)
S-512 E	ZnS:Cu, Cl	5100	13.5	3.6
			(14.3)	(3.9)
S-502 U	ZnS:Cu, Cl	5130	8.6	2.0
			(8.6)	(2.0)
S-504 E	ZnS:As, Cl	5750 +4550	10.7	3.5
			(3.6)	(1.2)
S-481 E	ZnO:Zn	5000	4.3	1.2
			(2.7)	(0.8)
S-483 E	ZnS:P, Cl	5220	10.7	3.0
			(17.1)	(4.8)
S-523 E	ZnS:Mn, Cl	5900	5.7	2.1
			(2.1)	(0.7)

x 0.01 $\mu a/cm^2$

(x) 1 $\mu a/cm^2$

CONCLUSIONS CONCERNING TRANSLUCENT VAPOR-REACTED PHOSPHOR FILMS

As can be seen from Table III, the lumen/watt efficiencies of two or three vapor-reacted films have reached values of 13 to 17. These are to be compared to values of about 45 for the present P-20 image tube powder screens, and values from 20 to 25 for the older P-1 powder screens. Several films, those shown and others, exhibit energy efficiencies from 3 to 5 per cent. For comparison, the energy efficiency of P-20 and P-11 screens is about 10 per cent and that for P-1 powder screens between 4 and 5 1/2 per cent.

As regards resolution, the values obtained optically are quite high, especially for the etched samples which offered 115 line pairs/mm. The present P-20 screens give about 40 line pairs/mm. Since there is no reason why the best efficiency and best resolution found to date could not be produced in a single specimen, the performance of films is found for the first time to be competitive with the P-20 screens on the basis of a simple efficiency-resolution product. As viewing screens, these green ZnS:Cu,Cl or ZnS:P, Cl samples should be more attractive than P-20 fine-grained screens, if the optics involved dictate that resolution should be somewhat more important than efficiency. Blue-green emitting films of ZnS:Cu, Cl,used with either S-11 or multi-alkali photocathodes, offer slightly better efficiency-resolution products than P-11 powder screens. Hence they may find use in cascaded tubes. For such cascaded tubes, where one may desire a single phosphor to be used at both the intermediate and viewing stages, the blue-green emitting films of ZnS:Cu, Cl would be best suited.

In short, many of the scattering vapor-reacted deposits investigated here have exhibited cathodoluminescent efficiencies considerably higher than any made to date by other film methods. Some of these deposits of high resolution and general quality will find use in special cathode ray tubes in addition to image tubes. Since there is no theoretical reason why such translucent or scattering sulfides should not some day be just as efficient as their powdered phosphor counterparts, further development effort should lead to translucent thin film screens with the presently achieved resolution of 120 line pairs/mm and an energy efficiency nearer to 10 per cent.

INTRODUCTORY COMMENTS ON CEL INTENSIFYING SCREENS

In addition to being the most efficient phosphors under cathode ray excitation, granular zinc sulfides represent the best electroluminescent material known to date. Furthermore, related materials such as cadmium sulfides and selenides are very sensitive photoconductors to the visible and infrared. For some time, it has been hoped that a series combination of a photoconducting and electroluminescent layer (PC + EL) would offer a solid-state amplitying screen(8-10) that would perform as well as, and eventually replace, vacuum image converter tubes. However, the characteristics sorely needing improvement before this replacement can be seriously considered are the slowness of response, the insensitivity to very low radiation levels, and the inherently poor resolution (~2 lines/mm). (8)

Single-layer PEL screens(1) have also been considered as possibilities for image tube replacement. The important advantage over the two-layer intensifiers is that of much higher resolution. The PEL phenomenon is observed with vapor-reacted layers of ZnS:Mn, Cl, ZnS:Mn, X, Cl and ZnS:X, Cl where X is either P, or As, or Sb. These phosphors are grown on TiO_2 coated glass, the transparent TiO_2 film being one electrode and a metallic layer applied on top of the phosphor the other (see Fig. 5). When an image of radiation in the near ultraviolet or blue region of the visible falls upon the screen and a d-c voltage (usually less than 100 volts) is impressed across the phosphor as shown, this type of solid-state amplifier emits an image in the yellow region of spectrum whose intensity is more than 10 times that in the incident beam. This intensification is accomplished(11) via a control exerted by the input radiation on the ability of the phosphor to electroluminescence, i. e., to derive electrical energy from the voltage source and convert it into visible light.

Although better in resolution than a (PC + EL) screen, the PEL intensifier still does not compete with conventional image tubes at very low light levels. However, there was yet to be explored the related solid-state phenomenon of cathodoelectroluminescence (CEL),(1) i. e., the control of electroluminescence in these screens exerted directly by incident electrons rather than photons (see also Fig. 5). The remainder of this report has to do with this CEL effect, not as a phenomenon competing with electronic image conversion, but rather for its possibilities of improving over-all performance of these image tubes as a replacement for present viewing screens. Since the phosphors were to be no more than about 5 microns thick, and could be

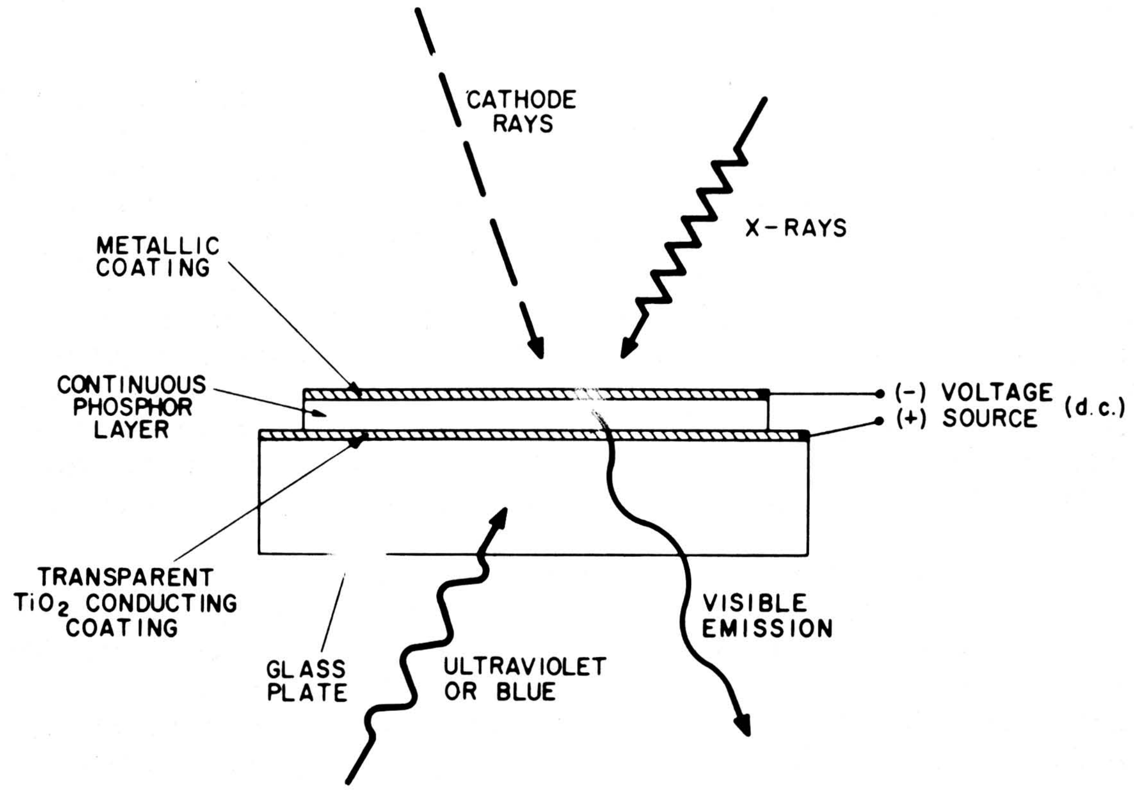

Fig. 5 Arrangement for observing PEL and CEL effects.

polished if desired, no serious resolution problem was anticipated. Furthermore, the screens appeared to function best in a region of cathode ray intensity from 0.25 to 250 μwatt/cm^2, very much in the realm of present image tube operation. Since the CEL layer would not be required to detect an image at low levels at which it arrives at the photocathode the obstacle of sensitivity at very low intensities would be circumvented.

Effort on CEL was devoted primarily to efficiency-resolution improvement, but related things such as memory or image retention were given some attention.

CEL SAMPLE PREPARATION

Pyrex disks were coated with transparent TiO_2 to a thickness of about 0.3 micron. These coatings were formed by the usual technique of reacting $TiCl_4$ vapor with H_2O vapor while the samples are held at approximately 250°C. Subsequent deposition of zinc sulfide phosphors leads to chemical reduction of the coatings such that they become semiconducting and can serve as transparent electrodes.(2)

Various phosphor modifications were prepared on these TiO_2 coated bases. The activator manganese is a necessary impurity(11) and was included in preparation of all samples. However, since other activators such as phosphorus, arsenic, and antimony can produce PEL(12) or influence PEL characteristics of manganese phosphors,(11) they were also examined.

The coactivator chlorine seems to be a second important impurity for CEL phosphors. It is considerably more effective than other halides. Properties like resistivity and photosensitivity do not depend to first order on manganese, but they do on this coactivator. Chlorine content was intentionally varied for some of the preparations. A few samples were prepared with group IIIB coactivators such as Ga and In, alone and in conjunction with chlorine.

Other variations made for the purpose of influencing CEL properties involved thickness of samples, surface nature (unpolished or polished), and final electrode identity. The electrode materials were all directly evaporated metals about 0.1 micron thick--namely aluminum, indium, gold, copper, and silver. Aluminum and gold electrodes behaved similarly and reasonably well for all screens, with aluminum preferred in general.

EXPERIMENTAL RESULTS AND CEL BEHAVIOR

The following comparison is typical of that made between a CEL screen and an aluminized P-20 granular phosphor. Both phosphors were bombarded side by side in a demountable cathode ray tube with a raster of appropriate size. The CEL screen was a polished, non-scattering ZnS:Mn, As, Cl phosphor with a top electrode of 0.1-micron aluminum, nearly the same thickness as that on the P-20 viewing screen. With no voltage applied to the CEL screen, its light output was considerably lower than that of the P-20. However, with a d-c voltage of 85, the brightness under 15 kv became considerably higher than that of the P-20, particularly at the low current densities. A plot of steady state brightness vs current density for each screen is shown in Fig. 6. The plot for the P-20 is essentially linear, indicating a constant efficiency of 45 lumens/watt. (This corresponds to an energy efficiency of about 10 per cent.) The numbers adjacent to the CEL curve

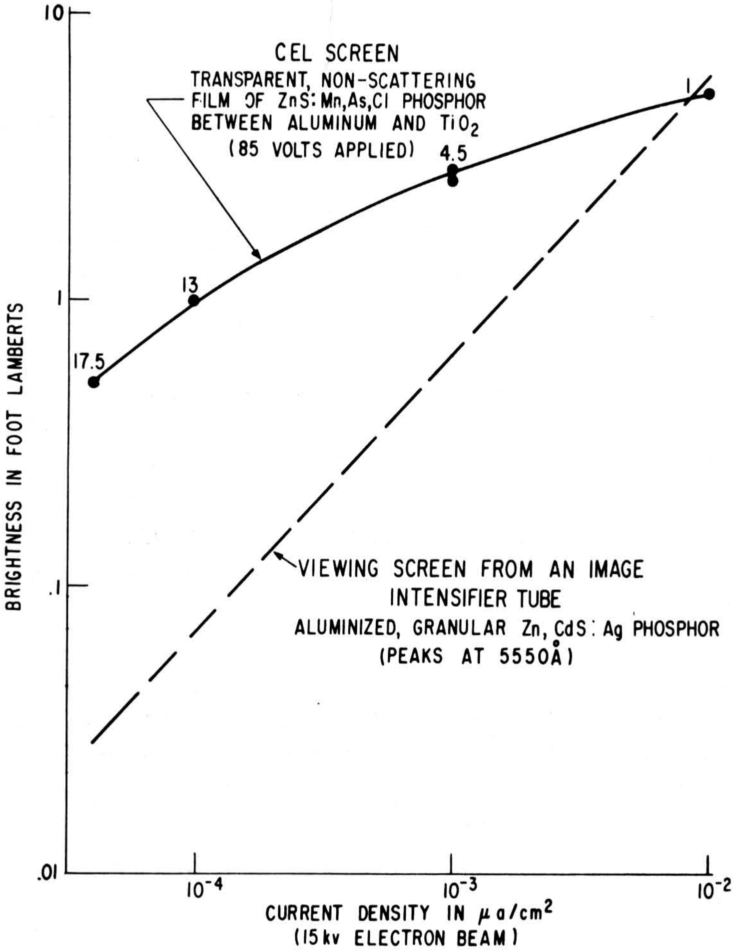

Fig. 6 Brightness vs current density for a CEL screen and a P-20 viewing screen from an image converter tube. Brightness ratios of CEL to P-20 noted along solid line.

give the brightness ratios of CEL to P-20 phosphors at various current densities. At about 4 x 10^{-5} microamperes/cm^2 the energy efficiency of the CEL screen is about 200 per cent. In essence, this means that via cathode ray control of d-c electroluminescence it is possible to produce twice as much energy in visible emission than is present in the cathode ray beam itself.

Another manner of presenting steady state data is shown for a second sample in Fig. 7. Here, the CEL brightness is plotted against that of the P-20 screen under the same excitation. The dotted straight line is one of equal brightness. Data are shown for several voltages. A fair appreciation of the CEL mechanism can be obtained by subtracting the cathodoluminescent (no field) light output from the CEL output. The results are plotted as dotted lines on the same figures. These curves now show saturation with increasing P-20

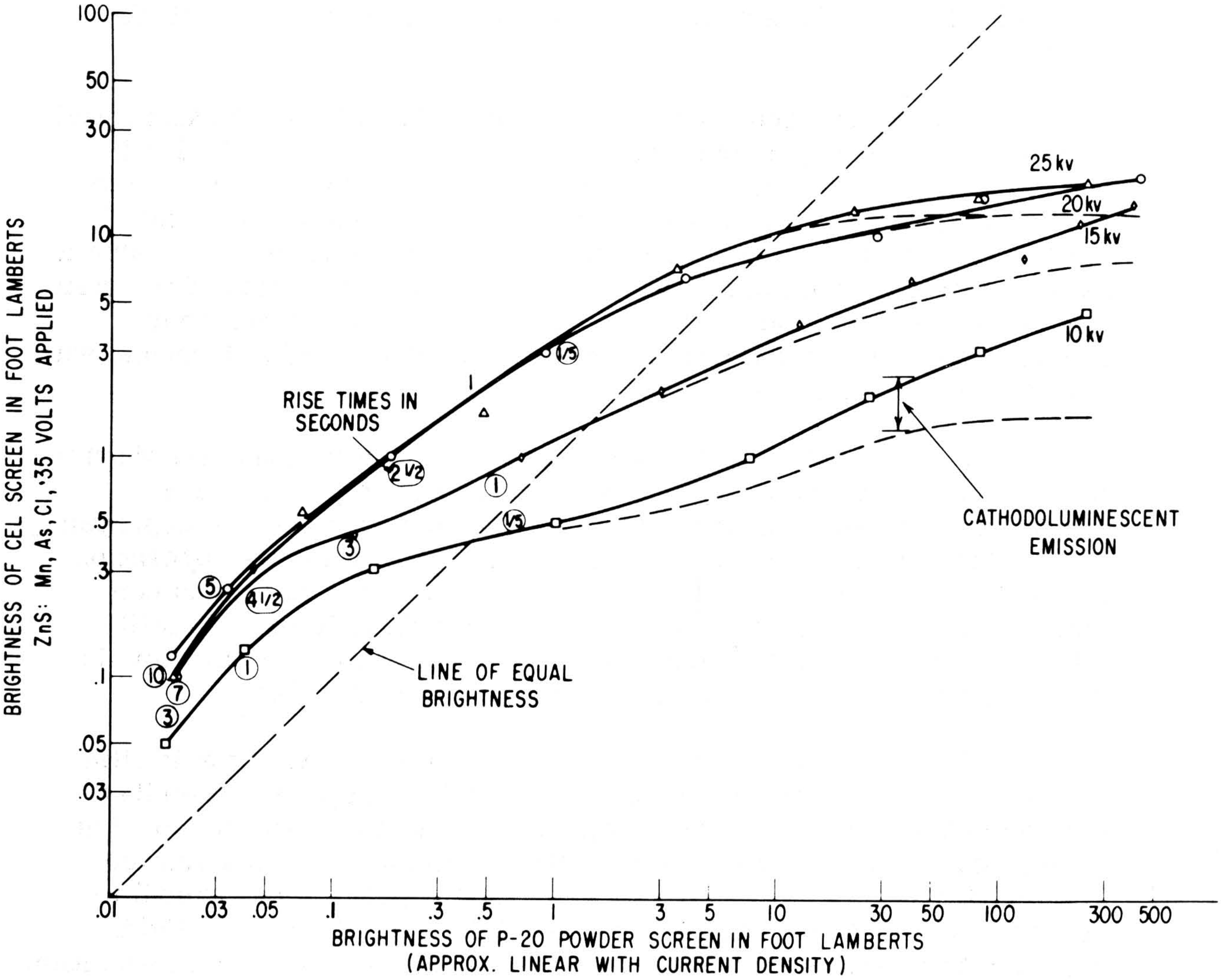

Fig. 7 CEL screen vs P-20 screen brightness for several beam voltages. Encircled numbers give CEL rise times under operating conditions given by nearest section of solid curves.

brightness; in other words, increasing current density. The saturation value increases with bombarding voltage, but eventually saturates too. Briefly, for each bombarding voltage, there is a certain value of d-c electroluminescence which can be "turned on" in any fraction, or in full, by proper choice of incident electron density. Also, there is a maximum amount that can be "turned on" regardless of the value of bombarding voltage. The latter is about 13 foot-lamberts for the sample of Fig. 7 but can be as high as 50 ft-L in other cases. Such values, for only 40 volts applied, are consistent with maximum d-c EL which can be obtained by special surface treatment of these same zinc sulfide samples.(11)

The buildup and decay of light output in CEL is not exponential with time. However, a rough idea of the time it takes for the light output to increase to about 2/3 of its steady-state value following the switching on of a cathode ray beam of a given current density and voltage is given in Fig. 7. The "time constants" in seconds are shown as encircled numerals and pertain to that particular section of the solid line curve they are closest to. As can be seen, the buildup times decrease with increasing current density and also seem to increase with bombarding voltage.

The decay times, for some phosphor preparations, are shorter than the buildup times at high intensity but approach them at low intensity. For other screens, however, the decay times are appreciably longer than the rise times. For these samples, pulsed d-c operation (f~100 cps or less) was able to help by shortening decay times considerably, but this had little or no effect on buildup times. In still other samples currently under study, attempts were made to actually increase decay times for image storage tube possibilities.

A CEL sample, electroded with a semitransparent gold film (~75 A), was examined in the optical resolution equipment described earlier in this report. Without applied voltage, the resolution of this sample was observed to be about 65 line pairs/mm. With a voltage applied, the resolution was easily seen (the brightness increased) to stay the same. There was no apparent field-spreading of the light. Although this measurement was actually one of PEL, the CEL resolution is bound to be the same or possibly better.

CONCLUSIONS CONCERNING CEL INTENSIFYING SCREENS

It has been shown that CEL screens consisting of vapor-reacted zinc sulfide films subjected to electric fields exhibit greater light output than P-20 image tube screens under identical electron bombardment. The bombardment range is from 10^{-5} to 10^{-2} $\mu a/cm^2$ and 5 to 25 kv, well in the operating range of the final stages of image converter tubes. In the current density region between 10^{-5} and 10^{-4} $\mu a/cm^2$, the ratio of CEL to P-20 brightness can be greater than 10. The resolution of the CEL phosphors, measured optically, is about 65 line pairs/mm or 40 per cent better than that of P-20. Hence, the efficiency-resolution product of image tubes can be increased markedly by employing CEL screens in place of P-20 screens for the viewing phosphor.

A disadvantage of CEL screens for some image tube applications is the slowness of response, particularly in the lower current density region where the efficiency-resolution improvement is greatest. It is shown in the Appendix to this report that it is not likely that rise times can be improved greatly since the present zinc sulfide layers are exhibiting nearly maximum performance as cathodoconductors. Hope for further improvement lies in (1) lower resistivity CEL samples, (2) lower resistivity cathodoconductor plus electroluminescent thin film screens, or (3) considerably improved electroluminescent efficiency during CEL. Nevertheless, it is strongly believed that the true worth of the CEL screens as they now stand can only be evaluated in actual image tube operation (demountable or otherwise). It is urged that this be carried out in the near future.

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APPENDIX

It is obvious, for some image tube applications, that the CEL screen response times will be a disadvantage which more than offsets the improvement in efficiency-resolution that would be achieved by using a CEL screen. That this situation cannot be markedly improved by making small order refinements in zinc sulfide preparations is evident from an appreciation of the CEL mechanism. The analysis is by no means precise but does place a reasonable limit on what can be obtained with the present approach and materials.

In CEL, incident electrons control the number of free electrons in the phosphor, and these in turn produce radiant energy in the form of visible light by accelerating in the direction of the field and giving up part of their energy in exciting luminescent centers. By considering the CEL mechanism as composed of two parts, the first effect becomes one of cathodoconduction and the second, one of d-c electroluminescence. The first is the time-dependent, radiation-sensitive process. Similarly, the PEL mechanism could be thought of as photoconductive and d-c electroluminescent part, here photoconduction being the rate-determining process depending on the incident ultraviolet or visible intensity.

For the photoconductive process, the Rose-Redington(1, 2) theoretical analysis has led to a maximum performance equation

$$\frac{(\text{Gain in electrons/incident photon})}{(\text{Response time in sec.})} \leqslant \left.\frac{1}{(\text{Res. in ohms})\ (\text{Cap. in farads})}\right]_{\substack{\text{Measured under}\\ \text{irradiation}}} \tag{A1}$$

which determines the maximum gain and shortest time constant for a given condition of operation in terms of the measurable quantities

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of resistance and capacitance during operation. We can extend this to apply to cathodoconduction under 25-kv electron bombardment by writing

$$\frac{\text{(Gain in electrons/incident electron)}}{\text{(Response time in sec.)}}\;(5 \times 10^{-4}) \leqslant \left.\frac{1}{\text{(Res. in ohms) (Cap. in farads)}}\right]_{\substack{\text{Measured during}\\ \text{bombardment}}} \qquad \text{(A2)}$$

The numerical factor of 5×10^{-4} above takes into account the fact that it takes about 12.5 ev to form each electron hole pair from the incident 25-kv electrons. (This value is estimated from the 20 per cent cathodoluminescent efficiency of zinc sulfide phosphors.)

A CEL screen, with 40 volts applied and a cell area of 1 cm^2, exhibited a steady-state cathodocurrent of 1.5 ma under 25 kv and $10^{-4}\,\mu\text{a/cm}^2$ electron bombardment. The cathodoconductive electron gain is thus 1.5×10^7 and the resistance 2.7×10^4 ohms. (These figures, incidentally, represent a cathodoconductive electrical power gain of $\sim 2.5 \times 10^4$.) The capacitance, although not measured during bombardment as it rigorously should be, is estimated from other measurements to be in the neighborhood of 4×10^{-9} farads. Substitution of these values in Eq. (A2) above gives

$$\text{(Response time in sec.)} \geqslant 0.75 \text{ sec.}$$

The response time measured experimentally for this sample under the excitation conditions above is about 2 seconds.

Within the accuracy of this approximate analysis, then, the CEL screens are exhibiting maximum cathodoconductive performance.

GENERAL ELECTRIC
Research Laboratory
SCHENECTADY, NEW YORK

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Title Page

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TITLE

Special Phosphor Screens for Image Tubes

ABSTRACT

Two means of improving the performance of luminescent elements used in image tubes are discussed. Translucent vapor-reacted zinc sulfide layers have been produced with resolutions, measured optically, of up to 115 line pairs/mm. At the same time, such layers have exhibited cathodoluminescent efficiencies from 13 to 17 lumens/watt. Although the efficiency-resolution product turns out to be the same as for P-20 powder screens, these films should be useful where resolution is more important than efficiency, such as, for example, in multi-stage image tubes.

Vapor-reacted zinc sulfide layers which exhibit enhancement of luminescence under applied voltage and during electron bombardment offer up to an order of magnitude of improvement in efficiency-resolution. These CEL (i. e., cathodoelectroluminescent) screens are brighter than P-20 screens in the range from below 10^{-5} to 10^{-2} micro-amperes/cm^2--by more than 10 times at the lower end of this range. A disadvantage of CEL screens for some image tube applications are the long rise

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times when compared to those for P-20 or other simple cathodoluminescent phosphors. The long decay times of CEL screens need not be a similar disadvantage.