

implies a highly localized photoeffect, i.e., a drift length for the photocarriers in the field direction small compared to the image width (0.1 cm).

In the case of cell No. 2, the time constant for the decay of the photoresponse is stated by the manufacturer to be 2×10^{-4} second. If it is assumed that this time constant represents the lifetime τ of the free photocarriers, then the expected drift length w for the higher-field case (taking the mobility μ to be of the order of $1 \text{ cm}^2/\text{volt sec}$)³ would be

$$w = \mu E \tau = 0.15 \text{ cm,}$$

a distance large compared to the drift length implied by Table I. The most likely explanation of this discrepancy is that the time constant is very much longer than the free lifetime owing to the phenomenon of trapping⁴ in these layers. The importance of trapping has heretofore not received recognition in theoretical treatments of this subject (summarized in reference 3) and complicates greatly the task of deriving an adequate theory.

We are indebted to H. Müser and to J. R. Haynes for helpful exchanges of correspondence relative to this experiment.

¹ H. Müser, *Z. physik. Chem.* **198**, 52 (1951).

² In private correspondence Dr. Müser has expressed his agreement with this explanation.

³ R. A. Smith, *Advances in Physics* **2**, 321 (1953).

⁴ A. Rose, *RCA Rev.* **12**, 362 (1951); J. R. Haynes and J. A. Hornbeck, *Phys. Rev.* **90**, 152 (1953); H. Y. Fan, *Phys. Rev.* **92**, 1424 (1953); **93**, 1434 (1954).

New Class of Ferroelectrics

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WE find that guanidine aluminum sulfate hexahydrate,¹ $(\text{CN}_3\text{H}_6)\text{Al}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$, is ferroelectric from as high a temperature as it will stand for a short time (about 200°C) down to the temperature of liquid N_2 , the lowest we have employed. The material is trigonal, with perfect cleavage in the basal plane; the direction of spontaneous polarization is along the trigonal axis. Ferroelectricity is not usually observed when electrodes are applied to naturally grown faces; the effect can be seen when new faces are generated by abrasion or better by cleavage.

At room temperature the saturation polarization is about 0.35 microcoulombs per sq cm, and the coercive force is between 1200 and 1500 volts per cm measured at 60 cps. These quantities increase with decreasing temperature. The small-signal dielectric constant is about 15 along the axis and about 5 perpendicular to the axis. Of isomorphous substances, we have so far

examined those in which D_2O replaces H_2O , in which Ga^{3+} and Cr^{3+} replace Al^{3+} , and in which $(\text{SeO}_4)^{2-}$ replaces $(\text{SO}_4)^{2-}$. These substances show essentially the same properties. Dr. S. Geller and Dr. E. A. Wood have in progress a determination of the crystal structure of the material; they inform us that the space group is $C_{3v}(2)-P31m$, and the unit cell contains three molecules. The material bears no obvious structural relation to previously known ferroelectrics.

¹ F. Ferraboschi, *Proc. Cambridge Phil. Soc.* **14**, V, 473 (1908).

Radiation-Controlled Electroluminescence and Light Amplification in Phosphor Films

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THIS is a preliminary report of a new phenomenon observed when voltage is applied to a layer of ZnS:Mn,Cl phosphor during excitation by uv or x-rays. The luminescent layer (about 10 microns thick) is deposited by vapor reaction.^{1,2} As contrasted with the granular phosphor commonly used for electrolumines-

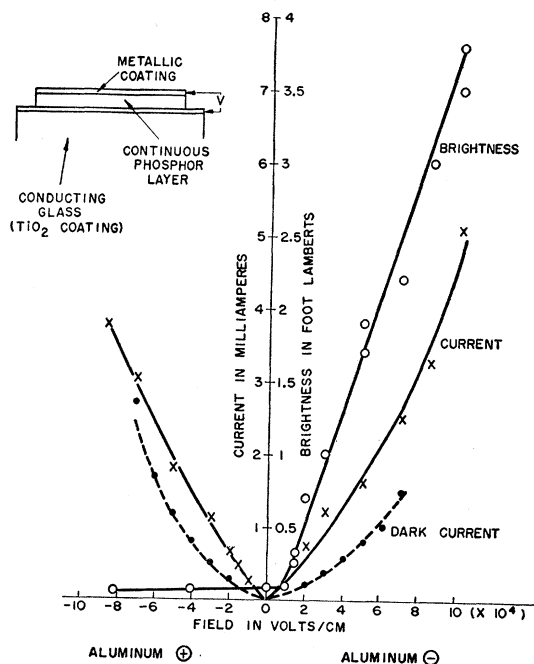


Fig. 1. Dependence of cell brightness and current on the average dc field (for constant 3650 Å excitation intensity).

cent sources, this phosphor consists of a solid structureless sheet which makes unbroken contact with the electrodes. (See Fig. 1, upper left.) Such a cell exhibits negligible emission when a dc or ac potential is applied

to the electrodes. However, when the layer is excited by uv or x-rays and emits the yellow luminescence typical of manganese, the simultaneous effect of the electric field increases the brightness markedly. For dc, this occurs when the metal electrode of the cell is negative. The behavior of a typical cell under constant 3650 Å excitation is shown as a function of the average field in Fig. 1. Increase in brightness of eightyfold has been observed. Equally large changes have been seen with x-ray excitation. Previous work on granular phosphors involving x-rays and ac fields has been reported by Destriau.³

For 3650 Å, the dependence of enhancement on excitation intensity is shown in Fig. 2, where the average field is fixed at 10^5 v/cm. In the given range,

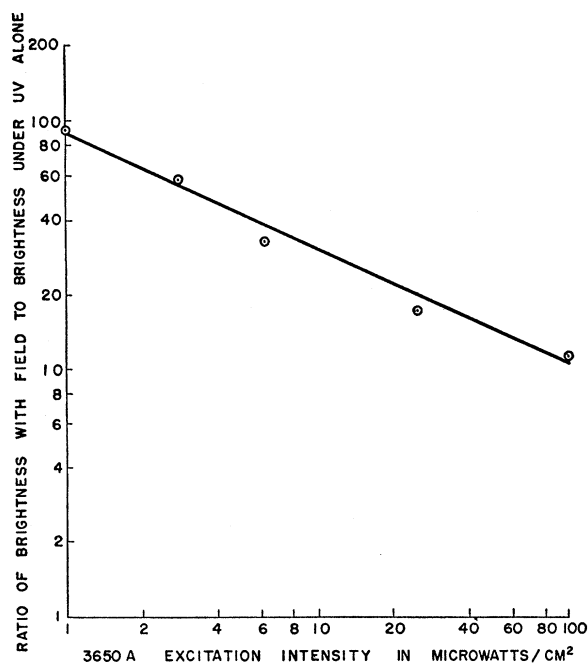


FIG. 2. Dependence of enhancement (i.e., ratio of the brightness with field and uv to that with uv alone) on 3650 Å excitation intensity (for fixed dc field = 10^5 v/cm).

the enhancement varies inversely as the square root of the excitation intensity. By computing the visible output in relation to the incident ultraviolet, one finds (for low excitation intensity) as many as 10 photons of visible light are produced for each photon of 3650 Å. For higher uv intensities, the photon amplification ratio decreases until it reaches unity in the neighborhood of 100 microwatts/cm². In spite of the wavelength conversion, this represents true light amplification, in the sense that more radiant energy is emitted than is incident on the layer.

The over-all efficiency of the light production is not very high if one considers the energy derived from the voltage source. Neglecting only the dark current, which

may be leakage at weak points in the layer, the luminous efficiency is found to be approximately 0.2 lumen/watt. With regard to time constants, the light emission responds in milliseconds to changes in the dc field, provided these changes occur above the threshold shown in Fig. 1. In contrast, the time constants associated with changes in exciting radiation increase with decreasing intensity, approaching two or three seconds in the 1-microwatt/cm² region. The emission spectrum itself is seen to shift approximately 100 Å toward shorter wavelength with high field (10^5 v/cm).

More detailed information will be presented in a subsequent paper. The general phenomenon is interpreted as the initiation and control of electroluminescence through the absorption of electromagnetic energy. Based on the theoretical work of Piper and Williams⁴ on electroluminescence, Williams⁵ earlier suggested the possibility of light-amplifying phosphors.

¹ D. A. Cusano and F. J. Studer, U. S. Patent 2 685 530.

² F. J. Studer and D. A. Cusano, *J. Opt. Soc. Am.* (to be published).

³ G. Destriau, Electrochemical Society Meeting in Chicago, 1954 (unpublished). *M. Destriau, Compt. rend.* **238**, 2298 (1954).

⁴ W. W. Piper and F. E. Williams, *Phys. Rev.* **87**, 151 (1952); *Brit. J. Appl. Phys., Supplement* **4**, 39 (1955).

⁵ F. E. Williams, following Letter [*Phys. Rev.* **98**, 547 (1955)].

Theoretical Basis for Light-Amplifying Phosphors

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THE electroluminescence of ZnS:Cu single crystals has been interpreted on the basis of a mechanism involving the creation of charge carriers in a high-field region where acceleration of the charge carriers to kinetic energies sufficient for the excitation or ionization of activator systems by inelastic collisions occurs. The charge carriers are created by field ionization of deep donor levels in an exhaustion layer formed at the cathode contact by ionization of shallow donors.¹ The series of sequential events required for electroluminescence suggested several years ago the possibility of control of electroluminescence by incident radiation and of radiation amplification in phosphors. Specifically the creation of charge carriers in a high-field region by photon absorption, rather than by field ionization of impurity systems, followed by acceleration and multiplication in the high-field region was recognized as a feasible mechanism for light amplification. Amplification depends on sufficient local field so that either the charge carriers created by the incident radiation attain sufficient kinetic energy for the excitation by impact of the activator systems several times in their mean lives,