Photo-Conductivity in Amorphous Selenium

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IN contrast to the vast number of papers[1] which have appeared on the photo-conductivity of gray metallic selenium, very little attention has been given to the possibility of photo-conductivity in the red amorphous form. Although Gudden and Pohl used red monoclinic crystals of selenium for their classic studies of primary and secondary photo-currents,[2] the usual statement in the literature concerning the amorphous form of selenium is that it is an insulator showing no photo-conductivity.[3] The work described in this letter has indicated that amorphous selenium is a photo-conductor[4] possessing markedly different properties from those of either the common metallic form or the red monoclinic crystals.

Thin films of amorphous[5] selenium were deposited by distillation or by evaporation on to glass targets which had been previously covered with a transparent conducting coating. The second electrode on top of the selenium film was obtained by evaporating a thin metal coating on to the selenium or by scanning the selenium directly with an electron beam.[6] The selenium films prepared in the above manner are a deep red in color and have a dark resistivity of greater than 10^{12} ohm-cm, as compared to 10^5 ohm-cm for the metallic form. They exhibit the following photo-conductive properties measured through the film.

(1) Sensitivities approaching unity quantum efficiency have been obtained for those wave-lengths in the visible giving highest response.

(2) The excessive time lags associated with the secondary currents in gray selenium have been absent.

(3) The spectral response in general is peaked in the blue-green portion of the spectrum (clearly on the short wave-length side of the absorption edge[7]) with very low response in the red (Fig. 1). This may be contrasted with the gray form of selenium for which the sensitivity is a maximum to red light.[3]

(4) The range of the carrier of the photo-current in amorphous selenium exceeds the range of penetration of the blue and green light by a factor of 10 to 100.

(5) Space-charge effects owing to trapped charges are encountered with thick films or weak applied fields.

These observations suggest that the blue sensitive photo-conductivity in amorphous selenium is largely of primary nature.[8] Item (4) allows one to determine the sign of the carrier by adjusting the polarity of the illuminated electrode. Higher response is obtained by illuminating the positive electrode indicating hold conduction in amorphous selenium to be predominant over electron conduction. This result has been confirmed by Pensak[9] for conductivity induced by high voltage electron bombardment.

The range of the holes is found in some samples to exceed 10^{-3} cm. Ranges of this length in insulators have been previously verified only in crystals such as diamond or carefully annealed silver chloride.

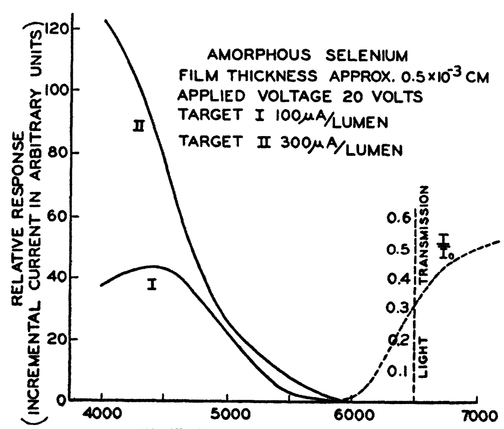

FIG. 1. Spectral sensitivity characteristics for equal values of radiant flux at all wave-lengths. Spectral response curves for photo-conductivity in amorphous selenium measured through a thin film of selenium with a low velocity scanning beam serving as one electrode.

[1] G. P. Barnard, *The Selenium Cell* (Richard R. Smith, Inc., New York, 1930).
[2] B. Gudden and R. Pohl, Zeits. f. Physik. **35**, 243 (1926).
[3] Hughes and DuBridge, *Photoelectric Phenomena* (McGraw-Hill Book Company, Inc., New York, 1932).
[4] During the course of the work described here, a paper has appeared by R. M. Schaffert and C. D. Oughton, entitled "Xerography: A new principle of photography and graphic reproduction," J. Opt. Soc. Am. **38**, 991 (1948). Although it is not stated directly, it is probable that the selenium used in this process is amorphous selenium.
[5] Electron diffraction photographs by E. G. Ramberg showed only faint rings corresponding to the red monoclinic crystals. It was concluded that the evaporated films are primarily amorphous with a very slight amount of monoclinic crystallinity.
[6] Weimer, Forgue, and Goodrich, Electronics, 70 (May, 1950).
[7] Becker and Schaper, Zeits. f. Physik, **122**, 49 (1944).
[8] This statement is no longer true when a slight impurity is added to the selenium. Under these conditions, the greatly increased sensitivity and time lag along with an altered spectral response indicates a strong secondary photo-effect.
[9] L. Pensak, Phys. Rev. **78**, 171 (1950), following letter.

Electron Bombardment Induced Conductivity in Selenium

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MEASUREMENTS of bombardment induced conductivity were taken on films of red, amorphous selenium obtained by evaporation in vacuum. This work is an extension of that described earlier[1] on measurements on silica. Although there are reports on the bombardment of selenium,[2-4] there has been no indication of it having been other than the gray, metallic form.

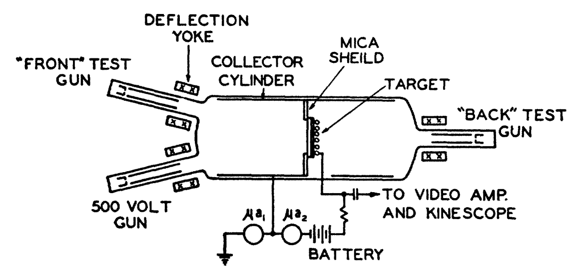

FIG. 1. Experimental tube.

The experimental data were obtained using a three-beam cathode-ray assembly in a demountable vacuum system as shown in Fig. 1. One beam at 500 volts and approximately 2 μa is scanned in a television raster. The other beam on the same side is also scanned over the same area but with different voltages, and is called the front bombarding beam. The third beam is called the back bombarding beam. The target was a sheet of fine mesh of approximately 50 percent transmission on which was picked up a very thin film of collodion to form the base for an evaporated layer of aluminum. The selenium was evaporated onto the aluminum and the target faced toward the two-gun side of the test chamber and bounded by suitable shields. A video signal was taken out as shown, to check the location of the beams in the target and a d.c. connection was made to apply various voltages to the aluminum.

Figure 2 shows typical data where the conduction ratio (ratio of increase in target current to bombarding beam current) is plotted against the test beam voltage while the selenium surface potential is held by the secondary emission of the 500-volt beam.