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Citation: J. Appl. Phys. 26, 166 (1955); doi: 10.1063/1.1721954
View online: http://dx.doi.org/10.1063/1.1721954
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Published by the American Institute of Physics.

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Relation of Antimony Transmission and the Photoelectric Yield of Cs—Sb

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(Received April 5, 1954)

The relation of transmission of thin films of antimony as a function of thickness expressed in micrograms per cm² has been determined for blue, red, and white illumination. An abrupt change in optical properties of the antimony layer has been noted at the phase change. The transition occurs at a transmission of approximately 30 percent. Photocathodes have been prepared by activating the deposited antimony films with cesium. The photoelectric yield for both regular and reverse illumination has been determined for different antimony thicknesses. For reverse illumination the peak response occurs between 5.5 and 6.0 micrograms per cm² of antimony. Expressing the photoresponse for reverse illumination of green light with decreasing transmission of the original antimony layer for blue, white, and red light shows peaks at 82, 88, and 92 percent, respectively. The transmission of the photosurface, which is substantially independent of processing or photoelectric efficiency of the surface, is given for blue, green, and white light.

In the commercial practices of preparing semitransparent photosurfaces, the thickness of the photosurface is determined and controlled by optical transmission measurements of the base metal, e.g., antimony, silver, and bismuth-silver, for Cs—Sb, Ag—O—Cs, and Bi—Ag—O—Cs photosurfaces, respectively. The degree of oxidation in the two latter surfaces is quite often followed and controlled by observing the changes in optical transmission. An important factor, therefore, in the manufacture of uniform, maximum sensitivity photosurfaces is the correlation of the optical characteristics of the constituents with the photoelectric properties of this class of photosurfaces.

For a cathode in which the illumination is incident on the surface farthest from the collector (usually referred to as reverse illumination), thickness is critical because the combined paths of an absorbed quantum and the associated electron must traverse the entire thickness of the surface.

In this paper only the cesium-antimony surface will be considered.

EXPERIMENTAL

The tubes specially constructed for this investigation consisted of a mounted 25X75 mm microglass slide, a shielded antimony bead evaporator, and a source of cesium. Two longitudinal strips of platinum along the face of the slide were fired into the glass. Hanovium Liquid Platinum Bright No. 1 was used as the source of platinum. These strips served as electrical connections to the photosurface, and were contacted by inconel springs. All other metal parts and leads were made of nickel.

In the usual procedure a tube sealed onto the pumping position was baked at 375° to 400°C for 8 to 10 hours in a vacuum of the order of 10⁻⁶ mm Hg. The cesium source was then outgassed and antimony vaporized by resistive heating at temperatures below visible heat. Cesium was then released by eddy current heating a mixture of silicon and cesium dichromate. The surface was then sensitized at 100° to 180°C and the excess cesium pumped out of the tube.

A number of tubes were prepared with the antimony previously vaporized onto the slide at a vacuum pressure of 3X10⁻⁶ mm Hg in a demountable exhaust position. Antimony so deposited permitted greater evaporation to slide distances and, hence, a more gradual variation in antimony thickness. Tubes prepared with these pre-evaporated slides were baked at 270°C. Except for lower over-all sensitivity, these tubes gave the same results as those of the previous type.

Transmission was determined as the ratio of the light intensity transmitted through the film and glass support to the light transmitted, prior to the layer deposition, of the glass alone. The resultant values of transmission, therefore, do not take into account the reflectivity of the vaporized films. In the case of the completed photosurface, particularly at the higher thicknesses, this factor is of some significance.

Antimony transparency was measured in the mounted envelope for tubes of the first type, and for both the individual slide and the mounted tube for those of the second. Photosurface transmission was measured in the completed tube. A Photovolt 520M photometer and a tungsten lamp with and without glass filters were used for transmission measurements. The spectral response of the 2848K tungsten lamp-filter combinations was determined by means of a G.E. Spectroradiometer, and the response of the 1P21 photomultiplier of the Photovolt was measured with a Beckman DU monochromator and a calibrated tungsten light source.

Photoelectric yield was measured along the slides using a 2848K tungsten lamp source with and without filters. The projected beam for reverse illumination on the slide was the width of the slide and about 3 mm high. Thickness of antimony layers was calculated from the amount of metal vaporized and the evaporation distances. The response of the lamp-filter combinations,
indicated by the Corning designation, is given in Fig. 1 along with the sensitivity curve for the photomultiplier tube of the photometer. The response curves are brought to a common maximum. The true spectral curve for transmission is, therefore, the product of this last curve and that for a particular filter. The effect of the 1P21 response on the blue filter is negligible. However, in the case of the red filter, the peak of the effective curve is shifted toward the blue by about 20 mµ.

Points on the slide were characterized by the transmission of antimony; they were then correlated with the results of transmission of cesium-antimony after sensitization. The photoelectric yield for these points was then referred against the transmission of the photosurface. Therefore, though the method of determining the relation of antimony thickness (as expressed in µg/cm²) to antimony transmission may be subject to considerable error, the interrelation of antimony transmission, photosurface transmission, and photoelectric yields was unaffected by any such errors.

RESULTS AND DISCUSSION

Beyond a certain thickness of antimony deposited at room temperature, it has been reported that the second modification of antimony "grows" with time from small circular areas until the entire surface is covered by the more opaque phase. This apparent "growth" or crystallization occurs subsequent to the discontinuation of the antimony vaporization and lasts for several minutes. In conjunction with this investigation, such behavior was observed on glass surfaces under certain conditions: when the vacuum was relatively poor (greater than 5×10⁻⁵ mm Hg), and the antimony was deposited onto an underbaked or insufficiently cleaned glass surface. The latter condition appeared to be the more critical. Under these circumstances the gradual phase transition was observed. The time necessary for the change depended upon the degree of contamination of the surface, increasing with the amount of surface impurity. The mottled circular pattern was never observed for a wedge of antimony vaporized on a clean surface. Instead, there was a clear line of demarcation dividing the two phases and tracing a path corresponding to a uniform thickness. This transition line was consistently straddled by values of optical transmission indicated at the break in Fig. 2. Although this sharp change was readily observable in the antimony layer, no such demarcation was visible after cesiation. Nor were there any marked corresponding changes in photoresponse at the phase boundary. Consequently, it is believed that the transition from the first modification of antimony (the metastable form) to the second form is very rapid on a clean glass surface at room temperature at the critical thickness.

The variation of transmission with the color of the incident beam of light as indicated in Fig. 2 shows an increasing transparency of the antimony film from blue to red. For the second modification of antimony, the difference in transparency is considerably reduced. This is in close agreement with the observations of Soezima, who found an abrupt change in optical characteristics corresponding to the change in phase. The variation of the visible light transmission with wavelength is so reduced with thicker layers that d’Or and Pirlot have suggested the use of antimony films as optically neutral filters at about 10 percent transmission.

The relative transmission for the photosurface is

\[
\text{Transmission of antimony in percent vs thickness expressed in } \mu g/cm^2 \text{ for three sources illumination: } \quad \text{white light, } \quad \text{blue (5-74), and } \quad \text{red (2-78). The break in the curves at 11 } \mu g/cm^2 \text{ is due to a phase change.}
\]

**Fig. 2.** Transmission of antimony in percent vs thickness expressed in µg/cm² for three sources illumination: —— white light, — — — blue (5-74), and — — — red (2-78). The break in the curves at 11 µg/cm² is due to a phase change.

**Fig. 1.** Spectral responses of three narrow-band-pass Corning filters in combination with a 2848°K tungsten lamp, maximized at a common value. The broken line is the spectral sensitivity curve of the 1P21 photomultiplier of the detector.

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FIG. 3. Transmission in percent of Cs–Sb vs thickness of the original antimony layer expressed in \( \mu g/cm^2 \): \( \bullet \) = white light, \( \square \) = blue (5–74), and \( \bigcirc \) = green (4–105).

given in Fig. 3 for blue, green, and white light. The overall relation is in close agreement with a similar plot of transmission of the cesium-antimony surface given by Dyatloviskaya. Optical constants for this photosurface have been reported by Morgulis, et al. Several of these values were later corrected by Dyatloviskaya.

Figure 4 gives the photoelectric yield for reverse illumination of blue, green, and white light as a function of the original antimony thickness. Of particular interest are the relative slopes below and above the optimum thickness. For illumination of lower wavelength, the response drops more rapidly as the thickness of the surface is increased beyond the optimum thickness. However, decreasing the photosurface thickness in the region below the peak results in a more gradual drop in response for the blue as compared to higher wavelengths. This is in keeping with expectations based on the spectral absorption for cesium-antimony, which peaks in the blue and drops toward the red. For reverse illumination in which a released electron must travel \((d-x)\), where \(d\) is the thickness of the photosurface, and \(x\) is the depth at which a quantum is absorbed, increasing \(d\) results in a rapid diminution in response for \(d \gg x\); i.e., beyond the peak. For a given thickness of photosurface in this region (to the right of the maximum), the depth of photosurface which an electron must traverse, \((d-x)\), is less for longer wavelengths than for the blue because of the greater light absorption.

Table I. Relative photoelectric yield of Cs–Sb for reverse illumination of three illuminants maximized at 10 and the corresponding transmissions of the antimony layer.

<table>
<thead>
<tr>
<th>Percent transmission of antimony layer</th>
<th>Relative photoelectric yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5\text{-}74)</td>
<td>(2\text{-}78)</td>
</tr>
<tr>
<td>White</td>
<td>(2\text{-}78)</td>
</tr>
<tr>
<td>91.4</td>
<td>95.0</td>
</tr>
<tr>
<td>89.0</td>
<td>93.2</td>
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<tr>
<td>86.5</td>
<td>91.3</td>
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<tr>
<td>81.8</td>
<td>88.0</td>
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<tr>
<td>80.4</td>
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<tr>
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<td>84.0</td>
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<td>73.3</td>
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<tr>
<td>20.7</td>
<td>22.3</td>
</tr>
<tr>
<td>18.5</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Fig. 4. Relative photoresponse of Cs–Sb under reverse illumination as a function of thickness of the original antimony layer expressed in \( \mu g/cm^2 \): --- white light, --- blue (5–74), and --- green (4–105).

resultant photosurface with white, blue (5–74), and green (4–105) illumination. An examination of this table reveals the following information: the maximum photoelectric yield for both green and white reverse illumination corresponds to a thickness for which the transmission of blue (5–74), red (2–78), and white light of the original antimony layer is 81.8 percent, 92 percent, and 88 percent, respectively.

For irradiation with blue light the corresponding transmissions are slightly greater. Also, it may be seen that a variation in transmission with white light from 95 percent to 88 percent for the antimony layer results in a change in relative response from 6.10 to about 10 for the resultant photosurface under blue (5–74) light radiation, whereas under white light a considerably greater variation (4.50 to 10) is found. In addition, with the tabulated data, such questions as: "How great is the variation in response on a cathode which has a given fluctuation in antimony transmission?" can be quantitatively answered.

From Table I, then, can be evaluated the nine functions of photoelectric yield with transmission of the antimony base layer. One of these relations, photoresponse of 4–105 with antimony transparency of 5–74, is plotted in Fig. 5. (The ordinate is not maximized at 10 as in Table I.) The steeply rising portion of the curve at high transmission values indicates the poor uniformity of photoresponse with small variations of antimony transparencies in this region. Shifting the photosurface illumination toward the blue decreases the slope of this portion of the curve, whereas a shift toward the red increases the slope. The reverse effect is noted in the region of negative slope; shifting the irradiating wavelength to the blue causes a steeper slope, while a shift to the red results in a somewhat less severe drop. Changing the color of the light used in the transmission measurements of the antimony film from blue to red results in the following changes: (a) as noted above, the peak response is shifted from 82 percent to 92 percent transmission, (b) the slope of response with percentage transmission in the ascending region is considerably steeper, and (c) the slope of response with percentage transmission in the descending region is also somewhat steeper. It is evident, therefore, that a consideration of the color of light used in the transmission measurements of the antimony film, as well as in the illumination of the photosurface, is necessary in order to control photoresponse variations of a cathode.

Khorosh has reported that the maximum sensitivity in μA/lu for a Cs–Sb photocathode occurs at a thickness corresponding to a white light absorption of 50–60 percent in the antimony layer. Since these photosurfaces were reportedly prepared as individual cells of uniform antimony thickness from 10 to 90 percent light absorption, it is believed that the frequent large fluctuation of response from tube to tube may in part be responsible for this reported transmission value of antimony at the peak. In this investigation, the tube-to-tube fluctuation was obviated by employing a wedge. Under these conditions various thicknesses were treated under identical conditions.

In Fig. 6 is plotted the function of photoresponse for forward illumination (5–74 and 4–105) with antimony thickness expressed in μg/cm². The ordinate scale is in the same relative units as in Fig. 2, with the thickness of the peak reverse illumination response set at about 10. It can be seen that at greater thicknesses the curve is not a sensitive function of thickness and approaches the behavior of an opaque surface. The shape of this curve has been explained in terms of reflectivity of the surface which shows a counter-phase relation with response for forward illumination. Therefore, a plot of forward illumination as a function of light absorption rather than transmission would be expected to yield a smoothly rising curve without changes in sign of the slope.

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