Modifications in Photomultipliers with Total Internal Reflection Enhanced Sensitivity

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Several recent reports[1-3] have described the use of multiple total internal reflection within the windows of semitransparent photocathode photomultipliers to improve light absorption efficiency. Large sensitivity increases were obtained but the acceptance angles were rather low.[3]

The permissible range S_θ of incidence angles on the outside of the window is determined by (see Fig. 1): (1) the incidence angle θ on the inside surface of the window must be larger than the critical angle $\theta_c = \arcsin 1/n$ of the window material; (2) as θ increases, the number of reflections within a window of a given length-to-thickness ratio decreases; (3) as $\theta - \theta_c$ increases, the interaction between the beam and the cathode layer is reduced.[4] However, this reduction is gradual for the usual cathode materials and thicknesses.

Obviously, if high index windows are used to reduce θ_c, S_θ may be increased within the bounds set by conditions (1) or (2).

Condition (2) may be complied with by arbitrarily fixing either θ_{max} or θ_{mean} at a low enough value. The dependence of S_θ on window index may be seen in Fig. 2, for various values of θ_{max} and θ_{mean}.

For a full angular coverage ($S_\theta = 180°$) these relationships simplify to $\theta_c = \theta_{mean(2)} = \theta_{max(3)}$. Here, of course, violation of condition (3) reduces the sensitivity enhancement.

The high index materials for this application could be sapphire (index 1.76) in the uv-visible and strontium titanate (index 2.41) in the visible spectral region. Availability of rutile (indexes 2.62 and 2.92) would be desirable. Of course antireflection coatings would be required on the entrance face.

The maximum size of the entrance face is another important matter. In the usual configuration of an entrance prism contacted to the window, it is proportional to window thickness. This is, in turn, fixed by the window size and the desired number of internal reflections. The value of this ratio may be read from Fig. 3 as a function of window index for the same θ_{max} and θ_{mean} values as before. It is assumed that there is no physical obstruction and that the full angular spread of the beam is incident over the entire entrance face.

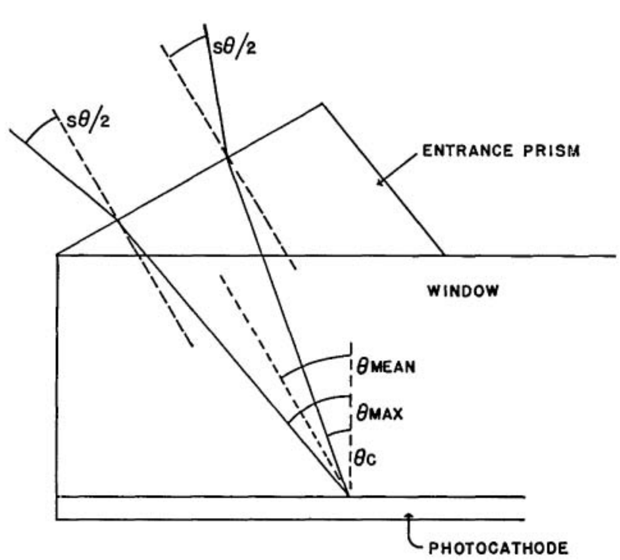

Fig. 1. Definition of terms for photomultipliers with TIR sensitivity enhancement.

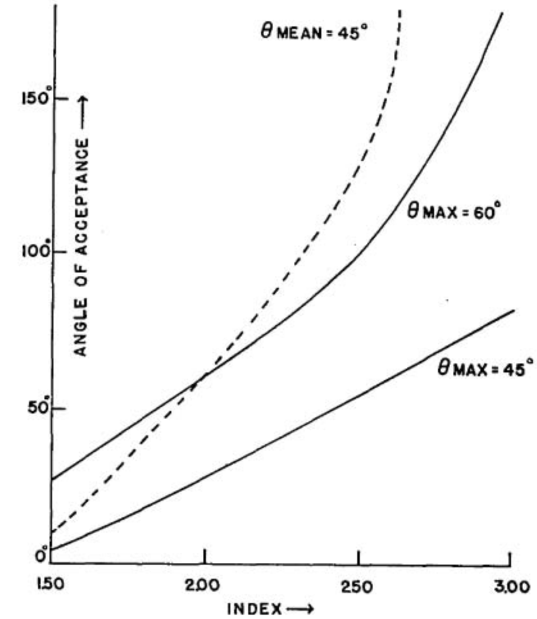

Fig. 2. Effect of window material index on angle of acceptance.

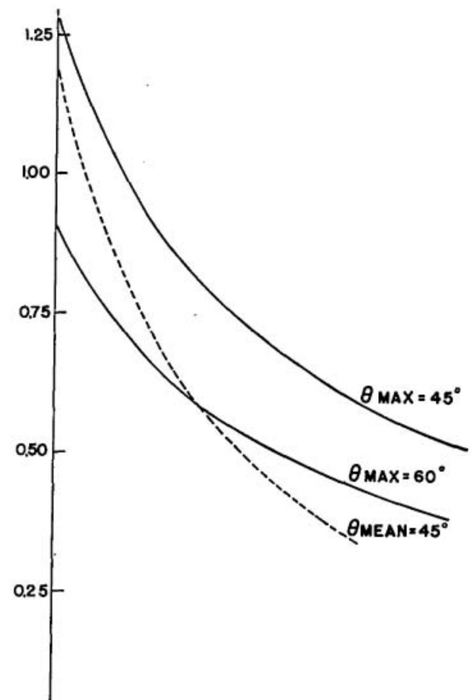

Fig. 3. Maximum entrance face size/window thickness vs index of refraction of window material.

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The Influence of Cathode Thickness and Aging on the Photoelectric Yields of LiF and CsI in the xuv

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Lukirskii *et al.*[1,2] first observed photoelectric yields near 80% for the alkali-halides and the alkaline earth-halides at several wavelengths between 1.5 Å and 113 Å. Duckett and Metzger[3] also observed similar high yields for the alkali-halides between 600 Å and 1200 Å, and used a random walk model of electron scattering to interpret the observed high yields. The model proposed by Duckett and Metzger assumes that, if the photoelectrons produced in a solid can undergo many quasi-elastic scattering events, the probability is high that they will diffuse to the surface of the cathode and escape. The predominant scattering process in the alkali halides is an elastic electron–phonon process where the electron loses an energy of approximately 0.01 eV per collision. Since the energetic primary photoelectrons produced by the absorption of radiation in the xuv can experience many scattering events and still be emitted, the requirements for the random walk treatment appear to be fulfilled.

Measurements of the dependence of the photoelectric yield of the alkali-halides on the thickness of the cathode also indicate that multiple scattering of the photoelectrons does occur. The two materials selected for this study were LiF and CsI. Several cathodes with thicknesses between 100 Å and 2000 Å were prepared by Thin Film Products Inc., Cambridge, Massachusetts, by evaporating the material on stainless steel disks and then transferring it to the analyzer of a photomultiplier detector instrumented for photoelectron counting. The cathodes were exposed to air for about 10 min during their transfer into the vacuum chamber of the monochromator. The detector was similar to that described previously by Heroux and Hinteregger[4], except that eight different cathodes could be mounted in a cathode turret assembly and inserted individually into the analyzer of the detector without interruption of the vacuum exhaust cycle. The cathodes, therefore, could be compared under identical operating conditions of the light source, environmental pressure, and

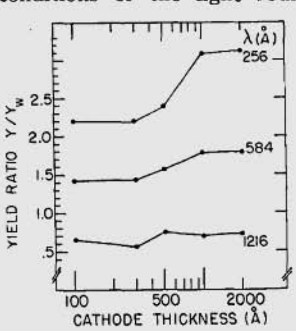

Fig. 1. The dependence of the yield of LiF relative to tungsten on film thickness for the three wavelengths 256 Å, 584 Å, and 1216 Å. The samples were aged in air for about 10 min before the data were obtained. The solid lines merely connect the data points.

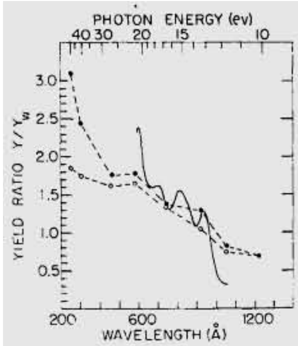

Fig. 2. The dependence of the yield of LiF relative to tungsten on time of exposure to air. The cathode was 1000 Å thick. ●, cathode aged in air for 10 min; ○, aged in air for 80 h; solid curve, data of Duckett and Metzger.[3] The dashed lines merely connect the data points measured here.

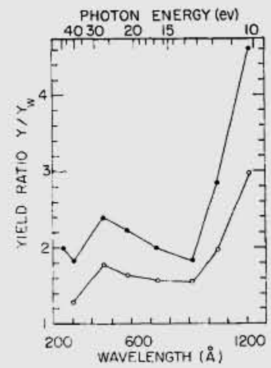

Fig. 3. The dependence of the relative yield of evaporated CsI, 1000 Å thick, on time of exposure to air. ● aged in air for 8 min; ○ aged in air for 84 h.

identical aging times. One of the cathodes in the turret assembly was a tungsten reference cathode. The ratio of the yield of the sample Y to the yield of the tungsten reference cathode Y_W was determined from the ratio of the photoelectron counting rate with the sample and reference cathode inserted into the analyzer of the detector.

Measurements of the ratio Y/Y_W for LiF for five cathode thicknesses and for three wavelengths are presented in Fig. 1. The photoelectrons emitted at 1216 Å probably originate from the hydrolized surface of the cathode which is formed during exposure to air.[5] Absorption in the volume of the cathode will be negligible because of the low linear absorption coefficient μ (cm^{-1}) of LiF[6] at 1216 Å. Those photons not absorbed at the front surface of the cathode, therefore, will be absorbed either in the stainless steel base or in the interfacial region between this base and the LiF. The contribution of these rear surface photoelectrons to the observed yield at 1216 Å cannot be large, however, since this contribution would have to decrease rapidly with increasing cathode thickness. Because the absorption length ($1/\mu$) for LiF at wavelengths shorter than 1050 Å is approximately 100 Å, the incident photon beam not absorbed by the front surface of the cathode will be absorbed predominantly in a region close to the cathode surface. If multiple scattering occurs, the energetic photoelectrons produced by photon absorption will diffuse to the front surface of the cathode and contribute to the high yield that is characteristic of the alkali-halides. The rear surface of the cathode for film thicknesses near $1/\mu$ (100 Å) would be expected to interfere with the back-scattered electrons and lower the measured photoelectric yield. Increasing the film thickness increases the possible number of elastic scattering events in the volume of the cathode before the back-scattered electrons reach the interface between the LiF and the stainless steel base. The probability of photoelectron diffusion to the front surface of the cathode, therefore, should increase with film thickness until the thickness is much larger than the absorption length. This general behavior is apparent in Fig. 1 where a significant increase in yield with film thickness is observed as the thickness is in-