Improvements in Photomultipliers with Total Internal Reflection Sensitivity Enhancement

Tomas Hirschfeld

An improved geometry for coupling a beam into a photomultiplier with total internal reflection sensitivity enhancement is described which allows this technique to be used with large sized beams. The equations giving the increase of the photocathode's absorption efficiency by the use of internal reflection within the window are discussed and conditions for best performance specified. The calculations, based on modifications of experimentally verified equations employed in internal reflection spectroscopy, predict that cathodes only a few monolayers thick could be made to absorb almost all the light falling on them in very few reflections. It then is shown that this will result in high quantum efficiencies with a much reduced spectral dependence. Particularly high increases may be expected for the less efficient cathodes such as S–1. The procedure is shown to relax the requirements on electron escape depth and absorption coefficient of the cathode material so much that the range of possible materials is considerably enlarged. Also, surface and defect level photoemitters will become practical. This and the change of work function with material thickness raise the possibility of extending the region of operation of photomultipliers more into the ir. Photomultipliers so built could also show a higher frequency response to modulated light beams. Finally, means of reducing the dark current and obtaining the multiplex gain in these photomultipliers are discussed.

Introduction

Photomultipliers with a total internal reflection sensitivity enhancement have now been known for some time,[1–6] but their limited acceptance angle (typically about 6°) and the small size of their light collecting area (typically of the order of the window thickness) have limited their application. In fact, for the designs reported so far, the minimum f number of the associated optics has been so high and the ratio of the light collecting area to the photocathode area (to which dark current is proportional) so low that the ratio of signal current to dark current in a given system could actually be worse than with the original photomultiplier.

The first problem having been dealt with in a note,[7] a solution to the second one is now indicated. Once this is done, several new improvements become possible, whose theory forms the main subject of this report.

Methods for Increasing the Light Collecting Area

As the entrance face's size is a function of the window thickness, we first double this without reducing the number of reflections by surrounding the window with a vertical mirror surface, making the totally reflected beam double back and be reflected a few more times.

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If we now replace the entrance prism by a truncated pyramid, the light beam will be condensed on entering the window, as shown in Fig. 1 (this system has four reflections at an incidence angle of 30°). It can be seen that here the central part of the beam will not be totally reflected, making it advantageous to split the image with a mirror, in order to have all the light fall on the useful part of the entrance face.

To obtain an even number z of reflections at an incidence angle θ in a window of diameter D it must have a thickness l equal to:

$$l = D/2z \tan\theta, \qquad (1)$$

where a mean value may be taken for θ if its spread is not too high.

For a collimated beam, the usable portion w of the entrance window will be given by

$$W = 2w \cos\theta, \qquad (2)$$

where w is the maximum width of the lower part of the entrance pyramid (or cone, if skew rays can be tolerated).

If the beam has an angular aperture $\Delta\theta$ the full value of which is assumed incident over the entire entrance face, the effective aperture inside the window will be reducted by refraction to

$$\Delta\theta' = 2 \arcsin \left[\frac{\sin(\Delta\theta/2)}{n_1}\right], \qquad (3)$$

where n_1 is the window's index.

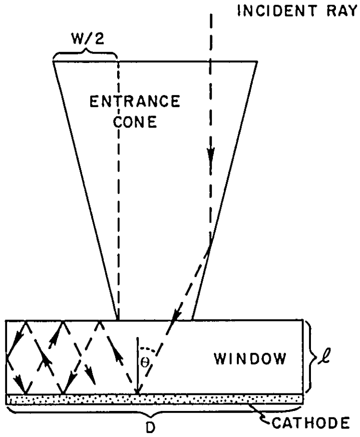

Fig. 1. Entrance optics for photomultiplier with total internal reflection sensitivity enhancement.

Under these conditions Eq. (2) becomes:

$$W = w \frac{2\tan\theta/2}{\tan(\theta + \Delta\theta'/2) - \tan\theta/2}. \qquad (4)$$

The maximum value of w is a function of the window thickness, and by taking Eq. (1) into account we can write

$$W = \frac{D}{z}\,\frac{\tan(\theta - \Delta\theta'/2)}{\tan\theta}. \qquad (5)$$

The second factor in this expression reduces to 1 when $\Delta\theta = 0$.

We can now calculate the width of the light collecting area as a function of the window's original width:

$$\frac{W}{D} = \frac{2}{z}\,\frac{\tan(\theta - \Delta\theta'/2)}{\tan\theta}\,\frac{\tan\theta/2}{\tan(\theta + \Delta\theta'/2) - \tan\theta/2}, \qquad (6)$$

which for $\Delta\theta = 0$ reduces to

$$W/D = (2/z)\cos\theta. \qquad (7)$$

Figure 2 displays the change of WD as a function of θ with $z = 4$, $n_1 = 2$, and $\Delta\theta = 0°$ or $10°$.

These values are significantly larger than those possible with previous arrangements,[7] and allow a much smaller phototube (with smaller dark current) to be used in studying a given sized beam.

Techniques for Using Very Thin Photocathodes

Total internal reflection is used in photomultipliers to give better absorption of light in a thin photocathode and thus increase quantum efficiency.

If advantage is taken of this enhanced absorption to make photocathodes thinner and more transparent to the generated photoelectrons, a large further gain in quantum efficiency results.

It is therefore advantageous to study ways in which this enhancement can be maximized. An appropriate theory exists that describes the enhancement possible in a single total internal reflection, if the film is very thin and the absorption constant is not too high.[8–11]

If we call d the thickness of the cathode, k its absorption coefficient, n_2 its index, n_1 the index of the prism, and λ the wavelength, the absorptivity of the cathode will be given by

$$A = (4\pi/2.303)\, d_e(kn_2/\lambda), \qquad (8)$$

where d_e is the effective thickness of the film.

The total reflection absorption enhancement can be described as the ratio of this effective thickness to the real one whose values for each polarization are given by:

$$(d_{e_{s/d}}) = (4n_2n_1\cos\theta)/(n_1^2 - 1); \qquad (9)$$

$$(d_{e_{p/d}}) = \frac{4n_2n_1^3\cos\theta[\sin^2\theta(1 + 1/n_2^4) - 1/n_1^2]}{\sin^2\theta(n_1^4 - 1) - n_1^2 + 1}. \qquad (10)$$

The last equation can be simplified for the usual high indexes of photocathode materials to give

$$(d_{e_{p/d}}) = \frac{4n_2n_1^3\cos\theta\,(\sin^2\theta - 1/n_1^2)}{\sin^2\theta(n_1^4 - 1) - n_1^2 + 1}. \qquad (11)$$

These equations are valid for angles of incidence ranging from the critical one, given by

$$\theta_c = \arcsin(1/n_1), \qquad (12)$$

when the photocathode is thin enough, and grazing incidence. Within this range $(d_{e_{s/d}})$ has a maximum at the critical angle and $(d_{e_{p/d}})$ is largest at an optimum angle given by

$$\theta_M = \arcsin\left(\frac{(2n_1^2 - 3 + 1/n_1^2 + ((2n_1^2 - 3 + 1/n_1^2)^2 + 4(n_1^4 - 1)(1 - 1/n_1^2))^{\frac{1}{2}}}{2(n_1^4 - 1)}\right)^{\frac{1}{2}}. \qquad (13)$$

The values of both angles can be read off Fig. 3 as a function of window index. Figure 4 shows the corresponding values of the enhancement calculated for $n_2 = 3$ (typical S–20 photocathode material). It can

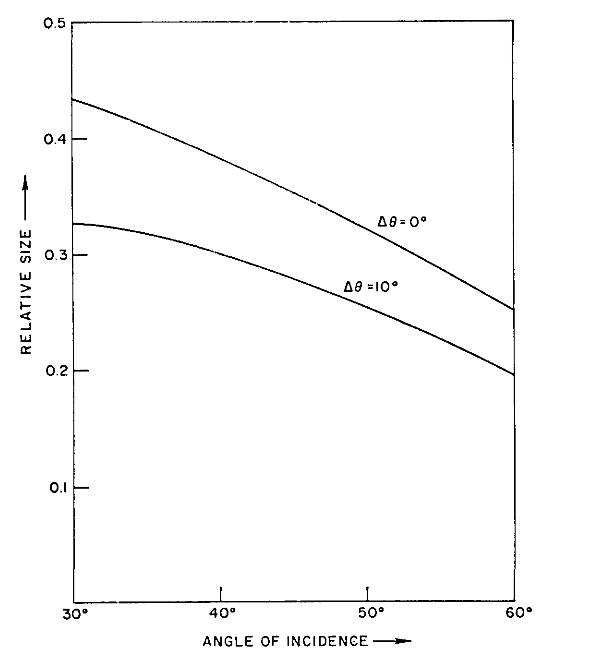

Fig. 2. Relation of entrance face and window sizes for a four-reflection system.

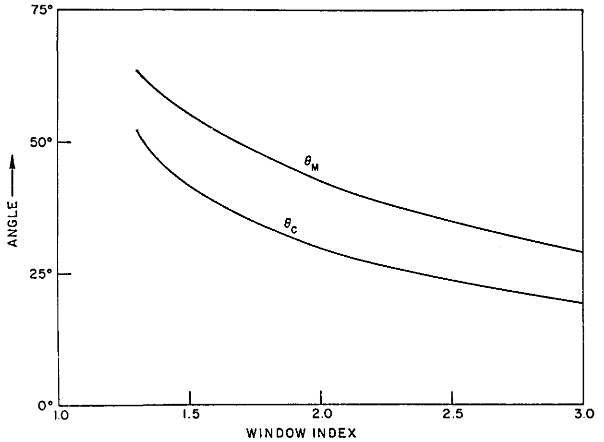

Fig. 3. Critical and optimum incidence angles as a function of window index.

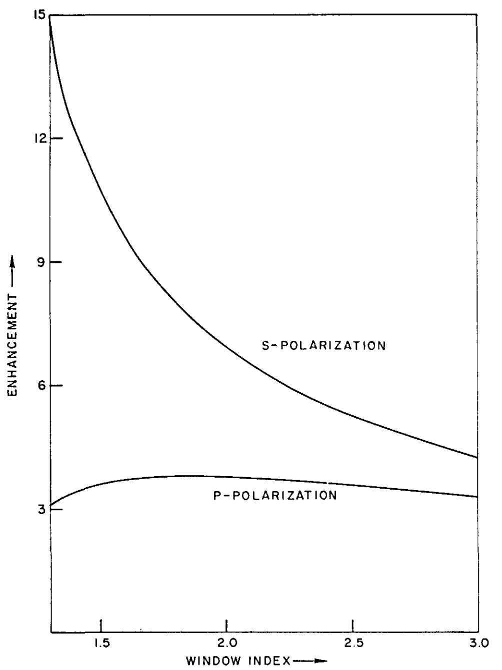

Fig. 4. Absorption enhancement as a function of window index.

be seen that the best values are obtained always for an s polarized beam, and for best results this must be used with the lowest window index possible. For example, a LiF window would give more than twelvefold enhancement. A p polarized beam will have a much lower enhancement, peaking at a window index of 1.9 (lanthanium glass) with values only slightly larger than four.

A different situation arises when the beam is not collimated, having an angular aperture $\Delta\theta$. Here $\Delta\theta$ must be small enough so that after refraction at the entrance face, the range of internal incidence angles does not extend out of the range θ_c to 90°. It can be shown that for an entrance face normal to the beam, the maximum value of $\Delta\theta$ is given by

$$\Delta\theta = 2 \arcsin[(n_1^2 - n_1)/2]^{\frac{1}{2}}. \tag{14}$$

This value increases with n_1 becoming 180° at $n_1 = 2.0$, after which further increases are not worth taking advantage of. Instead, we can use the smaller internal incidence angle spread to get higher enhancements. Figure 5 shows the variation of $\Delta\theta$ and the mean incidence angle with n_1. An analytical study of the enhancement possible under these circumstances for the s polarization shows that while the enhancement possible for a collimated beam at critical incidence is

$$(d_{e_{s/d}})_{\theta_c} = 4n_2/(n_1^2 - 1)^{\frac{1}{2}}, \tag{15}$$

here the enhancement will be only

$$(\overline{d_{es/d}})_{\Delta\theta_{\max}} = \frac{4n_2}{(n_1 + 1)(\pi/2 - \arcsin 1/n_1)} \tag{16}$$

at the highest possible field of view when $n_1 \leq 2$ and

$$(\overline{d_{es/d}})_{\Delta\theta = 180°} = \frac{4n_2(n_1^2 - 2)}{n_1^2(n_1^2 - 1)\arcsin 1/n}, \tag{17}$$

with a 180° field of view when $n_1 > 2$.

These enhancements are plotted for $n_2 = 3$ as a function of n_1 in Fig. 6. They show a maximum of about eight for very low index windows and are quite stable at about four for $n_1 > 2$.

Analysis of the smaller enhancements available for the p polarized case is much more difficult. However, by looking at the $(d_{e_{p/d}})$ vs θ curve of Fig. 7, we see that the curve has a negative concavity at all points, and that $(d_{e_{p/d}})$ approaches 0 at both θ_c and 90° (this curve also is for $n_2 = 3$). This allows one to make the triangular approximation:

$$(\overline{d_{e_{p/d}}}) = \tfrac{1}{2}(\overline{d_{e_{p/d}}})_{\theta_M}\{1 - (90° - \theta_{\max})^2/[(90° - \theta_M)(90° - \theta_c)]\}, \tag{18}$$

which is both fairly good and always on the conservative side. The values resulting from this approximation for the largest possible $\Delta\theta$ when $n_1 \leq 2$ and for $\Delta\theta = 180°$ when $n_1 > 2$ are shown in Fig. 8, also for $n_2 = 3$. The enhancement, while much lower, will reach 1.75 at an

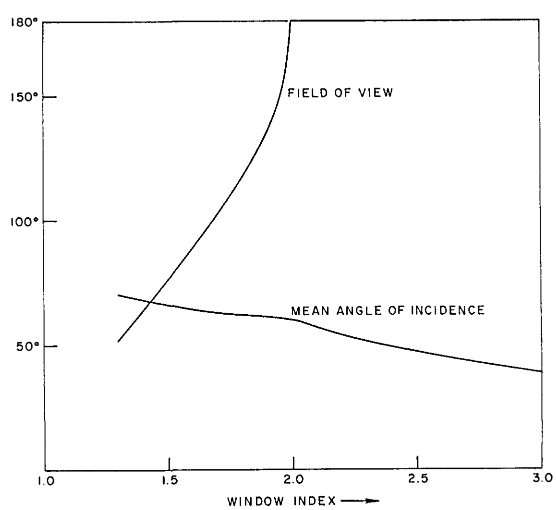

Fig. 5. Maximum field of view and mean incidence angle as a function of the window index.

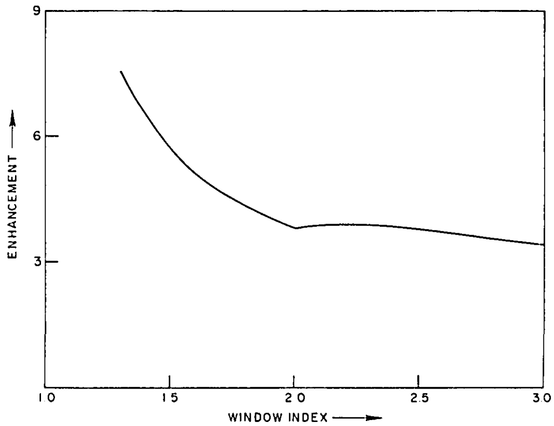

Fig. 6. Enhancement for s polarized light at maximum field of view as a function of the window index.

window index of 1.6 and nearly 2.25 when this index is >2.5.

All these enhancements are for a single reflection and in practice must be multiplied by the number of reflections used.

Given the values of absorption intensity shown by common photocathode materials, as for example about 5×10^5 cm^{-1} for S–4 or S–20 photocathodes,[12] it becomes apparent that even for two or four reflections, nearly complete absorption will result from photocathodes only one or a few monolayers thick; for example, nearly 90% of the light can be absorbed in a 10-Å thick layer of material with this absorption value after only two reflections.

For less absorbing materials or thinner layers, even larger enhancements can be had in a narrow wavelength and angular region with s polarized beams by interposing another layer between the photocathode and the window[13–15]. For example, we may put $\lambda/4$ layer of very low index in this position, which, at near critical incidence angles, will result in a further gain given by

$$(d_{e_{s_{\text{layer}}}})/(d_{e_{s_{\text{initial}}}}) = (n_1^2 - 1)/(n^2_L - 1), \qquad (19)$$

where n_L is the layer's index.

Figure 9 shows the total gain possible for the s polarization as a function of prism index when using this technique with a cryolite intermediary layer (n_L = 1.33).

The large gains thus possible are practical for laser detectors, where the wavelength and angular range can be smaller and where work is often done at longer wavelengths where photocathodes absorb more weakly.

While these very thin layers will show some deviation from the bulk optical constants, there is no reason to expect these to be extremely large. Spectroscopic observations of the absorption of monolayers by total internal reflection have shown satisfactory agreement with the equations from which the ones used here were derived.[8,20] While one would expect that some of the light absorption mechanisms would be perturbed in such thin layers, this is not so for the photoelectric effect still present for isolated atoms in the gas state.

Layers as thin as these will be hard to realize in practice, and isothermal adsorption, instead of evaporation and condensation techniques, will probably be necessary. This will also help in reducing the tendency of the layer to agglomerate by recrystallization leaving clear spaces between crystallites.

The very large enhancements shown here are at variance with those calculated by Sizelove and Love,[4] but, as Seachman[16] has already pointed out, the addition of the intensities they use in their multiple reflection calculations is not correct for such extremely thin films, much smaller than any reasonable coherence length for visible radiation. The basic formulas employed here, derived from Harrick's approximate electromagnetic theory treatment, are not subject to this criticism, and have been experimentally confirmed through internal reflection spectroscopic work in thin films.[9]

Advantage of Very Thin Photocathodes

The use of photocathodes whose thickness is of the order of a few monolayers makes possible a number of very significant improvements in photomultiplier performance.

(1) *Higher quantum efficiencies.* The QE of a photocathode can be described as the product of four factors: (a) the fraction of light absorbed; (b) the proportion of the absorbed photons that generates photoelectrons whose energy is higher than the potential barrier at the photocathode–vacuum interface; (c) a factor one-half arising from the fact that half the electrons will diffuse to the photocathode window instead of the photocathode–vacuum interface; and (d) the fraction of the electrons that loses so much energy during diffusion to the surface as to be unable to cross the surface potential barrier.

In ultrathin photocathodes with TIR enhancement, the first factor can be kept high by using an appropriate number of reflections. Since the mean escape depth for photoelectrons in the usual photocathode materials is several hundred angstroms, the last factor will become practically unity in this type of photocathode. Even

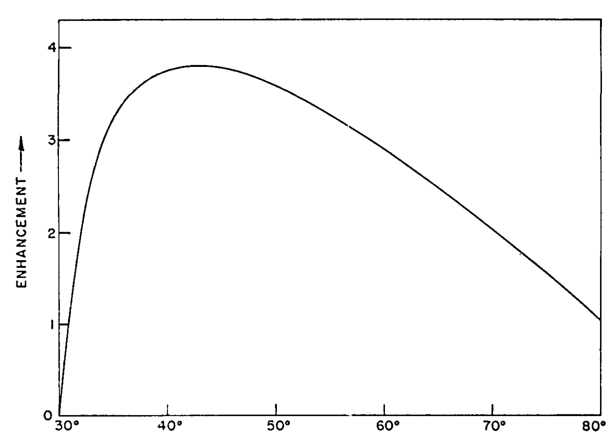

Fig. 7. Enhancement as a function of angle for $n_1 = 2$ and $n_2 = 3$.

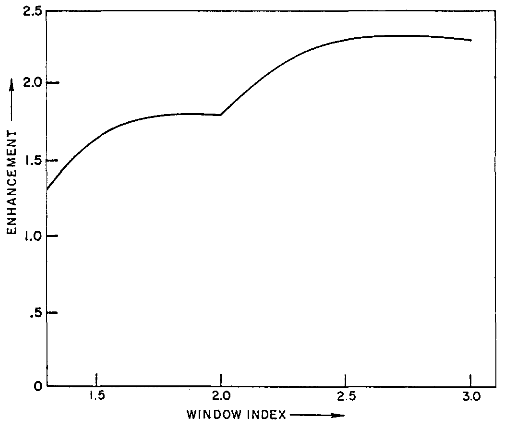

Fig. 8. Absorption enhancement for p polarization at maximum aperture as a function of window index.

the third factor may be improved in them, since electrons that may be reflected at the photocathode–window interface no longer find double traversal of the layer nearly impossible. Since the second factor is usually quite large, very high QE's, of the order of 50% or more, should thus become possible.

For work with higher energy photons, it might even be possible to have high emission probabilities for photoelectrons after they generate a few electron–hole pairs in the cathode material. (Here, careful attention to the definition of the term quantum efficiency is required to prevent it from being >100%.)

(2) *A flatter spectral distribution of the QE.* In ordinary semitransparent photocathodes, the QE decreases on both sides of a peak wavelength, at longer wavelength because the lower optical constants make the cathode too transparent and at shorter ones because the higher optical constants make it too reflective and lengthen the mean diffusion path of the photoelectrons.

These effects are obviously absent for very thin cathodes with ample absorption enhancement by TIR. One thus expects the QE to be very nearly uniform from near the long wavelength cutoff on downwards.

(3) *A wider choice of photocathode materials.* Since the requirements on both absorption intensity and transparency to photoelectrons are considerably relaxed in this type of cathode, the range of materials for possible photocathode use is enormously broadened. Metal photocathodes, easier to make, more stable, and much less saturable then semiconductor ones might, for example, show good quantum efficiencies in this type of construction.

(4) *Use of surface and defect level photoemitters.* These have not been practical before (except in the case of S–1, which may show defect level photoemission in its long wavelength tail[17]) because the low maximum absorptions associated with these cases have precluded the obtention of high quantum efficiencies. Thicker layers are obviously no solution in the first case and are precluded in the second because of the limited electron mean escape depths available. These problems can be quite easily circumvented by TIR absorption enhancement.

(5) *Extended infrared response.* One of the valuable byproducts of (3) and (4) above is the possibility of finding (or creating by suitable doping of low electron affinity materials) photocathode materials whose work function is lower than 1 eV (which corresponds to S-1, the best ir sensitive photoemitter currently known). Sommer's[12,17] work about thermionic emission in S–1 here suggests it is possible to make this material work out to 0.7 eV (1.7 μ) if only the photons could be effectively coupled to high lying energy levels in that material. In this context it would be interesting to consider the minima in work function found by several investigators[18,19] for certain low values of the cathode thickness in many materials. By enabling cathodes in this thickness range to absorb light effectively, it will be possible to take advantage of these phenomena for extending the operating range of photomultipliers more into the ir.

(6) *Reduced transit time dispersion.* Probably the most fundamental limit to very high frequency response of photomultipliers to modulated light is the dispersion in the transit time of electrons from the cathode to the first dynode. This arises because the electrons leave the cathode within a range of energies from zero to the difference of the photon energy and the work function owing to their statistical energy loss during the diffusion process. In a thinner cathode, the average energy loss of the electrons will be lower, and their energies will show a much more strongly peaked distribution, thus reducing the transit time spread and improving maximum frequency response of the device. Here, the field distribution during total reflection, which restricts the range of possible initial electron directions, will also be helpful.

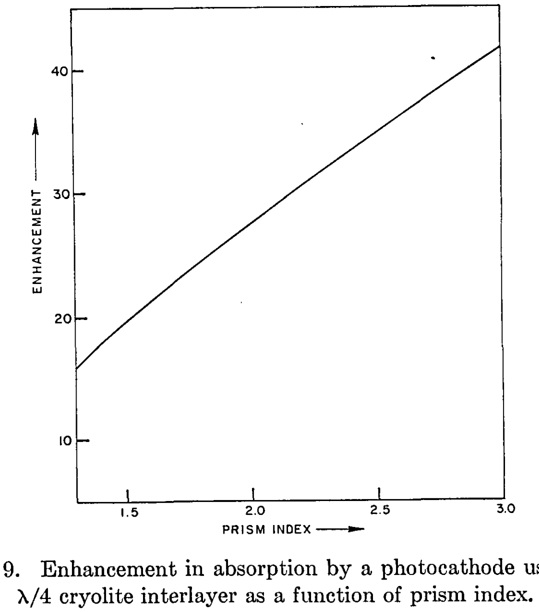

Fig. 9. Enhancement in absorption by a photocathode using a $\lambda/4$ cryolite interlayer as a function of prism index.

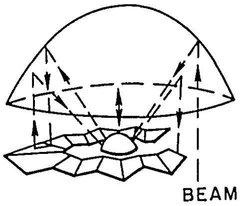

Fig. 10. Multiple internal reflection unipoint system.

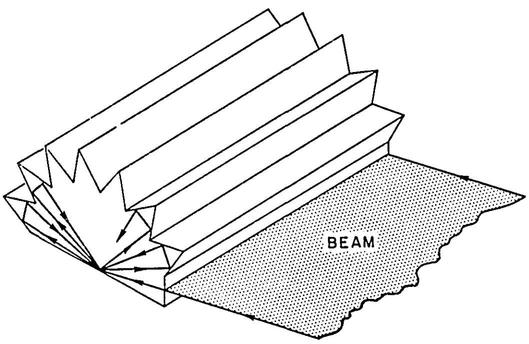

Fig. 11. Multiple internal reflection uniline system.

Dark Current Reduction in Photomultipliers with TIR Sensitivity Enhancement

Even with the optical techniques described above, the photocathode area required for a beam of a given size will be larger than for an ordinary photomultiplier, which results in higher dark currents and dark currents and dark current noise. In ordinary photomultipliers, dark current reduction is accomplished by either reducing the cathode temperature or by shrinking its sensitivity area down to a point[21] on which the light beam is then focused. As cooling of photomultipliers is often impractical, an adaptation of the second method to photomultipliers with total internal reflection sensitivity enhancement would be quite useful.

Multiple reflection unipoint devices, as described for internal reflection spectroscopic use, would drastically reduce the needed photocathode area when more than a single reflection is used. However, both the rosette[22] and the ridged hemisphere[11] types do not focus the beam at each reflection, and to achieve this considerable additional complication in already hard-to-make optics would be required.

For this reason the multiple reflection unipoint device shown in Fig. 10 was developed. The beam enters through the cutout in the crown wheel mirror, and is focused by the parabolic mirror through the central hemisphere (the photomultiplier window) on its flat back surface. After reflection from this, the beam goes back to the paraboloid and from here as a parallel beam to the crown wheel mirror. Each tooth of this acts as a retroreflecting roof top mirror that displaces the beam along the circumference and sends it back to the parabolic mirror. The sequence of events is now repeated as many times as the crown wheel has teeth, with the beam progressing along its circumference. Just before completing this path, the beam strikes a flat part on the crown wheel mirror and returns along its original path in order to double pass the entire arrangement.

This system is much simpler to build than current multiple reflection unipoint devices, involving only an assembly of flat mirror faces in the crown wheel, a hemisphere, and a paraboloid. For good optical efficiency, very high quality mirrors and an antireflection coating on the hemisphere will be required. Alternatively, the whole system can be constructed as a parabolic solid with a crown wheel mirror cut into its base. One flat face here would be antireflection coated for the light entrance and the other mirror coated for double passing the beam. This system would be simpler and have a higher optical efficiency, but would be somewhat more difficult to build.

Livingston[23] has recently proposed the use of an image tube for simultaneous measurement of an entire spectrum. Here, also, multiple TIR was achieved by using a photocathode whose area was substantially larger than that of the beam. This can be avoided by using a multiple reflection uniline system, where a line of light (the spectrum in the case mentioned) is multiply reflected on a line photocathode, preferably in focus at each reflection.

Such a system is shown in Fig. 11, similar in principle to the ridged hemisphere multiple reflection unipoint cell. Each ray of the incoming beam strikes the center, is reflected to the retroreflecting teeth, and redirected to the center at a different incidence angle, and the process is repeated until the incidence angle is nearly critical, at which point a flat reflecting plate provides double passing. The faces of each tooth are curved so as to focus the beam on the center at each reflection. However, the practicality of any device producing multiple reflection at a variable incidence angle is doubtful, as reflections at angles shallower than critical are much less effective in providing added enhancement.

Here, configurations capable of producing just two superimposed reflections of a spot, line, or image (for high sensitivity image intensifiers or night vision equipment) become very valuable. Possible systems such as this are shown in Fig. 12. Of course, if the beam is not collimated, the incidence and mirror faces will have to show curvature, or the mirror face may even have to be replaced by an external catadioptic system.

Conclusions

With perfect input optics it is possible to obtain four to six reflections in the window of a photomultiplier with

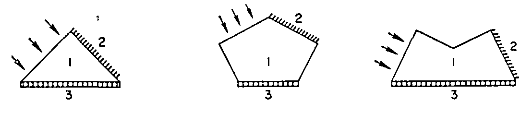

Fig. 12. Double internal reflection imaging systems. 1—prism, 2—mirror, and 3—photocathode.

total internal reflection sensitivity enhancement, using a photocathode only two or three times larger than the actual cross section of the beam.

By optimizing all parameters involved in the total reflection phenomenon, it becomes possible to obtain adequate absorption from photocathodes only one or a few monolayers thick. For weakly absorbing cathode materials this is eased by putting a $\lambda/4$ thin low index layer between the cathode and the window. The equations involved have been verified in spectroscopic sampling applications. From this type of photocathodes higher peak quantum efficiencies, falling off more slowly with changing wavelengths, may be expected. The technique also has the promise of greatly enlarging the range of possible photocathode materials, by including in them materials having low absorption coefficients or low electron mean escape depths. This, in turn, may allow photocathodes to be developed having an ir sensitivity extending further to long wavelengths than S–1. Higher frequency responses in this type of photomultiplier would be an interesting byproduct.

Multiple reflection unipoint devices can be used to reduce drastically the dark current at a given temperature from photomultipliers having TIR sensitivity enhancement. For analyzing entire spectra at once or viewing images in an image intensifier using TIR enhancement, multiple reflection uniline or uni-image devices can be used.

The author is on leave of absence from the University of Uruguay.

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Ninth IEEE Annual Symposium on Electron, Ion, and Laser Beam Technology, Berkeley, 9–11 May 1967

Reported by C. Susskind, University of California at Berkeley

The annual symposium is the outgrowth of meetings originally organized by Alloyd Corporation and concerned with the generation and control of radiant energy for the purpose of modifying the shape or nature of materials, including processes such as melting, refining, welding, machining, and evaporating. In recent years, nonthermal interactions with materials have also been included, notably such topics as scanning electron microscopy (an active research area at Berkeley), electron probe microanalysis, and high precision measurements, as well as novel instrumentation and the applicable physics.

Other topics covered at the Berkeley meeting last May included microelectronic fabrication and examination, information storage, and biomedical applications of beams—a subject that occupied two whole sessions.

The meeting was cosponsored by the Institute of Electrical and Electronics Engineers and the University of California's College of Engineering.

Charles Susskind and R. F. W. Pease, both University of California, served as Symposium chairman and program chairman, respectively. RCA vice president James Hillier, himself an electron microscopy pioneer, gave the keynote talk. Laboratories in Britain, France, Germany, and Japan were represented by papers.

The nearly fifty papers presented at the Ninth Annual Symposium on Electron, Ion, and Laser Beam Technology held last May are now available in book form. With one exception, all papers presented at the Symposium appear in the hardcover printed *Record* (which also contains a bibliography of over 200 items on scanning electron microscopy prepared at the IBM Laboratories in Yorktown Heights, N. Y.). Copies may be ordered for $20 from San Francisco Press, Incorporated, 255 12th Street, San Francisco 94103. The exception is a lecture given by L. Marton *National Bureau of Standards* on the early history of the electron microscope, which will be published separately by San Francisco Press as one in its series of History of Technology Monographs.

Second Atomic Spectroscopy Symposium, National Bureau of Standards, 11–14 September 1967

Reported by Bartley L. Cardon and Harold P. Larson, Purdue

The Second Atomic Spectroscopy Symposium of this decade was held last September at the new NBS facilities in Gaithersberg, Maryland. Some 168 scientists from Canada, Europe, Israel, New Zealand, and the U. S. A. attended and delivered seventy-six papers, during the four days of consecutive sessions, on radiation, high resolution spectroscopy, spectra of complex and rare earth atoms, Zeeman effect, autoionization, fine and hyperfine structure, isotope shift, beam sources, instrumentation, measurements, astronomical spectra, plasmas, line profiles and intensity, and theory.

Staying in downtown Washington D. C., many of the visiting scientists made the thirty-minute bus trip to and from Gaithersberg, affording them a chance to see the surrounding countryside and to visit before and after the sessions. Although the symposium had originally been planned as a small select meeting with the reading of a few papers and a lot of informal discussion, so many good papers were prepared and submitted that the four-day schedule left little time during the sessions for informal questions and discussion. The coffee break at mid-morning and mid-afternoon was certainly welcomed.

The spacious, tastefully designed white marble buildings of the National Bureau of Standards are situated on a large, well groomed tract of land. An interior square patio with fountain, pond, and benches, not to mention a direct descendant of Newton's famous apple tree growing outside to the north, add to the attractiveness of the administration building where the conference was held.

On Monday morning Karl Kessler *NBS* opened the first session by welcoming us and appropriately dedicating the symposium to the memory of William F. Meggers. Details of the many papers given can be found in the program and abstracts of the symposium; suffice it to say here that the scope and number of the papers indicate a definite vitality and growth in atomic spectroscopy, reminiscent of the golden age of spectroscopy at the beginning of this century. Indeed, many exciting and complex spectroscopic problems remain to be solved. In many of the papers, use of computers has led to solutions of complicated spectroscopic problems that could not be handled by hand computational techniques. For example, slow but steady progress is being made in unraveling the complicated energy level arrays of the lanthanides and actinides. Even in the simplest spectra where resolution of fine and hyperfine structure is still difficult, line structures are being unambiguously resolved by computer techniques. The laser and associated phenomena, reported in their initial development by Dr. Schawlow in the 1961 Argonne Atomic Spectroscopy Symposium, were carefully reviewed by Ali Javan *MIT*. The past six years has seen an enormous growth in the development and utilization of the laser as a powerful laboratory tool with great versatility. Work with the laser by the French at the Laboratoire Aimé Cotton in the study of hyperfine structure and isotope shift has been successful. Professor Edlén *Lund University, Sweden* once again stressed the need for more precision work with standard lines and determination of Ritz standards in the vacuum uv. Work in the vacuum uv region has been hindered by the absence of very precise standards. L. M. Branscomb *JILA*, lamenting that the study of the spectra of negative ions has no doubt been hindered by the absence of the Greek letter for zero, received progress with this novel problem. A new technique–beam foil spectroscopy—has made its arrival into the family of spectroscopic methods, and was reported upon by Drs. Bickel and Jordan of the University of Arizona and Rice University, respectively. This is a method for producing, easily and abundantly, high stages of ionization for laboratory study. The need to identify unambiguously the coupling conditions for electrons in complex atoms when labeling their energy levels was stressed by R. D. Cowan *Los Alamos* In performing intensity calculations, for example, this can be troublesome to the unwary user of tabulated energy levels.

During the Wednesday lunch hour Joseph Reader *NBS* escorted a group through the spectroscopy laboratory. The new vacuum uv grating spectrograph, under the supervision of Victor Kaufman, was most impressive.

On Wednesday evening the banquet was held in the South Cotillion Room of the Sheraton Park Hotel in Washington, D. C. The room, located one floor beneath the lobby, was in keeping with the natural gravitation of spectroscopists to basements and subbasements to carry out their dark designs. McPherson Instruments generously provided a liquid warm-up prior to the serving of dinner, after which all were relaxed and receptive to the speakers. With Dr. Kessler acting as Master of Ceremonies, Drs. Edlén and Shenstone related some of their personal encounters and experiences with Dr. Meggers. This was particularly enjoyable for some of us younger spectroscopists for whom Dr. Meggers is now a fascinating personality as well as a formidable figure in the history of atomic spectroscopy. As we had anticipated, E. U. Condon, the main speaker of the evening, kept us attentive and entertained with his experiences as director in charge of the hunt for the elusive UFO and its identification. Once again the need for spectroscopic data was emphasized (not without a certain amount of humor). Dr. Kessler expressed our sympathy by hoping that Dr. Condon's responsibilities with the UFO project would soon terminate and that he then would have the opportunity to proceed full speed with the revision of *The Theory of Atomic Structure.*

On Thursday morning, the last day of the symposium, Jesse Greenstein *Caltech* delivered an hour long review of the spectra of quasi-stellar sources and their interpretation. Although claiming his talk as comic relief, his plea for more fundamental spectroscopic information was highly relevant. Interpretation of astronomical phenomena relies heavily on the availability of such data as transition probabilities, and collision and excitation cross-sections, as well as the energy level arrays for many stages of ionization of the elements.

In conclusion, the truly international spirit of the symposium demonstrated that the problems of spectroscopy know no boundaries and that there exists a close knit, world wide community of enthusiastic scientists dedicated to vigorous and current research in spectroscopy. For the young and upcoming spectroscopist it was a unique opportunity to see and converse with some of the successful and mature figures in the history of spectroscopy, thus providing a lively continuity between the early years of spectroscopy and today. It was a very pleasant blending of the old with the new both in person and research in the problems of atomic spectroscopy.

Second SPSE Symposium on Unconventional Photographic Systems, Washington, D. C. 26–28 Oct. 1967

Reported by J. Gaynor, Bell & Howell Company

Following the highly successful First Symposium on Unconventional Photographic Systems in October 1964, the Society of Photographic Scientists and Engineers decided to sponsor this Second Symposium in 1967. The Symposium was dedicated to Jaromir Kosar whose sudden and untimely death grieved everyone who knew him. In memoriam, the New York Chapter of the

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