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STUDY ON THE ELECTRON GENERATION BY A MICRO-CHANNEL PLATE BASED ON EGS4 CALCULATIONS AND THE UNIVERSAL YIELD CURVE

B. S. Moon, S. H. Han, Y. K. Kim, C. E. Chung
Korea Atomic Energy Research Institute

Abstract - The conversion efficiency of a cesium iodine coated micro-channel plate is studied. We use the EGS4 code to transport photons and generated electrons until their energies become less than 1keV and 10keV respectively. Among the generated electrons, the emission from the secondary electrons located within the escape depth of 56nm from the photo-converter boundary is estimated by integrating the product of the secondary electrons with a probability depending only on their geometric locations. The secondary electron emission from the generated electrons of energy higher than 100eV is estimated by the 'universal yield curve'. The sum of these provides an estimate for the secondary electron yield and we show that results of applying this algorithm agree with known experimental results. Using this algorithm, we computed secondary electron emissions from a micro-channel plate used in a gas electron multiplier detector that is currently being developed at Korea Atomic Energy Research Institute.

INTRODUCTION

There have been various studies on photocathode materials to evaluate their conversion efficiency. Martin et al.[1] report the results of experiments performed to compare CsI, CsBr and a mixture of the two materials. They show that efficiency of CsI is better than that of CsBr, and that combining two different materials is no better than the least efficient component when the input X-ray energy is below 10keV. Burginyon et al.[2] made a comparative study on the detector efficiency of micro-channel plates with gold photocathode against BC422 plastic scintillator material for high X-ray energy in the range up to 100keV. Tremsin et al.[3] studied the gain of micro-channel plates with gold coated against nichrome coated.

In this paper, we use EGS4 calculations to compare the secondary electron emission by a micro-channel plate. The micro-channel plate is 0.5mm thick and has holes of diameter 25μm with pitch size 31μm. The top of the plate and inner parts of holes are assumed to be coated with a photocathode material. The plate is assumed to be made of PbO and the photocathode material is CsI with 1-5μm thickness. Some of the experimental results of Frumkin et al.[4] had to be used for estimating the electron range of secondary electrons due to the limitation of EGS4 for not being capable of transporting electrons of energy less than 10keV.

We start with calculating electron ranges in aluminum for different X-ray energies greater than 15keV, compare the results with experimental results[5] to see how much the limitations of EGS4 affect in transporting high energy electrons. Then to estimate the secondary electron emission from photocathode materials, we transport photons normally incident to a thin CsI plate using EGS4 until their energy become less than 1keV and the generated electrons less than 10keV. Then the results are compared with known experimental results.

The secondary electrons emitted from the plate are estimated in two parts. The first part is the secondary electrons generated near the plate boundary within the escape depth and the other part is the secondary electron yield from electrons of energy in the range from 100eV to 10keV. The first part is estimated by integrating the product of the number of secondary electrons generated and a probability function for electrons at different locations to get out of the plate. The second part is computed by using the 'universal yield curve'[4] along with the same probability function. We will check how the computed results based on this method compares with experimental results and will use this method to compute secondary electron emission from a hole of the micro-channel plate we use for our gas electron multiplier detector being developed.

SECONDARY ELECTRON EMISSION AND CONVERSION EFFICIENCY

In this section, we start with a comparison of electron ranges between computed values by EGS4 and experimental results. The incident electron is assumed to have energies greater than 15keV. Using EGS4, we computed how the electron flux changes as the electrons penetrate into photocathode materials assuming that the incident electron penetrates into the material as deep as where the generated secondary electron appears. Since we set the cutoff energy for transporting the electron to be at 10keV, the distance may be short by as much as 0.6μm which is the range for 10keV electron in aluminum [5]. Using the flux curves shown in Fig. 1, we computed the electron ranges for different energies and for different materials.

Table 1. Electron Range - Computed vs Measured

Energy(keV)	15	20	30	40	50	75	100	300	500	700
Known-Al(μm)	1.2	2.4	5.3	9.0	14	32	48	260	610	970
EGS4-Al(μm)	1.5	2.5	5.0	9.0	13	30	45	250	600	950
EGS4-CsI(μm)	0.6	1.5	2.0	4.0	5.5	12	20	110	250	350
EGS4-CsBr(μm)	0.9	1.5	3.0	5.5	8.0	20	30	170	350	500
EGS4-Au(μm)	0.3	0.6	1.0	1.5	2.2	6.0	12	45	60	8.5

Table 1 shows a summary of the calculated results for the four materials CsI, Al, CsBr and Au, along with the known values for Al in the second row. Recall that electron ranges are determined by examining tail parts of curves shown in fig.1 and hence that the numbers in the third row through sixth row in the above table have errors due to examiner's subjective judgment. Thus, the ranges in the third row obtained by EGS4 calculations for aluminum can be considered as comparable with the experimental results shown in the second row and the calculated ranges for other materials CsI, CsBr, and Au are valid.

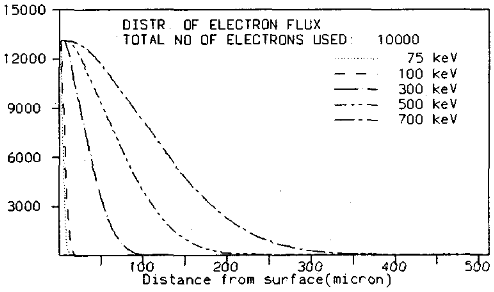

Fig. 1. Electron flux changes in aluminum

As a second validity check for our EGS4 calculations, we computed the detection yield[4] which is defined as the ratio of the number of detected events to the number of photons absorbed by the photocathode. Fig.2 shows an example of the detection yield curve computed for CsI using 100,000 normally incident photons with energy 60keV. The photons that made one or more interactions in CsI is considered to be absorbed by the photocathode material. To estimate the number of electrons emitted, we use the experimental results by Verma[7] which states that the escape depth of secondary electrons in CsI is 56nm when the energy of the electron is below 100eV.

If r is the distance from an electron to the nearest wall of the photocathode, then the probability p for the electron to move out to the hole can be computed by the ratio of A to $4\pi D^2$ where D is the escape depth and A is the area of a part of the sphere's surface with radius D surrounded by the points located distance r from the electron. When the ratio is computed, we obtain

$$p(r) = \frac{1}{2}\left(1 - \frac{r}{D}\right) \qquad \text{---------} \qquad (1)$$

where we will use D=56 nm. We divide the distance into 8 nm subintervals, assume the electron lies at the mid point, apply the above probability, and take the sum to obtain the number of emitted secondary electrons, i.e. to count the 'detected events'. Thus, the electron emission from within the escape depth from the boundary is computed as

$$\delta_0 = \int_0^D q(r)p(r)dr \approx \sum_{i=1}^{7} q_i p_i \qquad \text{-------} \qquad (2)$$

where q(r) is the number of electrons located at a distance r from the boundary. The computed results shown in Fig. 2 agree with the experimental results by Frumkin et al.[4] within 20% ~ 30% even though there are only four measured values in [4].

For the emission of secondary electrons generated by the electrons in CsI with energies from 100eV to 10keV, we use the 'universal yield curve'[6] given as below.

$$\delta = \delta_m \exp\left\{ - \frac{\left(\ln(\frac{E_p}{E_m}) \right)^2}{2\delta^2} \right\} \qquad \text{-------} \qquad (3)$$

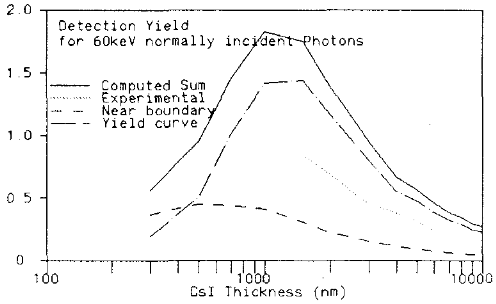

Fig. 2. Detection Yield for CsI calculated by EGS4

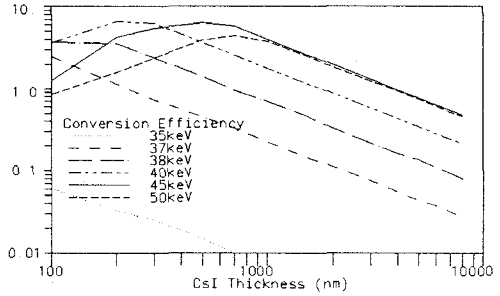

Fig. 3. CsI conversion efficiency calculated by EGS4

where δ is the electron emission yield, δ_m is the maximum of δ at electron energy E_m, and E_p is the primary electron energy. We will be using δ_m=20, E_m=3.3 keV, σ=1.6 for CsI following the experimental results of Scholtz et al.[6]. For MgO, we use δ_m=12, E_m=0.95 keV, and δ_m=1.5, E_m=0.4 keV for metals. Whenever EGS4 stops to transport high energy electron, we compute the electron yield by (3) and multiply it by the probability (1) where the escape depth D is replaced by the electron range estimated by [7] as

$$R = f \times E^{1.35}, \quad f = \frac{11.5 \times 10^{-6}}{4.51} \qquad \text{-------} \qquad (4)$$

In the above relation, E is the electron energy in keV and R is in Cm. The resulting numbers can be added to obtain an estimate for the total yield.

In Fig. 2, a computed detection yield curve is shown along with the experimental results by Frumkin[4]. The sum of two components of the detection yield; one from the near boundary secondary electrons and the other computed by the universal yield curve is used to calculate the number of electrons detected in computing the detector yield. One can see from the figure that the calculated values are within 100% difference from the measured values. Applying the above method for computing secondary electron emission from a CsI plate, we computed the conversion efficiency or equivalently the detector quantum efficiency which is the number of electrons emitted by the photo-converter per incident photon. The results of calculations for photons of energies 37keV to 42keV are shown in Fig. 3. When the curve for 60keV is compared with an experimental result by Frumkin[4], we find that the maximum calculated efficiency is about 20% higher, while the trend of the efficiency as the thickness increases looks the same.

SECONDARY ELECTRON EMISSION FROM AN MCP HOLE

In this section, we describe the results of computations for the secondary electrons generated by CsI coated micro-channel plate based on the method described in the previous section. The results of a comparative study on the amount of secondary electrons generated with respect to the thickness of the CsI coating and for few different X-ray energies are described. The micro-channel plates we plan to use for our GEM detectors have holes of 25μm in diameter with 37μm pitches, and 1 mm deep. We will be using these dimensions throughout our calculations except that the depth of holes where CsI is coated is 0.5 mm since only upper and lower parts of holes are coated.

In order to reduce the amount of calculations, we further assume that the micro-channel plate has only one hole with the dimensions described above and the rest is made of PbO with CsI coated. For each of the calculations, we used one million photons of a single energy incident to the plate with a random azimuthal angle Φ in $[0, 2\pi]$ and a polar angle θ in $[0, \alpha]$ where α is taken so that the incident photon will hit inside a disk of radius 37μm. The polar angle was taken so that it is a square root of a random number which was necessary to have a unit area on a sphere have equal probability of receiving a photon.

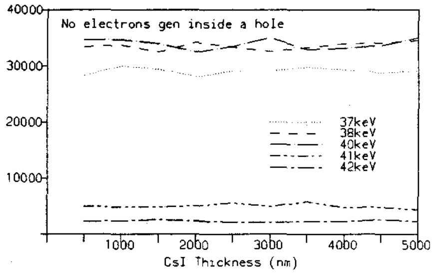

Fig. 4. Secondary Electrons Generated inside an MCP hole

The center axis of the hole is assumed to be coincident with the direction of normally incident photons. The results of calculations for photon energies from 50keV to 80 keV are shown in Fig. 4. Each curve is obtained from 10 calculations for thickness ranging from 0.5μm to 5μm with 0.5μm intervals. It is found that the high energy electrons generated inside the PbO material are not of a considerable amount and they are neglected. One can see from Fig. 4. that the number of electrons generated does not depend on the CsI thickness, and hence that more secondary electrons get absorbed by the photo-converter as the thickness gets larger.

The energy dependence of the electron counts is shown in Fig. 5. One can see from this figure that the most secondary electrons are generated when the input photon energy is in the range of 37keV to 45 keV.

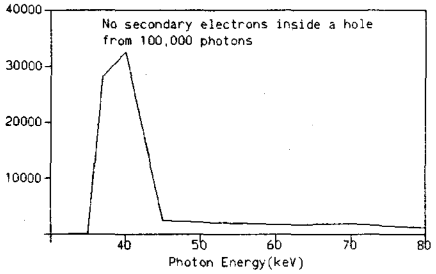

Fig. 5. Secondary electrons inside an MCP hole vs photon energy

CONCLUSIONS

Based on the known escape depth for the secondary electrons in CsI and the universal yield curve, we have developed an algorithm to compute the number of secondary electrons generated by a micro-channel plate using EGS4 computer code. To verify our algorithm, we computed the secondary electron emission and the conversion efficiency of a CsI plate, and compared the results with known experimental results. They are found to agree within 50 ~ 100% differences. We applied our algorithm to estimate the secondary electrons emitted into a hole of a micro-channel plate and found that the optimal input photon energy is in the range of 37keV ~ 45keV when CsI is used as a photocathode material. More extensive calculations are planned to compute optimal design parameters for the gas electron multiplier detector being developed at Korea Atomic Energy Research Institute.

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