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Very high quantum efficiency PMTs with bialkali photo-cathode

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Abstract

Since the mid-1960s and until today the classical PMTs with semitransparent bialkali photo-cathode provide peak Quantum Efficiency (QE) of ~25%. About 2 years ago we started a program with the PMT manufacturers Hamamatsu, Photonis and Electron Tubes for boosting up the QE of bialkali PMTs. In the mean time we have obtained several batches of experimental PMTs from the above-mentioned manufacturers and measured few samples with QE values as high as 32–36% in the peak. Also, we want to report on the modest (5–7) % increase of the QE of the PMTs with flat input window after sandblasting. Earlier we have reported that by coating the hemi-spherical input window of bialkali PMTs with a milky layer we could enhance their QE by ~10–20% for wavelengths ~320 nm. Assuming that the industry can reliably produce PMTs with 32–35% QE in the peak, by applying the milky layer coating technique to the PMTs with hemi-spherical input window one shall be able to achieve peak QE values of ~35–40%. Being by an order of magnitude cheaper and providing a matching level of QE such PMTs will become strong competitors for hybrid photo-diodes (HPD) with GaAsP photo-cathode.

PACS: 80

Keywords: Quantum efficiency; Photo-multiplier tubes; Bialkali photo-cathode; Light sensors; Low light level sensors

1. Introduction

The classical PMTs were invented in the mid-1930s. Their initial very low quantum QE of <1% soon has been improved to the level of a few percent and in the mid-1960s to the level of ~25% in the peak. Since then one cannot report any significant improvement of the QE. Improvement of the QE could be very important for many experiments and applications where one deals with scarce photon statistics. For example, all of the air Cherenkov and air fluorescence experiments are using large reflector sizes in order to collect photons from extended air showers. Most of these experiments have strong motivation to achieve a low threshold setting and the classical way one follows is to build reflectors of larger and larger size. The MAGIC air Cherenkov telescope, for example, has a reflector diameter of 17 m and still even larger reflector sizes are currently under discussions and/or in the design phase [1]. The stringent mechanical and optical constraints make the construction of reflectors of very large size prohibitively expensive.

Application of PMTs of higher QE can be considered as equivalent to building a telescope of larger reflector size. It is superfluous to mention that the use of PMTs with higher QE shall be substantially easier and cheaper than the construction of a reflector of equivalent larger size.

In recent couple of years we were collaborating with Hamamatsu, Electron Tubes and Photonis on the development of bialkali PMTs with higher QE. In the past time we have obtained several batches of PMTs of very high QE from the above manufacturers. Below we report on few PMT samples that show peak QE in the range of 32–36%. By using the front window matt lacquer coating technique it shall be possible for PMTs with hemi-spherical input window to further increase their QE towards the 35–40% level [2].

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2. The measurements of very high QE PMTs

In our measurements as a rule we have illuminated the central 15 mm diameter of PMT photo-cathodes. After applying a potential difference of 200 V between the photo-cathode and the 1st dynode we measured the photo-current. As a reference detector we used a calibrated diode of 10 mm × 10 mm size from Hamamatsu in all the measurements. A spectrophotometer assembled from commercial parts together with the calibrated diode was driven and read out via Lab-View under the computer control. We calculated the error of the QE measurements to be 2.34%, the major part being due to the calibration precision of 2% of the used photo-diode.

- *Hamamatsu PMTs*: The first measured tube from Hamamatsu of type R878 (serial #WS7454) showed a peak QE of 32–33% while the second one (serial #WS7354) showed a peak QE of 36% (see Fig. 1). For the latter tube the QE is above 30% for the wavelength range 320–460 nm and it is ~35% for the 370–420 nm range. Recently we have obtained two samples of 1″ size bialkali PMTs of the type Hamamatsu R7373A with hemi-spherical input window. Our measurements have confirmed the data from the manufacturer showing that these PMTs provide peak QE's of 31.5% and 33. 5%, respectively. Hamamatsu is reporting on high reproducibility and yield of improved light sensors.
- *Photonis PMTs*: The 3″ diameter Photonis XP-5312 type PMT #101521 showed a peak QE slightly more than ~30% while the PMT #101158 showed a peak QE of 29%. Unlike those two PMTs the 2″ experimental PMT of the type XP-3422 (serial #82410) showed a peak QE of 34% (see Fig. 2). Note that the QE curve of that PMT is unusually narrow. The steep drop of the QE below the wavelength of ~370 nm shall be because of the used simple type of glass with relatively low transmission in the near UV while the drop of the QE above 400 nm could be explained by the selected chemical composition of the photo-cathode materials as well as by the absence of specific technological processes in their treatment. Photonis provided us with further results of measurements of their PMTs with QE values in excess of ~33–35%. According to Photonis they have a reasonably high yield of PMTs with very high QE.
- *Electron Tubes PMTs*: The first tested PMT from Electron Tubes of the type 9265 KA showed a peak QE of 28% (serial #6744). The second tube (serial #6731) was sandblasted for enhanced QE and showed a peak QE of 30% (see Fig. 3). Note please that the QE of that tube was measured before the sandblasting and was by 5–7% less than the value reported above [3]. This is in agreement with the known fact that for flat entrance window PMTs one can slightly increase the QE by making the window surface matt: the path length of the photons scattered preferentially under large angles inside the photo-cathode material is increased while the probability for an electron to leave the photo-cathode remains the same. Also Electron Tubes is reporting on ~10% increase of the QE of their bialkali type PMTs.

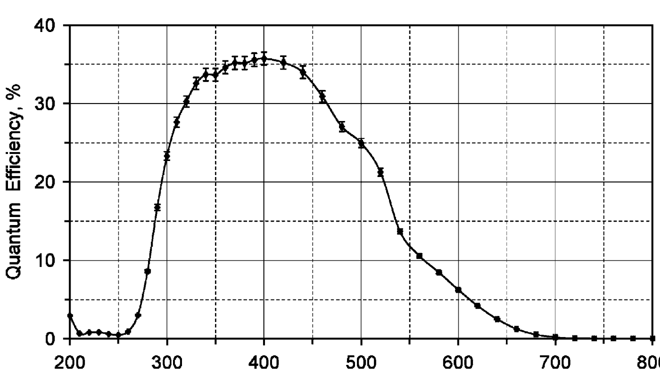

Fig. 1. Measured QE versus wavelength for the Hamamatsu PMT of type R878 (serial # WS7354). The peak QE is ~36%.

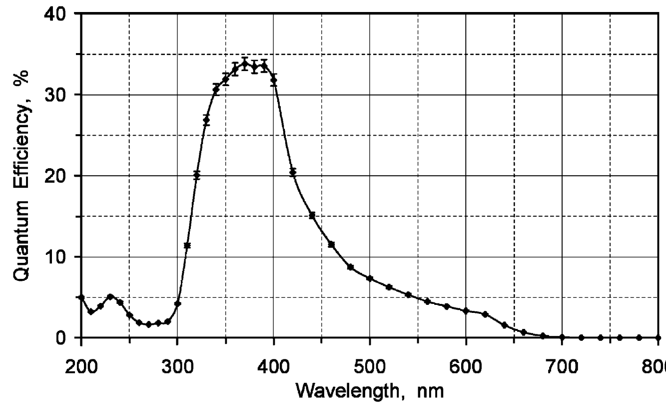

Fig. 2. Measured QE versus wavelength for the Photonis PMT of type XP3422 (serial # 82410). The peak QE is ~34%.

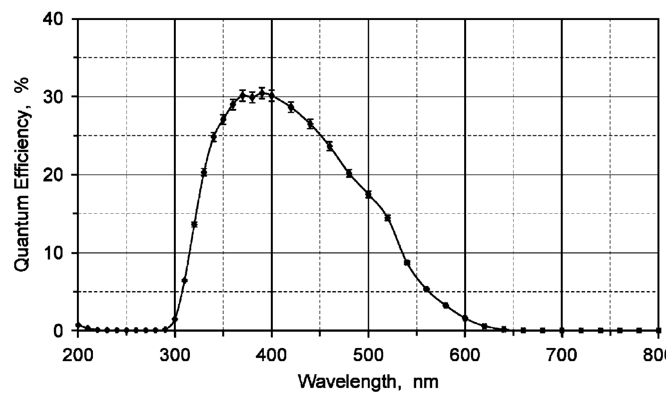

Fig. 3. Measured QE versus wavelength for the Electron Tubes PMT of type ET9265KA (serial # 67). The flat front window is sandblasted, resulting in 5–7% higher QE. The peak QE is ~30%.

3. Discussion

One may assume that achievement of the higher QE can be explained by the following possible reasons:

- Recycling of the photons that pass through the semi-transparent photo-cathode without kicking out of an electron by the PMT input chamber (increasing the reflectivity of the surrounding parts).
- By special *tuning of the thickness and composition* of the photo-cathode for optimal interaction with light, by application of new processes.
- By reducing the reflectivity from the photo-cathode using an anti-reflective layer between the photo-cathode and the glass window.

During the recent Beaune-2005 conference the representative of Hamamatsu Photonics reported about their *success in developing a new process* to produce photo-cathodes with an average QE of ~33.7% in the peak [4]. A similar statement came from Photonis.

One may conclude that the PMT manufacturers have improved the technology of producing bialkali photo-cathodes, so that now they can produce PMTs with peak QE ~32–35%.

4. Conclusions

The entire astronomy, astrophysics and astro-particle physics community as well as many other disciplines in science (for example, biology, biophysics) and technology (micro-LIDARs, …) could strongly benefit from very high QE photo-cathodes.

Please note, that by using the milky lacquer coating technique for PMTs with hemispherical shape input window one can anticipate a further ~10–20% increase of the QE of very high QE PMTs. For example, assuming that the PMT manufacturers could reliably produce hemispherical window PMTs of 32–35% QE in the peak, by applying the above mentioned technique one can obtain peak QE values of ~35–40%. Compared to bare, uncoated PMT such a PMT could provide up to a ~60% *higher QE*. The expected cost of the very high QE PMTs cannot be much different from that of the usual PMTs, the difference being just a somewhat different treatment of the photo-cathode. On the other hand the QE of these PMTs will become comparable to the QE of Hybrid Photo-Diodes with GaAsP photo-cathode [5] while the cost of the latter is by one-order of magnitude higher than the cost of PMTs.

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