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Tools for the inspection of PWO//APD gluing

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Abstract

The light produced in each of the 60 thousand $PbWO_4$ (PWO) crystals of the CMS barrel electromagnetic calorimeter will be readout by Avalanche Photodiodes (APD). The ratio detected to emitted photons also depends on the PWO//APD gluing quality that must be checked before the crystal mounting inside the calorimeter. In this paper two different tools are proposed: one for the visual inspection of the glue layer and the other for the quantitative evaluation of transmittance improvement when the glue replaces the air at the PWO//APD interface. Both the instruments are rugged and cheap. A sequence of operations and checks to be done in the Regional Centres is proposed.

1 Introduction

In a short time the construction of the CMS electromagnetic calorimeter [1] will start. The scintillating component of this new detector consists in 80 thousand $PbWO_4$ crystals. The light produced in each crystal of the barrel part (~ 60 000) will be readout by two Avalanche Photodiodes (APD). Because of the large dimensions of the project, the quality controls and mounting of the calorimeter require semi-automatic procedures. The study of automatic measurement set-ups is under-way, a proposal is accurately described in [2]. Crystals will be tested, coupled with APD, assembled in sub modules anf finally in modules, at two Regional Centres located at CERN and Rome (ENEA).

Among the different construction steps, the gluing of the APD on the crystal is a particularly delicate task because, when the optical contact is poor, the ratio of detected to emitted photons can be significantly reduced. The PWO//APD optical contact is poor when the glue: i) does not fill the whole interface; ii) contains air bubbles; iii) absorbs photons. The first two cases occur when the gluing dispenser works in no optimal conditions; the third, when the glue is not appropriate or degraded. In any case the check of the good gluing quality before the crystal allocation in the calorimeter, is strongly recommended. In this paper two different tools are proposed: one for the visual inspection of the glue layer and the other for the quantitative evaluation of transmittance improvement when the glue replace the air at the PWO//APD interface. Both the instruments are rugged and inexpensive.

2 *Bubble-viewer*: a qualitative tool

The first proposed tool is the *bubble-viewer*; it allows the visual inspection of the glue layer to pinpoint possible mismatching, bubbles and impurities. The scheme of the *bubble-viewer* is reported in figure 1. The PWO//APD interface is illuminated by a commercial focused halogen torch light, pointed on the small base of the tapered crystal with an incidence angle wide enough to avoid the reflected beam entering in the optics. Due to the PWO high refractive index (n_{PWO}~2.3 [3]), the PWO//APD interface acts as a virtual source placed about 10 cm far from the PWO small base [4]. The two lenses (*f* = 8 cm) have different tasks. The first one is about 6 cm far from the PWO, so that the PWO//APD interface and its real image are both about 2*f* far from the lens. The image, real and external to the PWO, is treated by the second lens working like a magnifying lens. The final image is virtual, upset and about 25 cm far from the human eye, that is the *least distance of distinct vision*. With this set up the *bubble-viewer* has a magnification ratio of about 3 (*least distance of distinct vision* / *f*) which allows a spatial resolution of 25 µm at the PWO//APD interface (*magnification* (3) x *eye visual acuity* (1/60 deg) x *image distance* (25 cm)) [4].

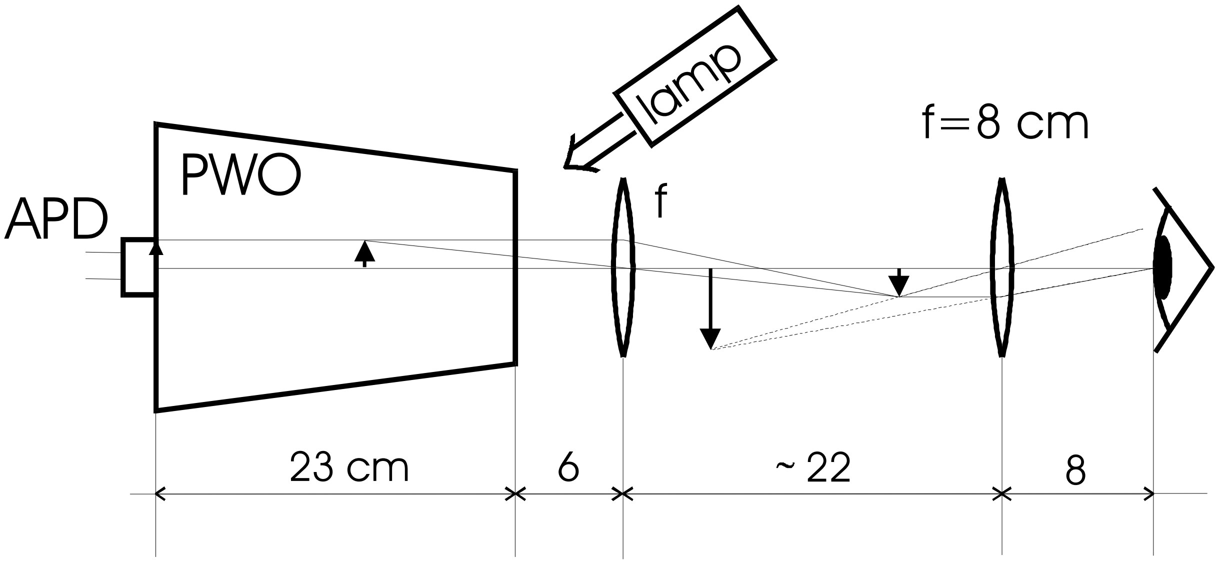
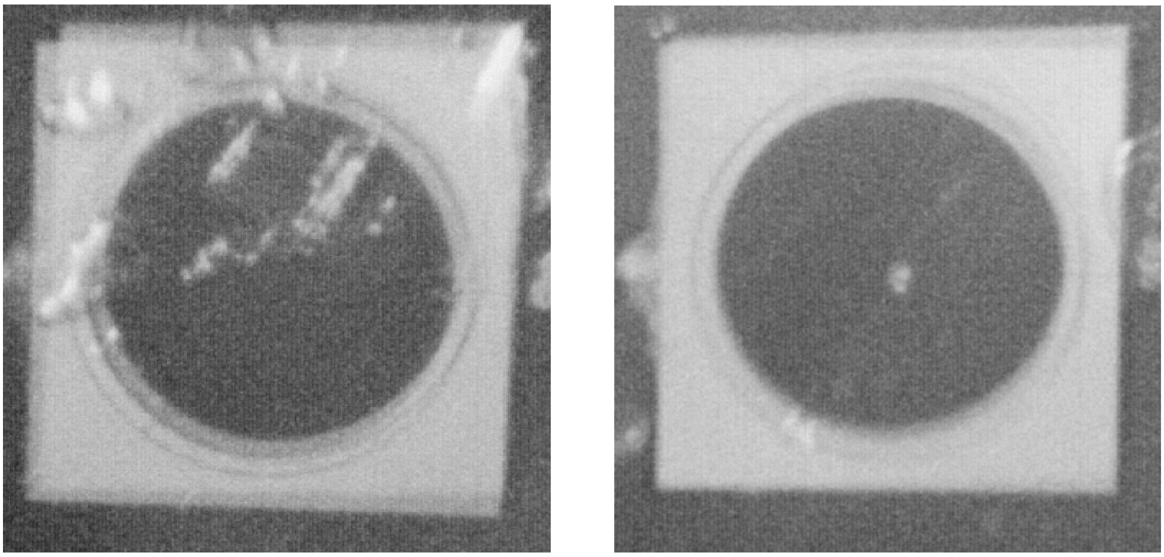


Figure 1: *bubble-viewer*

The *bubble-viewer* was tested by examining the PWO//APD interface filled with the Dow Corning 02-3067 optical grease in several cases. Figure 2a reports the image of the PWO//APD interface in the case of a poor optical matching: the optical grease does not completely fill the interface area and includes several air bubbles. Figure 2b shows a satisfactory optical matching: only a very small air bubble is visible. Because of the PWO birefringence [3], the APD image is lightly twined. This twining could be avoided by introducing a polarizer.

The PWO-APD gluing should be performed on several crystals at time, fixed on a dedicated tray, in vertical position. If this is the case, the introduction of a plane mirror, at 45 deg respect to the crystal longitudinal axis, between the PWO and the first lens, allows to arrange the *bubble-viewer* horizontally for a more comfortable use.



2a 2b

Figure 2: (2a) image of the PWO//APD interface in the case of a poor optical matching, the optical grease does not completely fill the interface area and includes several air bubbles. (2b) satisfactory optical matching: only a very small air bubble is visible. Because of the PWO birefringence, the APD image is lightly twined.

3 *Bubble-meter*: a quantitative tool by the APD readout

Elsewhere [5] the optical characterisation of EG&G and Hamamatsu APD surfaces and the optical coupling PWO-APD are widely discussed. As a result the light transmission from the PWO to the Si wafer of the APD can be computed on the basis of the knowledge of thicknesses and optical properties of the crossed media. Figure 3 reports the ratio of the transmittances from PWO to Si wafer of a Hamamatsu APD coated with 55nm Si_3N_4 film (CC type)

$$\eta(\lambda,\vartheta) = \frac{T(PWO//DG//W//\,Si_3N_4(55nm)//Si)}{T(PWO//air//W//\,Si_3N_4(55nm)//Si)} \tag{1}$$

(where DG is 0.1 mm thick layer of the Dow Corning 02-3067 optical grease and W is the APD silicon-rubber protective window of about 0.5 mm) versus wavelength at normal incidence and versus the incidence angle, PWO side, at 430 nm corresponding to the PWO scintillation peak [6]. When the air is replaced by the optical grease the transmittance improves; this improvement shows some dependence on wavelength and is almost a constant for incidence angle less than 10 deg.

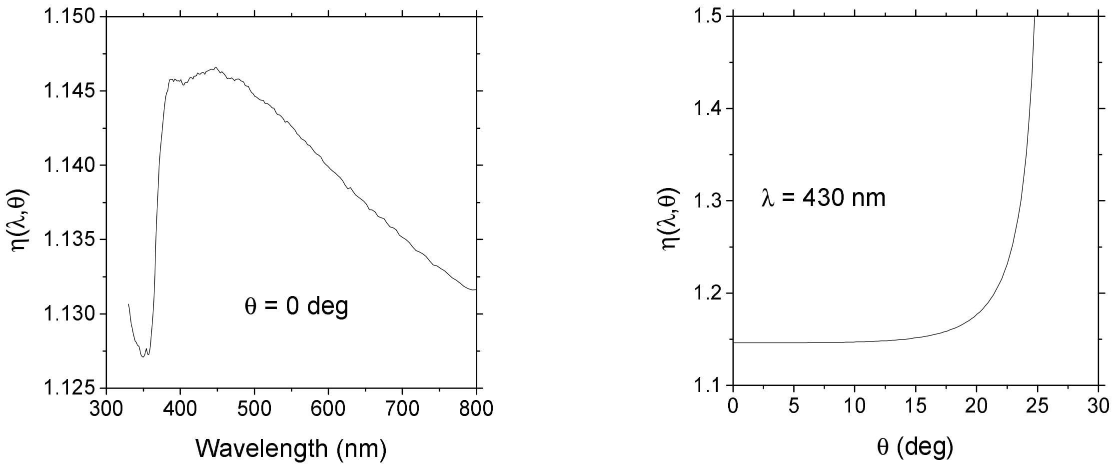


Figure 3: improvement of the transmittance from PWO to Si wafer, when the optical grease replace the air at the PWO//APD interface, versus wavelength at normal incidence and versus incidence angle at the PWO scintillation peak (430 nm)

The forecast transmittance improvement gives a quantitative criterion to establish the gluing quality when the experimental value is available. A very simple way to measure the transmittance improvement is to illuminate the interface PWO//APD and use the APD itself as detector, measuring the signals after and before the gluing. The precision of that measurement strongly depends on the stability of the light source and APD gain. The gain is very stable for both bias and temperature changes when the APD is biased in the region where no amplification takes place (between 10 and 50 V). Moreover the APD low voltage bias needs only a cheap power supply. On the whole, good results were obtained with the low cost set-up reported in figure 4, named *bubble-meter*. As a matter of fact, LEDs represent a low cost very stable light source and a remarkable variety, as spectrum emission and directionality, is now available. Figure 5 shows the experimentally measured emission spectra of some LEDs. The Kingbright L53mbd LED results to be very interesting because its emission spectrum is peaked at 430 nm, similarly to the PWO scintillation spectrum.

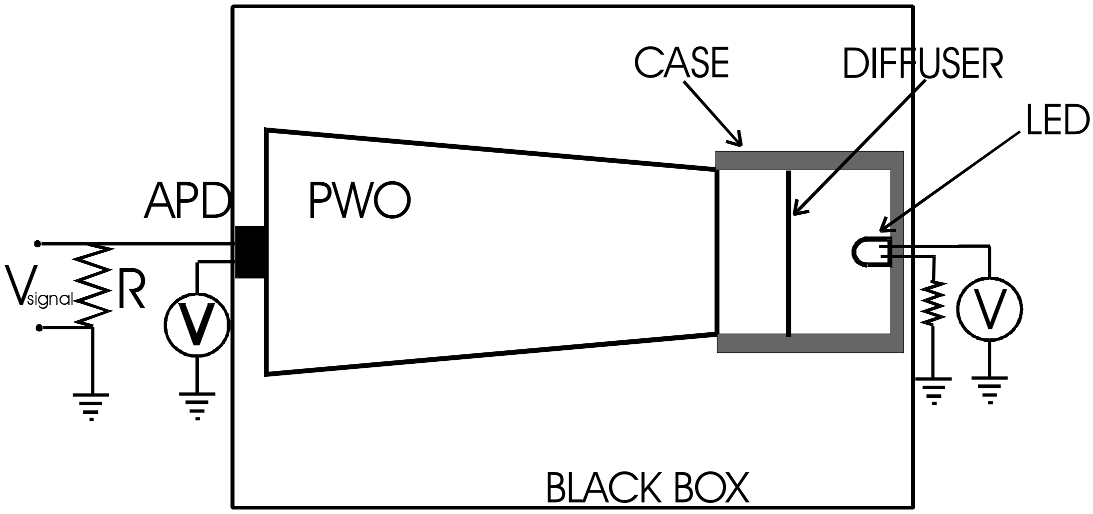


Figure 4: *bubble meter*

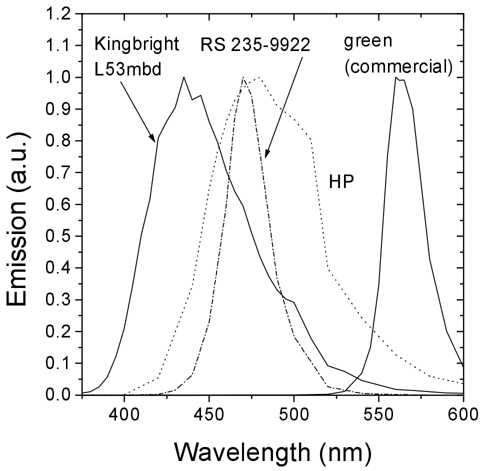


Figure 5: emission spectra of some LEDs

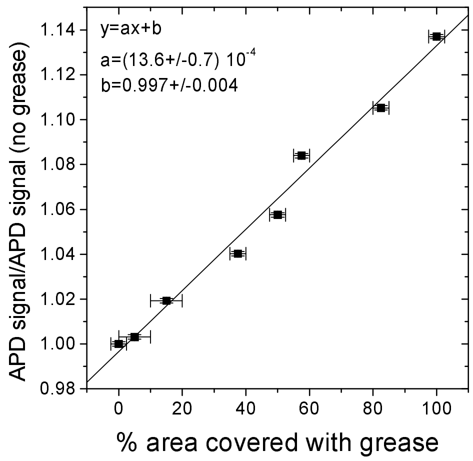


Figure 6: APD signal improvements, obtained for PWO//APD matchings of different quality, related with the percentage of the APD active area effectively covered by the optical grease, as eye-estimated with *bubble-viewer*

In order to be sure that all detected photons come from the small base of the PWO crystal and not from the lateral surfaces, the LED is enclosed in the black case, also reported in figure 4, having the circular section (diameter ϕ) just less than the PWO small base. As a second function, the rigid case allows the exact repositioning of the LED with a good reproducibility of the APD signal. Moreover in the black case there is a light diffuser (a thin paper sheet) making homogeneous the lighting of the PWO//APD interface and, consequently, the APD signal insensitive on the APD position. The distance of the diffuser from the small PWO base (L) gives the maximum limit to the possible incidence angles of photons impinging on the PWO small base and therefore, taking into account the light refraction [4], on the PWO//APD interface :

$$\theta \leq arsin\left(\frac{sin\left(artg\frac{\phi}{L}\right)}{n_{PWO}}\right) \qquad (2)$$

In our case ϕ=18 mm and setting L=60 mm, $\theta \leq 10$ deg, that is, as above discussed, the range where transmittance does not sensitively depend on the incidence angle. The effective APD signal improvement must be compared with the ratio η of equation 1, computed at normal incidence and averaged on the LED spectral emission $S(\lambda)$ and the crystal longitudinal transmittance $T(\lambda)$

$$\eta_{eff} = \frac{\int_{400}^{500} \eta(\lambda, \theta = 0) S(\lambda) T(\lambda)\, d\lambda}{\int_{400}^{500} S(\lambda) T(\lambda)\, d\lambda} \qquad (3)$$

The error of the *bubble-meter* readout, including LED instability, optical alignment reproducibility and digital voltmeter sensitivity (±0.01 mV), is about ±0.1% in the following conditions: i) 10 minutes warm-up; ii) the Kingbright L53mbd LED is supplied by a common laboratory DC supplier and protected with a 300 Ω resistance; iii) the APD is supplied at 30 V, so that the gain is unitary; iv) the signal is measured by a digital voltmeter at the 1MΩ load resistance; v) a black box totally screens LED, PWO and APD from the environment light. The last item loses importance when a more sophisticated measurement system, like a synchronous revelation technique (light chopper and lock-in amplifier) is adopted, but this would dramatically increase the cost so here it was not considered.

The *bubble-meter* effectiveness is proved by figure 6, where the effective APD signal improvements (η_{eff}), obtained for PWO//APD matching of different quality, appears linearly related with the percentage of the APD active area actually covered by the optical grease, as eye-estimated with the previously described *bubble-viewer*. A finer prove of the *bubble-meter* effectiveness is the η_{eff} dependence on the grease layer thickness, clearly observable when the grease totally cover the APD active area: at the beginning, the APD was pressed on the PWO without special care and η_{eff} ranging between 1.133 and 1.140 was observed although the single measure precision was ±0.001. On the other side assuming the grease layer 0.1 mm thick, by Eq. 3 the η_{eff} expected value for the PWO1451 is 0.146, that is higher than the observed range. After a deeper investigation the reason of this behaviour was found in the absorption length of the Down Corning 02-3067 optical grease (3.65±0.06 cm @ 430 nm) [5] that is enough large to make η_{eff} sensitive to the grease thickness. As a matter of fact: i) the rubber window of the used Hamamatsu APD resulted to be 0.25 mm depressed respect to the capsule, so that the expected best signal improvement is 1.141 instead of 1.146; ii) greater signal improvements, till to 1.140, were obtained when the APD was strongly pressed to the PWO crystal.

It should be noticed the low dependence of the η_{eff} expected value on the punctual longitudinal transmittance of the crystal: the expected value does not change (with the precision of ±0.001) when the true PWO1451 transmittance is replaced with the transmittance of more recent crystals. This makes the *bubble-meter* no suffering for errors on the longitudinal transmittance.

As a conclusion, in the case of no absorbing coupling medium, η_{eff} does not depend on the actual thickness of the PWO//APD interface and the *bubble-meter* allows measurement of bubbles up to 0.7% of the APD active area.

3 Gluing and check at the Regional Centre

At the Regional Centre, the gluing table will be equipped with the *bubble-viewer* and the *bubble-meter*. Both instruments must be positioned by a movable system that easily allow their turn-over on the crystals. Gluing and check should be accomplished according to the following procedure:

1) The tray with PWO crystals is placed on the gluing table.
2) The APDs are faced, without glue, to the crystals by the proper mechanical system [5].
3) The *bubble-meter* is successively positioned over each crystal and the APD signals are recorded.
4) The APDs are glued to the PWO crystals.
5) The glue layer of each couple PWO-APD is examined by the *bubble-viewer*. When bubbles are visible or the

APD active area is not completely covered, the gluing must be repeated.

6) The same of item 3

7) The gluings showing an APD signal improvement in good agreement with the forecast value are passed, the others are rejected.

4 Conclusions

Among the different construction steps of the CMS electromagnetic calorimeter, the gluing of the APD on the PWO crystal is a particularly delicate task because, when the optical contact is poor, the ratio detected to emitted photons is reduced. The check of the gluing effectiveness before the crystal allocation in the calorimeter, is strongly recommended. For this purpose two rugged and inexpensive tools are proposed: the *bubble-viewer* and the *bubble-meter*. In the Regional Centre, both these tools should be mounted on the gluing table by a movable system that easily allow their turn-over on the crystals. The *bubble-viewer* allows the visual inspection of the glue layer to pinpoint possible mismatching, bubbles and impurities. The *bubble-meter* gives a quantitative evaluation of the gluing quality by comparing the experimental APD signal improvement with the expected transmittance improvement, when the glue replaces the air at the PWO//APD interface. As a matter of fact, the transmittance, from the PWO to the Si wafer of the APD, can be computed on the basis of the knowledge of thicknesses and optical properties of the crossed media. On the other hand, even in the actual phase of research and development, the optical properties of APDs belonging to the same batch are very similar to each other. Then, in the phase of the calorimeter construction, the transmittance improvement at the PWO//APD interface forecast for the adopted APD structure is expected to be the same for all APDs and represents a criterion to pass o reject each PWO-APD gluing.

Beyond the application in the regional centre, at this time the *bubble-meter* can be also useful to compare the effectiveness of the different glue candidate for the PWO//APD sticking.

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