Characterization of MPPC coupled organic scintillator for RFP SXR spectra detection.

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Background

The detailed characterization of electron distribution function in RFPs is crucial in order to understand energy transfer between particle and magnetic field and to better understand the dynamo mechanism. SXR emission spectra is in principle able to return line-integrated informations on the electron energy distribution with a time resolution high enough (ms order) to discriminate different phases between Dynamo Reconnection Events (DRE) [1]. Pulse height analysis of SXR spectra has already been implemented [2] with APD detectors; in the following the possibility of using organic scintillators together with silicon photomultipliers is analyzed. With respect to APD, Silicon photomultipliers (or Multi Pixel Photon Counter, MPPC hereafter) offer higher gain, even taking into account the scintillator low conversion efficiency. Moreover, the detector can be shielded and possibly fiber-coupled with the scintillator, reducing noise and easing access and eventually cooling. Compared to vacuum photomultipliers, MPPC are insensitive to magnetic field and require much lower bias voltage, at the price of higher noise and non-linearity.

MPPC and scintillator choiche

The requirements on detection speed limits the scintillators choiche practically to organic materials; EJ-256 ® ([4]), with a lead content of 1.5 %, has been identified as a good compromise between speed, low energy response, output wavelegth (tab. 1).

The value of lhe linear attenuation coeffient μ_l practically sets a lower limit to the scintillator depth, of the order of a few mm in the 10 keV range, which corresponds to the energy range of interest. Actually, the lower energy limit is determined by the response curve of the scintillator (fig 1). For testing purposes, the scintillators have been manifactured in 3 x 3 x 50 mm prisms, and covered

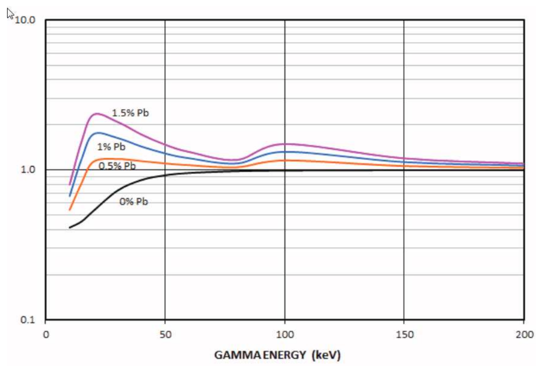

Figure 1: *Scintillation efficiency for EJ-256 material [4], as a ratio of anthracene (a standard material) response.*

response time ns	η(photons/keV)	output λ (nm)	LAC μ_L cm^{-1} @ 10keV
2.1	7700	425	4.07

Table 1: EJ 256 properties

with a reflective layer on the long faces; the uncoated ends are intended to be coupled with the MPPC.

The figures of merit involved in the MPPC choice are the dimensions (in order to match the scintillator exit area) and the detection speed; in particular, the lower the pile-up probability the higher the possible count rate.

From a practical point of view, a silicon MPPC is a matrix of parallel photodiodes, each one operating in Geiger-mode ($V_{bias} > V_{breakdown}$) and hence acting as a switch; a quenching resistor R_q is used to limit the current in each pixel. If C_p is the photodiode junction capacitance, switch on, recovery time and peak current are determined by [5]:

$$\begin{aligned} t_{on} &\simeq R_s C_p \\ t_{off} &\simeq R_q C_p \\ I_{peak} &\simeq (V_{bias} - V_{br})/(R_q + R_s) \end{aligned}$$

where $R_q \approx 10^5\Omega$ and R_s the photodiode dynamic resistance in breakdown conditions.

Hamamatsu ® MPPC module S12572-015 (3x3 mm, 15 μm pixels) and S12571-015 (1x1 mm) has been used as detectors. Both components ensure a suffient pixel number to be linear for the foreseen photon budget; S12571-015 is faster but suffers from a lower area and hence a worse coupling with the scintillator.

The x-ray source is a Hamamatsu vacuum tetrode (series N7599); it can produce a brehmstrahlung spectrum whose cutoff energy is determined by the supply anode voltage and limited to 12 keV.

Estimation of the photon budget

The number of visible n_{vis} photons reaching the detector for each x-ray photon with E_ν energy depends on the scintillator efficiency η_s, from the scintillators optical efficiency η_o and from the coupling η_c.

$$n_{vis} = E_\nu \eta_s \eta_o \eta_c \simeq 7 ph/keV \eta_o$$

The factor η_o can be estimated assuming an isotropic light emission, perfect transmission for totally reflected photon and integrating the reflection losses L_r along the scintillator for the others visible photons:

$$\eta_o = \frac{1}{2\pi}\left(\int_{\theta=0}^{\theta=\theta_{tr}} d\Omega + \int_{\theta=\theta_{tr}}^{\theta=\pi/2} \langle(1-L_r)_\theta\rangle\, d\Omega\right) =$$
$$\simeq 0.4 + \frac{1}{2\pi}\int_{\theta=\theta_{tr}}^{\theta=\pi/2}\int_0^{l_{max}} (1-L_r)^{\frac{l}{w\,cos(\theta)}}\, dl\, d\Omega$$

with dΩ the solid angle differential, and θ_{tr} the total reflection angle. For the polyvinyltoluene refractive index n=1.58, $\theta_{tr} = sin^{-1}(1/1.58) \simeq 0.69\, rad$. With an half l=50 mm, 3 mm width w and $L_r \simeq 0.1$, the second term can be estimated at around 0.3; the longer the scinitllator, the lower the second term contribution.

The upper limit for the detected photon n_{vis} @ 10 keV is around 40. When going to photo-electrons, this value has to be further reduced in order to account for the detector fill factor; this clearly affects strongly the uncertainty on xray energy measure.

Tests and results

The MPPC breakdown voltage V_{br} resulted to be 72 +/-0.5 V; in the measurements, both 74 and 75 V have been used as biasing voltage. The MPPC anodic exit is connected to ground with a 12 $k\Omega$ resistor and has been acquired with a Yokogawa DL4200 oscilloscope; the scintillator is placed 50 mm in front of the x-ray tube exit window. The single-photon noise level (dark counts) can be estimated from the single pixel peak current (eq. 1), $I_{peak} \simeq 2 \cdot 10^{-5} A$, equivalent to 1 mV on a 50 Ω cable impedance; consequently, the expected signal for an xray event should lay in the 10 mV range. The acquired trace is analyzed by autocorrelation with a given pulse shape; fig 2 (up) summarizes the results for different x-ray fluxes (flux is maximun with the control grid voltage V_{grid}= 22 V). While SXR events are clearly detected, there is no sharp cutoff at the high energy end, indicating that the overall photon budget is too low and statistical

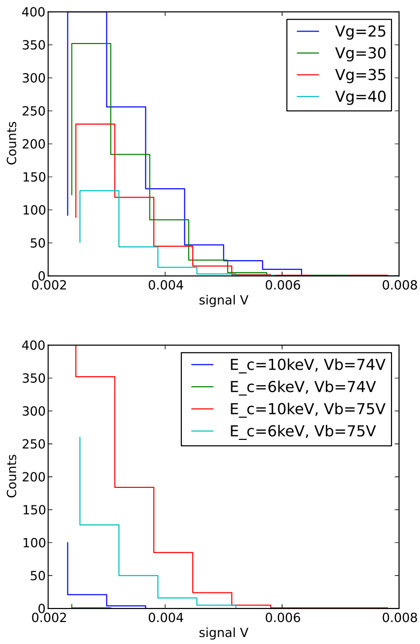

Figure 2: *counts for different xray fluxes (up) and cutoff energies (down)*

noise plays a major role. Fig 2 (down) shows the response at 6 keV compared to 10 keV for the same xray flux; the signal level does not scale as the cutoff energy; a possible cutoff in the scintillator response has to be taken into account.

Conclusions and future work

The combination of an organic scintillator and a silicon photomultipier proved to work in in geometries and energy ranges (3-10 keV) which are of interest for RFP's. On the other hand, energy discrimination of incident xray photons is problematic. In order to increase the photon budget, a double detector layout can be used (see fig 3), taking also advantage of a coincidence counter to suppress the dark-count contribution to noise. A second solution is the renounce to PHA, using the system as a flux monitor and exploiting the high elongation of the scintillator in order to increase sensitivity (scintillation fibers can also be foreseen).

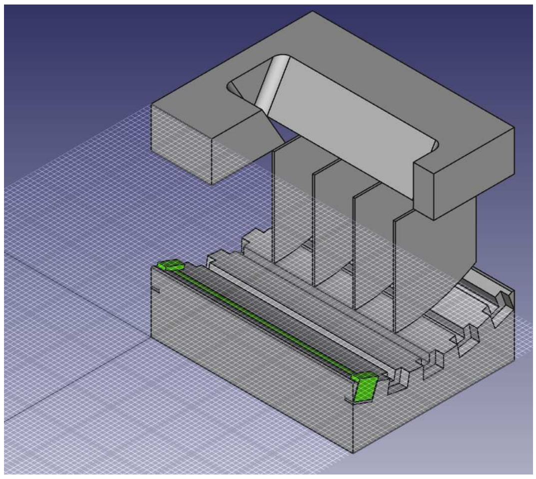

Figure 3: *possible arrangement for a scintillator array in a multichord diagnostic. Each scintillator is terminated with two MPPC*

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