THE APPLICATION OF THE BrillLanCe SERIES SCINTILLATION DETECTOR IN THE SPECTROMETER OF NEUTRAL PARTICLES FOR THE SATELLITE EXPERIMENT ZINA-NT

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Spectrometric detector complex ZINA-NT is intended to study a radiation conditions onboard satellite and characteristics of hard X-ray and gamma-ray fluxes from GRB, solar flares and to detect other non-stationary fluxes of cosmic gamma-rays. The advantages for using of this new detector for modification of present neutral particles detector on the base of CsI(Tl) are discussed. Scintillation detectors based on BrillLanCe series crystal have got very small lighting time, an excellent energy resolution and light output, more intensive than devices based on CsI(Tl). Using of BrillLanCe series crystal instead of CsI(Tl) ones allows to detect terrestrial gamma flashes (TGF), gamma ray bursts (GRB) and solar flares with smaller time durations and intensities. Moreover, the counts rate linearity region of BrillLanCe detectors is extended up to 10^6 s^{-1} and it allows to observe a very intensive events. So, the using of such type of detector permits us the possibility to separate gamma-quanta and neutrons on the timescales less than 50 microseconds.

Keywords: Pulse-shape discrimination; BrillLanCe series scintillators; detectors for satellite experiments.

1. Introduction

Spectrometric complex of scientific instruments ZINA-NT consists of multilayer scintillation spectrometer of charged particles (MSS)^{1,2} and detector of neutral particles (DNP)³. Data acquisition and registration of scientific information system (SSOI)^{4,5} is part of multilayer scintillation spectrometer but used for detector of neutral particles too.

The tasks of the experiment will be space weather and magnetospheric particles flows monitoring, studying flows of charged particles and neutrons during solar flares, investigation of X-ray and γ -emission up to 300 MeV during solar flares

(including 15.11 MeV and 20.58 MeV lines), Gamma Ray Bursts (GRB) and Terrestrial Gamma Flashes (TGF). Also DNP detector will allow detailed investigation of registered events energy spectra in wide band.

In 2011 it is planned to create experimental sample of apparatus. The experiment ZINA-NT will be installed onboard "Meteor-M" satellite which will be launched in 2015.

2. ZINA-NT apparatus short description

Multilayer Scintillation Spectrometer of charged particles (MSS) includes Multilayer Scintillation Detector (MSD) with high speed amplifiers and data acquisition and registration of scientific information system (SSOI). Main parameters of MSD detector and its outward view are presented in Table 1 and Fig 1a respectively. MSD consists of ten plates (C1-C10) from polystyrene scintillator (each of the top two plates divides by four strips) with different size viewed by 24 photomultipliers. Top three plates produce the trigger signal and plates from 3 to 9 are used as charged particles calorimeter. Bottom plate works as anticoincidence shield with efficiency better than 0.99.

The construction and the function diagram of DNP are presented on Fig 1b and Fig 2. This device consists of spectrometric detector C11 on the base of crystal scintillator for hard X-ray and gamma-ray analysis fully surrounded by plastic anticoincidence shield (detectors C12-C14). This complex of detectors viewed by three groups of photomultipliers. Registration efficiency of anticoincidence shield is about 0.999 for reliable neutral particles identification. For this system trigger will be:

$$MST = (\overline{AC}) \text{ AND } C11, \quad (1)$$

where

$$AC = (C14 \text{ OR } C13 \text{ OR } C12 - 1 \text{ OR } C12 - 2 \text{ OR } C12 - 3 \text{ OR } C12 - 4).$$

Electronics of DNP contains of preamplifier-shaper for triggering the detector and spectrometry system for neutral particles identification. The discrimination between neutron and γ -ray events is performed using the pulse-shape discrimination technique for the light pulse emitted by a scintillation detector based on the

Table 1. The main parameters of MSD (preliminary).

Parameter	Value
<i>Energy bands:</i>	
Electrons and positrons	4 - 25 MeV
Protons and He nuclei	40 - 110 MeV/nucleon
<i>Energy resolution:</i>	
Protons and He nuclei	1,5 - 4%
Electrons	6 - 8%
<i>Geometric quotient</i>	40 cm ² × sr
<i>Aperture</i>	80°
<i>Time resolution</i>	100 ns

Fig. 1. The construction of the detectors MSD (a) and DNP (b)

dependence of the ratio of the light-output components intensities, with different fluorescence decay times, on the average ionization density produced by charged particles in the detector material⁶.

Previously we plane to use CsI(Tl) crystal with diameter 76 mm and 76 mm height. When neutrons with energies of $\sim 5 - 10^3$ MeV interact with Cs and I nuclei, highly ionizing particles are produced: hydrogen and helium isotopes with average energies of ~ 10 and $\sim 15 - 20$ MeV, respectively. As a result of γ -quanta

Fig. 2. The function diagram of the detector DNP: front view (a) and top view (b)

interactions, electrons and positrons are generated, for which the specific ionization produced in the substance at energies of several hundreds keV and higher is close to its minimum. A scintillation flash in CsI(Tl) consists of two main fluorescence components with decay times $\tau_{\text{fast}} \sim 0.4 - 0.7 \mu\text{s}$ and $\tau_{\text{slow}} \sim 7 \mu\text{s}$, and the ratio of the slow component intensity Q_{slow} to the fast component intensity Q_{fast} depends on the specific ionization of the interacting particles. This ratio changes from ~ 1 for relativistic particles down to ~ 0.25 for α -particles with energies of $\sim 10 \text{ MeV}$.

Information from DNP is received by SSOI MSS and translates to onboard satellite telemetry system.

Both detectors now developed in National Research Nuclear University "MEPhI" and SSOI system is constructed in Physics Institute of National Academy of Science of the Republic of Belarus.

3. Comparison of BrillLanCe series crystal with wide used scintillators of other types

Scintillator class BrillLanCe was used firstly in Delft University (Netherland). These scintillators are produced by SAINT GOBAIN CERAMICS & PLASTICS. In this work two types of such crystal will be inspected: BrillLanCe350 ($\text{LaCl}_3 : \text{Ce}$ (10%Ce)) and BrillLanCe380 ($\text{LaBr}_3 : \text{Ce}$ (5%Ce)).

The main characteristics comparison of NaI(Tl), CsI(Tl) and BrillLanCe crystals (all have got at least two light output components) is presented in Table 2 (compilation from⁷). The temperature dependence of relative pulse height for different scintillators is shown on the Fig 3. It is seen, that the most week dependence of pulse height on temperature is for crystals B350 (BrillLanCe350) and B380 (BrillLanCe380) in the ranges $25 - 125^\circ\text{C}$ and $25 - 175^\circ\text{C}$ correspondingly. Also more

Table 2. The main characteristics of NaI(Tl), CsI(Tl) and BrillLanCe crystals.

Characteristics	NaI(Tl)	CsI(Tl)	$\text{LaBr}_3 : \text{Ce}$	$\text{LaCl}_3 : \text{Ce}$
Light output, quanta/keV	38	45	65	48
Fast time (tf), ns	220	700	18	25
Slow time (ts), μs	1.4	2-5	0.8 unstable	0.5
Relation between components ($C_{\text{fast}}/C_{\text{slow}}$) at 25°C , %	85:15	55:45	90:10	80:20
Fluorescence from high energy charged particles	weakly	up to 20 ms	weakly	weakly
Density, g/cm^3	3.67	4.51	5.08	3.85
λ , nm	410	565	380	350
(at which light output is max)				
Mechanical stress resistance	low	high	high	high
Energy resolution (662 keV)	7%	9%	2,9%	3,8%
Water resistance	yes	no	weakly	weakly
				(at high T°)
Radiation hardness, rad	10^5	10^7	$1,5 \times 10^7$	10^7

Fig. 3. The temperature dependence of relative pulse height for different scintillators. Compilation from⁷.

or less linearity regions occur for scintillators CsI(Tl), CsI(Na) and BC438 in the bands 25 – 70°C, 25 – 55°C and 25 – 120°C respectively.

But from discussed scintillators only three of them have got several light output components with different timescales (see Table 2) and could be used for sorting of the particles with different ionizing capability by the pulse shape analyzing method. Unfortunately second component in the B380 crystal is unstable and it leads to some difficulties with particles identification in wide temperature band. The detailed shapes of pulses on the input of ADC for CsI(Tl) and B350 crystals are shown at the Fig 4.

The possibility of particles discrimination with proper accuracy by detailed analysis of light pulse shape using BrilLanCe series scintillators discussed in some works^{8,9} but in this case it is necessary to use very high speed digital ADC (because of very short pulse duration).

Fig. 4. The detailed shapes of pulses on the input of ADC for the crystals: a) CsI(Tl) and b) B350 (adopted from¹⁰).

The energy spectra from the radioactive source ^{137}Cs ($E_\gamma = 662$ keV) in the CsI(Tl) and B350 scintillators are presented at the Fig 5. Energy resolution of the combination of $3'' \times 3''$ CsI(Tl) crystal with PMT FEU-110 is $(\Delta E/E)_{\text{CsI(Tl)}} \sim 13\%$ but one of the combination of $3'' \times 3''$ B350 crystal with PMT EMI9265-B53/FL is more than twice better and $(\Delta E/E)_{\text{B350}} \sim 5.4\%$. The energy resolution of this crystal is slightly worse than 3.8% according to Saint Gobain data¹². This fact

Fig. 5. The energy spectra from the radioactive source ^{137}Cs ($E_\gamma = 662$ keV) measured a) by the combination of $3'' \times 3''$ CsI(Tl) crystal with PMT FEU-110 and b) by the combination of $3'' \times 3''$ B350 crystal with PMT EMI9265-B53/FL (adopted from¹¹).

can be explained by using the self mounting assembling of $\text{LaCl}_3 : \text{Ce}$ crystal with photomultiplier instead of manufacturer assembling.

Unfortunately all of the BrillLanCe series crystals has the weak internal radioactivity due to ^{227}Ac (γ -quanta with energies 323, 329, 338 and 351 keV) and ^{138}La (γ -quanta with energies 789 and 1436 keV) but the typical level of this activity is ~ 2 counts/s/g¹² and it is too small for space born apparatus. Also such background could be used in the onboard inflight calibrations during satellite experiment similar to activation lines (for example, in CsI(Tl) crystal). This lines could be subtracted during experiment using preflight calibrations (similar to internal line from ^{40}K ($E_\gamma = 1461$ keV) in the glass used in PMT and lightguide).

Fig. 6. The dependence of measured counts rate from real counts rate (adopted from¹¹).

The BrillanCe series scintillators practically have not dependence of misplaced counts on the activity of the measured source up to 1.5×10^6 counts/s¹¹. The dependence of measured counts rate from real counts rate is shown the Fig 6. It is seen that more or less linearity region both for B350 and B380 crystals is $1 \div 1.5 \times 10^6$ counts/s and corresponding dynamic range of these scintillators is more than 6 magnitudes.

4. Conclusions

As we can see BrillanCe crystals have got very best relative light output and energy resolution, highest linearity and excellent temperature stability. In the case of use BrillanCe series crystal in DNP instead of CsI(Tl) we will obtain following advantages:

- energy resolution is better (the factor of 2-3) hence low limit of detector energy band will be ~ 20 keV instead of 100 keV;
- temperature stability is better;
- light output components are faster (by the factor of the order) hence
- the time resolution will be $\sim 5 \mu\text{s}$ (instead of 1 ms) for γ up to 20 MeV, and $\sim 15 \mu\text{s}$ (instead of 10 ms) for events that need analysis of pulse shape (γ and neutrons);
- possibility of registration of more intensive fluxes;
- no problem with fluorescence from high energy charged particles.

There are two possible opportunities of DNP in ZINA-NT experiment:

- CsI(Tl):

- (a) energy band 100 keV-300 MeV (γ -quanta);
- (b) minimum time resolution ~ 1 ms;
- (c) problem with high intensity events;
- (d) problem with fluorescence from high energy charged particles;
- BrilLanCe350 ($\text{LaCl}_3 : \text{Ce}$ (10%Ce)):
 - (a) energy band 20 keV-300 MeV (γ -quanta);
 - (b) minimum time resolution ~ 5 μs ;
 - (c) no problem with high intensity events;
 - (d) no problem with fluorescence from high energy charged particles.

Also we plane to use several parallel timescales: $\sim \mu\text{s}$ (or $\sim\text{ms}$ in the dependence of used crystal), 1 s, 10 s, 64 s and 128 s (for events with low statistic – 15.11 and 20.58 MeV nuclear lines in solar flares, GRB extended emission and so on). Such set of timescales allows us more efficiently investigate events with strongly changing intensity.

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