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DUAL HARD AND OPTICAL RADIATION DETECTORS FOR FAST NUCLEAR PROCESSES

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ABSTRACT**.** The registration and monitoring of rapid nuclear processes in degenerate plasma is a field of our consideration. The flows of hard and optic radiation are considered from outlying astrophysical and atmospheric objects. For their detecting it was suggested to use dual semiconductor type detectors. Simultaneous flow measurements allow obtaining high-precision positions and spectral properties of the objects under study. Due to the high energies of hard radiation and the nature of the nuclear processes, it is shown that the probability of their detection is high. In this case, the detector does not enter in saturation mode. At the other part of this detector optical matrix and reflection mirror are located. It is determined that the characteristics of useful signals are considered for the same instrumental function.

Keywords: semiconductor detectors, hard and optic radiation detection, fast nuclear processes, γ-ray's registration.

АНОТАЦІЯ. Реєстрація та моніторинг швидких ядерних процесів у виродженій плазмі є предметом досліджень. Розглядається рівень та структура потоків жорсткого та оптичного випромінювання від віддалених астрофізичних та атмосферних об'єктів в яких відбуваються вибухи. Для детектування таких випромінювань було запропоновано використовувати здвоєні детектори напівпровідникового типу. Показано конструктивні переваги бінарних детекторів нового типу.

Запропоновано новий метод дослідження симбіотичних бінарних систем, в яких лунають термоядерні вибухи на поверхні білого карлика. Зроблено висновки про структуру інтерфейсу, необхідного для функціонування бінарного детектора та його калібрування. Одночасні вимірювання потоку дозволяють отримати високоточні положення та спектральні властивості досліджуваних об'єктів. Завдяки високим енергіям жорсткого випромінювання та характеру ядерних процесів показано, що ймовірність їх виявлення висока у разі виконання критеріїв моніторингу.

Отримано, що зазначені критерії моніторингу дозволяють відповідати фізичним умовам и динаміки явищ ядерних перетворень в космосі і в атмосфері Землі. У цьому випадку детектор не переходить в режим насичення і фізична інформація не втрачається. В іншій частині цього детектора розташована оптична матриця і відбивне дзеркало. Визначено, що характеристики корисних сигналів розглядаються для однієї інструментальної функції. Щоб уникнути перенавантаження інтерфейсу детектора зроблено не тільки підбір швидкодіючих мікропроцесорів, а і кодів для відсіву непотрібних фонових даних. Для формування потрібного сигналу необхідно, щоб на мікропроцесор входили сигнали з інтервалом часу 10^{-4} секунди. Отримано, що для системи AM Her протягом року необхідна кількість вимірювань протягом року складає $4 \cdot 10^{13}$ для матриці 20x20 cells.

Ключові слова: напівпровідникові детектори, детектування жорсткого та оптичного випромінювань, швидкі ядерні процеси, реєстрація γ-променів.

1. Introduction

Simultaneous registration of fast processes in the energy range of hard radiation using semiconductor detectors I limited by energies of 0.1 – 10 MeV for γ-rays and 0.1 - 4 eV for optical ones. The current pulse generated by the quanta of these two energy ranges is formed due to the phenomenon of the internal photoelectric effect, which allows electrons to overcome the band gap of the semiconductor. The part of the detector that faces directly at the source of hard radiation consists of a grown semiconductor crystal containing atoms of heavy elements. Heavy atoms of the indicated semiconductor interact with the γ-quantum included in it according to the following most probable scheme. The γ-quants are interacting with the K-electron, less often with the L-electron the energy of the ejected K-(or L-, M-) electrons correspond on average to the energy of its binding to the nucleus. That is, the energy interval is limited to 8-14 KeV for elements heavier than iron. The formed chain of consecutive vacancies should be filled with superior 2p-electrons from the L-level or 3d-electrons of the M-level, with the transit passage of the p-electron vacation of the L-level. In the atoms of heavy elements, in addition to the removal of strong excitation in the form of marked radiative transitions. However, a transfer of part of the excitation energy to higher-standing electrons which freely leave the band gap is observed with a high probability. Such electrons are called Auger electrons. In ideal cases, one γ-quant generates $10^6 - 10^8$ conduction electrons (n-charge) and same positive dots on average. The second section is devoted to more accurate calculations of the energy distribution of current pulses. In the third section, we studied interactions between γ-quanta's and optic matrix and relaxation time of optics quanta flows. In forth section we presented breadboard installation, where the binary detector is located. The conclusions are devoted to the studied physical objects in which fast processes occur. We carried out a modular experiment with the aim of the subsequent development and manufacture of a new generation of binary detectors that record rare events of a nuclear nature in Fig.1.

2. Physical aspects of hard radiation ilumination of the semiconducotrs

New material together with nanotechnology application is a modern effort in the higher precision γ-ray spectroscopy. This made it possible to create and model complex spatial images of radiating and absorbing biological and physical objects. Our attention will be focused on thermonuclear explosions during that simultaneously formed optical and γ-quanta in a partially degenerate dense plasma. In this case γ-quanta with energies of 0.1–10 MeV are illuminated. For detecting γ-radiation, detectors must meet several general requirements. First, they must have a high atomic number in order to provide a high cross section of γ-quanta; second, they must have high radiation and hardness. Third, γ-rays can undergo four different processes when they enter into the detector. However, because (Gould, 1980,1990) we do not consider Rayleigh (coherent), Compton scattering and pair formation in this energy range. Mainly, declared processes take place for photoionization. In next section, we will present numerical results from Auger effect electron production after formation of the K-L-dots.

3. Electron prodution in the semiconductor peroxite

The recent work dedicated to halide perovskites (Liu, Wu, Wei et al., 2022), confirmed that their crystals have superior advantages over other types of hard radiation detectors. The accurate calculation of the Auger electrons production for elements before Ni are presented in (Kaastra & Meve, 1973), (Doikov & Khrapatyi, 2020). In present paper, I used only common physical principals and experimental data for Auger electron production from for elements after Ni in periodic elements table. The subjects of investigation are halide perovskites crystals which are easy to grow and have important electro physical properties suitable for their advantageous use in the planning of our experiments. The technology of growing CsPbBr3, CsPbCl3, Cs2AgBiBr6, Cs3Bi2I9, Cs3Bi2I3 is presented in (Liu, Wu, Wei et al., 2022). For the monitoring rapidly changing glow of hard radiation, the most convenient are crystals CsPbBr3. In present paper, we considered the spectrum of Auger electrons produced by each of next elements: Cs, Pb, Br. After formation of the K-, L- or M-dot from incident on the atom γ-quantum a redistribution of the stored energy of a strongly ionized state has been observed. The main part of the Auger electrons in detectors crystals in a narrow energy range. Every Auger electron with energies, presented in the second column, forms secondary ionization for this semiconductor. In the third column the derivation dN/dE is the gradient coefficient for the distribution function N(E) of the Auger electrons. NF(E) are full number of the electrons – dot pairs. The presence of Auger spectra of the marked atoms makes it possible to obtain the distribution of secondary electrons, which actually cause the internal photoelectric effect of the semiconductor. I considered redistribution is after internal atomic photo effect due from γ-quants in halide perovskites crystal CsPbBr3 (Table 1).

Table 1: Distribution of the Auger electrons in CsPbBr3

Atom	**Halide Perovskites Crystal CsPbBr3**		
	Energy of Auger electrons E (in eV) from single atoms	**dN/dE**	**NF(E)**
Cs (55)	47, 407, 420, 479 , 491, 583, 575, 620, 636, 650	0.57	10^6
Pb (82)	60, 90, 117, 130, 159, 181, 204, 249, 267, 389, 412, 458, 475, 693, 1160, 1286, 1407, 1431, 1488, 1617, 1637, 1717, 1910, 1987, 2048, 2186, 2283, 2319	0.71	10^7
Br (35)	56, 102, 108, 1172, 1210, 1270, 1285, 1318, 1396, 1442, 1479	0.71	10^5

No more than the half of ionization energy transforms in Auger kinetic energy for atomic numbers $4 < Z < 30$ (Kaastra & Meve, 1973). In other part of the periodic table Auger energy fraction increases drastically and kinetic energy of the Auger electrons is more and more gentle. The data presented in the table on the experimentally determined Auger resonant energies of electrons do not coincide with the energies of the bound electrons of individual atoms entering the crystal. This phenomenon can be explained by the fact that in crystals valence electrons can make a transition to a vacancy formed by ionization because they are already in orbitals for which the transition is already allowed by the selection rules. The themalisation of the Auger electrons in inner part of the CsPbBr3 crystal leads to the transition of valence electrons through the band gap to the conduction band. From (Liu, Wu, Wei et al., 2022), band gap energy equals 4.5 eV. The energy fraction of radiative transitions during K-L ionization reaches 30%. However, the crystal mainly absorbs such quanta after ionization of the L-M-N levels. Under the conditions of the task, this effect for heating the crystal is insignificant. In the energy range of γ-quants 0.1-10MeV, the average multichannel efficiency of creating electron-hole pairs is 30-40%. Finally, the excitation of the common bound electron N-O-levels in CsPbBr3 crystal produces electron-hole pairs. For mean part of γ-ray, Spectra Energy is 5 MeV. Including efficiency, every quant produces $10^5 – 10^6$ pairs. Time interval of rapid processes is a 10^{-3} sec. Number of γ-quants is 177. Finally, we have current $I=2.72*10^{-8}$ A. In binary detectors such a weak signal is recorded by a significant potential difference (before 800-900V).

4. The Gamma-ray signal structure and him treatment

The structure of the process under study is such that the dependence of the received energy on time has a delta-like character. This makes it easier to apply the formal base.

Based on which the signal processing is carried out and the errors of the measured values are estimated. In (Liu, Wu, Wei et al., 2022) authors presented methods of dealing with dark currents and semiconductors degradations. Here we dwell on the problems of separating emerging false γ-signals when monitoring fast γ-flares of cosmic origin. Calibration sources in this case can be isotopes that give γ-lines in the interval of interest to us. When observing cosmic rays from high-mountain stations, such isotopes may be located near the instrument.

However, X-ray pulsars are also good standards for the hard X-ray region. Among them, one can notice a small amount, which gives stable γ-radiation. The resulting current pulses are much smaller and this complicates the calibration.

The construction of the instrumental function (therefore IFUN) is an important step in the study of the rapid thermonuclear physical processes in Space. IFUN lies in the influence on the radiation and current impulse from detectors and other constructive elements. In our case, this is relaxation time T_{rel} after interaction of the single γ-quants with detectors. Due to the weak fluxes of γ-radiation, the saturation mode is not observed in the presented detectors. The resulting current pulse during one millisecond is made up of current pulses of 177 γ-quanta. The structure of the resulting impulse carries detailed information about the considered physical process and its characteristic time.

5. The hard ware realization of the monitoring detecting systems

In presented paper only a many layer halide perovskites crystal CsPbBr3 with mean layers' number 10^3 has been considered. This number is sufficient for my tasks. As noted previously, the characteristic time of information registration from the entire surface of the matrix is 10^{-4} sec. In other words, 10^7 current impulses in ideal cases should be processed in one second. Given that a useful signal is rarely formed for a short time, it is necessary to exclude the zero signal from the records.

The signal from the optical and gamma matrix goes to the microboard where it is further processed by the processor, which converts the voltage of the incoming pulses into digital form. The further digitized data is buffered where it is then sent to the computer. But in order for the PC to receive and process the data, it must first pass through the interface board. This in turn sends the data to the PC's RAM.

Since we are monitoring and analyzing gamma and optical radiation, we need to filter out the noise. To do this, you need to create a separate monitoring program written in C ++ and Assembler. Since our events will take place in a fraction of a second and with a large data flow, we need a powerful processor with characteristics like the ADSP-BF704. Below I presented layout modeling of the binary detector with emulating it in the LabWiev environment. This emulation consists of the shot noise of a semiconductor and a useful signal composed of the cumulative summation of impulses caused by γ-quanta characteristic of the fast process under study. In our case required method of signal processing that takes into account pulses signals from different detectors

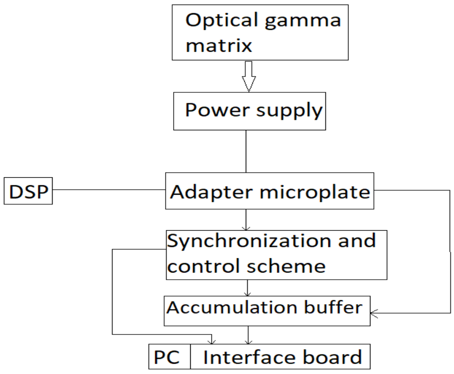

Figure 1: Block-diagram of binary detector

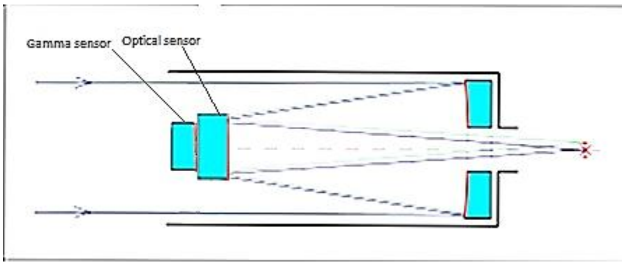

Figure 2: Structure of the binary detector

layers and him summed up. More energetic quants cover a larger number of layers, the length of the quantum path is determined by the total ionization losses of γ-radiation in the substance. Using the environment LabWiev we carried out a model calibration of the resulting signal from one or more quanta of a given energy. For solving the problems of constructing of the time and energy spectra from distant faint objects, I created an algorithm for separating quanta of different energies based on the coincidence method.

At the current 6 μJ flows described in this article, the temperature effect does not affect the sensor readings. The processes that occur during the passage of cosmic rays in the energy range under consideration cause the formation of secondary and so on particles called cosmic lines. In the structure of cosmic lines, there are both positrons and gamma quanta accompanying the processes of their formation and annihilation.

6. The optical detectors

The reverse side of the binary detector is facing the reflecting mirror and is an ordinary light-sensitive matrix with given transmission curve. A characteristic time of considered events is $10^{-3} - 10^{6}$ s for different types of Symbiotic system. Left part of this interval is important for rapid processes produced from cosmic rays (therefore CR) in Earth atmospheres. Accompanying information obtained in optics makes it possible to restore the physical structure of the object of study. The main advantage of a binary detector is the high accuracy of coordinate referencing to the object of study. The optical observations of cataclysmic stellar systems have been carried out for many decades and are important for considered effects. In many cases optical flash has been in much greater periods of time. But in several cases in periodical Novae the times of maximum glow in gamma and optical rays are comparable during the day after detonation on the surface of a supermassive white dwarf. Unfortunately, this events are very rare. The time interval of optic flyers allows you to accumulate a useful signal with a high temporal resolution. The controller fixing and processing the activity of cataclysmic variables in time allows you to synchronize the flow of information from both parts of the binary detector.

Bogdan Pachinsky promoted this approach back in the 1990s for γ-busters. However, the technical capabilities of the detectors of interest to us did not allow us to solve such a problem. In space mission Fermi this event has only been registered for γ-rays with energies after 100 MeV. Therefore, perovskite detectors overlap the γ-radiation energies considered by us up to 26 MeV. In addition, these detectors produce good shielding of the optical part of considered devices and it can be noted, that cataclysmic systems in space are usable for many other objects that manifest themselves in a similar way.

7. The signal emulation and detection

The monitoring equipment consists of detectors of hard- and optic radiation. Every time after sequence of events associated with the input of γ- and optical quanta, an internal photoelectric effect is observed, current pulse is formed in the corresponding part of the semiconductors under consideration. Together with other semiconductor properties detector produces impulses that are described by an instrumental function. This means that the quantum that enters the corresponding perovskite layer corresponds to a pulse characterized by a width (signal dispersion) and its amplitude. In ideal cases in initial time the sniggle quant has the same amplitude and zero width. In the time required for the response of the detector and the operation of the entire electrical circuit, the considered amplitude of the output signal is formed. In the case of perovskites, such a response is formed, as previously mentioned, in 10^{-6} seconds. In this regard, perovskites have a much higher sensitivity and saturation of the detector occurs at much higher photon fluxes.

In this paper, I consider only multilayer perovskite detectors. This means that the signals are in the form of current pulses from each layer. In more deep layer we have more energetic quants. In special case when considered emits an annihilation and its accompanying quantum, who connect with corresponding decay reaction or synthesis of radioactive, proton-excess isotopes. From (Doikov, 2022) these are quants with energies 0.511 MeV and accompanying them γ-quants from specific nuclear reactions leading to the appearance of positrons in cataclysmic systems and events in Earth atmosphere. The free pass length of this γ-quants is much different and finalized in differ semiconductor layers.

At the other hand, more energetic γ-ray's photon can cause ionization losses in those layers of the detector that are responsible for the registration of γ-quanta of lower energies. The selecting of these events depends on the simultaneous operation of the controllers operating from the signals recorded in the corresponding perovskite layers on the ADC. The energy selection (resulting γ-spectra) of the incoming analog data depends on the information about signals from all layers.

7.1. Method of formation of the initial data

The Peroxide-based gamma sensors require multilayer partial honeycomb structures. In the problems of positron spectroscopy of flares occurring in various space objects that we are considering, we will restrict ourselves to the following gamma lines that arise under the following scenarios:

1) During proton-proton chain reactions e^γ=0.511 MeV.

2) Processes of thermonuclear combustion in periodic New (E_γ=0.511,5.65, … 10 MeV) .

Basically, gamma quanta formed by the decay of proton-rich light nuclei are limited to 10 MeV. Therefore, the thickness of the detector sufficient for registration (total absorption) reaches several centimeters, this is due to the fact that the CsPbBa3 semiconductor detector under consideration has a large average atomic mass (near 57.3 a.u.m.).

To construct a model detector sample, a model of a peroxide semiconductor with 10 layers is adopted, and the total thickness of the detector must correspond to the path length of a gamma quantum with E_γ=10 MeV. When the flow of gamma quanta enters the peroxide, gamma quanta with energies of 0.511 MeV should be absorbed by the upper layer (for example, layer No. 1). The current impulses coming from high-energy gamma rays form impulses in all lower layers. This means that the registration of gamma quanta with low energies will be the most problematic.

To solve this problem, I proposed a simulation model similar to the method of coincidence of events in nuclear physics. If the current pulse is formed in all layers simultaneously, then with a high probability we have a gamma quantum of the highest energy. If similar current pulses enter the signal analyzers at the same time, then these pulses are summed up and refer to the action from one photon.

The corresponding approach makes it possible to form the resulting pulse from gamma quanta of other energies. To obtain the spectrum of objects under study, the described events are sorted by their number and energy. The studied spectra have a pronounced emission character. The contour of each emission line characterizes the power of the process. One of them is the intensity of reactions leading to the formation of gamma quanta.

The width of such a contour is determined by both physical and instrumental parameters of the processes. To determine the instrumental function, when creating a layout, an "ideal" delta-shaped signal is formed and the resulting signal is studied after the interface has worked. To do this, I proposed a simulation model in which the real detector is replaced by a signal generator with the necessary pulses in shape and frequency, corresponding to a real physical process. Then, using the LabVIEW program (by National Instruments Corporation) virtual environment is formed in which the analog signal generator and the receiving interface device are located.

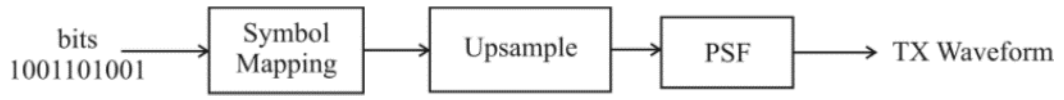

Figure 3: Block diagram of a modulating oscillator located in the LabVIEW environment

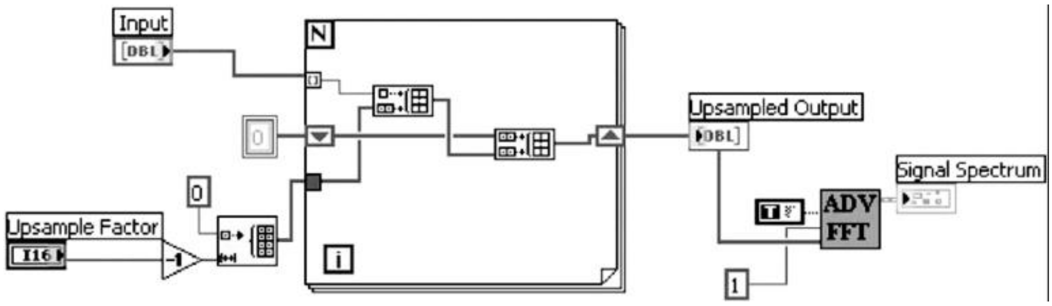

Figure 4: Block diagram of signal discrediting for shaping signals according to predicted physical effect

8. Conclusion

The morphology of the objects in Space is presented with binary system in which one of its components is WD. After sometime in WD hydrogen accumulates, causing surface thermonuclear detonation. For reliable identification, it is necessary to observe such a process in the gamma and optical ranges simultaneously. This circumstance led to the need to turn to the development of binary detectors operating simultaneously in the specified spectral ranges. Theoretical calculation of detonation in the WD surface are presented in (Doikov & Yuschenko 2021). The character time and hard radiation led to the fact that gamma-ray flashes have not yet been detected. At the other time so-called hydrogen-hydrogen (therefore P-P) detonation produced positrons and its annihilation quants with energies 0.511 and 1.022 MeV. In this cases halide perovskites crystal CsPbBr3 are suitable. Moreover, most importantly, we note that such detectors make it possible to solve the problem in the monitoring mode on short-focus instruments. In this case, we avoid the possibility of losing registration of such rare events.

To solve the problem of registration of the rare events in the gamma range, we take into account that the frequency of picking up a signal from a detector pixel should be 100 kHz. Taking into account the physical processes of an explosion in a degenerate plasma, the shape of such a pulse has the form of a delta function with a small signal dispersion.

The signal generator sends a pulse to the device in the form of an analog ADC converter. The second device must operate at that frequency. The third stage is to take advantage of this program. In the considered monitoring device inter drastically pulses number. But useful signals are rare, and the current pulses created by gamma quanta have a sufficiently large momentum in relation to noise and to simplify the solution of the problem. I decided to use a peroxide crystal detector that does not require cooling of the receiving device in which this crystal is placed.

In most of considered cases a proposed scheme to register each individual γ-quant operates in the monitoring mode. A significant potential difference, up to several kilovolts, is applied along each layer of the detector. To combat invariably occurring noises, the detector's own noise is studied in the background at the proposed characteristic times of the process. Noise has a shot thermal character and in most semiconductors the only way to remove it is to noticeably cool the receiving matrix. However, peroxides, as semiconductors, consist of heavy atoms whose average atomic weight can reach up to 50 -70 in atomic mass units. This leads to the fact that peroxide as a semiconductor has a large energy band gap, which is much larger than the energy of thermal motion at room temperature. That is, under normal conditions, the ratio between them is 187.91 times greater than the energy of thermal motion. Therefore, the energy of the electric field, which does not lead to a regular transition of electrons from the band gap to the conduction band, should not exceed 4.5 Ev. This means that the conduction electrons are mainly involved in the noise structure. At a difference of 1Kev, the contribution of the band gap electrons is 187.91 times smaller than the contribution of the conduction electrons. The impulse generated by the noise current must be much smaller than the amplitude of the useful signal. In the previous section, the amplitude of the current that occurs when 177 gamma quanta with energies 511Kev and 5460Kev hit is determined. Given the impulsive nature and short signal time, it becomes necessary to deal not only with noise, but also with random events leading to the formation of similar impulses. For example, the frequency of passage through 1 square cm of cosmic rays is 10 particles per second, each of these particles is able to cause the corresponding current pulse, so peroxides effectively absorb the marked particles in the upper layers of the crystal, the particles do not reach deeper layers, thereby not causing false pulses.

9. Discussion

The selection and formatting of γ-color images of volumetric objects is an urgent problem. In this paper, we consider the interpreting weak rare γ-radiation signals from distant objects in space. When monitoring in γ-radiation, it is necessary to take into account the background values of the hard radiation of the environment in which the detector is located. Usually, during observations at sea level, this background is 10–20 CR particles per second. In the observed observation modes, this means that the error created by the background is much smaller than the instrumental noise over the observation interval. In the mountains, background measurements are also required for calibration, which is much higher. In this case, we plan to model the background with signals random in time and energy. Signal distortion by optical noise is the problem for future.

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