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Development of silicon matrixes and channels of amplification of signals for a telescope - Spectrometer of charged particles

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Abstract. The silicon detectors will widely be used at registration of cosmic rays. If it is required to determine angular distributions of particles, will be used multi-element (for example, matrix) receivers. In the report the outcomes of development of the silicon matrix detector of the format 6x6 units and multichannel systems of preamplification - formation of signals intended for a satellite telescope of charged particles are adduced. The area of a unit of the detector is 0,5 cm^2, depth of a slice is 300-400 microns, concentration of an impurity in a substrate 10^{12} cm^{-3}. The role of effects of ionic drift on a surface of the detector inverse channels, initiation derivation of leakage is analysed. For their supression will be used of a protective dielectric film and guard rings of a special design.

In outcome the level of an electrical noise of a unit matrix makes 5 keV at T=25^o C and 10-16 keV at T=40^o C. It provides the sure registration of electrons of high energy, that confirms also by analysis of β-spectra. The energy resolution of a unit matrix on a-particles makes about 10 keV. It is possible to lower a degree of influence of a γ-background up to 10^{-5}.

At mining the multiway unit of preamplifiers - shapers of signals it is necessary to take into account as the customary requirements (low noise, fast response time, high volume range etc.), and feature of operation of satellite instrumentation (temperature range, interference on the power supply circuit, low power consumption, high level of a radiation dose). The route of mining of amplifying channels with the purpose are analysed to satisfy with all these requirements. On samples are obtained a input noise of a channel an 10 keV, displacement of a stationary value of component on an output at a temperature variation and loading of a channel < 1 mV, volume range more than 60 dB, power consumption in one channel less than 150 mW.

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1. Introduction

The silicon detectors find broad application in satellite devices for registration of charged particles. If it is necessary to determine angular distributions of particles, the silicon detectors will be used multi-element, sensing to coordinate: strip-detectors or diode arrays (Cook et al., 1993). In the given report the outcomes of mining and research of silicon matrixes, and also multichannel system of an analogue signal processing of matrixes (amplifiers and shapers of signals) for a satellite telescope - spectrometer of charged particles are set up. The given telescope - spectrometer is intended for definition of distribution of particles in 1024 solid angles, type definition of particles and their energy spectrums. The design of a telescope is conventional: on an input of a telescope two silicon matrixes of a transient-time type on definite distance from each other sequentially are arranged, behind them two scintillation detectors place.

2. Silicon matrixes

The silicon matrix has 6x6 units. The area of each unit 0,5 cm^2, fissile area of a matrix 18 cm^2. The interval between units makes 150 microns, so the inactive area makes 3,5 % from the full area of a matrix. The silicon chip is fixed on plate from fiber-glass plastic, on which the electrical solder contact of die backers are arranged. Depth of a chip of silicon 350 microns. The silicon p-type as with concentration of an impurity 10^{12} cm^{-3} will be used.

The technology of manufacturing of diodes of a matrix actuates known technological methods of creation of silicon detectors of radiation (Maisch et al.,1990) : absence of high-temperature thermal processes, application of several methods of gettering of fast diffusing impurity, including oxidation of silicon in medium, keeping chlorine. The parts in sequence and modes of master schedules play a determining role in formation of major parameters of silicon detectors: a level of leakage currents of diodes, which determine electric noises, and also quantity of low-voltage breakdowns in a matrix.

2.1 Main specifications of matrixes

The leakage current of a die backer at temperature $T=20^oC$ and bias voltage V=40V, conforming to depth of depletion in silicon 200 microns, is equal 10-15 nA. Dispersion of leakage currents makes ≈15 %. The temperature relation of leakage currents pursuant to the theory is determined by activation energy approximately 0,5 eV.

The capacitance of a unit at V=40V makes (27±3) pF. Dispersion of capacities has in the main radial character and is determined by known radial relation of specific resistance of silicon. The silicon of the corporation Wacker was used. The volt-farad characteristic looks like $C\sim U^{1/2}$. Voltage of full depletion about 100V. With high enough percent of an output we received matrixes, in which there were breakdowns at this voltage.

Energy spectrum on α-particles ^{241}Am at bias voltage U=60 V is adduced in a fig. 1. In the same figure the spectrum of a generating peak, measured in the same conditions is adduced. It is possible to divide the measured energy resolution on components of a dispersion. The energy resolution of a generating peak actuates a detector noise and noise of the preamplifier. Taking into account, that the noise of the preamplifier with capacity on an input, equal capacity of the detector, is equal 4,5 keV, we receive for a detector noise value 6 keV. Decomposing the full energy resolution on α-particles 20,9 keV on components - a noise of the preamplifier, resolution of an α-source (17 keV) and resolution of the detector, we shall receive for last value value 11 keV. This value also is possible is to decomposed on two components - by an electrical noise (6 keV) and dispersion, bound loss of charges, mainly, with a planar non-uniformity of losses. The dispersion, bound loss, is equal 9,2 keV. Let's remark, that at usage of the semiconductor detector for registration of charged particles in space the most important characteristic from above reduced is the electrical noise. Value of a noise in the obtained matrixes are at a level best known is model.

Unfortunately, the customary measurements of an electrical noise on a dispersion of a generating peak do not yield a precise estimation capabilities of the detector at registration of low level signals. The adequate estimation can be made of the analysis of spectra of an electrical detector noise. In a fig. 2 the noise spectrum is adduced, from which the energy of noise pulses can be calculated, the frequency of noise pulses is higher with which has prescribed value. For example, from a fig. 2 follows, that the frequency of noise pulses with energy 9,4 keV makes 1 pulse within one minute.

The parameters of a silicon detector can easily and over a wide range be controlled bias voltage U on the detector. In figure 3 the relations of the energy resolution of a generating peak, α-peak and threshold of energy are adduced, the frequency of noise impulses is higher which is equal 1 within minutes. As it is visible from a figure, all three values poorly change in a broad band of voltage, but at V > 20 V are sharply augmented. The cause it is increase of a noise of the preamplifier in connection with increase of capacity of the detector. This circumstance is necessary for taking into account by selection of a mode of actuation of a silicon detector.

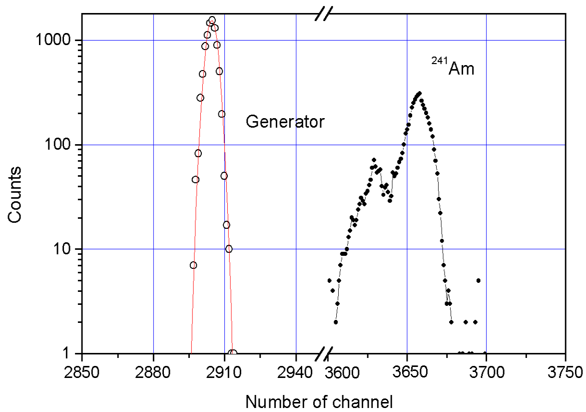

Fig.1. Energy spectrum of the α-particles of ^{241}Am.

2.2 Registration of electrons in a silicon matrix

The registration of electrons is most composite problem. At first, usually minimum measured to energy of electrons are set below, than for other particles. Besides is high energy electrons create in silicon small energy losses, about 32 keV on 100 microns of run. The difficulty is aggravated some more subjects, that the noise of silicon diodes rather strongly grows with increase of temperature (with activation energy about 0,3 eV). Therefore problem of registration of electrons demands of a silicon detector of

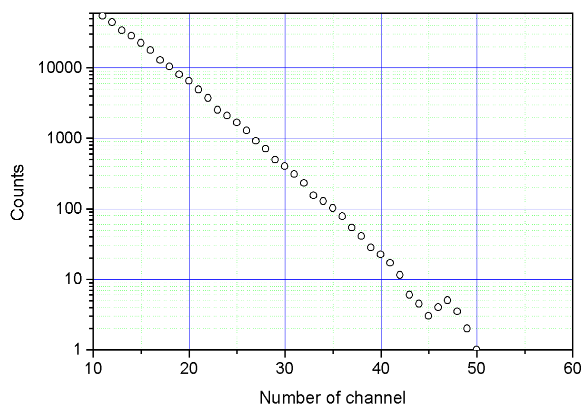

Fig.2. Spectrum of energy loses of the electrons.

peak response, i.e. first of all it is high quality technologies of its manufacturing.

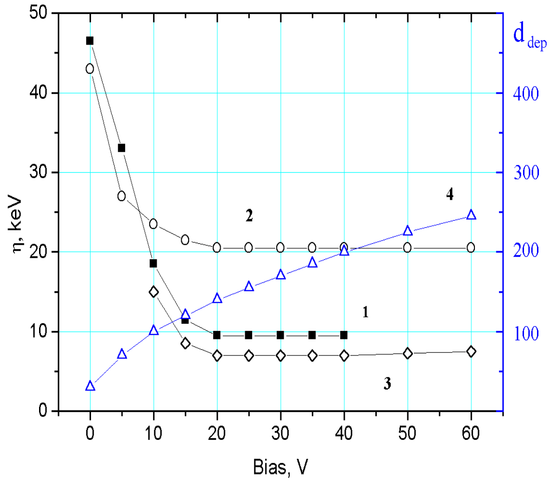

Fig. 3. The energy resolution of a generating peak, α-peak and threshold of energy

The problem is reduced, that the frequency of noise impulses at maximum temperature of measurements was much lower, than minimum frequency of desired signals of electrons. Let's take conditionally minimum tolerance frequency of noise impulses behind a 1imp/min. Thus it is necessary to set a level of discrimination of impulses on amplitude. It is determined by a minimum signal amplitude of an electron. In any case the level of discrimination should

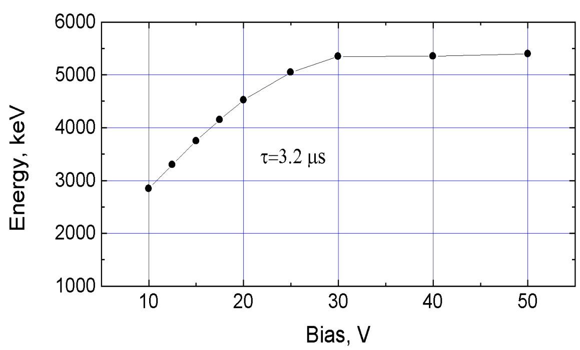

Fig. 4. The relations from U and τ of amplitudes of signals are adduced at irradiation of a back side.

be lower than a signal amplitude of high energy electrons (with energy > 800 keV). Let's estimate last value. At depth of a silicon slice 350 microns, full depletion and normal falling of an electron the signal from of high energy electrons is equal ~ 110 keV. It is necessary to mark, however, that the mode of full full depletion is very rigid and can result in to refusals. Operation voltages > 100 V can result in to amplification of low-voltage breakdowns and to creation of surface inversion channels due to drift of ions on a surface of a slice. Strictly speaking, the full congregating of an ionization charge in a slice of silicon can be ensured and without full depletion. A charge collected in the detector at registration of a particle

$$Q = Q_{dep} + Q_{dif} \sim d_{dep} + L_{Def}, \qquad (1)$$

Where Q_{dep} - charge which is generating in a layer of depletion, Q_{dif} - charge generating in quasi-neutral area and collected in junction due to diffusion of vacant electron sites, d_{dep} - depth of depletion, L_{Def} - effective length of diffusion of vacant electron sites.

At qualitative technology of manufacturing of detectors the value L_{Def} can be great. We offer to estimate L_{Def} on relation of a signal amplitude to voltage U at irradiation by α-particles of a back side of a slice of silicon. In a fig. 4 such relation is adduced. From it follows, that only at V < 30 V is watched noticeable decay of a signal

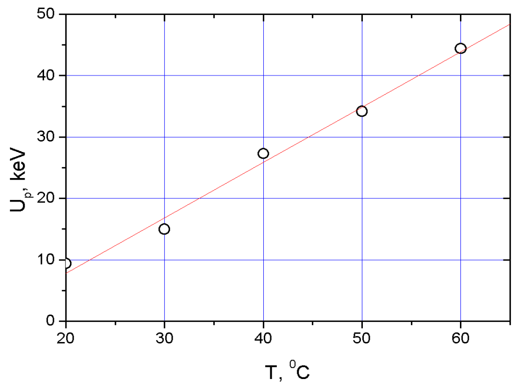

Fig. 5. Relation of a threshold of energy of noise impulses of array cells to temperature.

amplitude, i.e. inexact congregating of a charge. The relation d_{dep} (V) is adduced in a fig. 3, d_{dep} = 170 microns at U = 30 V. By the definite indicated way L_{Def} = 200 microns. Thus, the qualitative enough technology of silicon detectors allows to lower operation voltages till 30-40 V, providing thus a full congregating of a charge. As it was marked above, the minimum response of electrons thus is equal 110 keV.

Further we shall consider parameters of an electrical detector noise. Taking into account above-stated, we shall stay on a mode of actuation of the detector at U = 40 V. In item 2.1 was shown, that in standard conditions (T = 20 ^{o}C) the energy of noise impulses conforming to frequency of noise impulses 1 imp/min, is equal 9,4 keV. The noise spectrums, similar reduced in a fig. 2, were gauged at heightened temperatures. The outcomes are shown in a fig. 5. The matching of energy of noise impulses with minimum energy of electrons with high energy (110 keV) displays, that high energy electrons can confidently register at temperatures even above 50 ^{o}C. If temperature does not exceed 50 ^{o}C, the low limit of energy of registered electrons can be established on 30 keV. Thus, the obtained matrixes allow to register electrons in broad power and temperature ranges. Thus the mild mode of actuation of matrixes (V = 40-60 V), increasing their reliability is recommended. In a fig. 6 the spectrum of losses of electrons from a source Y+Sr is adduced.

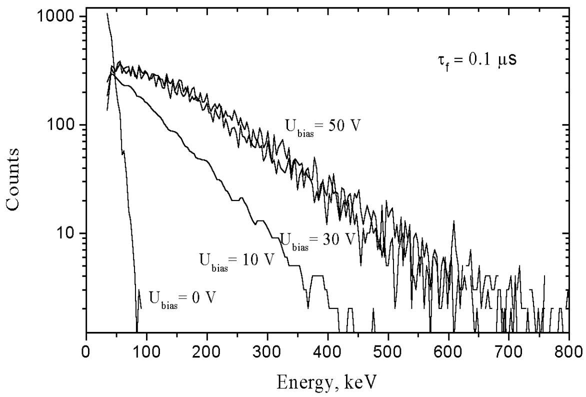

Fig. 6. The spectrum of losses of electrons from a source Y+Sr.

The maximum in a spectrum at energy about 120 keV is derivated by electrons of large energies, which loss group near to this energy. As it is visible, such electrons easily register. The contribution of noise on this curve misses.

3. Electronic units of amplifiers - shapers

The unit of an analogue signal processing include of a matrix actuates multiway plates of amplifiers and shapers of signals, and also secondary power source.

3.1 Preamplifiers

The multichannel device demands a maximum scale of integration of units. Among known microcircuits, including amplifier A250 of the corporation Amptek (Amptek, 2000), we have not found sufficiently approaching on a role of the basic amplifier element a charge sensitive preamplifier (CSP). Therefore we designed an own solid-state silicon-base microcircuit charge sensitive preamplifier. It consists of an input cascade on the field-effect transistor and non inverting fast-response low-noise amplifier of a current signal with transformation to voltage. The version of a microcircuit accepting connection of the external field-effect transistor for achievement of limiting parameters is let out. In a structure of a microcircuit there is a feedback loop with thermostable capacity 0,5 пФ and designing a role of the high-ohmic resistor special low noise by the scheme of a current divider. Power supply voltage of a microcircuit 3 - 12 V, the current of consumption of the built-in field-effect transistor and separately of bipolar part of a microcircuit can be regulated, so the full current of consumption can change from 0,8 mA up to 8 mA. At a current 8 mA a gain is about 105, frequency band about 300 MHz, pulse rise time 10 ns, noise density 2 $nV{*}Hz^{-1/2}$.

3.2 Shapers of signals

For a signal recovery from a noise and maintenance of a given transmission factor on energy the optimum filtration of a signal will be used. The standard processing of a signal with the help CR-RC of circuits as from the point of view of circuitry most compact is applied, and the link CR simultaneously serves for a galvanic isolation of an input of the shaper from an output CSP. With the count of a pole CSP in a CR-link of the shaper compensation of a pole of null eliminating occurrence in the formed signal of let of inverse polarity is applied. For calibration of a channel on a transmission factor there is a slide control of a gain of a RC-link. For maintenance of output displacement in rigid limits the links of the shaper are enveloped by monitoring feedback through a padding integrating amplifier. The output of the shaper is matched to a cable with an impedance of 90 Ohm.

3.3 Channel parameters the amplifier - shaper

8 channels of amplifiers - shapers together with frequency filters in the power supply circuit are arranged on one plate, which measures 134x137x15 mm. Power supply voltage of a channel - 9V, power consumption of a channel - 140 mW, charge sensitivity - 0,35 V/MeV, maximum output amplitude - 6 V. At a frequency drift of impulses with maximum amplitude and temperature variation in range from -50 ^{o}C to +50 ^{o}C a stationary value of component on an output changes no more than on 0,2 mV. The pulse duration at a level $0{,}5U_{max}$ makes 7,5 μs. At usage on an input of the external field-effect transistor 2П241 the initial noise (at C_{in} =0) is equal 4 keV, declination of a noise performance - 18 eV/pF. The outcomes on influence of a dose of γ-radiation on channel parameters and main components will be surveyed in individual message.

Summary

The silicon diode arrays and amplifiers shapers of their signals for a satellite telescope of charged particles are designed. The design and technological features of these devices and their limitations are parsed.

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