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MRS SILICON AVALANCHE DETECTORS WITH NEGATIVE FEEDBACK FOR TIME-OF-FLIGHT SYSTEMS

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Investigation of time characteristics of Metal-Resistive layer-Semiconductor structure based silicon avalanche detectors with negative feedback, proposed for time-of-flight, is described. Time resolutions of 550 ps on β-electrons and 250 ps on LED light pulses were obtained. Design and principles of operation are described briefly.

The investigation has been performed at the Laboratory of High Energies, JINR. Results were presented at SPHERE collaboration workshop, Varna, Bulgaria, May 31 — June 5, 1994.

Кремниевые лавинные МРП-детекторы с отрицательной обратной связью для времяпролетных систем

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Описаны исследования временных характеристик кремниевых лавинных детекторов на основе структуры металл-разистивный слой-полупроводник с отрицательной обратной связью, предлагаемых для времяпролетных систем. Получено временное разрешение 550 пс на β-электронах и 250 пс на световых импульсах от светодиода. Также приводится краткое описание конструкции и принципа работы детектора.

Работа выполнена в ЛВЭ ОИЯИ. Результаты были представлены на Рабочем совещании коллаборации «СФЕРА», проходившем в Варне (Болгария) 31 мая — 5 июня 1994 г.

Introduction

The present and future experiments in high energy and nuclear physics require detectors for the time-of-flight systems with high time resolution. There are few ways to solve this problem: using phototubes and scintillators or silicon avalanche detectors of different designs. But phototubes and scintillators require high voltage supply and large enough volume. Silicon avalanche diodes with p-i-n structure are compact but also require high voltage supply (300—2000 V) [1].

An additional way to solve this problem is the silicon avalanche detectors with a negative feedback [2—4]. Produced on low-resistivity substrate they are cheaper than avalanche detectors on high-resistivity silicon. These detectors operate at low voltages (about 40 V) and at room temperatures. Due to high gain of these detectors (10^3 - 10^5) it is possible to obtain good signal-to-noise ratio collecting charge carriers from the active layer 2 μm thick. Due to thin depletion layer it may be possible to collect charge carriers for a time about 100 ps or less. The main problem here is high intrinsic capacitance of the detector that makes high RC constant of detectors.

In this paper we describe the design and principles of operation of the detector and present some results of time characteristic measurements.

1. Silicon Avalanche Detectors with Negative Feedback

Silicon avalanche detectors with negative feedback (SiAD) were designed and produced by INR (Troitsk) group in collaboration with MELZ (Moscow) [2—4] and some detectors were produced at the Institute for Electronics of Byelorussian Academy of Sciences (Minsk). They are made on the low resistivity (1 $\Omega\cdot$cm) p-type silicon substrate 300 μm thick and have Ni-SiC-Si-Al structure. Schematically the structure of the detector is presented in Figure 1. The thickness of SiC layer is 0.2—0.5 μm. Application of bias voltage of only 37—42 V allows one to reach, in the region near the SiC-Si boundary, electric field more than $3\cdot 10^5$ V/cm that is enough for impact ionization.

A minimum ionizing particle (e.g., relativistic electron) creates in space charge region (depletion layer) about 100 electron-hole pairs. Due to avalanche amplification ($10^3\div10^5$) we can collect charge carriers on a

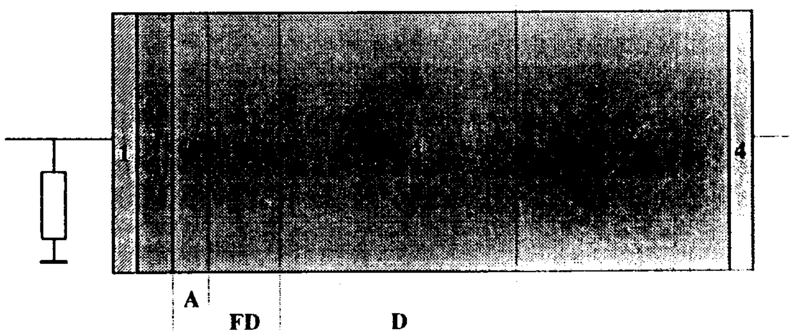

Fig.1. Simplified structure of the MRS detector: 1 — Ni; 2 — SiC; 3 — p-Si; 4 — Al; A — avalanche region, FD — full depletion layer, D — diffusion layer

readout electrode $10^5 \div 10^7$. It is compatible (or even two orders more) with conventional silicon detectors (without avalanche amplification — about $3 \cdot 10^4$ carriers for minimum ionizing particle). So more simple electronics may be used for such charge registration.

The avalanche occurs immediately after the incident particle passes through the avalanche multiplication region. Redistribution of the bias in the MRS structure and partial charge accumulation at the Si-SiC boundary takes place during the avalanche. Due to these processes the electric field at the avalanche multiplication region is decreased and it results in the self-stabilized avalanche process. So a local negative feedback occurs between the avalanche process rate and the potential drop across the resistive layer [4]. The working surface of the detector is covered by thin Ni film to provide optical transparency since these detectors originally were designed for light quanta registration.

Because these detectors are produced on low-resistivity p-type silicon it is possible to make detector and amplifiers on the same wafer. They also can be used as position sensitive devices, e.g., pixel or microstrip detectors with or without electronics on the wafer.

2. The Time Resolution Measurements

First result of the SiAD time resolution measurement was obtained in November 1993 with square detector of area 5×5 mm^2 produced by MELZ [5].

The silicon avalanche detector had been exposed to beta electrons from a source which has an end point energy of 3.5 MeV. The particles were collimated, passed through SiAD and two triggering scintillators with PMTs. The triple coincidence from SiAD and scintillators were used to trigger an event. The schematic diagram of the experimental setup is shown in Figure 2a. The gain of preamplifier was 7.

The resolution of the detector σ = 630 ps was measured. But this result was obtained using a simple custom designed preamplifier. The time spectrum of this detector is presented in Figure 3.

The same measurements were performed with a circular SiAD with diameter 3 mm (area 7 mm^2). A PHILIPS Scientific Pulse Preamplifier Model 6954 ($K_u \approx 20$, $\tau_{rise} = 180$, bandwidth 2 GHz) was used in these tests. Time resolution was obtained to be σ = 550 ps (Figure 4a). The time resolution of the detectors seems to be area-independent (detectors with 25 mm^2 and 7 mm^2 areas differ more than 3 times) but it is slightly difficult to compare these results because amplifier with different time characteristics

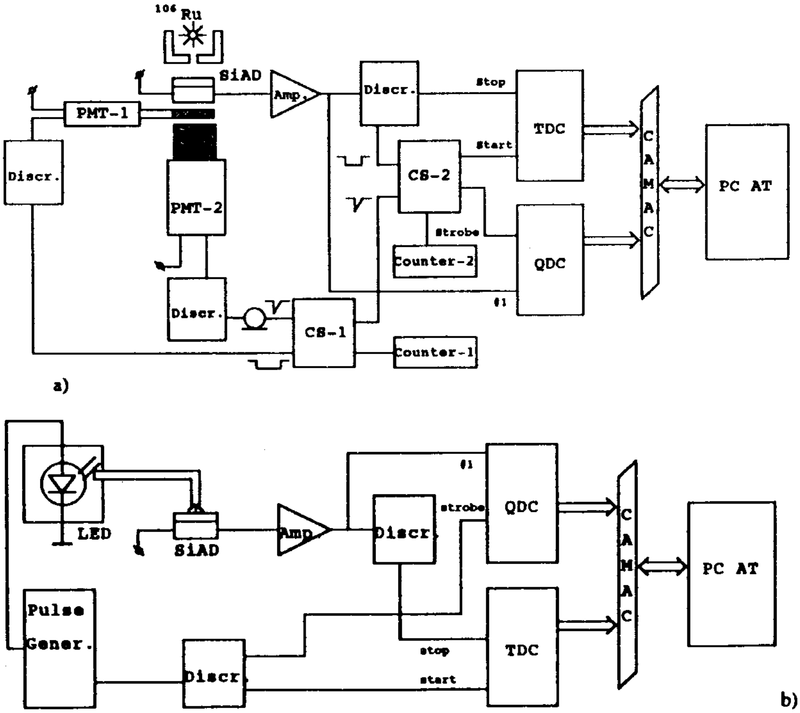

Fig.2. The measurement set-up block diagram:
a) with β-source; b) with LED.
QDC — charge-to-digit converter; TDC — time-to-digit converter;
CS — coincidence scheme; Amp. — amplifier; Discr. — discriminator

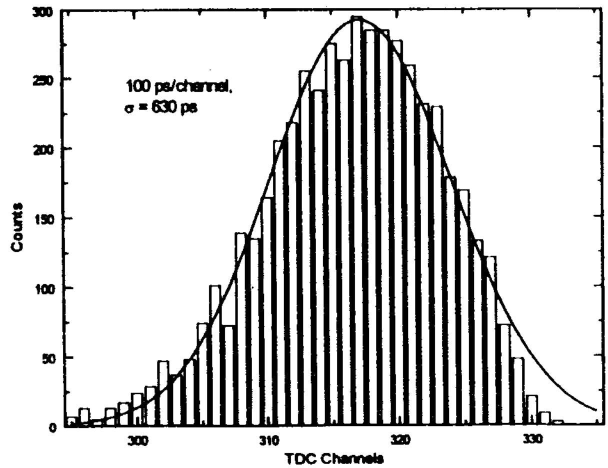

Fig.3. Time spectrum of the 5×5 mm^2 detector from ^{106}Ru β-source.

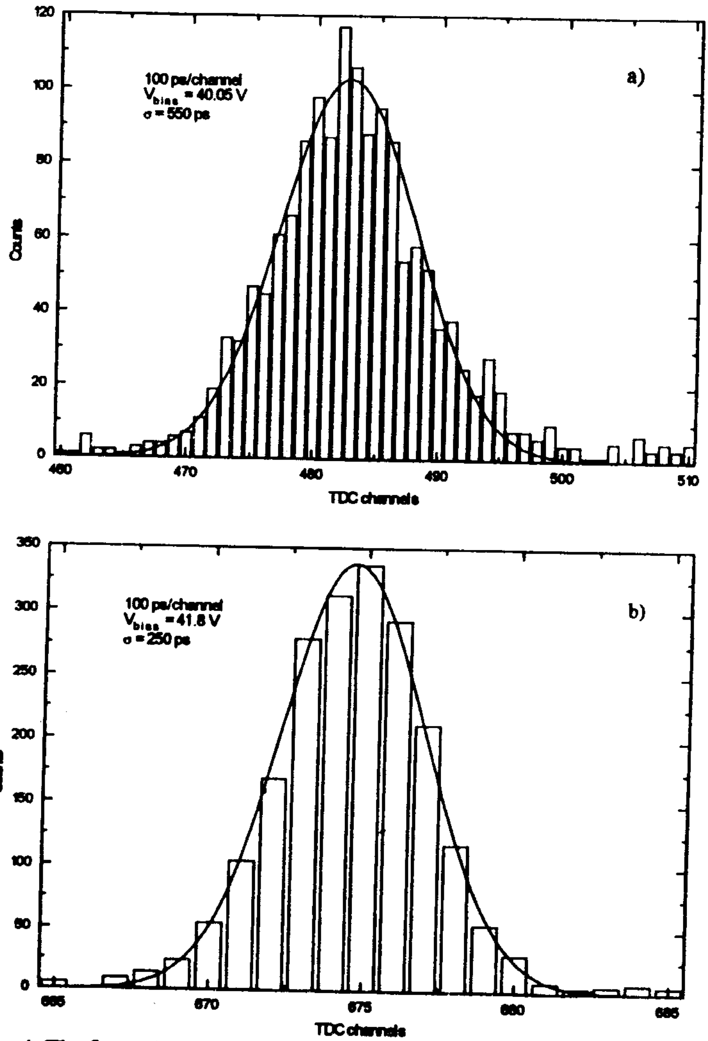

Fig.4. The 3 mm diameter SiAD time spectra:
a) with ^{106}Ru β-source; b) with LED (γ = 610÷780 nm)

were used and the detectors were produced by different enterprises, production conditions of which might differ.

Next test was with light pulses from an LED to study the possibility of improving the detector time parameters. The measured time resolution is σ = 250 ps (Figure 4b).

The test consisted of exposing the SiAD to LED light pulses with a wavelength 610÷780 nm. The LED was supplied with orthogonal pulse generator (pulse height is 50—100 V, risetime about 100 ps). Strobe signals of the generator were used as TDC «start» and the SiAD signals were used as «stop». Block diagram of the measurement set-up is shown in Figure 2b.

3. Work in Progress and Further Plans

Further theoretical considerations let us to conclude that better results may be obtained with modification and optimization of the avalanche detectors for time measurements purpose. Simulation of the detector parameters is in progress now to better understand principles of operation of the detector and optimize the parameters. We plan to investigate different types of the silicon avalanche detectors with negative feedback to obtain the best results. One of the possible ways to improve the detector characteristics is using more pure silicon substrate with more uniform and smooth surface. Also the radiation hardness of them is a subject for studying.

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