INVESTIGATION OF PHOTOELECTRIC CHARACTERISTICS OF SILICON AVALANCHE MICRO-PIXEL STRUCTURES WITH SURFACE DRIFT OF CHARGE CARRIERS

R. MEHTIEVA, A. NADZHAFOV
Institute of Radiation Problems, Azerbaijan National Academy of Sciences, Az-1143, H. Javid ave., 31A, Baku

M. MUSAEV
Azerbaijan State Oil Academy, Az-1007, Baku, Azadlig ave., 20

N. MUSAEVA, Z. SADYGOV, E. TAPTYGOV
Institute of Physics, Azerbaijan National Academy of Sciences, Baku Az-1143 , H. Javid str., 33

Photoelectric properties of a new high sensitive photodetector elaborated on basis of silicon avalanche micro-pixel structures being an adequate analogue of known vacuum photomultipliers are investigated. It was found that dynamic range of this device exceeds five orders at gain of photo signal of 250. The offered photodetector may be successfully used for registration of weak light pulses and gamma radiation.

During last decade the silicon avalanche micro-pixel photodiode (AMPD) is considered as one of perspective options for creation of the cheapest multichannel avalanche photodetectors [1-2]. In given article the first results on photoelectric properties of a new AMPD are presented.

Advanced properties the new AMPD is connected with a local negative feedback (LNF) effect, which significantly reduces influence of the crystal non-uniformity on the characteristics of the avalanche multiplication process. The LNF effect is achieved by forming an electric field of specific geometry in the multilayer silicon structure, which ensures localisation of avalanche processes and limits them to the micro-regions (micro-pixels) of 3-5μ in diameter depending of design. This results in a unique combination of high signal amplification and uniform avalanche multiplication over sensitive area of the device.

The new AMPD is produced on basis of low-resistive silicon wafer of p-type conductivity with specific resistance of 10 Ohm·cm. A schematic cross section of this AMPD is submitted in figure 1.

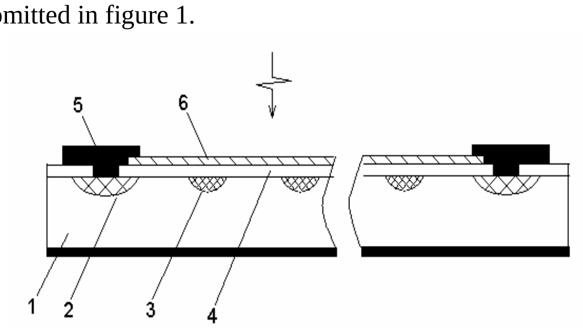

Fig.1. Cross-section of the avalanche structure.
1–silicon substrate with p-type conductivity, 2–guard ring of n-type Si, 3–matrix of p-n-junctions, 4–silicon dioxide layer, 5–aluminium layer, 6–semitransparent titanic electrode.

A silicon dioxide layer of 1000Å thickness was grown on silicon wafer, through which it was made ion implantation with phosphorous followed by annealing process at temperature of 1000C. The semitransparent titanic layer surrounded with an aluminium ring was used as a field electrode. Using this procedure and special photo masks, a matrix of small p-n-junctions with step about 8-10μ was made in sensitive area of structure. About 10,000 micropixel c/mm^2 are formed over the sensitive area of the proposed avalanche photodiode.

The operation principle of the AMPD is as follows. Positive bias voltage is applied to the field electrode, large enough to cause avalanche multiplication in the array of p-n junctions. At this bias the depletion region reaches the Si-SiO_2 boundary where a very thin (~10nm) layer of n-type conductivity with high resistance is formed. The value of the surface resistance of this layer determines efficiency of LNF effect. During the avalanche development time (~1 ns) most of the multiplied electrons are collected in the given p-n-junction as a charge packet. Dimensions of the packet are approximately equal to diameter of p-n-junction, which is about 3-5μ. The packet produces local decrease of the electric field at this p-n junction, thus locally quenching the avalanche process. After the avalanche process is suppressed, the charge packet (electrons) drifts along the Si-SiO_2 boundary to the peripheral drain electrode during 100-200ns. The short signal pulse is generated by the displacement current across the dielectric (silicon dioxide) layer.

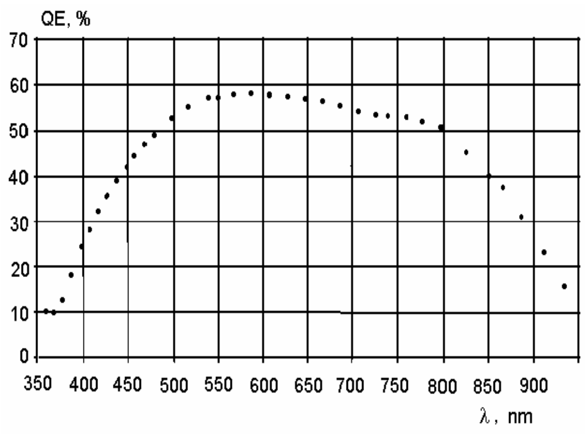

Fig.2. Spectral dependence of quantum efficiency.

Multiplication factor (signal gain) M was determined by formula $M=\Delta J_t/\Delta i_{ph}$, where ΔJ_t - an increment of the total avalanche current at potential U>50V (in the beginning of avalanche process), Δi_{ph} - an increment of photocurrent initiating avalanche process, which is measured at U=20V (e. g. at absence of avalanche process).

Figure 2 shows quantum efficiency (QE) of the AMPD vs. light wavelength. A mercury lamp was used as a light source for this measurement. Quantum efficiency of the AMPD sample was defined concerning spectral sensitivity known p-i-n diode S1223 from Hamamatsu.

It was found that the maximal value of quantum efficiency is about 58 %, and this value is limited by transparency of the titanic layer. Fall of quantum efficiency in range of short wavelength is connected with both high absorption factors for incident light and high rate of recombination process in the Si-SiO_2 boundary. Reduction of QE in the right part of this dependence is determined by lowering of absorption factor in the silicon wafers.

Dependence of photoresponse (an amplitude of photocurrent) on quantity of incident photons has been investigated at gains of M=250 and 4000. A light emitted diode with wavelength of 450nm was used for these measurements.

It was found that the dynamic range of photo response is determined by multiplication factor (gain) of avalanche process in semiconductor. As shown in figure 3 photoresponse increases linearly up to number of photons N_{ph} ~20000 at M=4000. However the AMPD may have linear photoresponse up to N_{ph}~500000 in conditions of M~250. This nonlinearly of photoresponse appearing at high gains may be explained by decreasing of electric field in p-n junction because the drain layer hasn't enough conductance to discharge avalanche region.

Thus, photoelectric properties of the new high sensitive photodetector made on basis of avalanche silicon structures being adequate analogue of known vacuum photomultipliers are investigated. Dynamic range the device may exceed five orders at gain of M~250. The AMPD offered may be successfully used for registration of very weak light pulses.

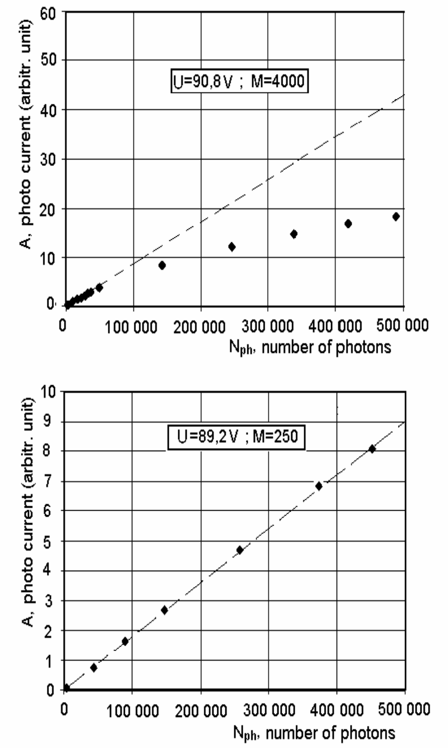

Fig.3. Dependence of photoresponse on number of falling photons in a pulse.

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R. Mehtiyeva, A. Nəcəfov, M. Musayev, N. Musayeva, Z. Sadıqov, E. Taptıqov

SƏTHİNDƏ YÜKDAŞIYICILAR AXAN SİLİSİUM ƏSASLI SELVARİ MİKRO-PİKSEL STRUKTURLARIN FOTOELEKTRİK XASSƏLƏRİNİN TƏDQİQİ

Məlum vakuum fotoelektron gücləndiricinin analoqu olan və silisium tərkibli selvari mikropiksel strukturların əsasında hazırlanmış yüksək həssaslıqlı fotodetektorun fotoelektrik xassələri tədqiqi edilmişdir. Bu qurğunun dinamik oblastının fotosiqnalın 250 dəfə böyüdülməsi zamanı 5 tərtibdən yuxarı olduğu tapılmışdır. Təklif olunan fotodetektor zəif işıq impulslarının və qama şüalanmanın qeydiyyatı zamanı uğurla istifadə oluna bilər.

Р. Мехтиева, А. Наджафов, М. Мусаев, Н. Мусаева, З. Садыгов, Е. Таптыгов

ИССЛЕДОВАНИЕ ФОТОЭЛЕКТРИЧЕСКИХ ХАРАКТЕРИСТИК КРЕМНИЕВЫХ ЛАВИННЫХ МИКРО-ПИКСЕЛЬНЫХ СТРУКТУР С ПОВЕРХНОСТНЫМ ТЕЧЕНИЕМ НОСИТЕЛЕЙ ЗАРЯДА

Исследованы фотоэлектрические свойства высокочувствительного фотодетектора, являющегося аналогом известного вакуумного ФЭУ и приготовленного на основе кремниевых лавинных микропиксельных структур. Найдено, что динамическая область этого устройства превышает пять порядков при усилении фотосигнала в 250 раз. Предложенный фотодетектор может быть успешно применен для регистрации слабых световых импульсов и гамма-излучения.

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