A NEW LOW-NOISE AVALANCHE PHOTODIODE WITH MICRO-PIXEL STRUCTURE

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A new design of the avalanche photodiodes with an array of micro-pixel p-n-junctions was developed on base of metal-oxide-silicon structure. The thermal oxide layer of 1000A thickness contains tunnel oxide regions with about 25A thickness. The device exhibits a noise factor ~ 4 at a high multiplication factor (M~10000). A high space uniformity of sensitivity was found for gain of M~ 1000.

INTRODUCTION

The use of the metal–insulator–silicon (MIS) structure as an avalanche photodiode was first proposed in [1, 2]. The traditional MIS-structures exhibited very high gains in comparison with ordinary avalanche photodiodes (APD). However, the mentioned avalanche MIS-structures need pulsed bias for operation because of a thick oxide layer. This disadvantage was avoided by using wide-gap resistive layers instead of the insulator (see [3–6]). In this case, carriers accumulated during avalanche process at interface silicon-resistive layer flow out through the high-resistive layer. A major disadvantage of such structures is the poor reproducibility of wide-gap layer.

In this study, we examine the characteristics of an avalanche photosensitive MIS structure, where carriers flow out from the avalanche regions to upper electrodes throw specially created pixels with tunnel oxide layer of ~25A thickness.

DEVICE DESIGN AND OPERATION

The device is intermediate between conventional avalanche photodiodes and photosensitive MIS structures intended for avalanche mode operation. This planar photodiode was made on p-Si wafer with a specific resistance about 1Ω*cм. The photosensitive area is covered with a silicon oxide (SiO_2) layer of ~1000A and a semitransparent titanium coating connected to a collector electrode of thick aluminium ring (Fig.1.).

The silicon oxide layer separates metal electrodes from a substrate. On a surface of silicon substrate a matrix of p-n-junctions was manufactured. Above the p-n-junctions a thin oxide of ~25A was made. The sizes of p-n-junctions were 2μ*2μ, and interval between them – 6μ. The amplification of photocurrent is yielded only in these p-n-junctions. Then the avalanche current flows out to contacts by tunnelling process throw thin oxide layer. This enables the MIS structure to operate in the avalanche mode at a continuous bias mode.

EXPERIMENTAL DATA

We studied photodiode noise properties using a conventional technique for low-signal radio engineering; i.e., a dc signal was measured after square-law detection of noise, which made it possible to restrict our measurements to a relatively narrow frequency range (3 MHz in the considered case).

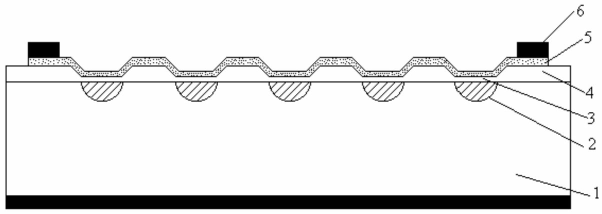

Fig. 1. Cross section of the avalanche MIS- photodiode; 1 - p-Si substrate, 2 - p-n-junction, 3 - thin oxide layer, 4- thick oxide layer, 5- semitransparent Ti layer, 6- thick Al layer.

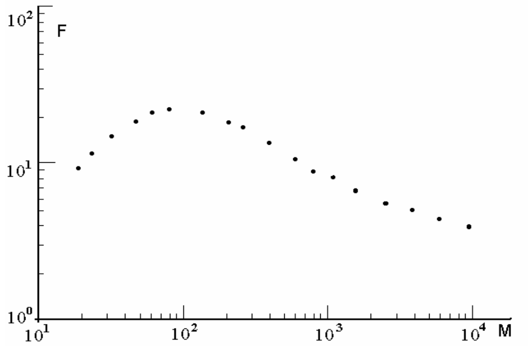

Fig. 2. Excess noise factor F versus the signal gain M.

Figure 2 displays the measured noise factor for the tested diode. The noise factor was measured using light emitting diode with λ~0.55μ, which is absorbed mostly in near-surface region. In this case, holes are injected into the diode active region, which is extremely adverse to the signal-to-noise ratio, as is evident from the data acquired at relatively low M. The avalanche MIS photodiode exhibited substantially better noise characteristics because of local negative feedback effect. It is necessary to note, that the noise factor measured at the highest M are lower than those calculated according to the McIntyre theory [7] for electron injection and for very small $k = 0.005$.

GAIN DISTRIBUTION OVER THE PHOTOSENSITIVE AREA

One of disadvantages of APD's with traditional design is its non-uniform photosensitivity over the working area, which becomes more pronounced with increasing multiplication factor. A negative feedback mechanism in MIS avalanche photodiodes substantially levels off this problem.

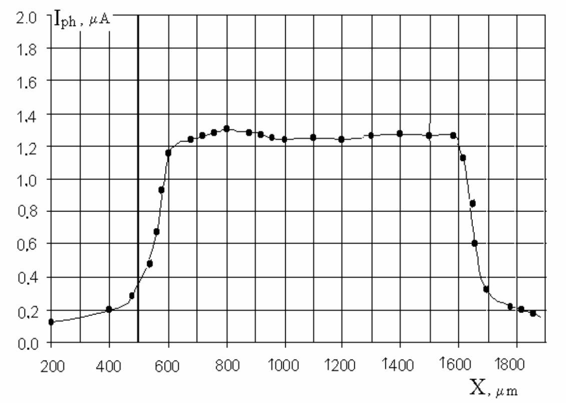

Fig.3. Coordinate dependence of photosensitivity at M~1000.

Figure 3 displays the measured coordinate dependence of photosensitivity at M~1000. The measurements were carried out using an optical probe with a diameter of 30μ. The non-uniformity found in the sensitivity over the area does not exceed 20%. The appreciable photo- sensitivity beyond the receiving area edge is caused by scattered radiation in the optical system.

CONCLUSION

A new type of avalanche photodiode high gain was developed on base of MIS technology. The micro-pixel avalanche photodiode demonstrates very low noise factor at signal gains more than 10^2. Further studies will be focused on increasing of signal gain up to 10^6.

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YENİ MİKRO-PİKSEL STRUKTURA MALİK AŞAĞI KÜYLÜ SELVARİ FOTODİODLAR

Metal-Oksid-Silisium strukturu əsasında mikro-piksel p-n-keçidlər massivinə malik selvari fotodioların yeni forması işlənib hazırlanmışdır. 1000 A qalınlığındakı oksid layı təqribən 25 A qalınlığında tunel oksid bölümlərini ozündə saxlayır. Yüksək gücləndirmə faktoru altında (M~10000) qurğunun küy faktoru təqribən 4-ə bərabərdir. M~1000 güclənməsi zamanı isə həssaslığın ən yüksək fəza bircinsliyinə malik olması aşkarlanmışdır.

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НОВЫЙ НИЗКОШУМНЫЙ ФОТОДИОД С МИКРО-ПИКСЕЛЬНОЙ СТРУКТУРОЙ

Новый шаблон лавинных фотодиодов с массивом микро-пиксельных p-n-переходов был разработан на основе Металл-Оксид-Кремний структуры. Термальный оксидный слой толщины 1000А содержит туннельные оксидные регионы толщины около 25А. Устройство демонстрирует фактор шума ~4 при факторе высокого умножения (М~10000). При увеличении фактора М~1000 найдено высокое пространственное однообразие чувствительности.