PACS: 29.40.Wk

PERFORMANCE OF A NEW PHOTO DETECTOR FOR IONIZING RADIATION

[1,2]A. Sadigov, [1,2]S. Suleymanov, [1,2]F. Ahmadov, [1,3]G. Ahmadov, [1,4]Z. Sadygov, [2]R. Madatov, [2]R. Mehdiyeva, [2]M. Nuriyev, [1]R. Akberov, [1]R. Valiyev, [1]N. Heydarov, [1]M. Nazarov

[1]National Nuclear Research Center, Baku, Azerbaijan.
[2]Institute of Radiation Problems of ANAS, Baku, Azerbaijan.
[3]Joint Institute for Nuclear Research, Dubna, Russia.
[4]Zecotek Inc., Vancouver, Canada.
saazik@yandex.ru

Abstract: In this article, our team offers a new concept of silicon photomultiplier-based on micro transistors, which is planned to create a micro pixel avalanche phototransistor (MAPT) as a modern design, where the transistors are used as an additional element to the internal gain of the device. It is shown that MAPT will increase the working area of the device more than 30 times in comparison with analogues. The probability of occurrence of cross talk and after-pulses is reduced with decreasing the coefficient of avalanche gain in avalanche photo diodes. Decrease in avalanche gain is compensated by the gain of micro transistors in MAPT.

Key words: Micro-pixel avalanche photodiodes, MAPD, Silicon photomultipliers, MAPT.

1. Introduction

In recent years, an advance in technology has given rise to the development of microelectronics, and that has enabled the creation of an array of micrometer sensitive pixels to photons known as photodiode. Today there are many varieties of this product. Such great corporations and firms as HAMAMATSU [1], KATEK, Philips [2], ZECOTEK [3] have in their production as well as avalanche photodiodes and conventional PIN diodes. But all of them have some drawbacks which affect to results of the research.

Currently, prevalent the standard construction of micro pixel avalanche photodiode MAPD (Figure 1) [4]. The device comprises of matrix of small p-n junctions (pixels) with individual quenching resistors. This allows each pixel to work in Geiger mode and have a gain equal to 10^6.

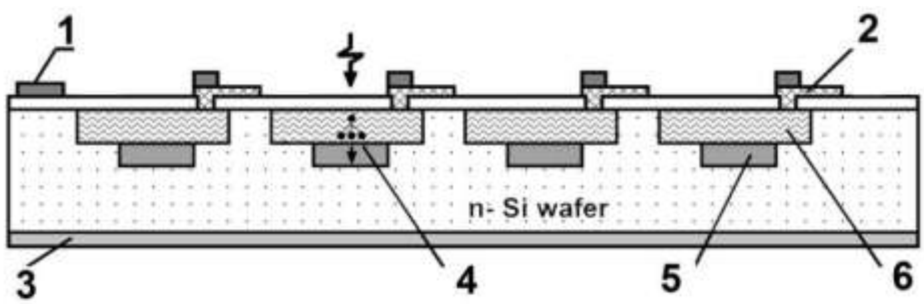

Fig. 1. Standard design of MAPD. 1 – micro-pixel output; 2 – micro-pixel quenching resistors; 3 –bias terminal (Al layer); 4 – avalanche gain region; 5 – avalanche area of n^+-Si; 6- pixel area of p^+-Si.

However, there are a number of drawbacks that limit the use of standard design of MAPD

- High probability (~ 20%) of occurrence of the optical crosstalk, worsening the linear region of the device (Figure 2a).

- High probability (~ 20%) of occurrence of the after pulsing, worsening the amplitude resolution of the device (Figure 2b).
- The high specific capacitance, limits the sensitivity area of a standard MAPD.

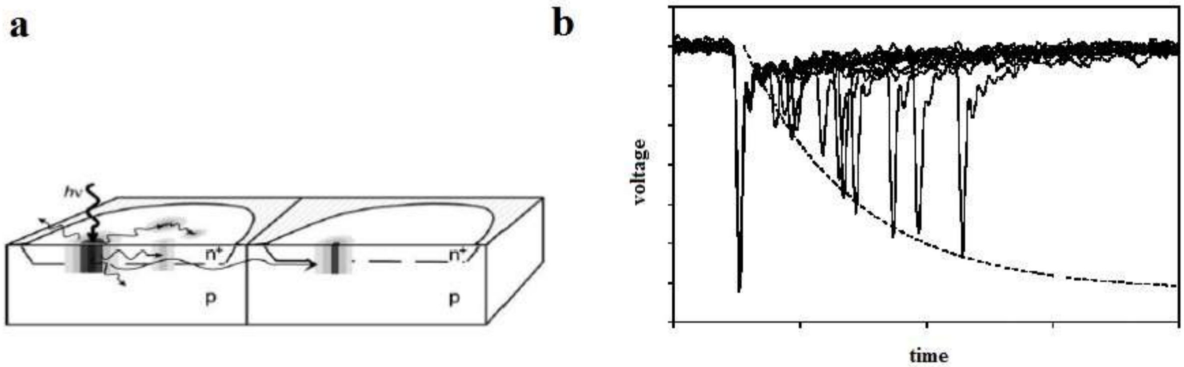

Fig. 2. Schematic representation of optical crosstalk (a) and waveforms corresponding to after-pulsing (b).

It is known that due to optical coupling between the cells formed in activated cell (in photo- or heat generation) the charge carrier may activate not only the cell, but also the neighboring pixels. Therefore, increasing internal amplification of the photodiode also increases the probability of the optical cross-talk. The gain of standard design MAPD and its analogues is 10^5-10^6. This amount of charge carriers passing through the cell, leading to the emission are more than 3 photons with a wavelength less than 1μ. The effect increases with increasing overvoltage of photodiode.

2. Results and discussions

One of the positive properties of silicon photomultipliers is the recovery time of the pixel due to the small quenching resistor (R ~ 100-200 Ω). Because of a crystal defect a few of charge carries in a primary avalanche process are trapped within the pixel and could not leave it. Just after a primary avalanche process these trapped charge carries could trigger a new avalanche process which is called after-pulsing.

In MAPD, the signal is taken directly from each pixel, and then it summed. This speed is determined by the capacity of the entire sensitive area of the device. The modern types of silicon photomultipliers capacity is estimated at a few tens of pF, which contributes the slow response to the photon and the relatively slow recovery of the photodiode.

Recently, we proposed a new type of avalanche photodiode – micro pixel avalanche phototransistor MAPT (Figure 3) [5]. The uniqueness of this device is the use of micro-transistor in the structure, which improves the properties of the photodiode. Bias voltage of about 2V falls on the quenching resistor Rp while the photoelectron avalanche process. The fall of the potential at the base of the transistor fully opens its emitter junction, and a large current flows, which limited by resistor Rq. In the absence of the full potential of the avalanche process, Up falls on a pixel with capacitance Cp ~ 50fF (on the other words, the potential drop in the Rq is zero), so the phototransistor is closed.

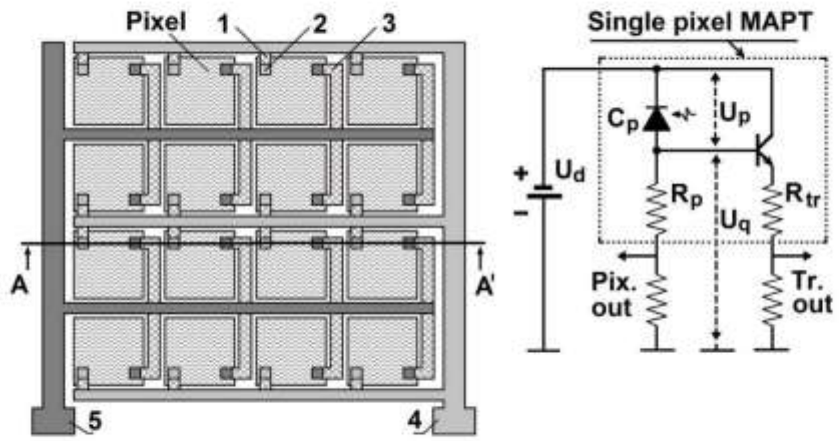

Fig. 3. Micro pixel avalanche phototransistor MAPT. 1 – micro-transistor ballast resistors; 2 – silicon n-p-n micro-transistors; 3 – micro-pixel quenching resistors; 4 – micro-transistor output.

The problem solving of optical crosstalk is to reduce the internal gain of the photodiode in several times. Thereby minimizing the probability of adverse effects. One of the features of using micro transistor is that his own gain, which amplify avalanche process. Decline the number of charges which participate in the avalanche process, also decrease the probability of capture of photoelectrons by traps.

Each pixel of MAPT consists of two parts. One of them avalanche area, another micro-transistor, the area of the last one 30 times smaller than the entire pixel area. If you take the signal from the electric circuit of micro transistor, the capacitance of the device will be 30 times less than the photodiode [6].

Transistors are working in binary mode "On - Off", and therefore it is possible to obtain a relatively short rise time (~ 0.5 ns) (Figure 4). The total gain of MAPT pixels $M_p=M_{av}\times M_{tr}$, where M_{av} - coefficient of avalanche gain, M_{tr} - micro-transistor amplification. This can significantly reduce the coefficient of r avalanche gain, leading to undesirable effects.

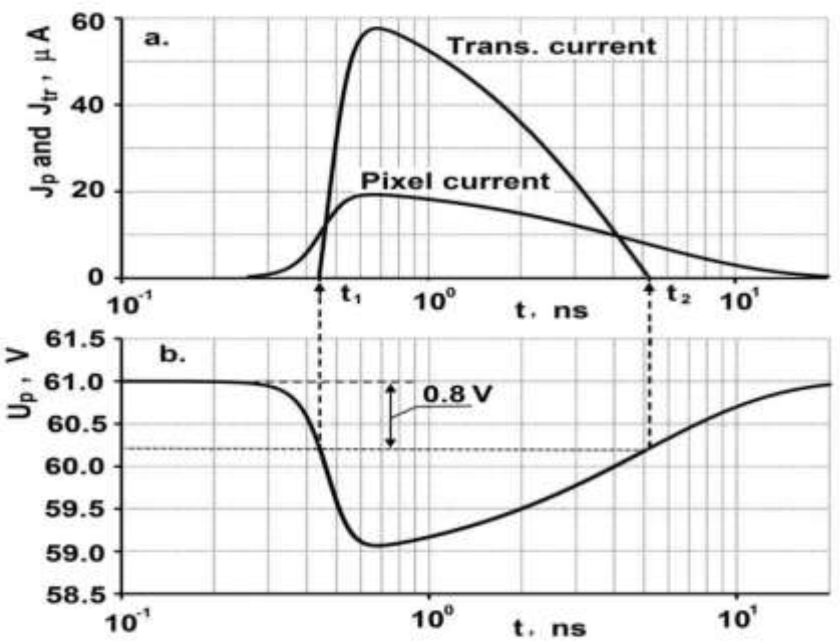

Fig. 4. Waveforms of single photoelectron currents (a) and voltage drop on the MAPT pixel (b).

3. Conclusion

The main results of this work can be summarized as follows.

- Design and topology (Photo masks) of the new silicon photomultipliers based on MAPT structure was developed.
- It is shown that MAPT will increase the working area of the device more than 30 times in comparison with analogues.
- The opportunities to reduce the probability of occurrence of cross talk and after-pulses by reducing the coefficient of avalanche gain in photo detectors.
- The required high gain of photocurrent provided by micro transistors.

Acknowledgment

This work was supported by the Science Development Foundation under the President of the Republic of Azerbaijan – **Grant № EIF-2014-9(24)-KEPTL-14/03/1**

References

1. http://www.hamamatsu.com
2. http://www.photonics.philips.com
3. http://zecotek.com
4. Z. Sadygov et al., *Nucl. Instrum. Meth. A* 567 (2006) 70.
5. Z. Sadygov and A. Sadigov, Russian patent # 2528107, published, September, 10 (2014).
6. Z. Sadygov et al., http://arxiv.org/ftp/arxiv/papers/1410/1410.2619.pdf

ЭФФЕКТИВНОСТЬ НОВОГО ФОТОДЕТЕКТОРА ДЛЯ ИОНИЗИРУЮЩЕГО ИЗЛУЧЕНИЯ

А. Садигов, С. Сулейманов, Ф. Ахмадов, Г. Ахмадов, З. Садигов, Р. Мадатов, Р. Мехдиева, М. Нуриев, Р. Акберов, Р. Велиев, Н. Гейдаров, М. Назаров

Резюме: В этой статье наша команда предлагает новую концепцию кремниевых фотоумножителей на основе микротранзисторов, которые планируются для создания микропиксельного лавинного фототранзистора (МЛФТ), как современный дизайн, где транзисторы используются в качестве дополнительного элемента к внутреннему тепловыделению. Показано, что МЛФТ увеличит рабочую зону прибора более чем в 30 раз по сравнению с аналогами. Вероятность возникновения перекрестных помех и остаточных импульсов понижается с уменьшением коэффициента лавинного усиления в лавинных фотодиодах. Снижение лавинного усиления компенсируется за счет усиления микротранзисторов в МЛФТ.

Ключевые слова: Микропиксельный лавинный фотодиод, МЛФД, Кремниевые фотоумножители, МЛФТ.

İONLAŞDIRICI ŞÜALANMADA YENİ FOTO DETEKTORUN EFFEKTİVLİYİ

A. Sadiqov, S. Süleymanov, F. Əhmədov, Q. Əhmədov, Z. Sadıqov, R. Mədətov, R. Mehdiyeva, M. Nuriyev, R. Əkbərov, R. Vəliyev, N. Heydərov, M. Nəzərov

Xülasə: Bu işdə bizim qrup fototranzistorlar əsasında yeni növ fotodetektor konsepsiyasını təklif edir. Yeni Mikropikselli Selvari Fototranzistor (MSFT) dizaynında, tranzistorlardan əlavə gücləndirmə elementləri kimi istifadəsi nəzərdə tutulur. Göstərilmişdir ki, yeni struktur əsasında cihazın həssas səthi analoqları ilə müqayisədə 30 dəfə qədər artırmağa imkan verəcəkdir. Bununla yanaşı fotodiodun gücləndirmə əmsalını azaldıqda çarpaz görüşmə və qalıq impulsların mövcud olma ehtimalını da azaldır. Azaldılan gücləndirmə isə tranzistorun gücləndirməsi isə kompensasiya olunur.

Açar sözlər: Mikro-piksel selvari fotodiodlar (MSFD), Silisium fotomultiplikator, MSFT.