Study, simulation and manufacturing of new Geiger-APD for applications in Astrophysics and Biology

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Abstract:
Nowadays, there are two types of sensors to detect the low luminous flux, PMT (PhotoMultiplier Tube) and Geiger-APD.
The Geiger-APD is a component on silicon that was developed in the early 90s to detect very low light flux [1], as is currently the PMT (PhotoMultiplier Tube). The main advantages of these devices on the PMT are a very high sensitivity to light (single photon), a very high time resolution (<100ps), integration into imaging made possible by a great homogeneity. Unfortunately, these components have some drawbacks compared to PMT; a very small sensitive area (20µm) and a leakage current (Dark Count Rate) higher per unit area.
A first technological process has already been studied by collaboration between the CESR and the LAAS [2] to develop a technology called "Geiger-APD" or "SiPM".
The second work to be done includes the integration into Microsystems, with ambition, in long term, to develop several applications in astrophysics, biology, optical detection, and most importantly, fast imaging systems. The manufacturing of imaging equipment in a new process must be defined by a detailed study on the imaging Geiger. Different applications in astrophysics are possible such as the detection of Cerenkov flash.
In this paper, we will present the main characteristics of the considered technology. A comparison between the old and the novel technology will be made, and results of simulations and studies of the considered technology will be explained in the main part of this paper.
During the last technological achievement, a characterization of the components was made and the conclusion of all measures gave principally that: the noise factor is the main disadvantage of this technology [3]. This parameter is related directly to the life time of the carriers in the crystal lattice.
On the figure below (fig. 1), a structure of the old technology is presented.

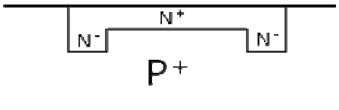

Fig.1: the structure of the Geiger-APD in the old technology.

In this structure, we can distinguish a substrate of type P+ who has a low resistivity (0.85 Ω . cm) and a very low life time of carriers (10µs).
With those characteristics of the wafer, the results are not expected to give a minimal of thermal noise. Measure of noise in function of the over bias voltage is represented in the next figure (fig. 2).

This graphic presents measures realized on different diodes, which were manufactured in the Clean Room of LAAS. This work was achieved by a PhD student in CESR, result of collaboration between the two neighboring laboratories.

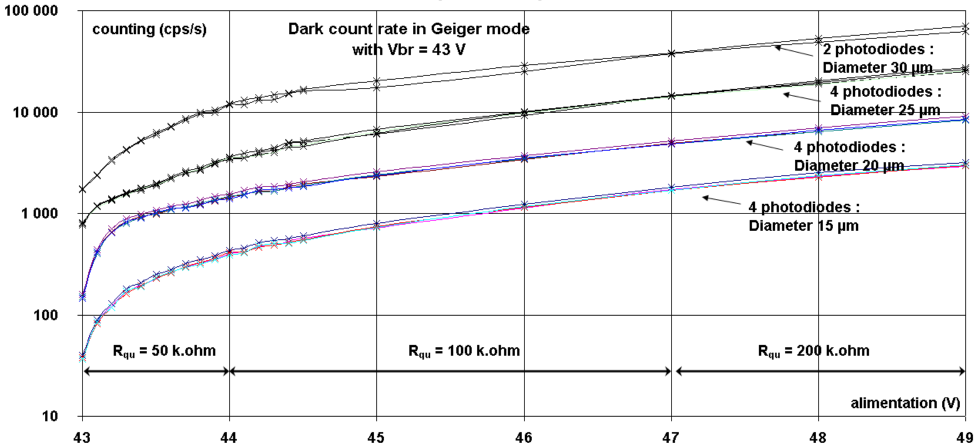

Fig.2: Dark Count Rate (DCR) of different diodes in function of over bias Voltage.

On the graphic of the fig.2, we can conclude a very high DCR of the components which increases with the increasing of sensitive area. This high DCR is due to the very low life time of the carriers.

In the new technology, a different concept has been adapted to avoid the problem of noise. Based on wafers belonging to a high resistivity type (>2000 Ω.cm), therefore a very high life time of carriers (>1500µs), studies and simulations on this new technology have been made and a new structure of the diode was adapted. The figure below (fig.3) shows the structure of this technology.

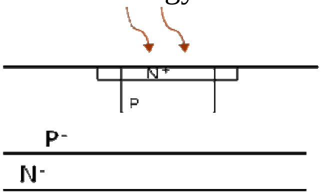

Fig.3: the structure of the new technology.

The results of simulations on this structure showed a breakdown voltage centered at the PN^{++} junction of the diode. The Geiger mode can be treated only if the breakdown voltage is controlled in this operating area. The simulations argue that the PN^{++} junction may be over-biased and the Geiger-mode can be established in this case. The characteristic I (V) of this structure is represented on the next figure (fig.4).

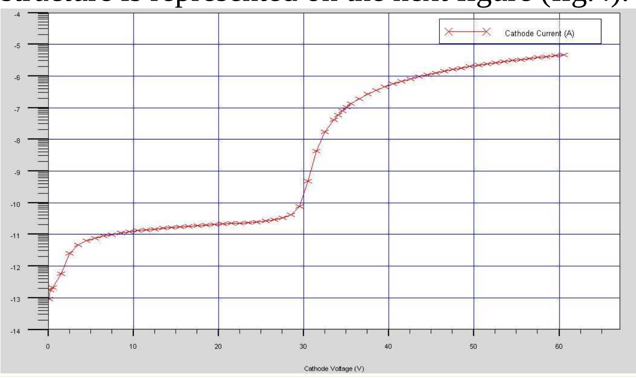

Fig.4: the characteristic I (Vbr) of the studied structure.

The choice of the wafer characteristics and the simulations result seem to be very encouraging, the manufacturing of components is in its final phase.

All characterizations of the new structure will be presented in the full paper. Explanation of the different kind of components achieved in this manufacturing process will be detailed.
Although the Geiger-APD is the principal structure and the base of detection in this domain, its pixellisation is very important for the domain of imagery for multiple applications. So that another structure which is the SiPM (Silicon PhotoMultiplier) will be also presented which we can briefly explain by a matrix of Geiger-APD regrouped in form of one pixel with one output signal. This idea is very recent and used only in the Geiger-mode components. The imagers are constituted generally by 8x8 pixels of SiPMs and others by 8x8 of Geiger-APDs.
In conclusion, the new structure is promoted to give important results in the domain of detection of low light intensity and new structures are included in this process for a new era of imagery in Geiger-mode.

References:

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