Silicon photomultipliers: on ground characterizations and modelling for use in front-end electronics aimed to space-borne experiments

Davide Badoni [a] Francesco Altamura [a] Alessandro Basili [a] Raffaele Bencardino [a] Vittorio Bidoli [a] Marco Casolino [a] Anna De Carli [a] Tom Froysland [a] Marcello Marchetti [a] Roberto Messi [a] Mauro Minori [a] Piergiorgio Picozza [a] Gaetano Salina [a] Arkady Galper [b] Mikhail Korotkov [b] Alexander Popov [b]

[a] *Phy.Dep.Univ."Tor Vergata", Tor Vergata Sect. INFN*

[b] *Moscow Engineering and Physics Institute*

Presented by: Davide Badoni

Abstract

Silicon Photomultipliers (Si-PM) consist of an array of semiconductor photodiodes joint on the common substrate and operating in limited geiger mode. A new generation of Si-PM is currently under test in INFN Rome Tor Vergata facilities: they consist of a 5625 element, $3 * 3\ mm^2$ array with an improved light response. These elements have been characterized. Furthermore, a functional model of the Si-PM has been developed to be used in a VLSI development of front-end electronics.

1. Introduction

Silicon Photomultipliers (Si-PM) consist of an array of avalanche semiconductor photodiodes[1] joint on the common substrate and operating in limited geiger mode. These diodes have been provided by Mephi group[2]. In this work we discuss the performance of the $3 * 3\ mm^2$ size Si-PM. It is composed by 5625 elements (pixel) and it has been tested and characterized (gain and aging) with a static stimuli configuration; furthermore, a functional model of the Si-PM has been developed to be used in a VLSI development of front-end electronics. For their linearity, low voltage and small dimensions, they are particularly suited for space applications.

2. Characterization

The current $I(V_b) = I_l(V_b) - I_d(V_b)$, where I_l and I_d are light and dark current respectively, has been used for the gain evaluation. The gain could be estimated by the formula $Gain(V_b) = \frac{I(V_b^*)}{I(V_{flex})}$[3], where V_b^* is the bias voltage V_b at the working voltage and V_{flex} is a flex on the $I - V$ characteristic: for $V_b < V_{flex}$ the increment of $I(V_b)$ would tend to an asymptotic value; for $V_b > V_{flex}$ $I(V_b)$ becomes sensitive to the avalanche effect. We present the results of two different measures: the first one is the $I - V$ characteristic at several temperatures (see fig.1) and the second one is the gain vs. aging at different bias voltages, according on the above definition (see fig.2).

Preprint submitted to Elsevier *22 November 2006*

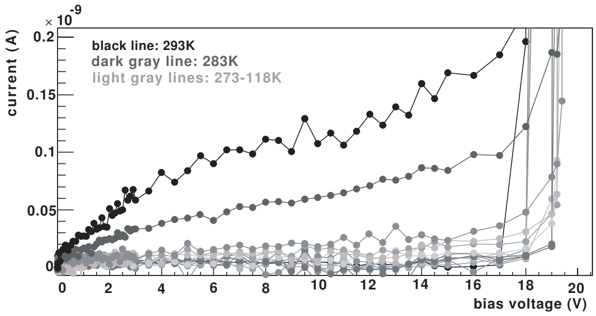

Fig. 1. I vs. V with different temperature. From top: $293K$, $283K$, $273 \div 118K$.

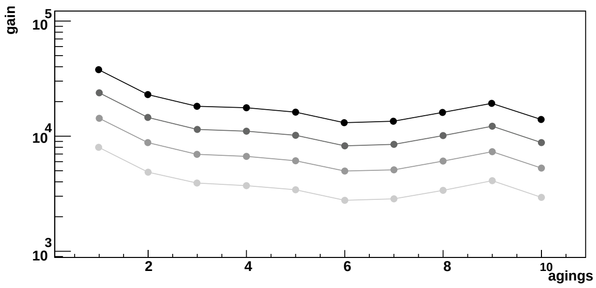

Fig. 2. Gain vs. aging. Different curves corrispond to different reverse bias voltage; from top to bottom: $21.0\,V$; $20.8\,V$; $20.6\,V$; $20.4\,V$. One unit of aging correspond to about 80 mC of integrated charge.

3. Si-PM Model

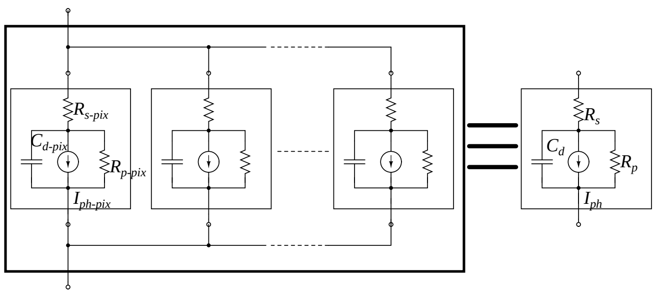

Fig. 3. Single pixel array vs. global representation.

In the fig. 3 are represented two alternative equivalent circuits of SiPM. With the approximation that parameters of all pixels are the same, the single pixel parameters (parameters with *-pix* extension in the left side of fig. 3) has a linear relationship with the parameters in the global representation (right side of fig. 3). The R_{s-pix} is the inserted ohmic resistor which causes the limitation in the geiger-mode. The others parameters are extracted directly from measures on SiPM (see fig. 4). The R_{p-pix} takes into account the thermal current: it depends on temperature and V_b and represent the time integral mean of the current. The junction capacitance C_{d-pix} also depens on V_b. The current generator I_{ph-pix} represents the incoming photons.

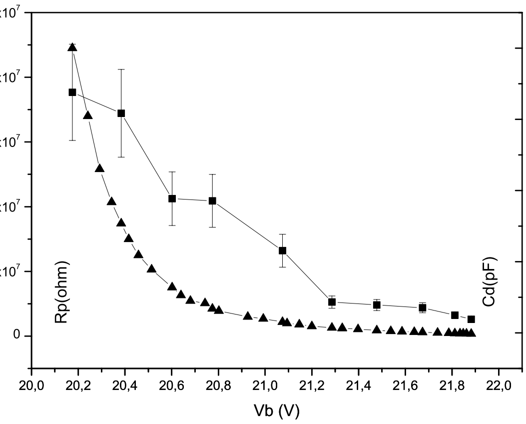

Fig. 4. Measures of capacitance $C_d(V_b)$ (■) and resistance $R_p(V_b)$ (▲).

References

[1] G. Bondarenko et al. *Limited geiger-mode silicon photodiode with very high gain.* Nuclear Physics B 61B (1998) 347.

[2] P.Buzhane et al. *Silicon photomultiplier and its possible applications.* Nucl. Instr. and Meth A A504 (2003) 48.

[3] A.Karar et al. *Characterization of avalanche photodiodes for calorimetry applications.* Nucl. Instr. and Meth A 428 (1999) 413.