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 avalanche 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 mm² 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 mm² 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 \( \text{Gain}(V_b) = \frac{I_l(V_b)}{I(V_{\text{flex}})} \) [3], where \( V_b^* \) is the bias voltage \( V_b \) at the working voltage and \( V_{\text{flex}} \) is a flex on the \( I-V \) characteristic: for \( V_b < V_{\text{flex}} \) the increment of \( I(V_b) \) would tend to an asymptotic value; for \( V_b > V_{\text{flex}} \) \( I(V_b) \) 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).
Fig. 1. $I$ vs. $V$ with different temperature. From top: 293K, 283K, 273 ÷ 118K.

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

3. Si-PM Model

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 depends on $V_b$. The current generator $I_{ph-pix}$ represents the incoming photons.

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

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

References