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Studies of silicon photodetectors for scintillator-based Hadron Calorimetry at the International Linear Collider

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Abstract

We present results on the operation and performance characteristics of the Metal/Resistor/Semiconductor (MRS) photodiode. These include measurements of threshold characteristics, noise frequency, dependence of signal amplitude on the applied voltage and temperature, and stability as a function of time and radiation dose. The single photoelectron separation for this photosensor is demonstrated with a light-emitting diode. The response of the photodetector to light produced in scintillator is studied with cosmic ray muons and a ^{106}Ru source. In addition, fiber-sensor alignment issues were evaluated. The results are promising and illustrate the potential use of MRS as photosensors in high energy physics detectors.

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Keywords: Solid-state photosensor; Geiger mode; Multipixel; Characteristics; Irradiation; Miniaturized photodetector

1. Introduction

Calorimeters, optimized for particle flow algorithms, are under active study for their promise of delivering superior jet energy resolution, essential to exploiting the full physics potential of a future e^+e^- linear collider. These calorimeters require fine longitudinal and transverse segmentation to efficiently resolve the showers initiated by the individual particles constituting a jet. For designs with small scintillating cells as the active medium [1], the large channel count imposes strong constraints on the cost and performance of photodetectors. This has directed our attention to solid-state photomultipliers working in the avalanche mode [2]. In spite of their relatively short history, these photodetectors may have an impact on the design of future detectors. For instance, photodetectors that are embedded in the scintillator reduce light loss and routing problems by eliminating the need for long clear fibers to carry the light from the scintillating material to the photodetector. This is possible since these Metal/Resistor/Semiconductor (MRS) solid-state photodetectors are small in size and are expected to perform well in strong magnetic fields.

The MRS photodiode is a multi-pixel solid-state device with every pixel operating in the limited Geiger multiplication mode. Avalanche quenching is achieved by a resistive layer on the sensor surface. The device has about 1500 pixels per $1\times1\,\mathrm{mm}^2$ sensor [2]. The detection efficiency of the device reaches 25% at 500 nm [3]. In this report, we have concentrated on the operating parameters and stability of the MRS, i.e., the dependence of amplification and noise count rate on the applied bias voltage, temperature and radiation dose. These parameters are important in a system with millions of channels. Also, the linearity of response was measured.

2. Experimental section

2.1. Working point

MRS amplification, detection efficiency, and intrinsic noise directly depend on the applied bias voltage, and this

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dependence varies from one individual photodetector to another. Thus, a particular bias voltage (working point) must be chosen for the above parameters.

The apparatus used to study these parameters is shown schematically in Fig. 1a. An eight-channel MRS board with preamplifiers from the Center for Perspective Technologies and Apparatus (CPTA) [2] serves as the MRS output amplifier and signal shaper (Fig. 1b). Each channel includes an MRS sensor, a bias voltage tuner and a preamplifier. Initially, all channels were tested under identical conditions with the same bias voltage and the same light signal from a green light-emitting diode (LED) with peak emission at ~510 nm. The MRS was excited by a LED; the signal was amplified, discriminated and recorded. The light from the same LED had been applied to each individual channel by physically switching the position of the fiber, thus similar responses were expected. Results from a few representative channels are shown in Fig. 2. The disparity of response observed indicates that the optimal bias voltage must be found and tuned individually for each channel. Also Fig. 2 demonstrates that the MRS is sensitive to single photoelectrons. Unless stated otherwise, all measurements were carried out at $22.6 \pm 0.2\,^{\circ}$C. The following tests were used to determine a working point for the sensor.

2.1.1. Noise count rate and bias voltage

First, a low frequency (~150 Hz) signal was applied to the LED that illuminated the photodetector through a clear fiber, and the noise rate was measured as a function of the applied bias voltage. The bias voltage was measured at the MRS directly. The preamplifier output was connected to a discriminator that, in turn, was connected to a counter/timer (Fig. 1). Counts were accumulated over a period of 1 min and converted into frequency. Fig. 3a shows the output signal frequency versus the bias voltage for three different threshold values (70, 80 and 90 mV). These values were chosen so that the amplitude of sensor's response is larger than the value of the thresholds for the majority of the bias voltages.

Fig. 3b shows the MRS dark noise rate as a function of the threshold applied for a set of bias voltages. These measurements were done for three different bias voltages. For illustrative purposes, the bias voltages chosen are at

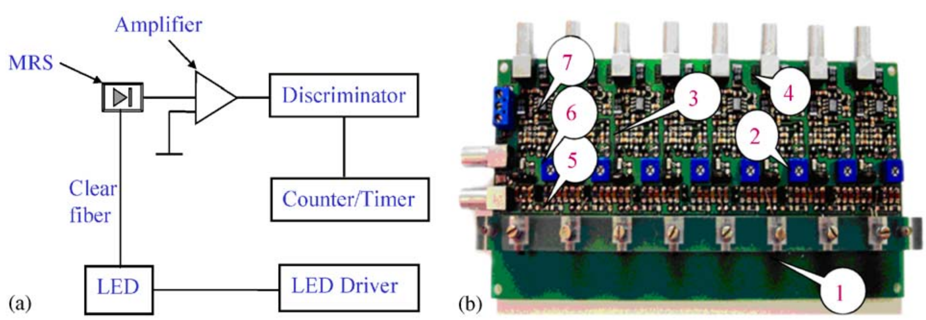

Fig. 1. (a) Block diagram showing the apparatus used for choosing the working point and (b) the eight-channel MRS board: 1—MRS sensor, 2—bias voltage tuner, 3—preamplifier, 4—signal output, 5—bias voltage input, 6—test signal input and 7—preamplifier power.

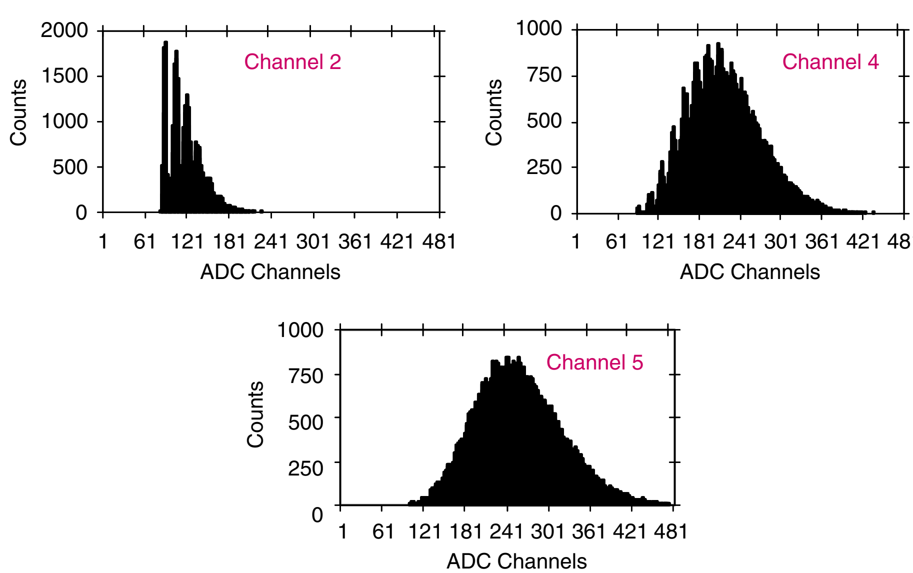

Fig. 2. Response of channels 2, 4 and 5 to the same LED signal for identical bias voltages.