Radiation hard avalanche photodiodes for CMS ECAL

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Abstract

Avalanche Photo Diodes (APDs) have been chosen to detect the scintillation light of the 61200 Lead Tungstate crystals in the barrel part of the CMS electromagnetic calorimeter. After a 8 year long R&D work Hamamatsu Photonics produces APDs with a structure that is basically radiation hard. Since a reliability of 99.9% is required, a method to detect weak APDs before they are built into the detector had to be developed. The described screening method is a combination of ^{60}Co irradiations and annealing under bias of all APDs and irradiations with hadrons on a sampling basis. The APD data handling and software for the analysis and for the APD rejection are discussed.

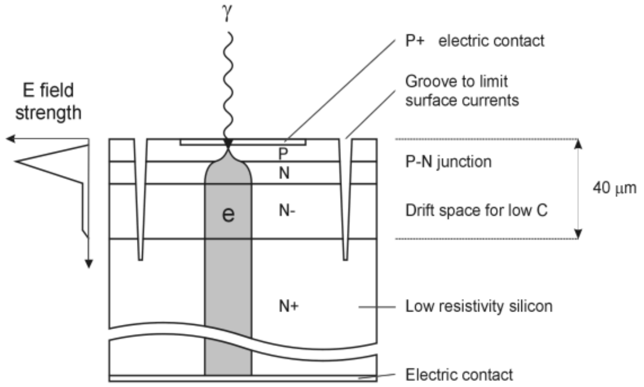

Figure 1: APD structure.

I. INTRODUCTION

Hamamatsu Photonics in close collaboration with the CMS APD group developed a large area Avalanche Photo Diode (Fig. 1) to detect the light from lead tungstate crystals in the barrel part of the CMS ECAL [1]. The APDs must satisfy the following requirements: operation in a 4 T field (the calorimeter will be located inside a high field solenoid), radiation hardness at the level of $2x10^{13}$ n/cm^2 and 2.5 kGray of ionizing radiation, speed (≤10 nsec), good sensitivity (the crystals have low light yield), stability, low sensitivity to voltage and temperature fluctuations as well as low sensitivity to ionizing particles passing through the diode [6]. The requirement of the experiment is that 99.9% of the APDs must be functioning after 10 years of LHC operation .

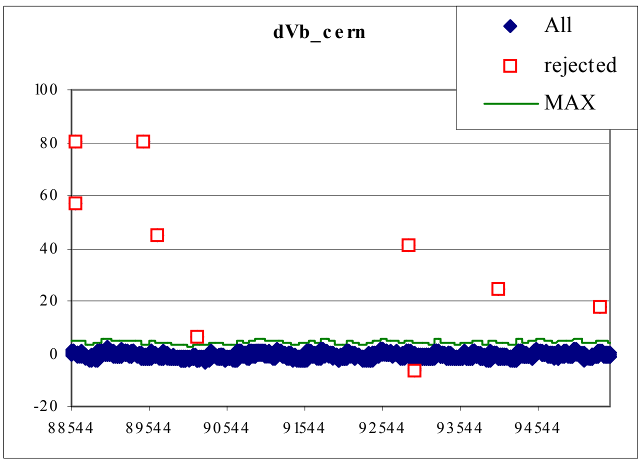

Figure 2: Changed V_b after cooking. The APDs, which show a change of the breakdown voltage bigger than 5V are rejected.

II. SCREENING

All the above requirements except the last and the radiation hardness are guaranteed by Hamamatsu Photonics [4,5]. A

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screening method has been developed to reject unreliable and not sufficiently radiation hard APDs before they are built into the detector. The screening is done in two steps: at PSI all APDs are irradiated with a ^{60}Co source to 5kGy at a dose rate of 2.5kGy/h. After a relaxation time of one day the breakdown voltage and the dark current at a gain of 50 are

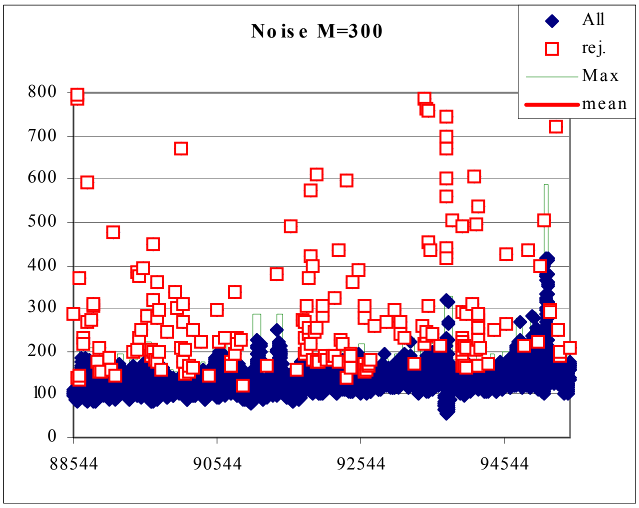

Figure 3: Noise at gain=300 after irradiation. The APDs, which have noise more then 4σ from the mean wafer value are rejected.

measured and compared to the measurements done by Hamamatsu Photonics before delivery to detect APDs that have been damaged by the irradiation. A few days later, at CERN, the noise power is measured at 4 different gains (1, 50, 100 and 300). Then the APDs are annealed under bias in an oven at 80C for 4 weeks (cooking). After this step the breakdown voltage (V_b) and the dark current (I_d) are re-measured. Based on these measurements faulty APDs are rejected. It was found that this treatment does not change the APD parameters except a small increase of the dark current which does not deteriorate the ECAL resolution.

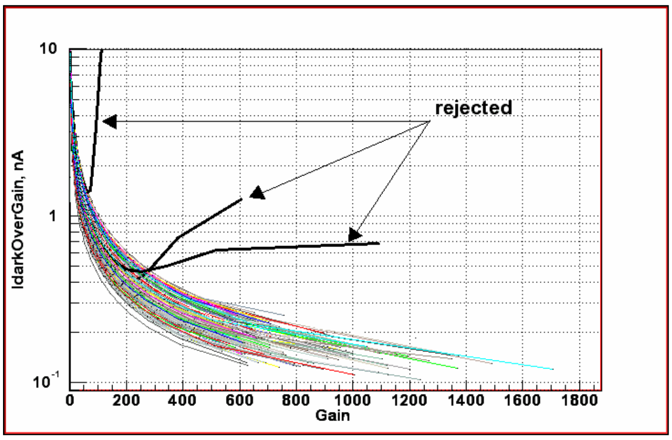

Figure 4: Id/M of the indicated APDs rises in the range of M=50 to M=400.

APDs are rejected if:

- V_b has changed by more than 5V after irradiation or after cooking (see. Fig. 2)
- I_d is significantly larger (3σ from mean wafer value) than I_d of the rest of APDs from the same wafer.
- The noise (at gain 1, 50, 150, 300) is significantly larger (4σ from mean wafer value) than noise of the other APDs from the same wafer (see. Fig. 3)
- I_d/M rises in the range of M=50 to M= 400, where M is gain (see. Fig. 4)

In order to find the effectiveness of the screening method (rejection of all weak APDs) almost 1000 APDs were screened twice. The double screening test indicates that the effectiveness of the screening method is around 99.9% (see example in Fig. 5).

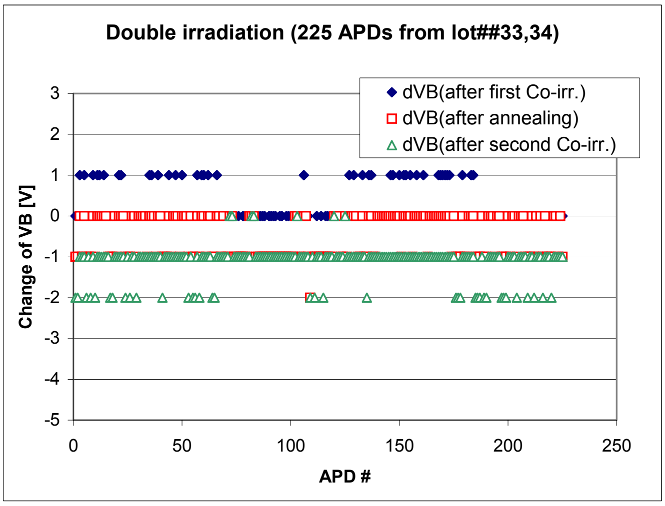

Figure 5: 225 APDs which passed the 1st irradiation and annealing were irradiated a 2nd time. No change of V_b>2V was found for these APDs.

III. DATA HANDLING AND SOFTWARE FOR THE APDS ANALYSIS

The APD data from the different measurement setups in Hamamatsu, PSI, CERN and at the University of Minnesota are transferred to Linux server at CERN in ASCII format. Then the data are passed through automatic filtering and checking procedures, inserted in a Data Base (DB) and a backup is made (Fig 6). The checking and filtering procedures check if the data format is correct or if a temperature was correct during the measurements or if the measured parameters are in the expected range or if the all data came complete to the Linux server. The procedures work during night. If something is wrong they send an email to a responsible person. The data in ASCII format are automatically saved in a special place on AFS during night as well as in a MySQL DB.

Also every night a special program calculates different APD parameters which are useful for the analysis. At night the APD data and these calculated parameters are inserted into ROOT files.

A dedicated software has been developed for the APD data analysis and for the rejection (using ROOT, C++, Visual Basic, and LabView). The analysis programs use these ROOT files. Using these programs it can analyze the APD data, reject the weak APDs, or check effectiveness of the screening method.

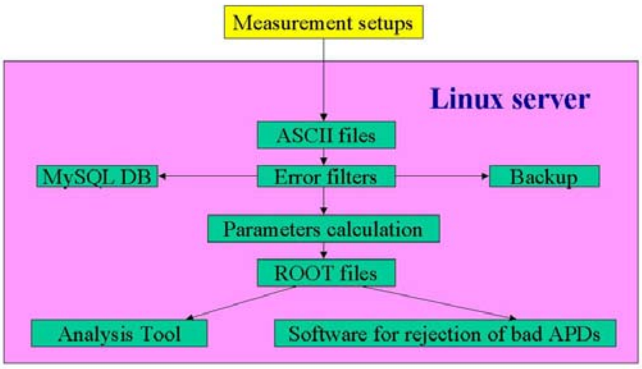

Figure 6: Data handling diagram.

IV. CONCLUSIONS AND STATUS

For the CMS electromagnetic calorimeter a very reliable detector, the Avalanche Photo Diode, has been developed. It is radiation hard with no change in characteristics after radiation equivalent to 10 years of LHC operation, except for the induced dark current. The APDs have the following typical parameters:

Active area	5x5 mm^2
Operating Voltage at T=25°C for M=50	340-420 V
Capacitance (M=50)	80 pF
V_b-V_r (M=50)	45 V
Dark Current (M=50, T=25°C)	3.5 nA
Quantum Efficiency at 420nm	73 %
1/M×dM/dV (M=50)	3.1%/V
1/M×dM/dT (M=50)	-2.4%/K
Excess noise factor at M=50	2.1
Effective thickness	6 μm

For a full description of the APD characteristics see [2-6].

After the screening procedure a reliability of better than the required 99.9% should be achieved for all APDs. A data handling system and analysis tools for the APD investigation and rejection have been developed.

V. REFERENCES

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