PD15

Investigation of avalanche photodiodes after irradiation with neutrons up to 5*10^{14} n/cm^2

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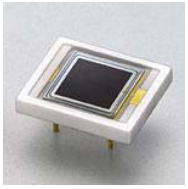


S8148 APD (developed by Hamamatsu and CMS APD group for the CMS experiment):

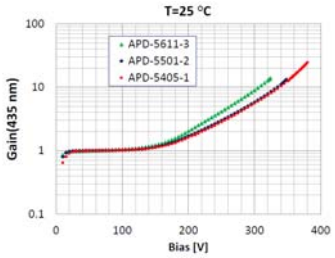
- Area: 5x5 mm^2
- V_{op}: 350-400 V
- Gain (V_{op}): 50
- QE(420nm): 75-80%
- Capacitance: 80 pF
- ENF(M=50): 2.2

Introduction

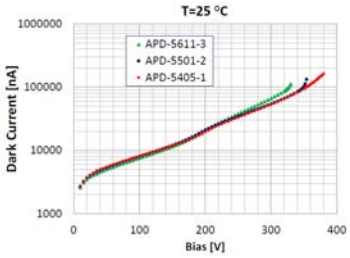
Resistance of the CMS ECAL APDs [1] to neutrons was previously studied in details up to 2*10^{13} neutrons/cm^2 (corresponds to 500 fb^{-1} at the LHC). It was found that QE and gain change was less than 5% at this neutron fluence. What will happen with the CMS APDs at 10 000 fb^{-1}? Will they survive? What will be the gain, dark current and QE change? To answer these questions we studied performances of 3 CMS APDs irradiated with 5*10^{14} n/cm^2 (1 MeV equivalent) at Lubljana reactor [2].

Dark current and gain vs. bias dependence were measured at T=25 °C, 15 °C and 5 °C after several years of annealing at room temperature. The gain vs. bias and QE vs. wavelength dependences were compared with that of non-irradiated APDs

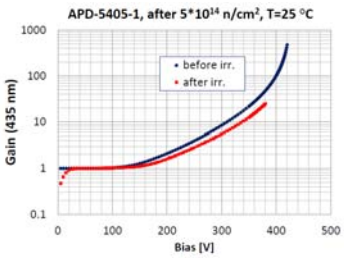
Gain and dark current before and after 5*10^{14} n/cm^2



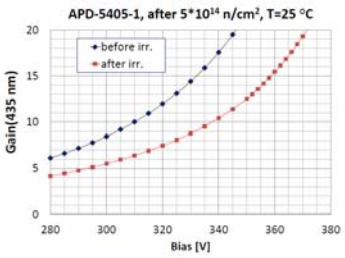
Gain vs. bias for 3 APDs after irradiation (measured using 435 nm LED light)



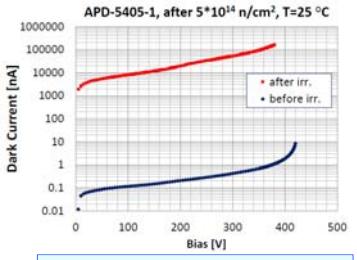
Dark current vs. bias measured for 3 APDs after irradiation



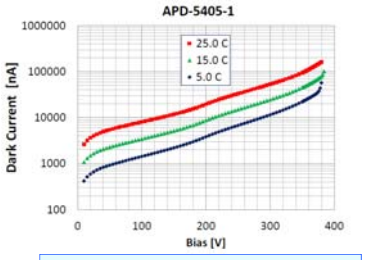
Gain vs. bias before and after irradiation



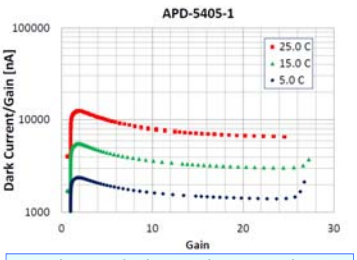
Gain vs. bias before and after irradiation for the APD-5405-1 (magnified)



Dark current vs. bias before and after irradiation

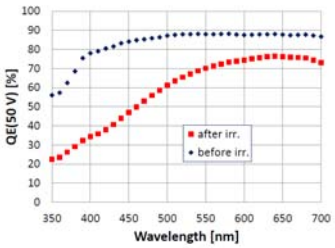


Dark current vs. bias measured at 3 temperatures after irradiation

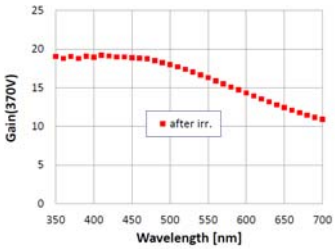


Dark current/Gain vs. Gain measured at 3 temperatures

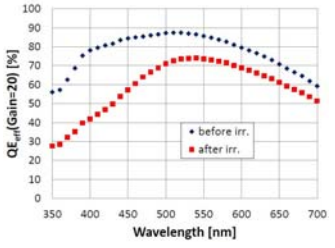
Spectral response before and after 5*10^{14} n/cm^2 (APD-5405-1)



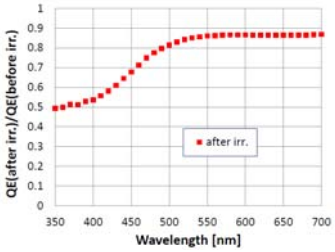
Quantum efficiency vs. wavelength before and after irradiation (U=50 V, Gain=1)



Gain vs. wavelength after irradiation (U=370V, T=25 °C)



"Effective" quantum efficiency vs. wavelength before and after irradiation (Gain=19, T=25 °C)



Quantum efficiency losses vs. wavelength after irradiation (Gain=19, T=25 °C)

Summary

The CMS ECAL APDs (produced by Hamamatsu) were irradiated up to 5·10^{14} n/cm^2 (1 MeV equivalent). This corresponds to > 10 000 fb^{-1} at the LHC.

Main results of the study:

- APDs are still operational as a light detector with gain>10 at T=25 °C
- Average QE losses ~40% were found for $PbWO_4$ crystal light (400-500 nm)
- The APD gain was substantially reduced due to doping profile change, caused by creation of active acceptor like states in the APD depleted region (effect was previously seen with the EG&G APDs [3]). Problem can be solved by ~30 V bias voltage increase
- The APD's dark current can be significantly reduced by reduction of temperature (~2.2 times per 10 °C)

References

[1] Y. Musienko, The CMS electromagnetic calorimeter, Nucl. Instr. Meth. A., vol. 494, 308-312

[2] A. Gorisek, I. Mandic, S. Korpar et.al, Uniformity of the APD response after irradiation, Nuclear Science Symposium Conference Record, 2004 IEEE Vol. 3, 1654 – 1656

[3] Y. Musienko, S. Reucroft, D. Ruuska, J. Swain, Studies of neutron irradiation of avalanche photodiodes using 252Cf, Nucl. Instr. Meth. A., vol. 447, 437-458