Annealing Studies of Avalanche Photodiodes

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Introduction

Avalanche **P**hoto**D**iodes (APDs), invented in the year 1952 by Jun-ichi Nishizawa [1], are devices which use "photoelectric" phenomenon to detect photons. APDs have an internal electric field (>10^5 V/cm) which helps in avalanche multiplication of charge carriers generated by the interaction of photons within the detector and hence they are the perfect candidate to detect weak scintillation light signals. APDs have found suitable applications in existing High Energy Physics (HEP) experiments like Compact Muon Solenoid (CMS) [2] at CERN.

Eight silicon **L**arge **A**rea **A**valanche **P**hoto**D**iodes (LAAPDs), each with an active area of (6.8 × 14) mm^2 have been annealed with different applied bias voltages at the "Annealing Facility" in Photo Sensor Laboratory (PSL), GSI. Before annealing, the APDs were irradiated with a γ-dose of 37 Gy. During annealing, the temperature was raised from room temperature to 353 K and was then kept constant. Annealing APDs under biased conditions at high temperatures help to recover them from the damage caused by irradiation. In this manuscript, the behavior of the leakage current of the APDs during annealing and other annealing parameters are reported. The goal of this study is to investigate the influence of different values of annealing bias voltage on designated annealing parameters like the time constant of trap recovery, the rate of change of current and current amplitude after γ-irradiation.

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Annealing results of the APDs

The APDs were annealed for ∼7.67 hrs under different applied bias voltages. Bias voltages of 100 V, 100 V, 150 V, 150 V, 200 V, 200 V, 300 V and 300 V were applied to the APD-1, 2, 3, 4, 5, 6, 7 and 8 respectively. Figure 1 shows the annealing curves of the APDs. It is clearly seen from Figure 1 that the current increases with an increase of the oven temperature until a temperature of 353 K is reached. After that, the oven maintains the temperature and the APD current starts decreasing. The initial decrease in the current is fast and it attains stability after a certain time. In order to investigate the stability of the current in the APDs, the tail parts of the curves (time > 11350 s) shown in Figure 1, were fitted with a linear function. The decrease in the rate of change of the leakage current values for all eight APDs is shown in Figure 2 with the RMS width of ∼30.9%.

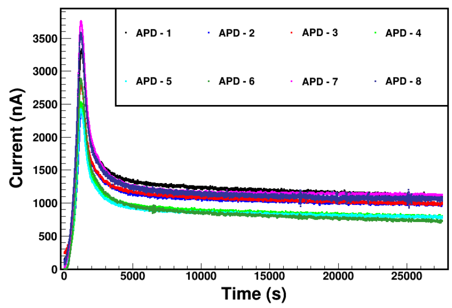

Figure 1: Annealing curves of eight different APDs.

The annealing curves of the APDs have been divided into three different regions viz. tail decay part, moderate decay part and fast decay part, along the time scale and fitted with exponential decay functions ($f1$, $f2$ and $f3$), as summarized in Table I. The obtained values of the time constants (β_1, β_2 and β_3) of the different regions of the APD currents

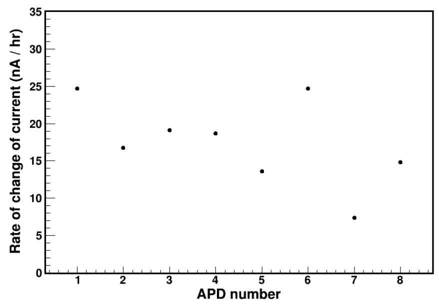

Figure 2: Decrease in the rate of change of the leakage current of the APDs during annealing. The error bars are within the marker size.

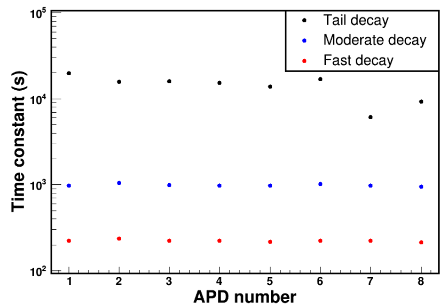

Figure 3: Time constant values of the APDs obtained from fitting of different current regions. The error bars are within the marker size.

have been reported in Figure 3. From Figure 3 it is clearly seen that the values of the time constant of "Moderate" and "Fast" decay regions are flat with the RMS widths of ~2.8% and ~2.9% respectively. The RMS width of the distribution of the time constant values of "Tail" decay region was found to be ~29.3%. The time constant values of the APDs at different current regions differ by ~ an order of magnitude from each other. Figure 4 shows the current amplitude values of the APDs in their different current decay regions. The RMS widths of the current amplitude values of all the 8 APDs for the "Tail", "Moderate" and "Fast" decay regions are ~22.26%, ~17.05% and ~24.06% respectively.

Table I: Fit regions along with the fit functions of the annealing curves of the APDs. β_1, β_2 and β_3 are the time constant values at different fit regions. α_1, α_2 and α_3 are the current amplitudes of the respective regions. γ_1 is a constant.

Decay region	Time interval (s)	Fit function
Tail	>6350 s	$\alpha_1 e^{-\frac{t}{\beta_1}} + \gamma_1 \equiv f1$
Moderate	1850 s - 6350 s	$\alpha_2 e^{-\frac{t}{\beta_2}} + f1 \equiv f2$
Fast	1350 s - 1850 s	$\alpha_3 e^{-\frac{t}{\beta_3}} + f2 \equiv f3$

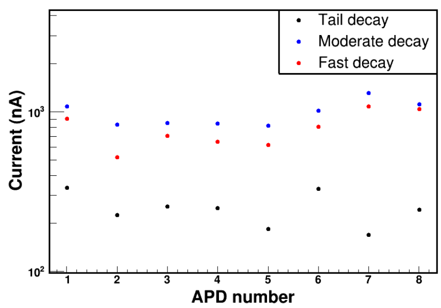

Figure 4: Current amplitude values of the APDs obtained fitting of different current regions. The error bars are within the marker size.

Summary

A set of 8 APDs were annealed at the annealing facility in PSL, GSI, Germany. The leakage current of the APDs was monitored. The annealing parameters like the rate of decrease of the current, time constant of trap recovery and current amplitude of different regions of the annealing curve were studied. It has been observed that there is no significant dependence of the applied bias voltage during annealing on the studied annealing parameters for short-term annealing. Long-term annealing studies are under investigation.

Acknowledgments

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References

[1] *Japan Quality Review*, **Vol.1 201105**.
[2] The CMS electromagnetic calorimeter project : Technical Design Report. , `http://cds.cern.ch/record/349375?ln=en`.