Uniformity of the APD response after irradiation

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I. INTRODUCTION

Avalanche Photodiodes (APDs) will be used to detect light from lead tungstate crystals in the barrel part of electromagnetic calorimeter (ECAL) in the CMS experiment [1]. These APDs are silicon photodiodes operated in avalanche mode. They have been developed by Hamamatsu in collaboration with CMS ECAL groups. Incident photons generate electron-hole pairs at the surface of the diode. The created electrons are accelerated to generate avalanche in the high electric field in the p-n junction. The diode structure is embedded in about 40 μm thick epitaxial layer grown on a low resistivity silicon base. Only the charge created in the top 5 μm thick layer is amplified. The diode has an active area of 5x5 mm. In the CMS experiment it will be operated at the gain of 50 which is achieved at an operating voltage of about 350 V.

In 10 years of operation in the CMS ECAL the APDs will be exposed to 1 MeV equivalent neutron fluence of $2{\cdot}10^{13}$ n/cm^2 and total ionization dose of 0.25 Mrad. Extensive irradiation studies have shown that these APDs can survive such radiation levels. The main effect induced by irradiation is the increase of dark current. However this anneals at room temperature and it was estimated that the current increase after 10 years of operation will amount to a few μA.

To explore the possibility of usage of these APDs in even harsher radiation environments they were irradiated with reactor neutrons up to 1 MeV equivalent fluence of $5{\cdot}10^{14}$ n/cm^2. This contribution reports on measurements of current voltage characteristics and scan of surface uniformity after irradiation.

II. IRRADIATIONS

Irradiations were done at the 250 kW TRIGA reactor facility of the Jožef Stefan Institute in Ljubljana [2], [3]. The APDs were exposed to neutrons in the irradiation tube which occupies the space of three fuel rods near the outer radius of the reactor core. The neutron energy spectrum in the irradiation tube spans from thermal energies to about 10 MeV. From the measured flux the NIEL equivalent flux of 1 MeV neutrons was determined using the known damage function for silicon [4]. APDs were irradiated at the reduced reactor power of 2.5 kW. At this power the 1 MeV equivalent flux is $4.5{\cdot}10^{10}$ n/cm^{2}s. Therefore the irradiation to the target fluence of $5{\cdot}10^{14}$ n/cm^2 took slightly over 3 hours. The 1 MeV equivalent flux is roughly equal to the flux of neutrons with energies E ¿ 100 keV. During irradiation the APDs were exposed also to about the same fluence of thermal (E ¡ 0.5 eV) and epithermal (0.5 eV ¡ E ¡ 100 keV) neutrons, which do not contribute significantly to the 1 MeV equivalent flux in Si, and to about 1 Mrad of ionization dose from the gamma background. Two sets of 3 APDs were irradiated: the first to an equivalent fluence of $2.5{\cdot}10^{14}$ n/cm^2 and the second to $5{\cdot}10^{14}$ n/cm^2. After irradiation the APDs were stored at room temperature.

III. CURRENT VOLTAGE CHARACTERISTICS

Dark current vs. bias voltage characteristics of APDs were measured with a Keithley 237 High Voltage Source Measurement Unit. Measurements were done at room temperature 2 weeks after irradiation. In Fig. 1 the measurements are shown for irradiated diodes. The current before irradiation was less than 100 nA at highest voltage.

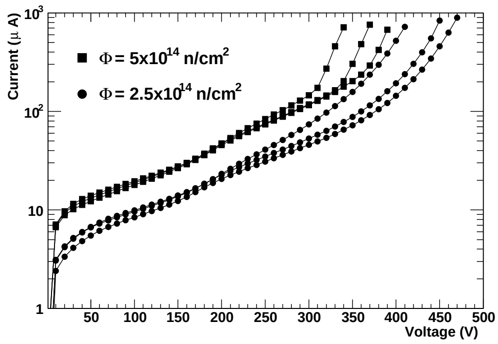

Fig. 1. Dark current vs. bias voltage for irradiated APDs at room temperature.

IV. SURFACE SENSITIVITY

APDs were then illuminated with a red laser diode which was focused with a telescope to a spot on the diode surface much smaller than 100 μm. The diodes were supplied with 300 V. They were moved on a 2D grid in the focal plane of a laser diode with a step size of 100 μm. Similar surface scans of multianode PMT were described in [5]. Two types of measurements were done at each point of the 2D grid. The current was measured with the Keithley 237 Unit and the shape of the pulse from the AC coupled charge sensitive preamplifier was recorded using LeCroy Wavepro 950 Oscilloscope.

Surface sensitivity of diodes was measured prior to irradiation and after the irradiation with two different fluences. In all cases, the homogeneity of pulse response measured trough the preamplifier was not affected by irradiation, while the pulse height was reduced to approximately 70% of the original height in case of a lower fluence (Fig. 2). In the case of APDs exposed to higher irradiation fluence the measurements after irradiation had to be done at a lower voltage of 250 V, where the diodes could be operated at a stable dark current. At higher bias voltage dark current increased to the limit set to 700 μA due to a self heating effect. In Fig. 3 the surface distribution of current is shown. The variation of current of irradiated diode seen in the vertical direction is caused by the change of ambient temperature during the 6 hour scan.

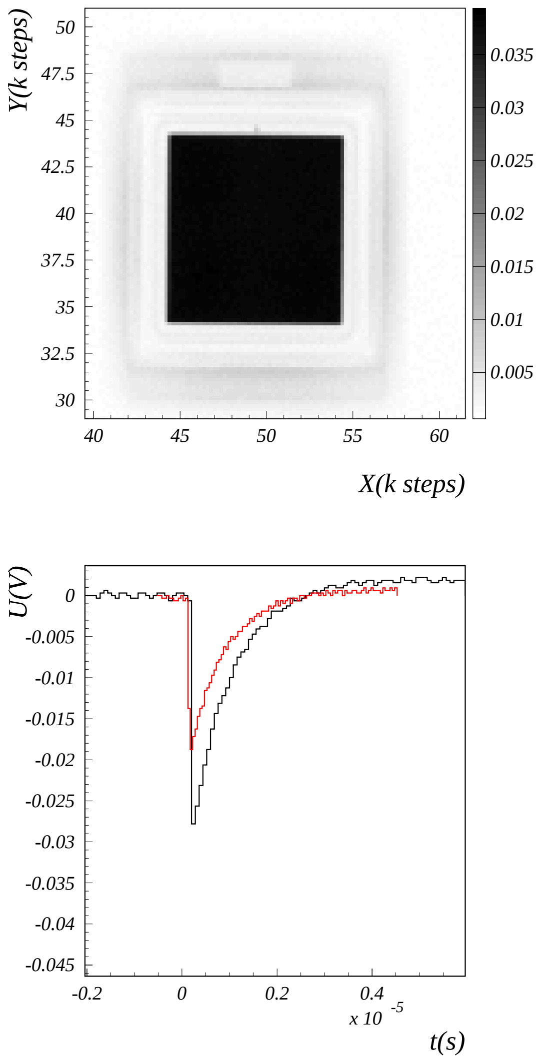

Fig. 2. Upper plot: 2D variation of pulse heights of non-irradiated APD at 300 V. The grey scale corresponds to pulse height in V. 200 steps in x and y direction correspond to a step size of 100 μm. Lower plot: Typical pulse shape at 300 V recorded with oscilloscope, before (black) and after irradiation to $2.5 \cdot 10^{14}$ n/cm^2 (red).

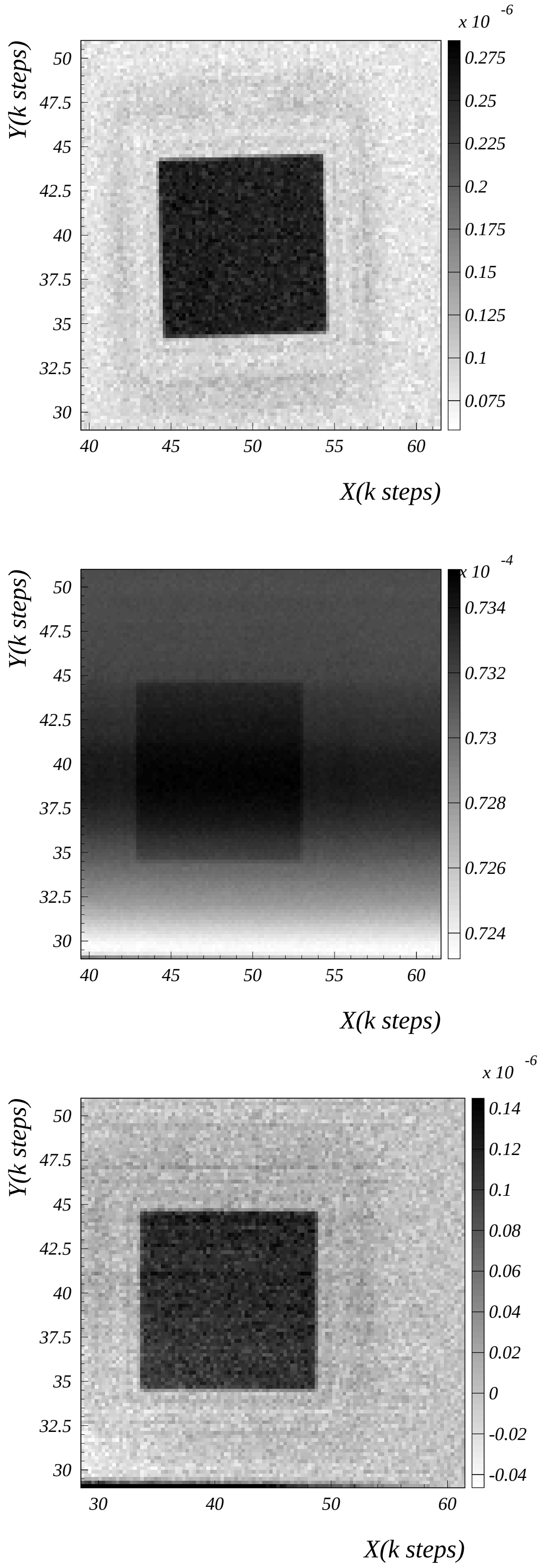

Fig. 3. Surface variation of current (grey scale corresponds to current in A). The upper plot corresponds to non-irradiated APD while the middle and the lower plot correspond to a APD irradiated to $2.5 \cdot 10^{14}$ n/cm^2. On the middle plot the variation of the dark current with ambient temperature is clearly visible in the vertical direction. On the lower plot this variation of the dark current was subtracted.

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