Radiation Damage Studies of Multipixel Geiger-mode APDs

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Introduction

Recently developed multi-pixel Geiger-mode avalanche photodiodes – G-APDs (also known as SiPMs, SSPMs, MRS APDs, AMPDs, MPPCs) are very promising candidates for many high energy physics (HEP) applications. They have many advantages over conventional photodetectors (such as photomultiplier tubes (PMTs), APDs and PIN photodiodes) because of their compact size, low power consumption, high gain, high photon detection efficiency, excellent timing properties, insensitivity to magnetic field, etc. Many of the high energy physics experiments where G-APDs are planned to be used (ILC detectors, the CMS detector at LHC, etc.) operate in harsh radiation environments which produce damage in different materials. As has been shown by many investigators, the radiation (gammas, electrons, neutrons, charged hadrons, etc.) can produce defects in silicon which generate additional free carriers and increase the dark count rate. Many of these defects are electrically active and can change doping concentration in silicon as well as causing charge trapping effects. As a result, parameters of G-APDs such as leakage current, dark count rate, gain, and photon detection efficiency may change during irradiation. How these parameters change during irradiation becomes one of the most important questions for the application of the G-APDs in high energy physics experiments. To answer this question several types of G-APDs (produced by Hamamatsu, CPTA and Mikron/Dubna) were irradiated with a 28 MeV positron beam at PSI (total integrated flux - $8*10^{10}$ positrons/cm^2)

G-APDs and their parameters before irradiation (T=22 C)

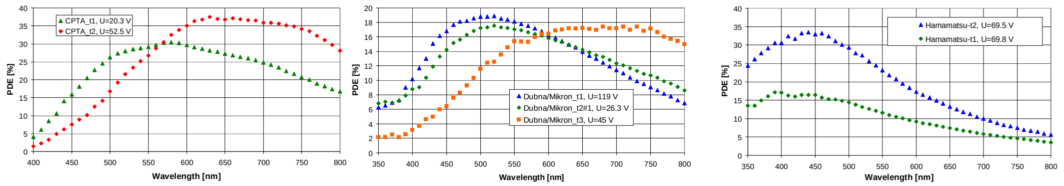
G-APDs	Producer's reference	Substrate	Area [mm^2]	# of pixels	Uop [V]	Gain*10^6 (Gate=60 ns)	PDE(515 nm) [%]	Dark Count [MHz]
CPTA-t1	SSPM-0606BG4MM-PCB*	p-type	4.41	1748	21	0.2	32	20
CPTA-t2	F1707	p-type	1	556	52.5	1.2	20	4
Dubna/Mikron-t1	MW-3	n-type	1	10 000	119	0.05	19	7
Dubna/Mikron-t2#1	p-INT-2	p-type	3.24	2436	26.5	1.5	18	8
Dubna/Mikron-t2#2	p-INT-2	p-type	3.24	2436	26	1.5	18	8
Dubna/Mikron-t3	pMP-3d-11	p-type	1	1024	45.5	0.9	12	5
Hamamatsu-t1	311-31A-001	n-type	1	1600	69.5	0.5	12	0.5
Hamamatsu-t2	311-53-1A-001	n-type	1	400	69.5	3.5	27	1.3

*Photonique SA reference

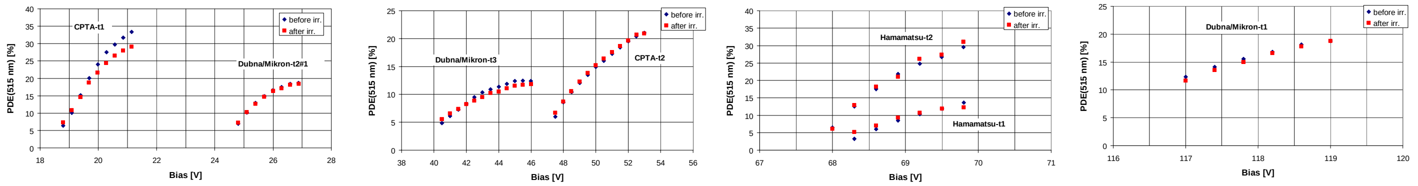
The reason we used 28 MeV positrons for APD irradiation:

- Excellent positron beam available at Paul Scherrer Institut (Villigen, Switzerland)
- Possibility to monitor and control beam intensity
- APDs are not activated during irradiation and measurements can be performed immediately after irradiation

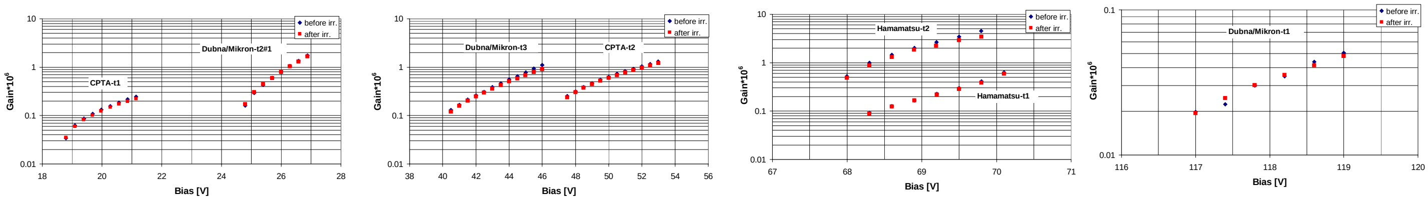
G-APDs spectral responses - measured at T=22 ºC



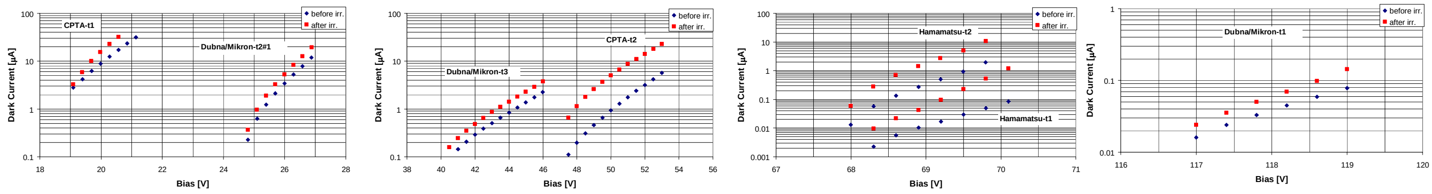
Photon detection efficiency vs. bias voltage dependence (before and after $8*10^{10}$ positrons/cm^2) measured at T=22 ºC



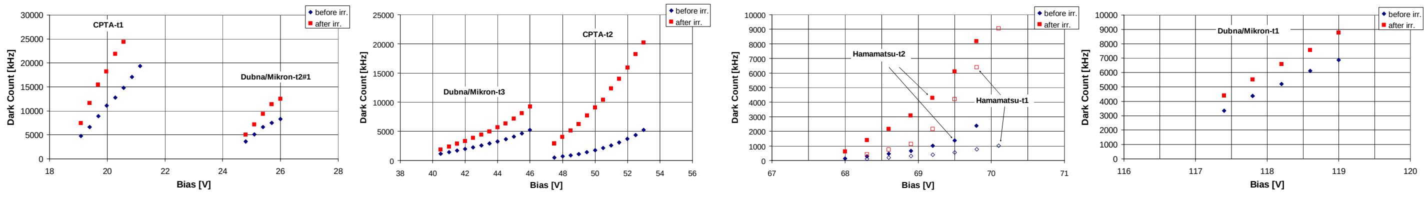
Gain vs. bias voltage dependence (before and after $8*10^{10}$ positrons/cm^2) measured at T=22 ºC



Dark current vs. bias voltage dependence (before and after $8*10^{10}$ positrons/cm^2) measured at T=22 ºC



Dark count vs. bias voltage dependence (before and after $8*10^{10}$ positrons/cm^2) measured at T=22 ºC



Dark count damage constant (DCDC) evaluation:

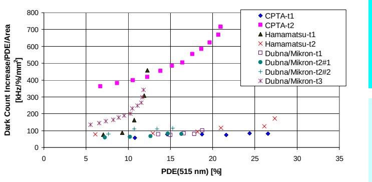
G-APDs studied have different area, geometric factor, depletion volume, etc. To compare the dark count increase produced by irradiation for each G-APD we calculated the ratio:
(Dark Count(after)- Dark Count(before))/PDE(515nm)/Area
and plotted it as a function of PDE(515nm).
This ratio was found to be in the range of 70÷110 kHz/%/mm^2 for 5 G-APDs out of 8 (see figure). For these G-APDs at T=22C:

DCDC(28 MeV positrons)~0.9÷1.4*10^{-6} Hz/%/mm^2/positron.

NIEL factor for 28 MeV positrons is ~30 times smaller than for 1 MeV neutrons (this was verified by irradiating S8148 Hamamatsu APD with 28 MeV positrons and 1 MeV neutrons). One can calculate:

DCDC(1 MeV neutrons)~2.7÷4.2*10^{-5} Hz/%/mm^2/neutron

Dark Count Increase/PDE/Area



Summary

Eight G-APDs (produced by CPTA, Mikron/Dubna and Hamamatsu) were irradiated with a 28 MeV positron beam at PSI. The G-APD's gain, photon detection efficiency, dark current, noise and dark count rate were measured before and after irradiation. A significant increase in leakage current and dark count rate was measured even after a relatively low positron fluence of 8x10^{10} positrons/cm^2 for all the devices. The change of the voltage dependence of the gain and of the photon detection efficiency was found to be small (less than 15%).

Acknowledgments

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