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Investigation of Electric field in SiPM active volume by volt-farad characteristics analysis

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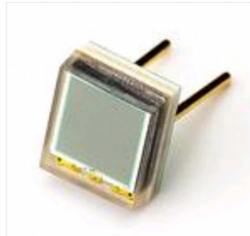
Motivation & plan

- Interaction of neutrons with Si bulk changes the material
- Important to know how efficiency changes during SiPM irradiation
- Understanding of process into detector

  - Why SiPM from KETEK?
  - Control of neutrons fluence
  - Setup and data analysis
  - Electric field into SiPM
  - Generation-recombination proc. and noise

Why SiPM from KETEK?

Simple structure
Low cost
Package NOT SMD



MAPD-3N (ZECOTEK)
Gain~10000, 15um/cell;

SiPM PM3375
Gain~10E6, KETEK 50um/cell;

Irradiated by neutrons :

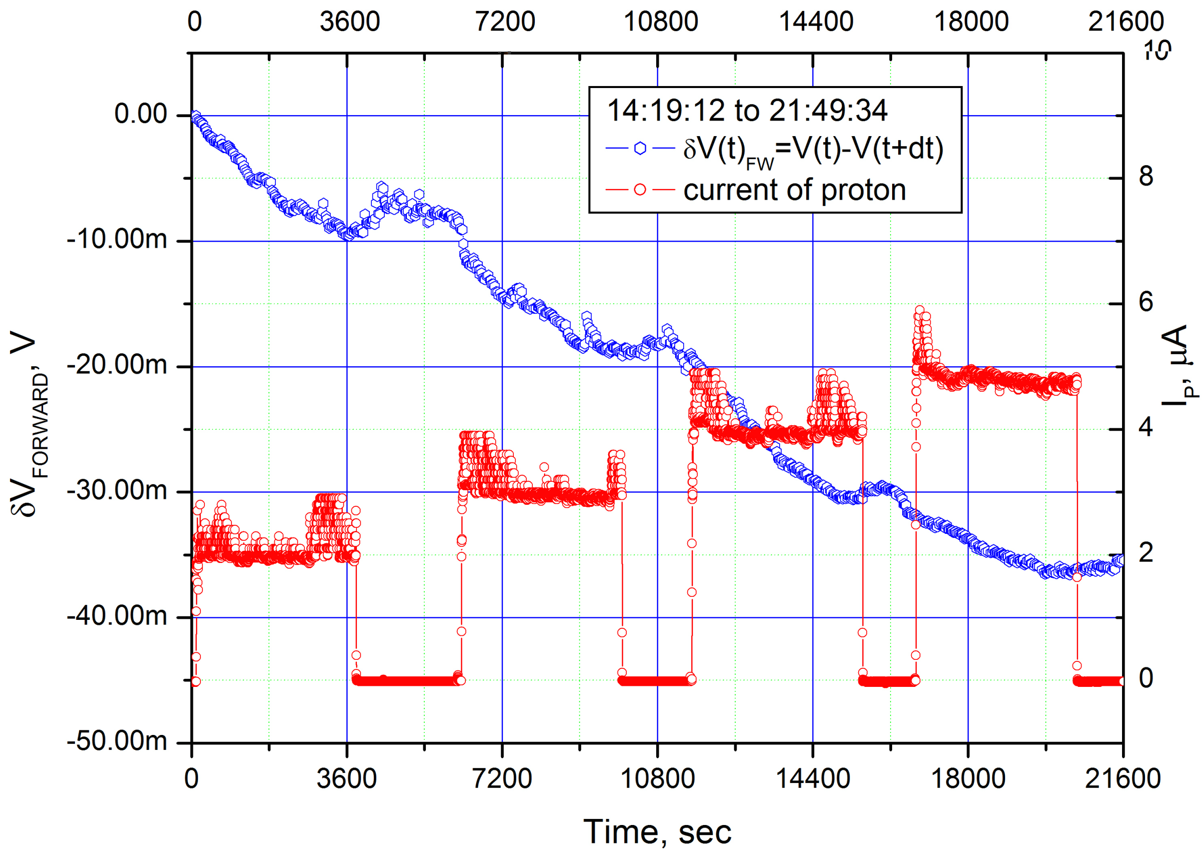
PM3375	2.5±0.2 10^{12} n/cm^2
MAPD-3N	3.4±0.2 10^{12} n/cm^2

Control the neutrons fluence

Neutrons fluence controlled in online mode during irradiation.

Value of fluence is in units calibrated to 1 MeV neutrons as n/cm2 .

Total fluence is $3*10^8$ n/cm^2 .



Setup & Steps of measurements

After irradiation the samples moved to laboratory to study of self annealing processes

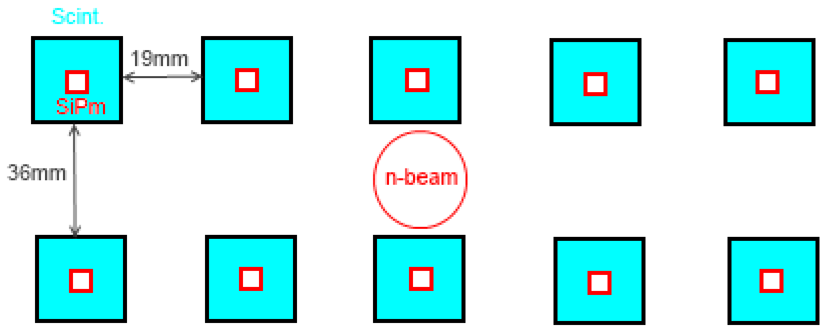
First hour ABM* : > 70% defects restored => we study dynamics of restoration and noise

Two hours ABM : I-V & C-V come back to stable status => static characteristics

1 day ABM : more reliable results

**ABM – After Beam Measurement*

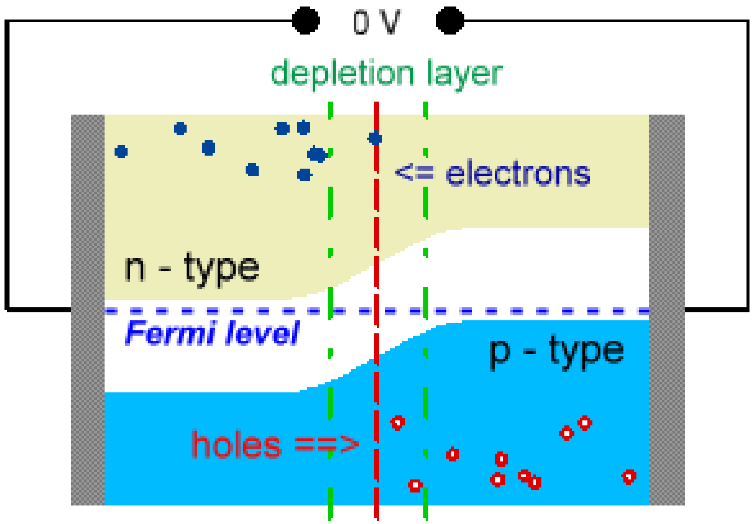
Geometry for irradiation

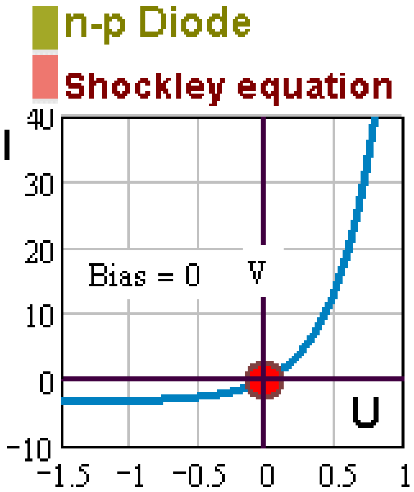


Measurements & data analysis

Cs-Rs circuit was used to exclude influence of serial resistance .

Temperature variates ~ 1C, but we recalculate (C-V,C-F,I-V) to 25 C





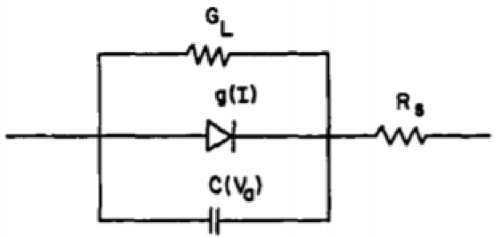


Figure 14. Small signal a-c equivalent circuit of a PN junction diode

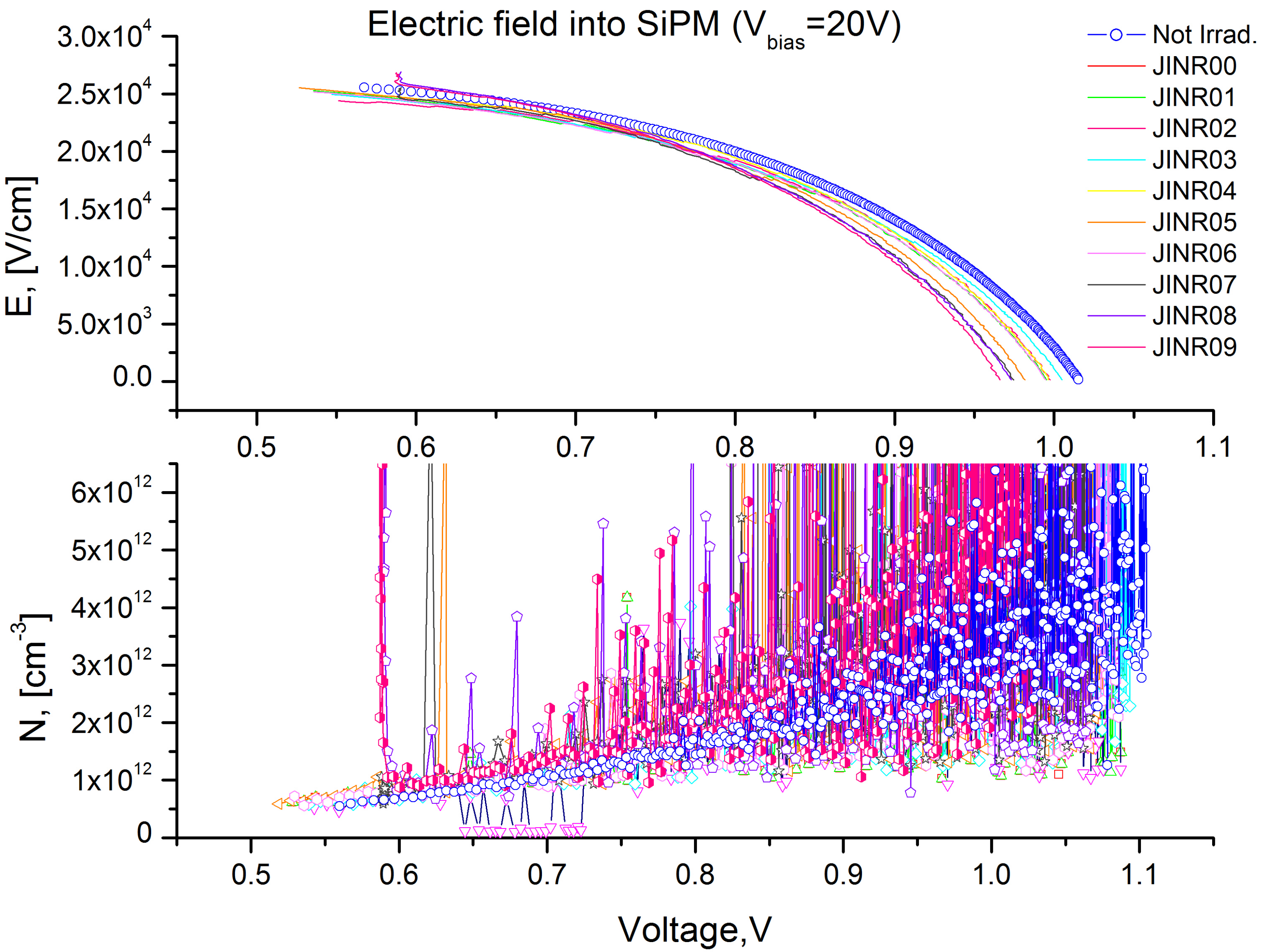
DATA ANALYSIS : 1) dependence of $1/C^2$ on Vbias

2) if it is smooth => differentiate with respect to Vbias

3) multiply by a coefficient to restore of impurities profile

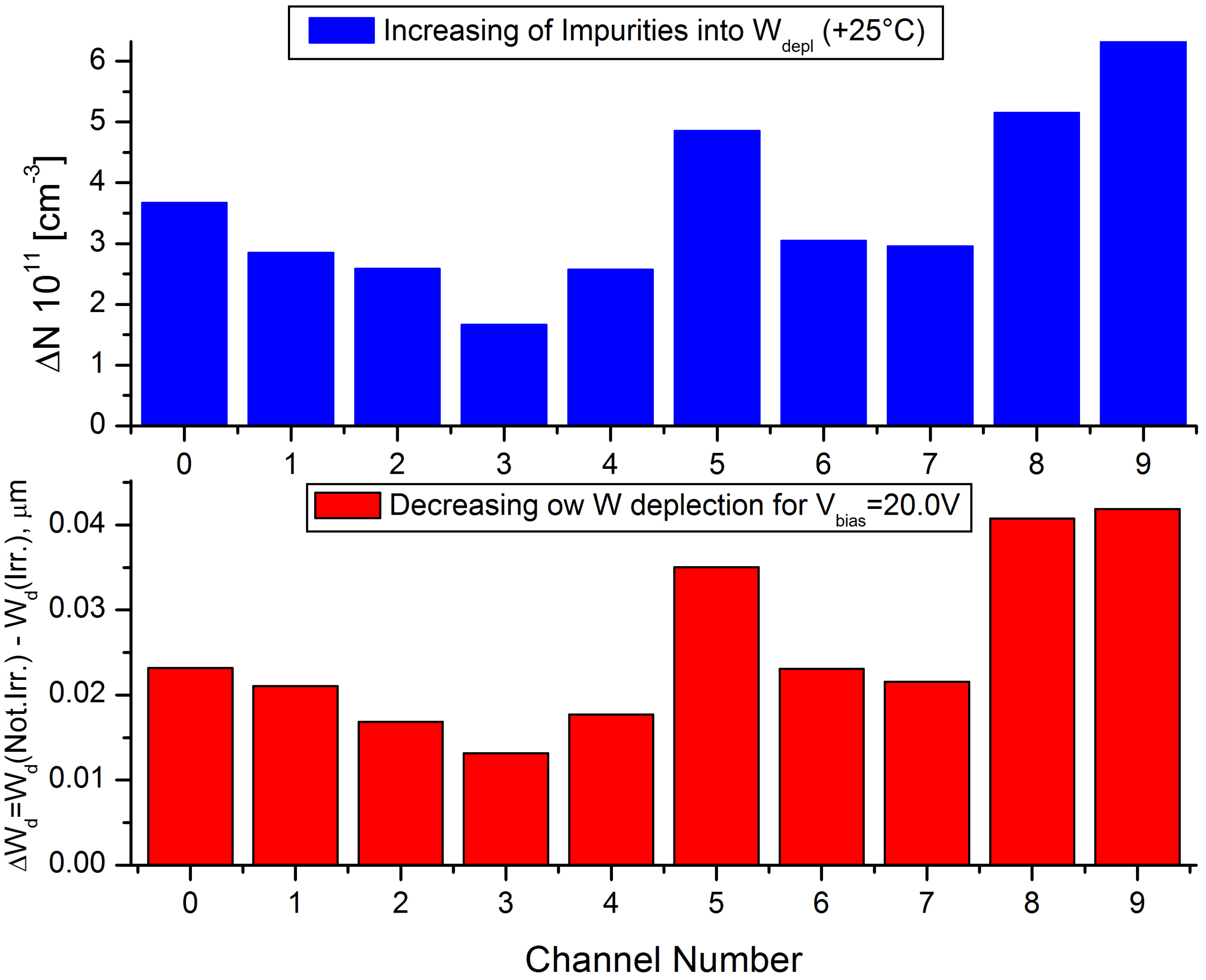
4) comparison of profiles

Electric field into SiPM (1)



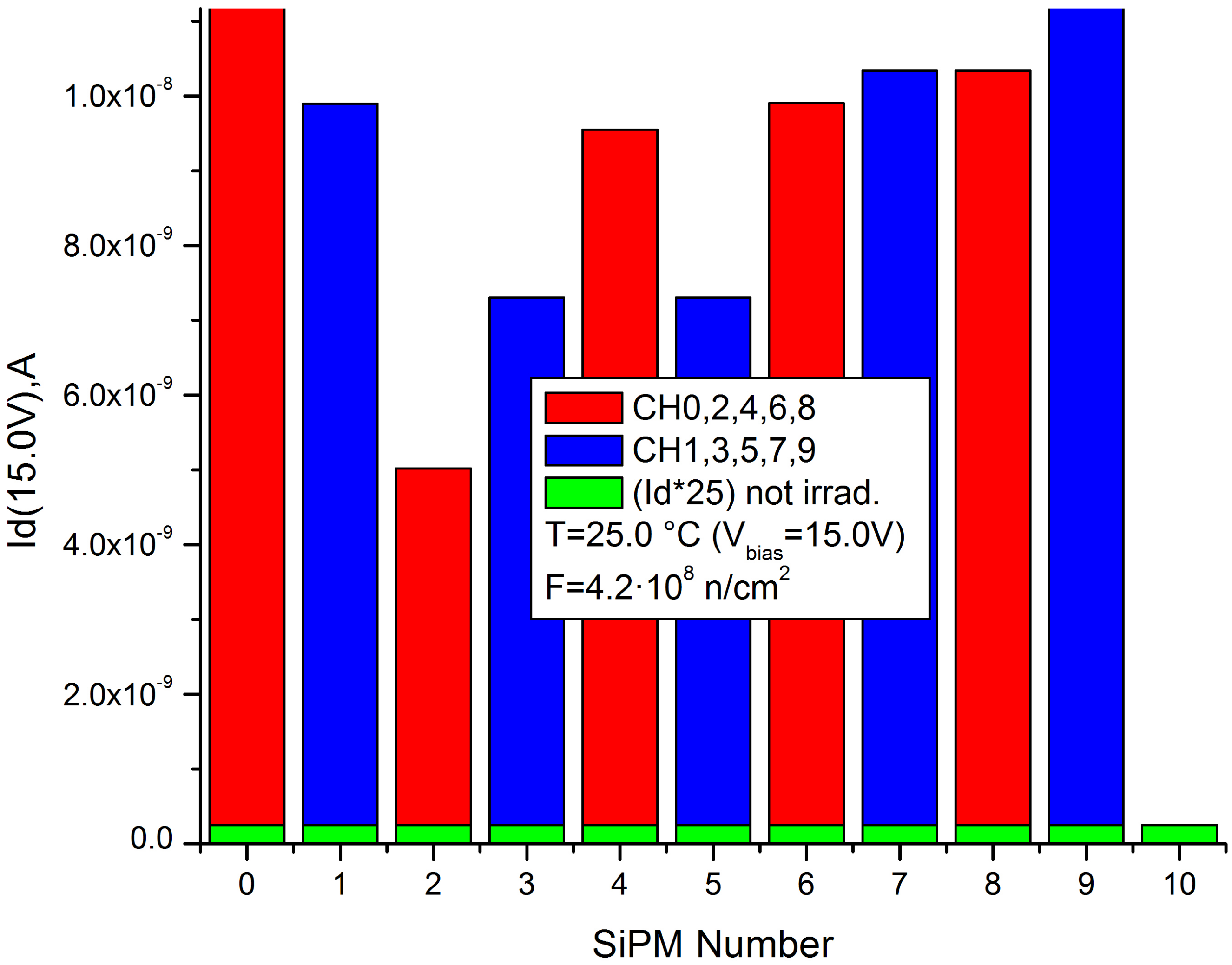
The results of calculations of the impurity and the electro-static field in the depletion region

Electric field into SiPM (2)



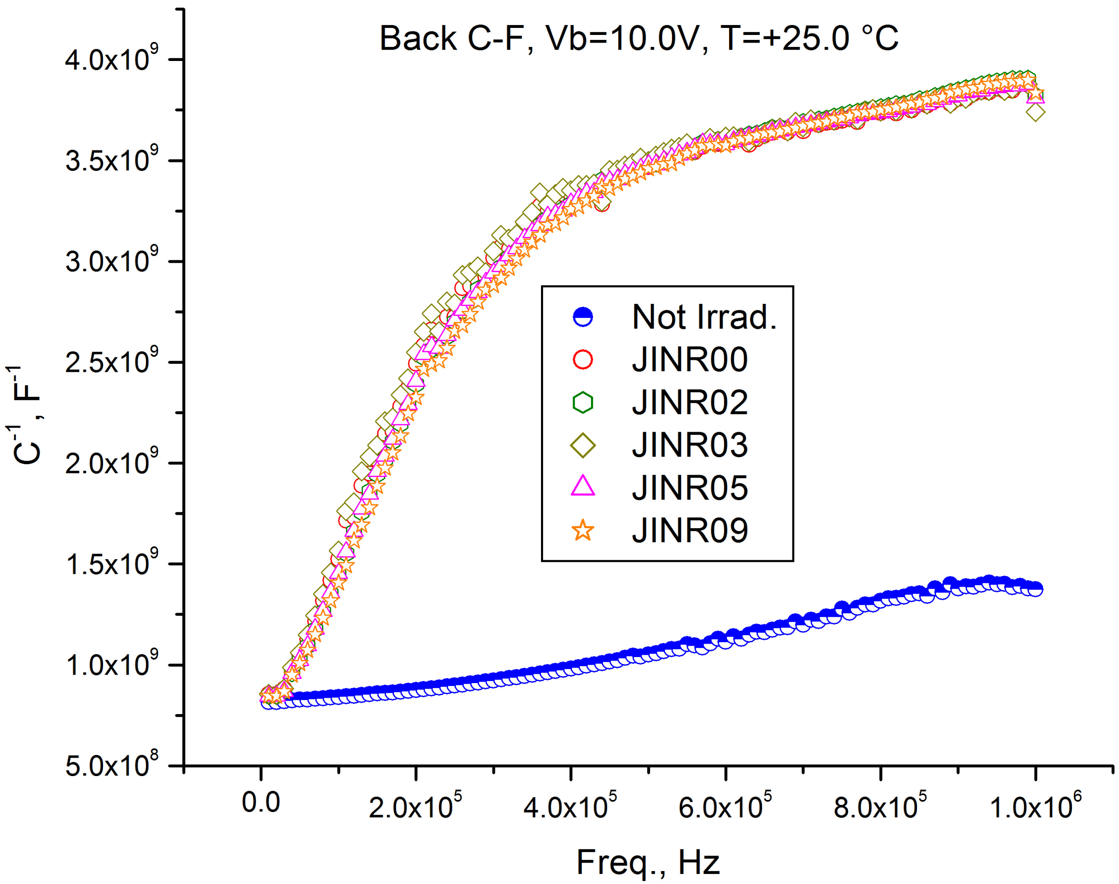
Changes in impurity concentration and depth of depletion area after irradiation

Generation-recombination & noise (1)



Changes in the dark current after irradiation

Generation-recombination & noise (2)

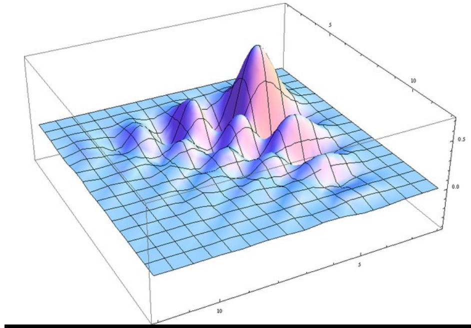


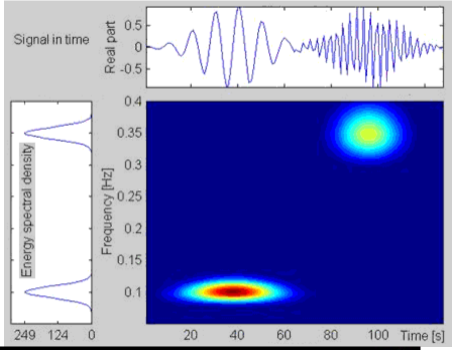
$$\frac{1}{C}(f) = \frac{1}{e} \cdot \frac{\langle \tau \rangle}{\langle N_t \rangle} \cdot \Delta\varphi \cdot f$$

Changes in the ratio of the lifetime of life in the traps to the average concentration of the centers of the traps as a result of irradiation

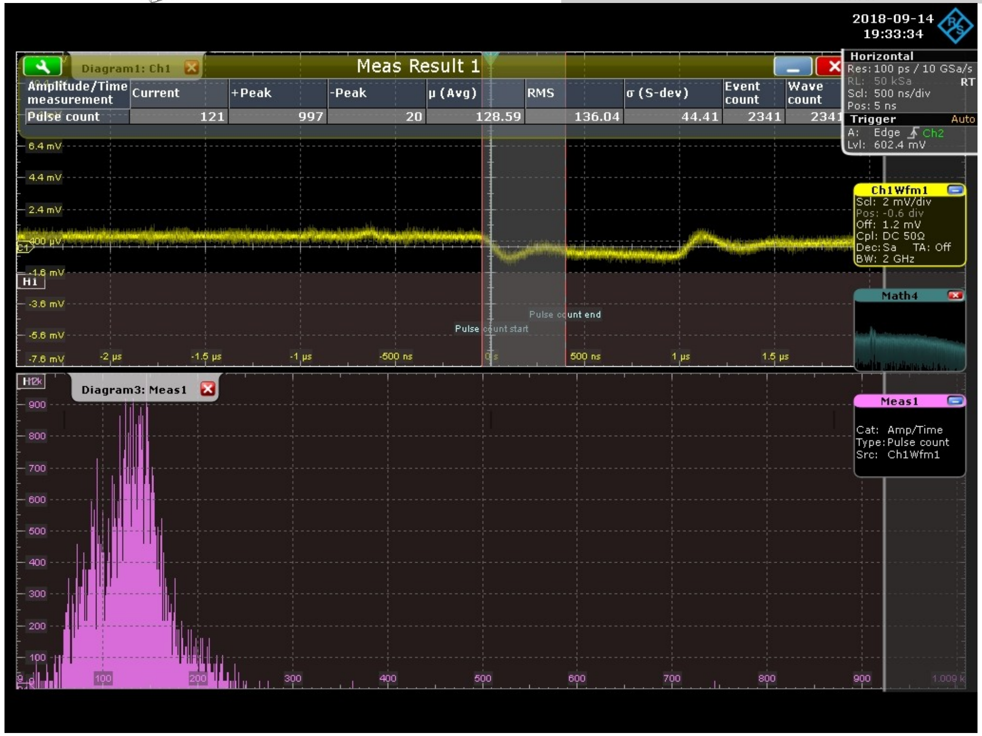
Generation-recombination & noise (3)

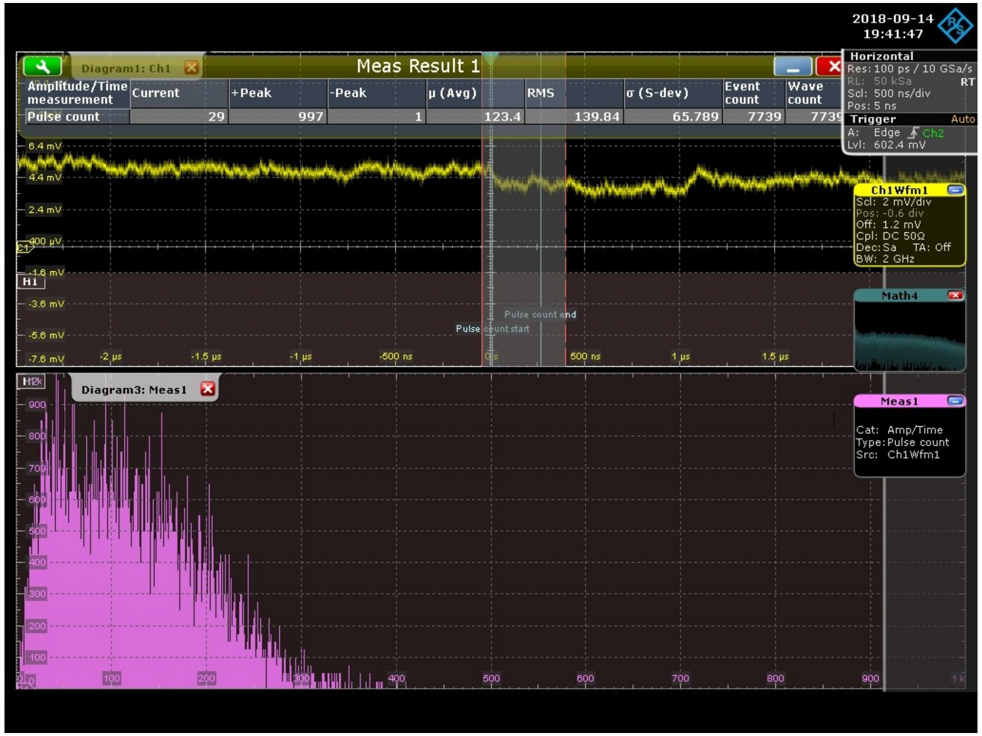
Daubechies wavelet





The wavelet transformation method
to study the variations in the noise spectrum

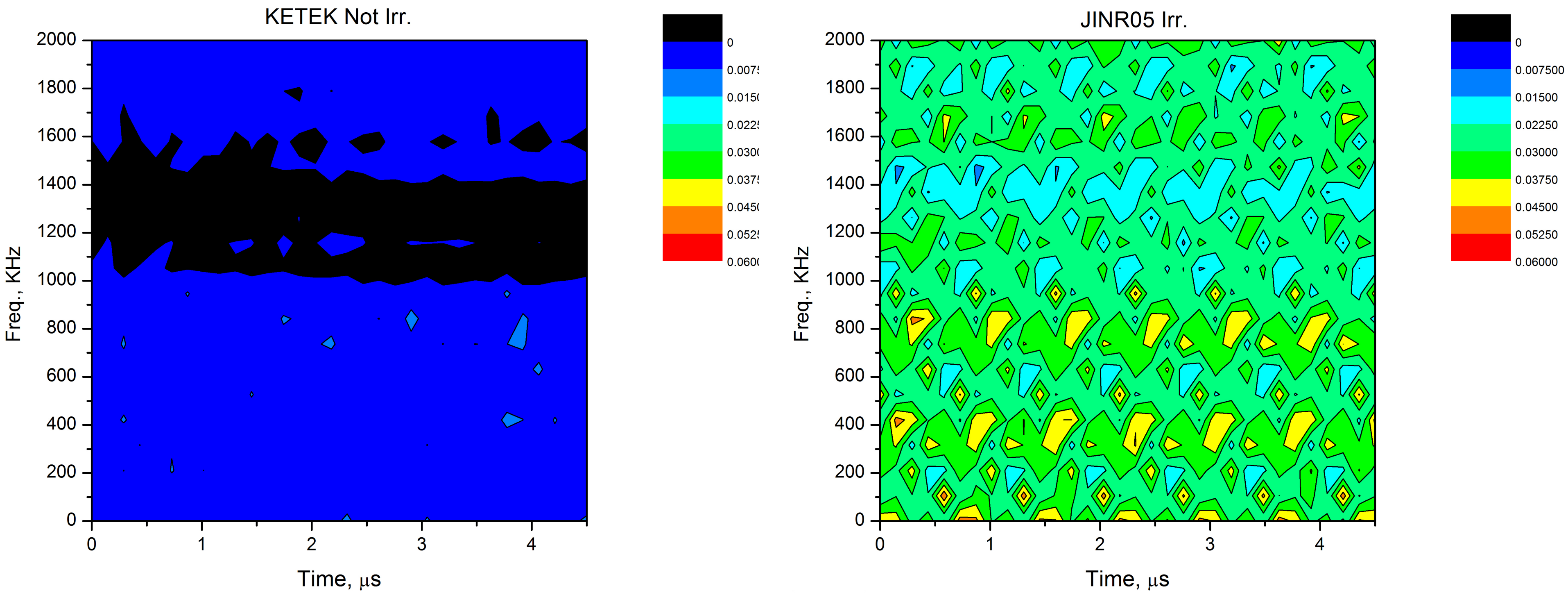




The signal and the amplitude spectrums for the non-irradiated and irradiated detectors at bias voltage of 23 V

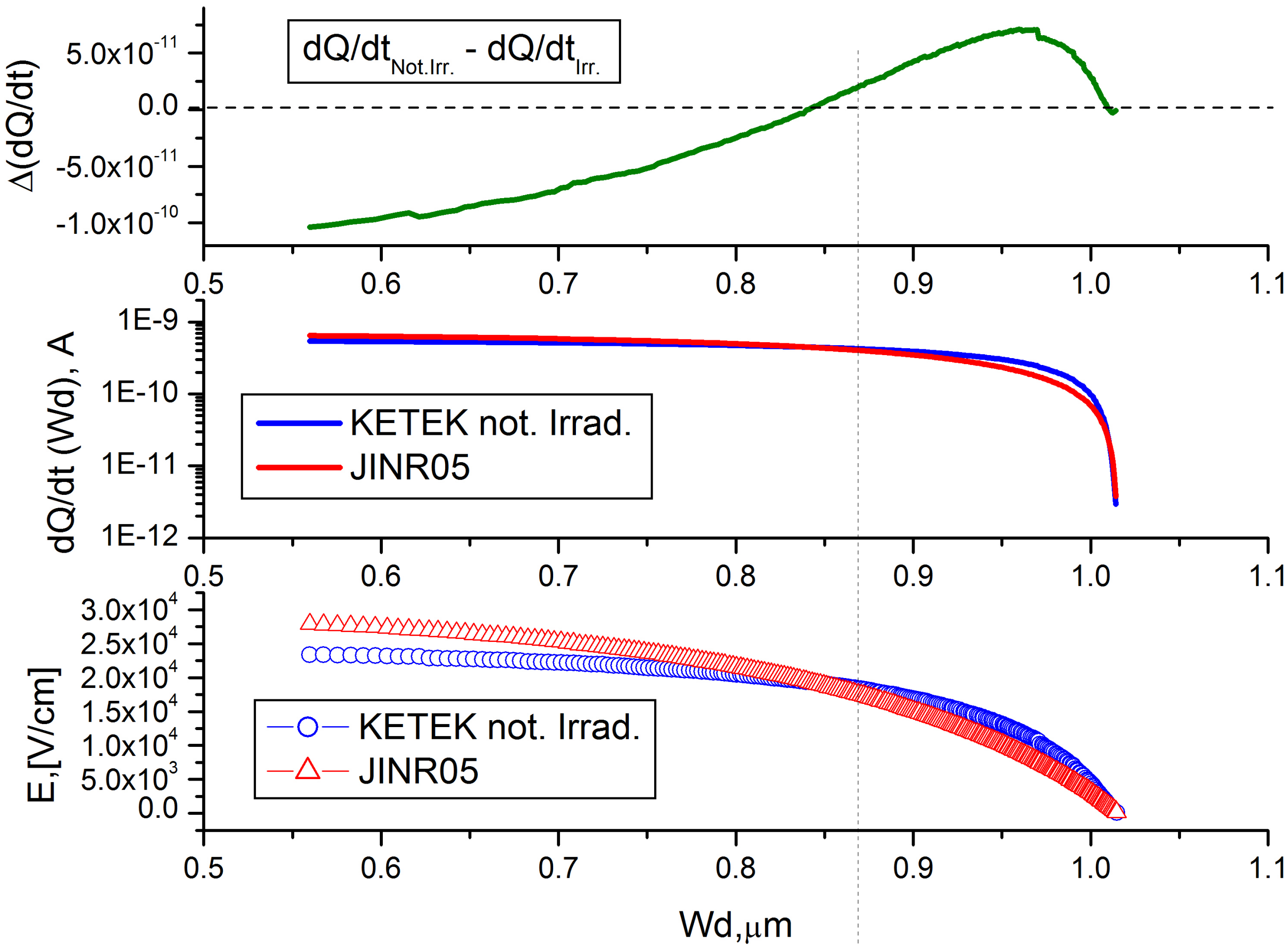
Generation-recombination & noise (4)

Preliminary Results



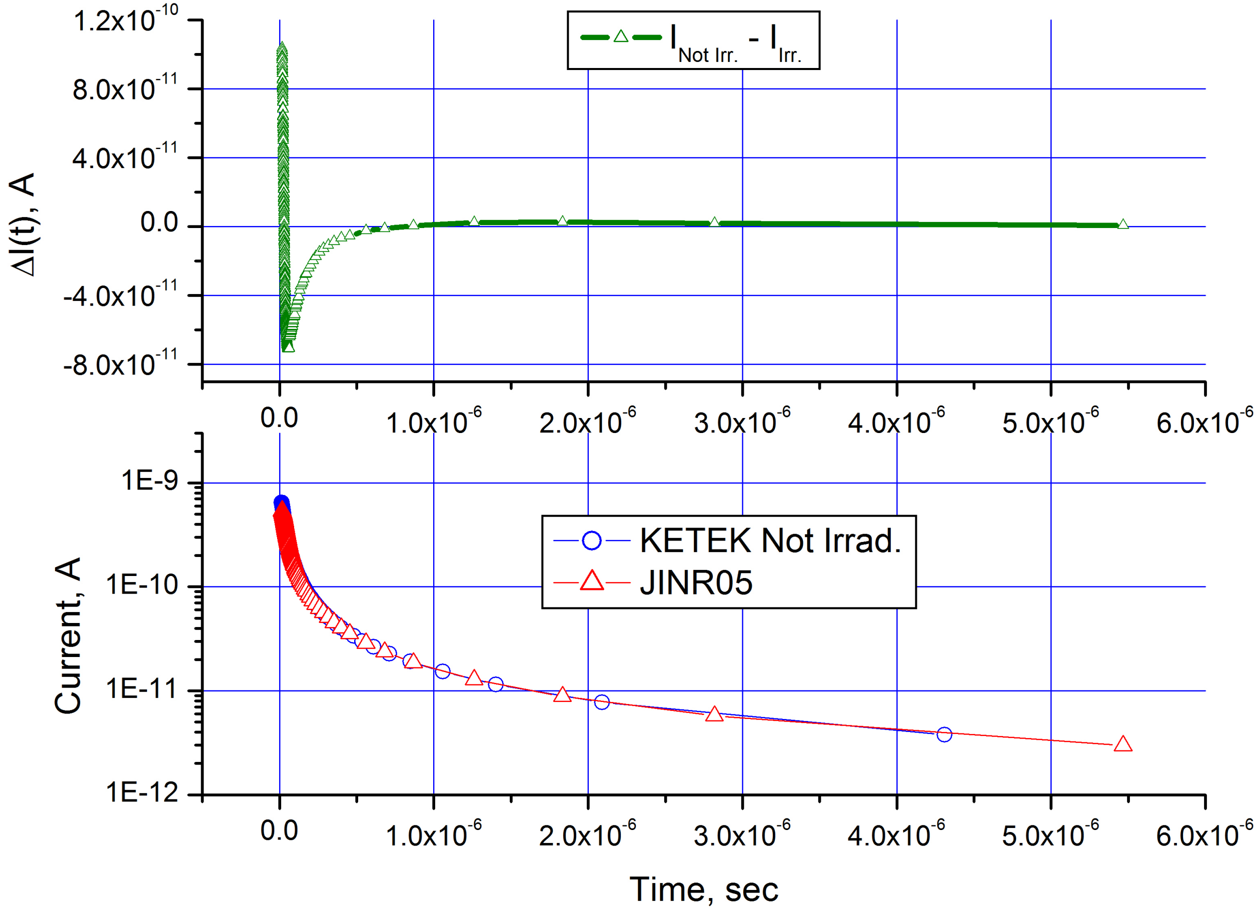
Wavelet spectrum of the noise for the non-irradiated and irradiated detectors at bias voltage of 23 V

Influence of E field on PDE (1)



Collection rate of local charge changes in the depletion region as a result of irradiation

Influence of E field on PDE (2)



Electric field changes in the depletion region on the front of the current pulse

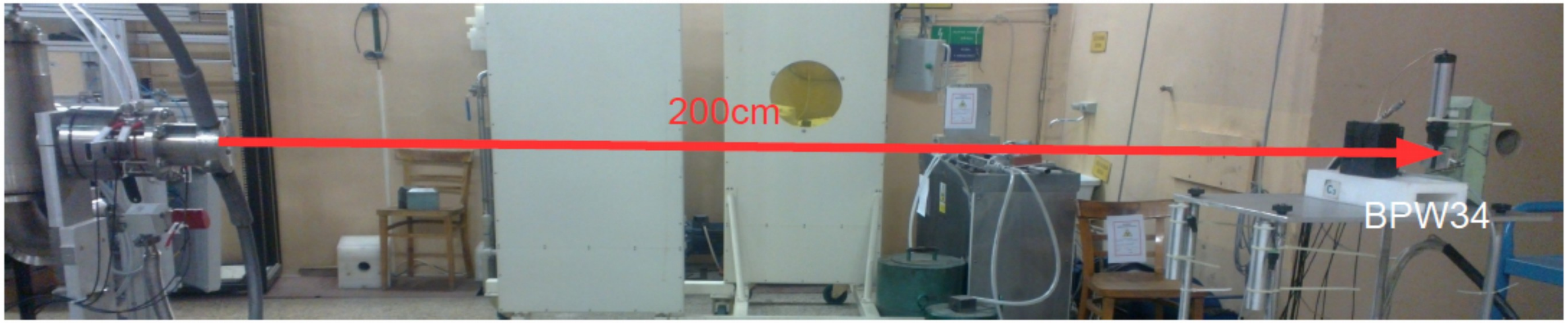
Conclusion

- 10 diodes were irradiated to a fluence of $4.5*10^8$ n/cm^2
- The total dose was accumulated for the period from Nov. 2015 to Sept. 2017
- C-F study shows a monotonous increase in noise after irradiation to a frequency of 100KHz and more smooth in the region of 100KHz - 1000KHz
- Study in the spectral power of noise shows a significant changes in the frequency range up to 2 GHz
- Profile of the electric field in the detector after irradiation shows that the value of field increases in the near-surface layer
- Profile of the electric field changes the dynamics of generation of the signal front. => The operation of the detector in triggers worsens.

Outlook

Setup 2015-2017

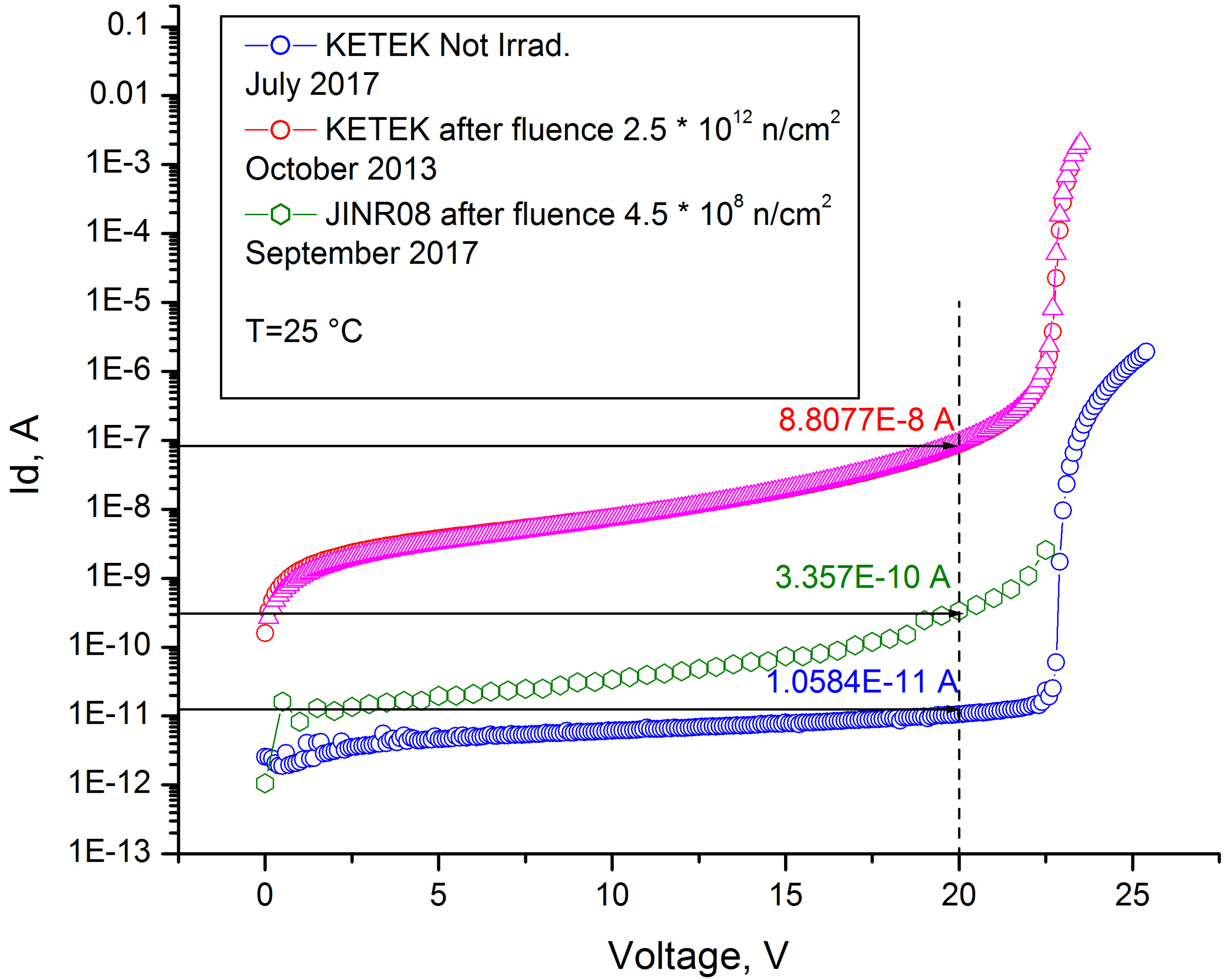
Experiments 21 Sep. and 23 Nov. 2016



Estimation and calculation of fluece from current of protons (distance 200cm, time 1h)

$I_{prot.}$,uA	Fluence (estim.) [n/cm^2]	Fluence (calc.) [n/cm^2] (Exp.1/2)
1	$5.06*10^{9}$	$5.53*10^{9}/5.06*10^{9}$
2	$1.01*10^{10}$	$1.06*10^{10}/1.06*10^{10}$
3	$1.51*10^{10}$	$1.54*10^{10}/1.54*10^{10}$
4	$2.2*10^{10}$	$2.19*10^{10}/2.19*10^{10}$
5	$2.52*10^{10}$	$2.42*10^{10}/2.42*10^{10}$

I-V 2013 KETEK



C-V 2013 KETEK

KETEK

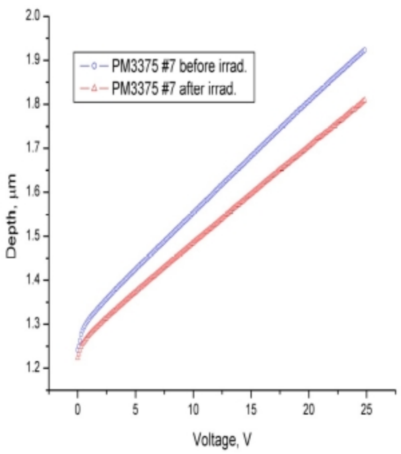


Fig. 2.1 Depletion width vs. V_{bias}

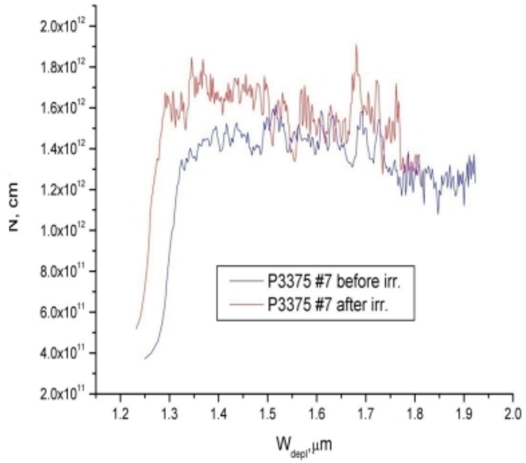


Fig. 2.2 Impurities produced in depletion region

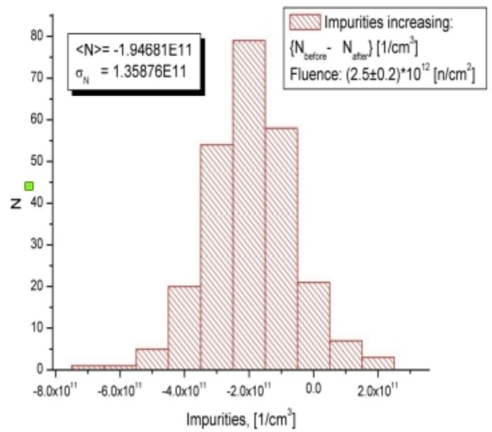


Fig. 2.3 The change of impurities after irradiation

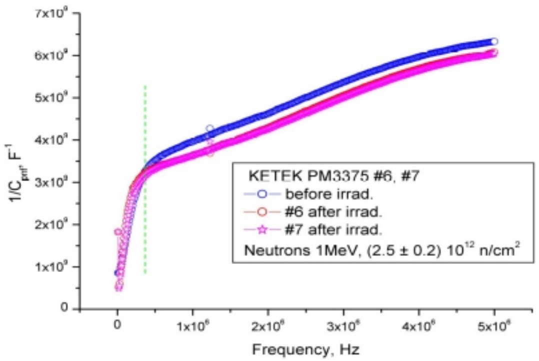


Fig. 2.4 Capacitance versus frequency

Internal resistance of KETEK SiPM decreases after irradiation that can be observed on Fig. 2.1 as depletion region shortening for the same voltages as before irradiation.

Generation–recombination noise $\delta\langle N_t^2\rangle$ depends on characteristics in Fig.2.4

$\delta\langle N_t^2\rangle/N_t \sim (4\tau_n/(1+(\omega\tau_n)))$; $\tau_n/N_t \sim 1/C(\omega)$; where Nt - average number of carriers from traps, τ_n — carrier lifetime; $\omega=2\pi f$; f - frequency [12,13].

Generation–recombination noise decreases for low frequency, but increases for high frequency.

We use KETEK SiPM for readout scintillator's hodoscopes during neutron beam test. Decrease of gain and increase of internal noise due to neutrons were observed. Hodoscope system was developed in JINR for position monitoring of neutron beam for Cyclotron U120 in NPI Rez.

Noise spectrum (slide 12)