Istituto Nazionale di Fisica Nucleare

16TH TOPICAL SEMINAR ON INNOVATIVE PARTICLE AND RADIATION DETECTORS (IPRD23)

HASPIDE: A PROJECT FOR THE DEVELOPMENT OF HYDROGENATED AMORPHOUS SILICON RADIATION SENSORS ON A FLEXIBLE SUBSTRATE

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SUMMARY

- INTRODUCTION
- PRO-CON AND POSSIBLE APPLICATIONS
- PERFORMANCES
- CONCLUSIONS

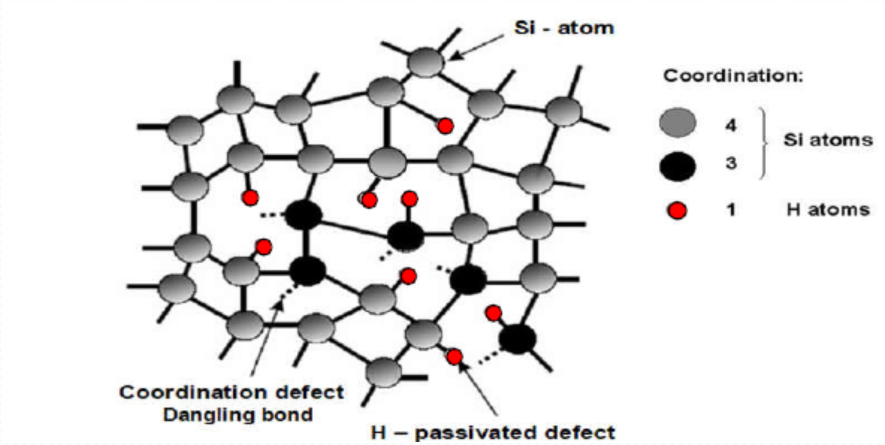
Hydrogenated Amorphous Silicon (A-Si:H)

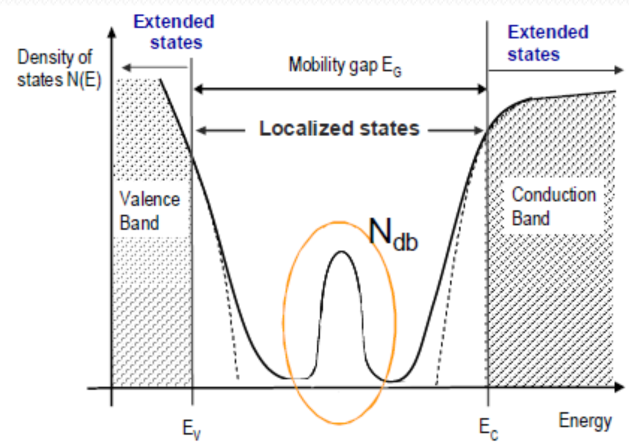
- **Amorphous**
  - **Order in the disorder** (short range order, ~ nm)
  - Disorder due the presence of di-vacancies
  - Disorder leads to localized states in gap

Coordination **defects**
Dangling bond, density $\mathbf{N_{db}}$ → **~ mid-gap states (recombination centers**

Fluctuations in Si-Si bond
Weak bonds → **Band tails (traps)**

- **Hydrogenated** Passivation of dangling bonds by H
  a-Si → a-Si:H : N_{db} : 10^{19} cm^{-3} → 10^{15} cm^{-3}



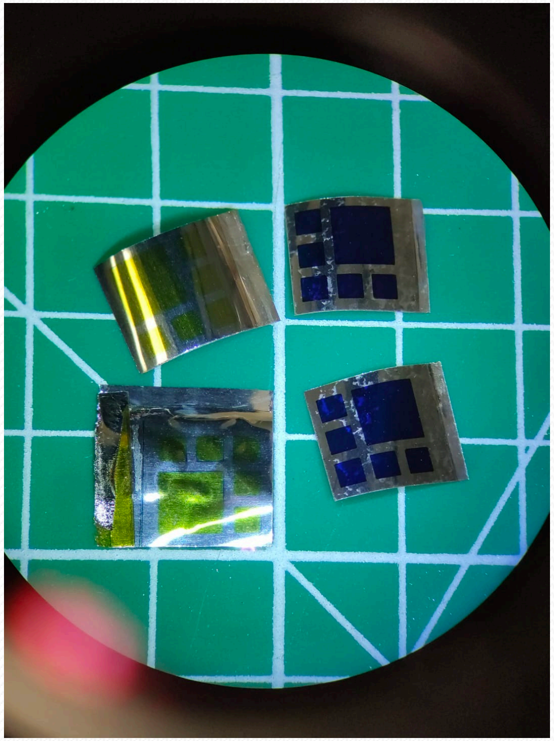


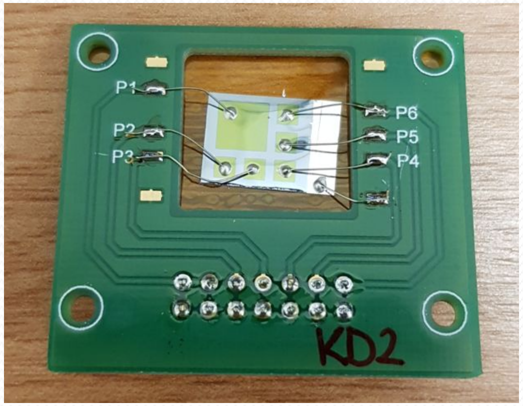
A-Si:H as radiation detector material pros & cons

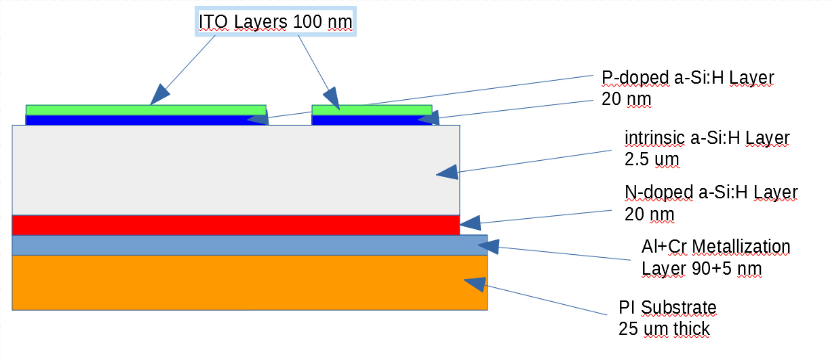
- Pros:
  - Extremely low radiation damage.
  - Low cost production.
  - Possible deposition in many different substrate materials
  - Good flexibility below 15 um
  - Photosensitive: usable in photodiode fabrication

- Cons:
  - High depletion voltage (about 1100 V for 50 um thickness)
  - Growth on a non-removable substrate
  - Maximum processing temperature 250-300 °C
  - Limited thickness of substrates (max 100-150 um)
  - Pretty low S/N ratio due to poor charge collection efficiency: below 50% (on a 30 um thick detector) energy to create a e-h pair similar to crystalline silicon (3.4-4.0 eV) and high leakage current (around uA/cm^2 on a 30 um detector)
  - Low mobility (from 1 to 10 cm^2 /Vs for electrons 2 orders of magnitude less for holes)

HASPIDE prototype







- Hydrogenated Amorphous Silicon PIxels DEtectors
- On Polyimide substrate (kapton) for flexibility
- Production Array of 20 2x2 mm^2 p-i-n diodes and 4 5x5 mm^2 p-i-n diodes
- 2.5 μm thickness

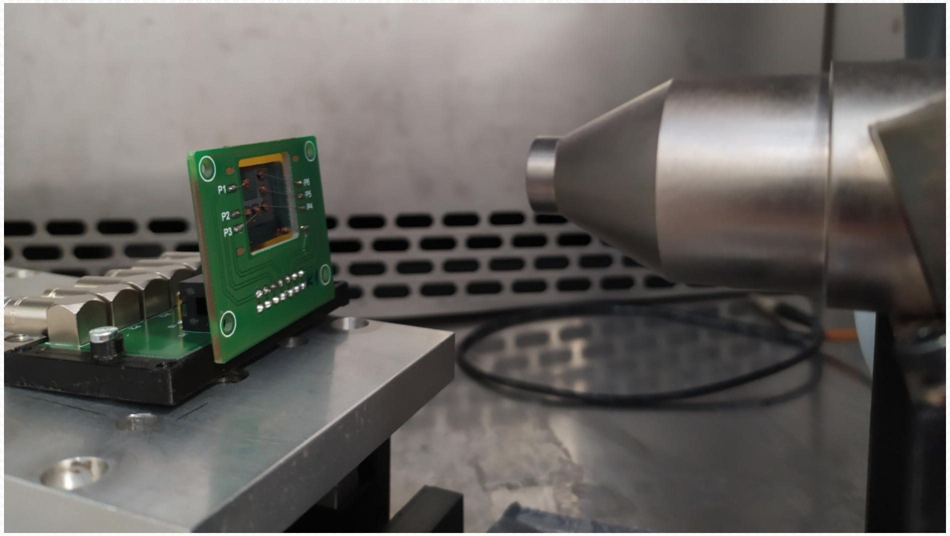
Application as a rad-hard flexible detector

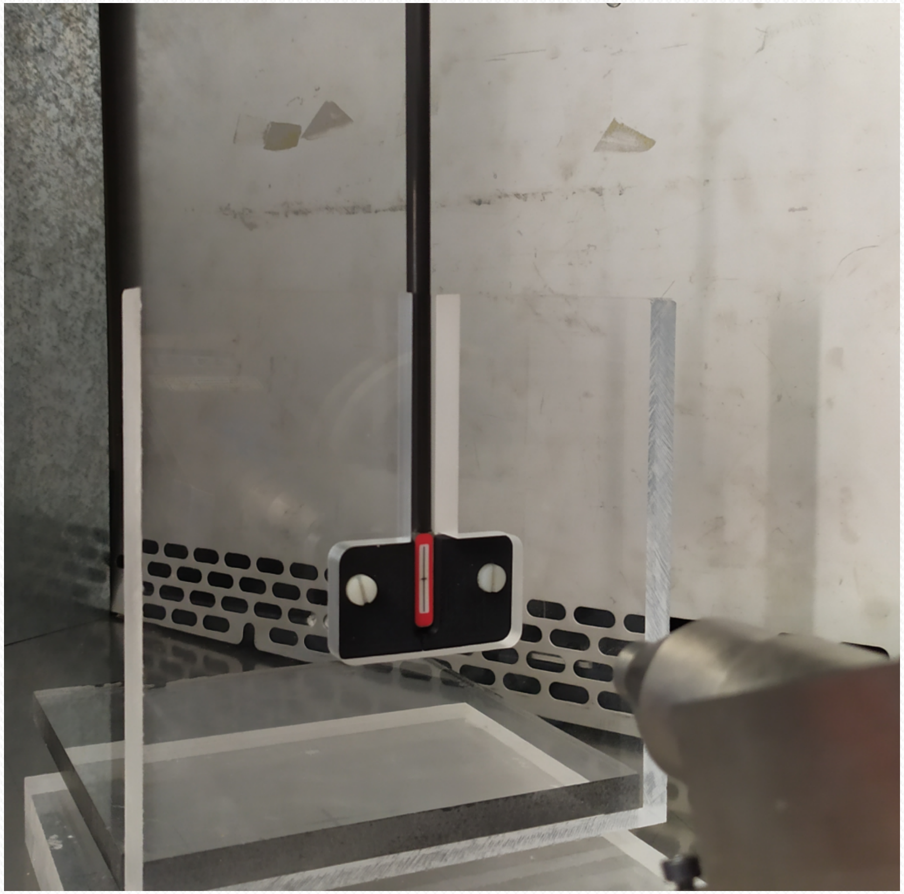
- Beam monitoring for dosimetry and beam profile (Active membrane)
- Beam dosimetry and beam profile for radiotherapy (X-rays, electrons, protons, possibly ions)
    - Possibility of dose measurement in the curved surfaces of a patient body
- Particle fluxes determination in solar events
- Thermal Neutron monitor with the addition of a Boron layer

Detector R&D

- Two device architectures
  - Planar P-i-n diodes (most commonly used and baseline option)
  - Charge selective contacts devices (MoO_x as hole selective contact and TiO_2 or Al:ZnO as electron selective contact)
- Three deposition techniques
  - PECVD (the most commonly used and baseline technique)
  - Reactive Sputtering for intrinsic silicon (in Hydrogen environment)
  - Reactive Laser Ablation (RLA) of doped and un-doped Silicon (in Hydrogen)
  - Plasma Laser Deposition (PLD) for the electrodes

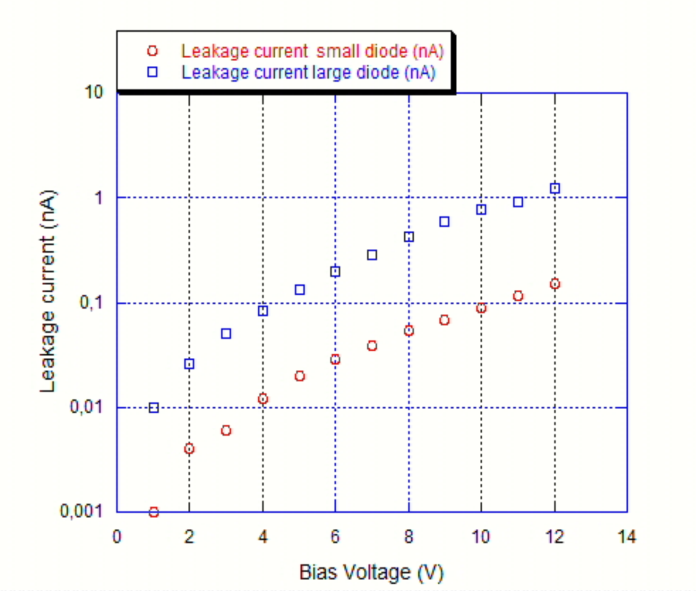
Test under X-Rays

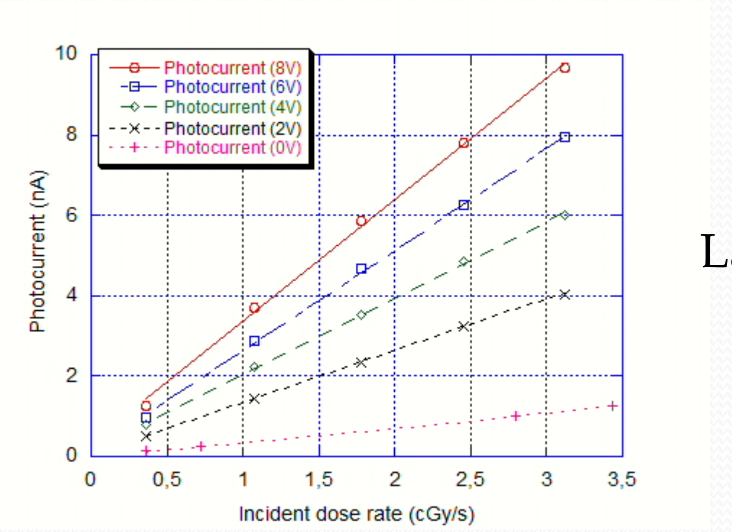




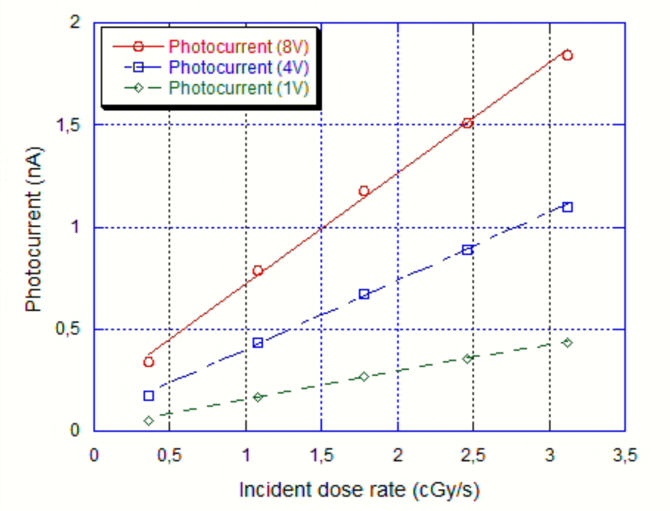
- X-ray tube 10 W by Newton scientific
- Vmax= 50 kV, Imax=200 μA
- Cobia Flex dosimeter using T20 probe
- Measuring range (1.5 μGy/s-1500 mGy/s)

Current response and dose rate (x-rays) linearity





Large



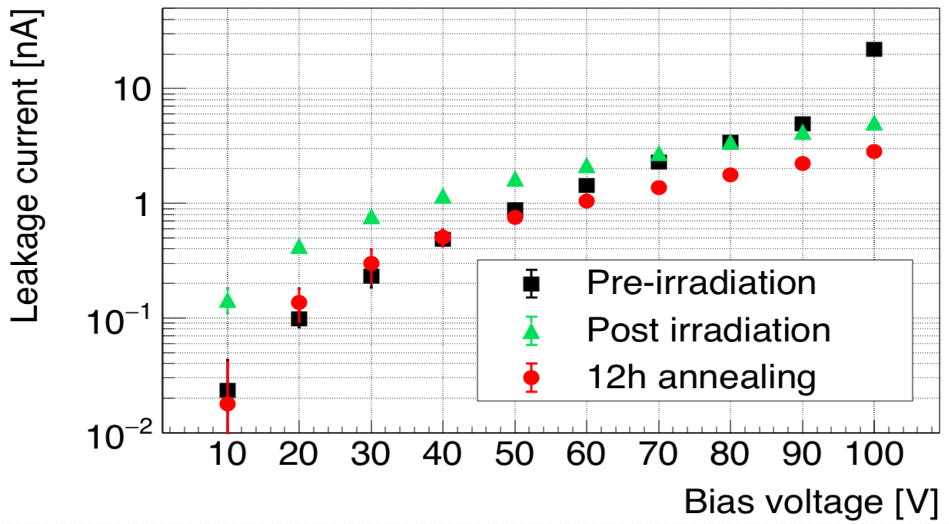
Small

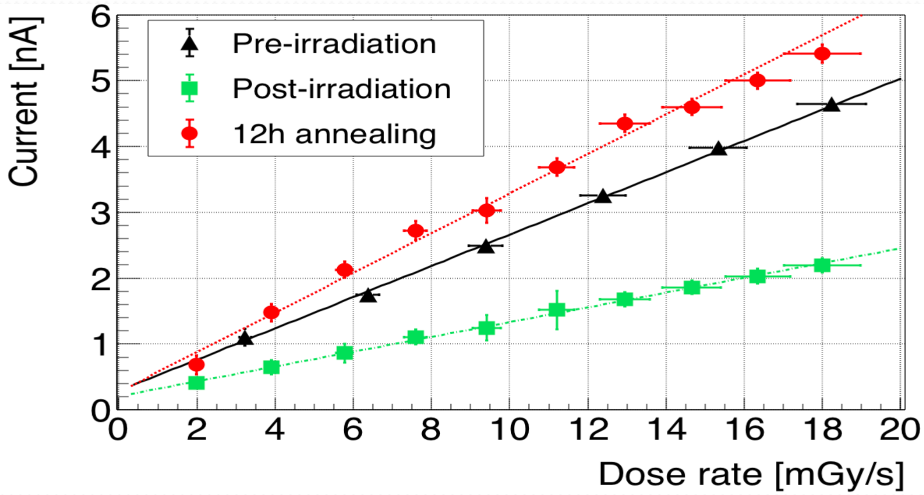
- linear sensitivity
- Dependence on reverse bias voltage

Preliminary radiation tests (c-Si)

- P-i-n deposited on c-Si
- Max Leackage current O(nA)
- Beneficial effect of the annealing procedure

Test at 10^{16} n_{eq}/cm^2

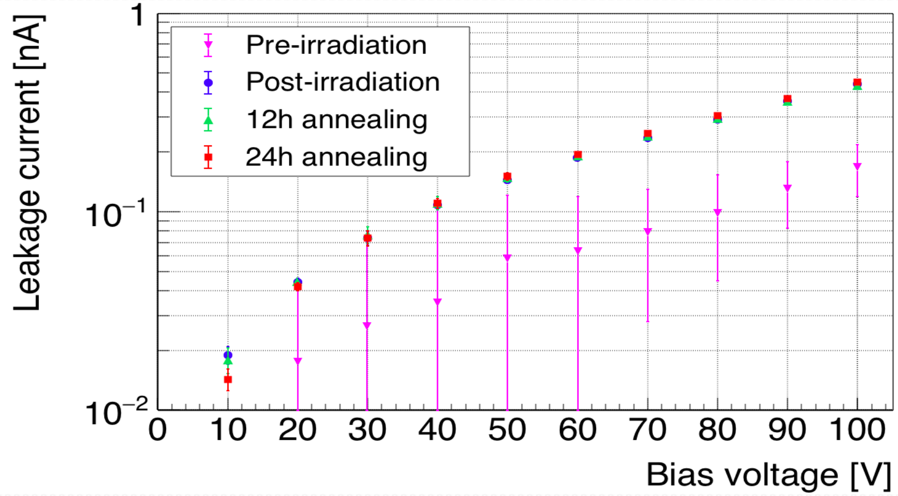


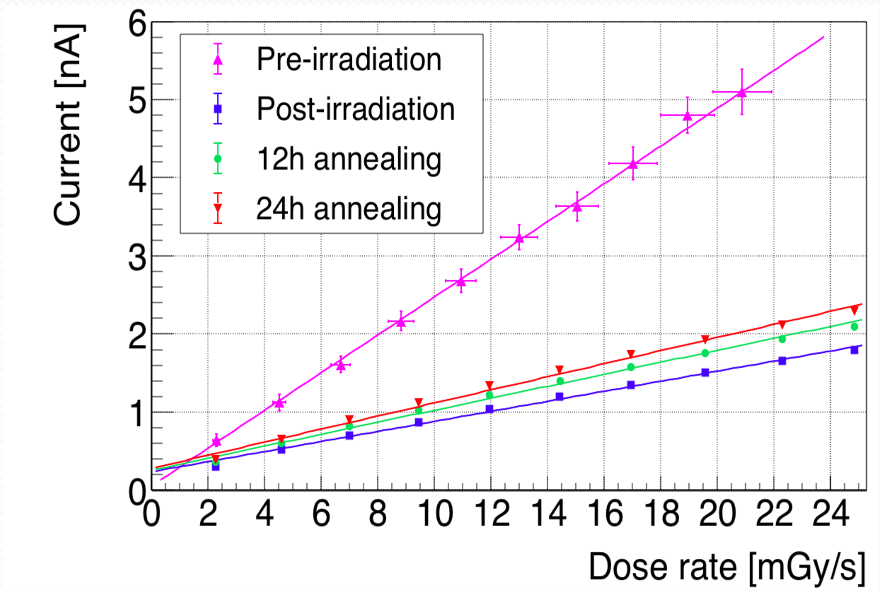


Preliminary radiation tests (kapton)

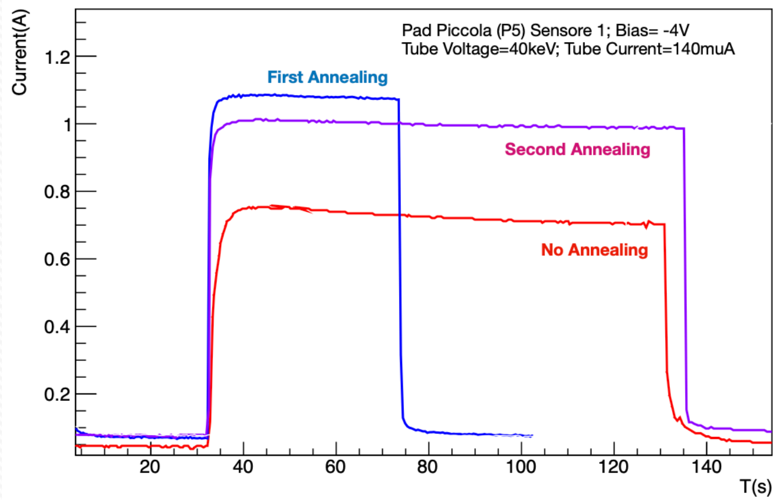
- P-i-n deposited on kapton
- Max Leackage current ~ c-Si O(nA)
- Less effect of the annealing procedure

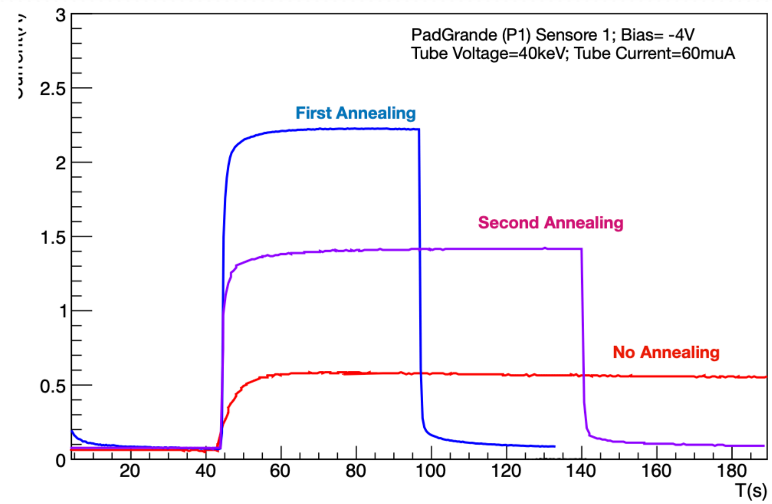
Test at 5 x 10^{16} n_{eq}/cm^2





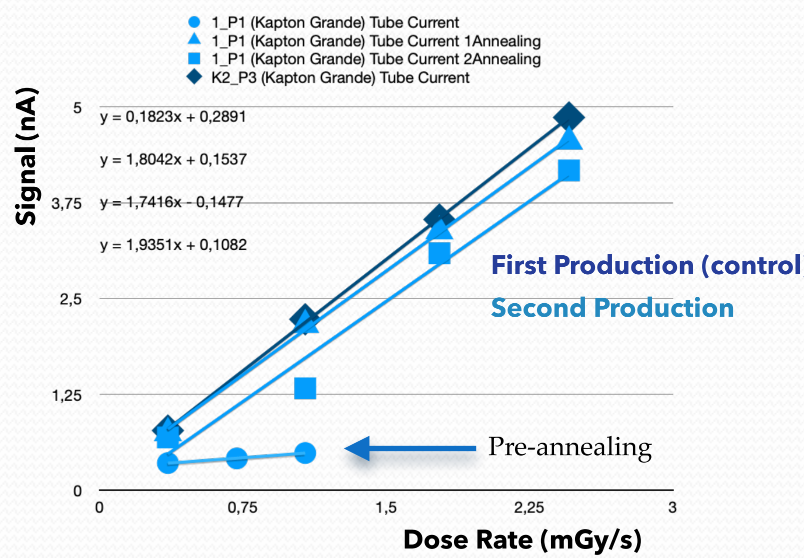
Annealing effect





X-rays Exposure for sensitivity measure and homogeneity of the batch

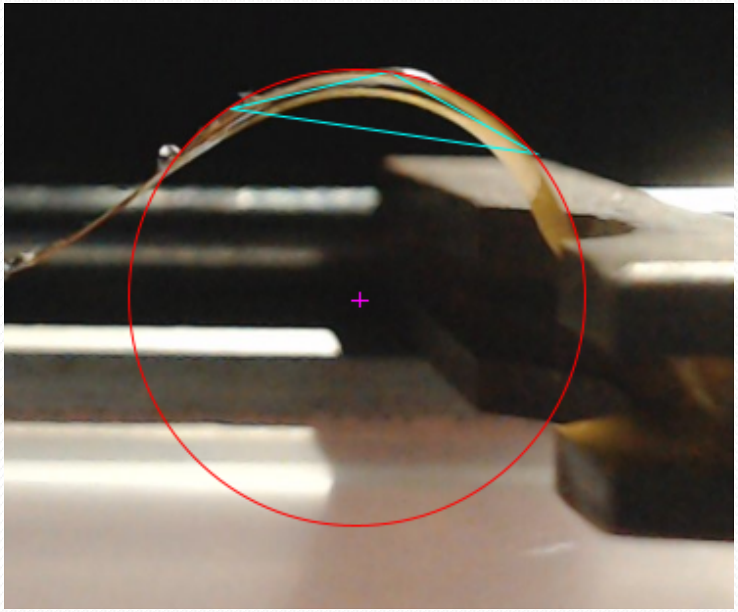
Sensors are annealed (ones at 100°C for 12h) to match the performances of the batch

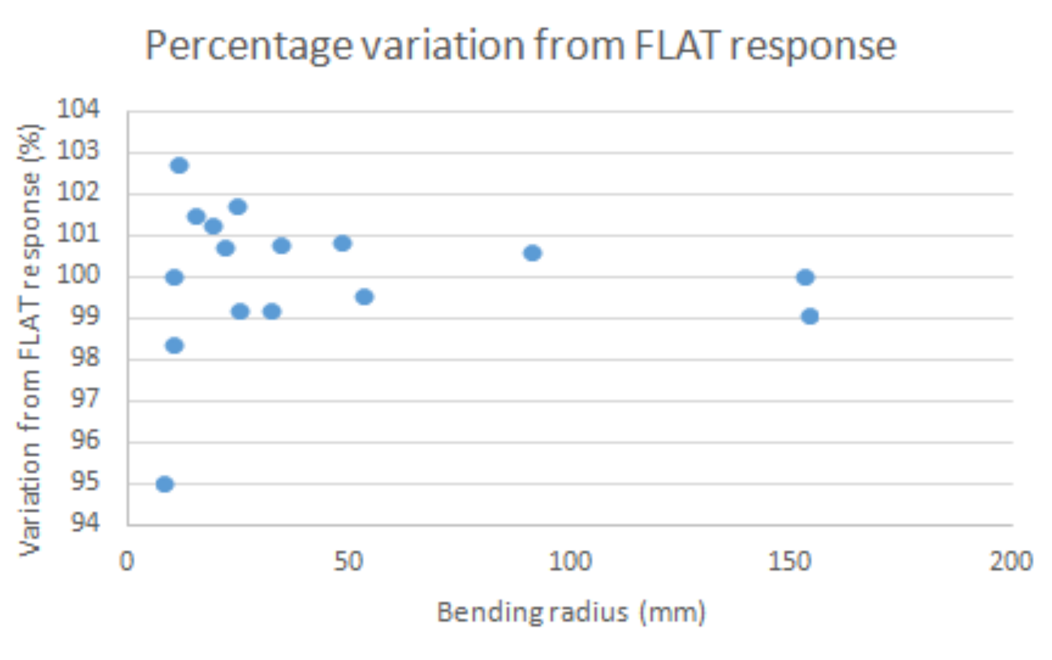


Long term stability

- 5x5 mm² device irradiated for ~6h (dose rate of 0.4 cGy/s, 40 kV tube bias voltage)
- linear extrapolation between the dark current before and after irradiation-> complete trend correction

Flexibility test (Australian WG)





- Detector is glued on a flexible Polyimide PCB support
- Deviation from the flat response is below 3%
- Little difference between flat to bend and bend to flat (relaxation) response

Conclusions and future plans

- We have initiated the development of a:Si-H flexible devices for flux measurement for beam monitoring applications, SEP flux evaluation, personal dosimetry, neutron detection.
- P-i-n prototype devices successfully fabricated on PI and characterized
- Future plans include:
  - Flux measurements on proton and electron beam of prototypes
  - Fabrication and characterization of new thicker p-i-n and CSC devices
  - Further radiation damage tests

Backup

Current response and dose rate (x-rays) linearity

	Device Area (mm²)	Bias Voltage (V)	Dosimetric sensitivity (nC/cGy)	Regression coefficient R
Large	5x5	0	0.367	0.99999
		2	1.283	0.99991
		4	1.900	0.99975
		6	2.505	0.99972
		8	3.027	0.99926
Small	2x2	1	0.137	0.99878
		4	0.335	0.99961
		8	0.540	0.99881

Detector type and bias	Pre-rad Sensitivity (nC/cGy)	Sensitivity after irradiation (nC/cGy)	Sensitivity after 12h annealing (nC/cGy)	Sensitivity after 24h annealing (nC/cGy)
CSC at 30V bias	11.1 ± 0.3	5.0 ± 0.1	6.5 ± 0.2	7.2 ± 0.2
CSC at 0V bias	0.86 ± 0.03	0.10 ± 0.02	0.24 ± 0.02	0.30 ± 0.02
P-i-n diode at 60V	2.39 ± 0.09	1.13 ± 0.08	3.0 ± 0.1	-

The HASPIDE collaboration

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Displacement damage on a 30 um a-Si:H planar detector