USE a:Si-H AS A DETECTION MATERIAL FOR IONIZING RADIATION FOR MEDICAL AND SPACE APPLICATION

DOTTORATO INTERNAZIONALE E INDUSTRIALE IN FISICA

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28/10/2022

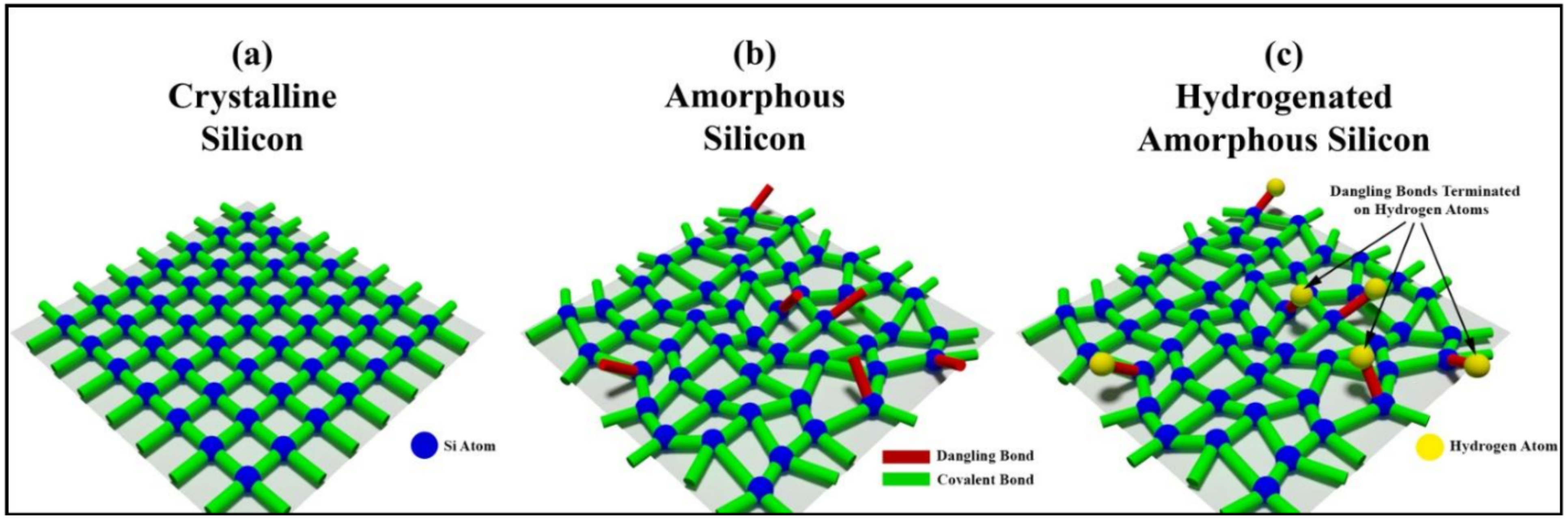
HASPIDE PROJECT: STATE OF THE ART

The PhD project is part of the research activity of the **HASPIDE** experiment

The **HASPIDE** project wants to explore the possibility to use **a:Si-H** as a detection material for ionizing radiation of different types.

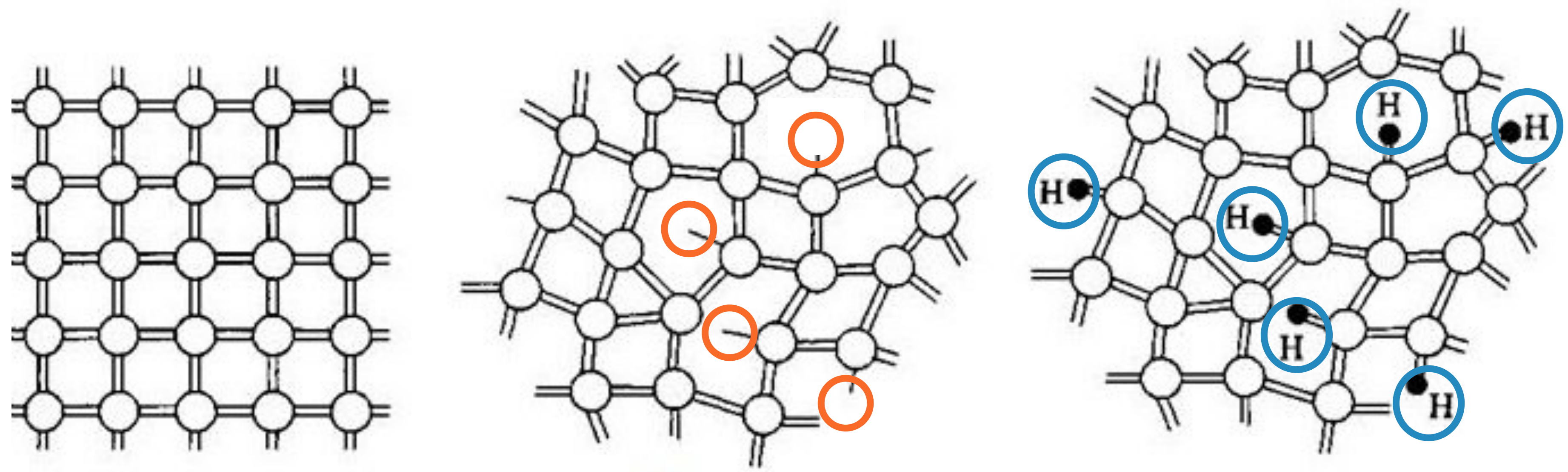
The material in itself is very **radiation-resistant**, can be deposited as a thin layer of few micrometres over many substrates, including flexible ones like **Kapton**, that potentially opens up the way toward many important applications:

- Beam monitoring of clinical and non-clinical accelerators;
- Detection of cosmic radiation in space;
- Neutron detection;



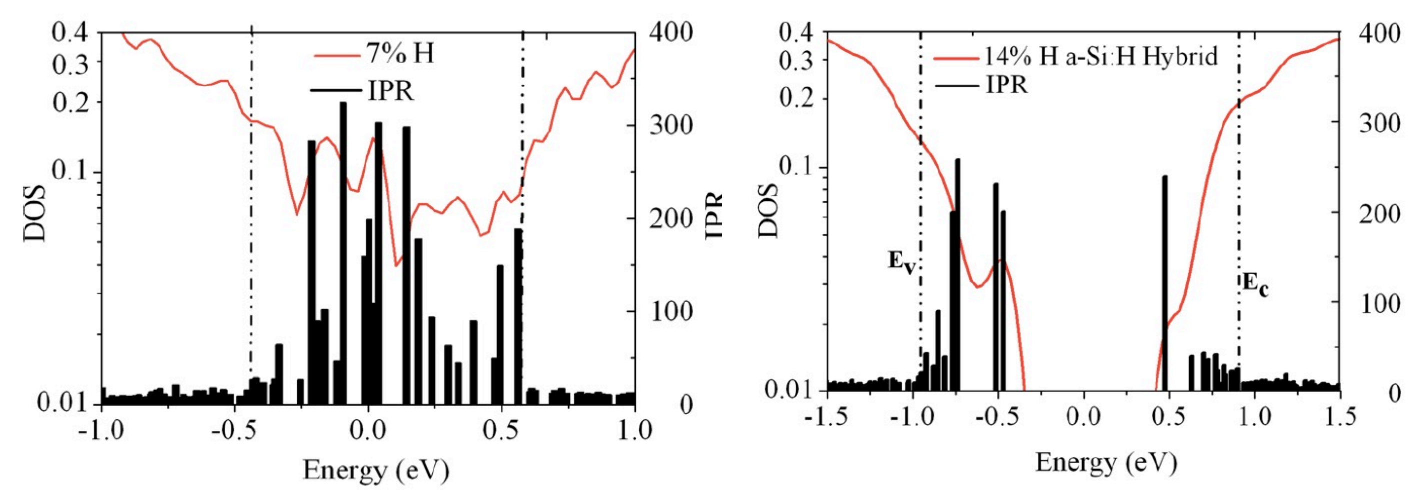
AMORPHOUS HYDROGENATED SILICON

The defining property of **amorphous silicon** in contrast to its well-known crystalline form is the absence of long-range order in the atomic positions.



Defects limit the efficiency through the additional electronic states that they generate in the band gap of a-Si

Hydrogen is introduced to help to lift the over-coordination by the formation of Si-H bonds and to saturate the defects arising from Si dangling bonds



Density of states for under saturated (7%), and saturated (14%) a-Si:H.

DOUBLE APPROACH

Goals of the project:

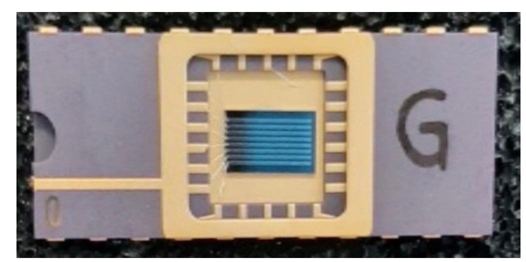
- Electronic performance and quality testing for device deposited on c-Si

  After prototype fabrication, quality testing will be performed by INFN-PG, INFN_LE and UOW. The basic tests on each prototype will include:

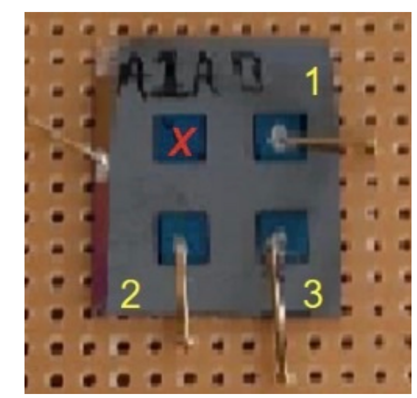
  I/V measurements;

  Radiation damage measurements;

  X-ray dosimetric calibrations;



a-Si:H Contacts: p-i-n



a-Si:H Contacts: CSC

- Quality of material testing (a-Si:H on c-Si and comparison with device performance)

  The prototypes must be characterized also from the aspect of the **quality of the material**, for example through spectroscopic techniques to study their electrical and transport properties.

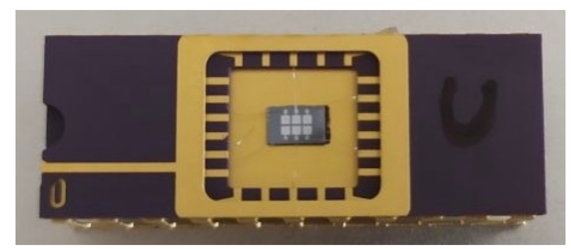
CHARACTERIZATION OF A-SI:H DETECTOR

One of the most important goals will be **detector fabrication**.

Basic detector configurations will be built to assess the performances of the various prototypes (basic physical, electrical and charge collection performances).

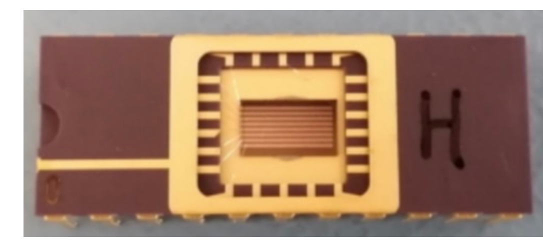
- Small arrays of **diodes** with different areas and diode spacings deposited on c-Si;

d=10 µm; V=0.0025mm^3



a-Si:H p-i-n Pad

d=10 µm; V=0.01mm^3

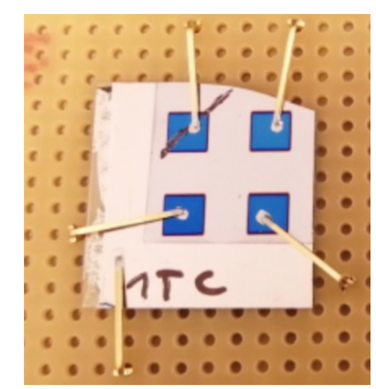


a-Si:H p-i-n Strip

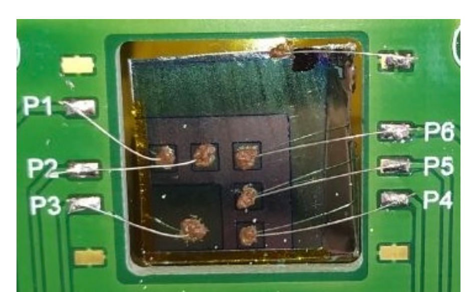
- **CSC (Charge Selective Contacts)** with various thickness;

a-Si:H CSC Pad

d=8.2 µm; V=0.13 mm^3



- **Diodes** with different areas deposited on Kapton (fundamental part of the second year of research);

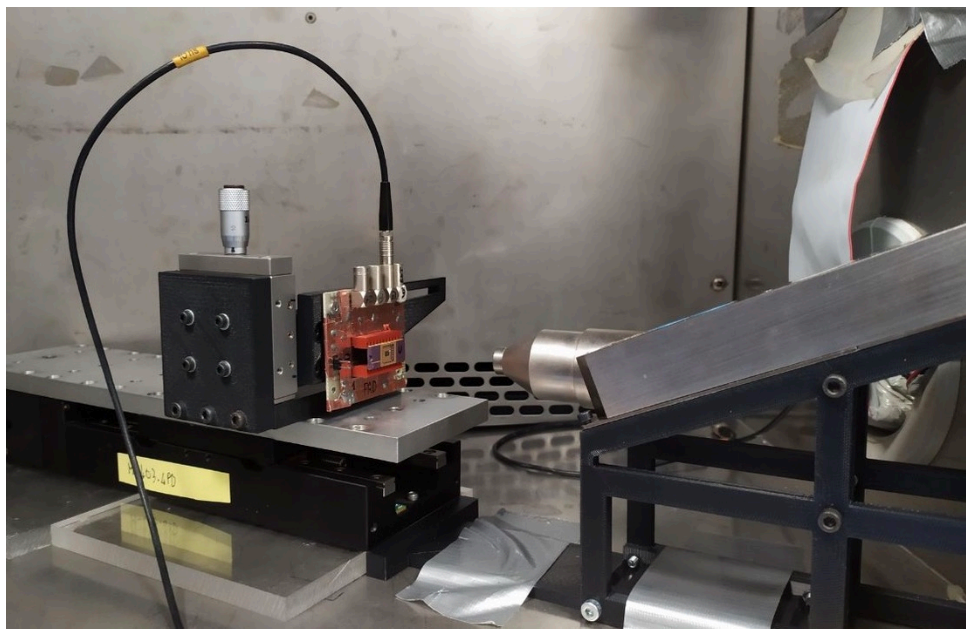


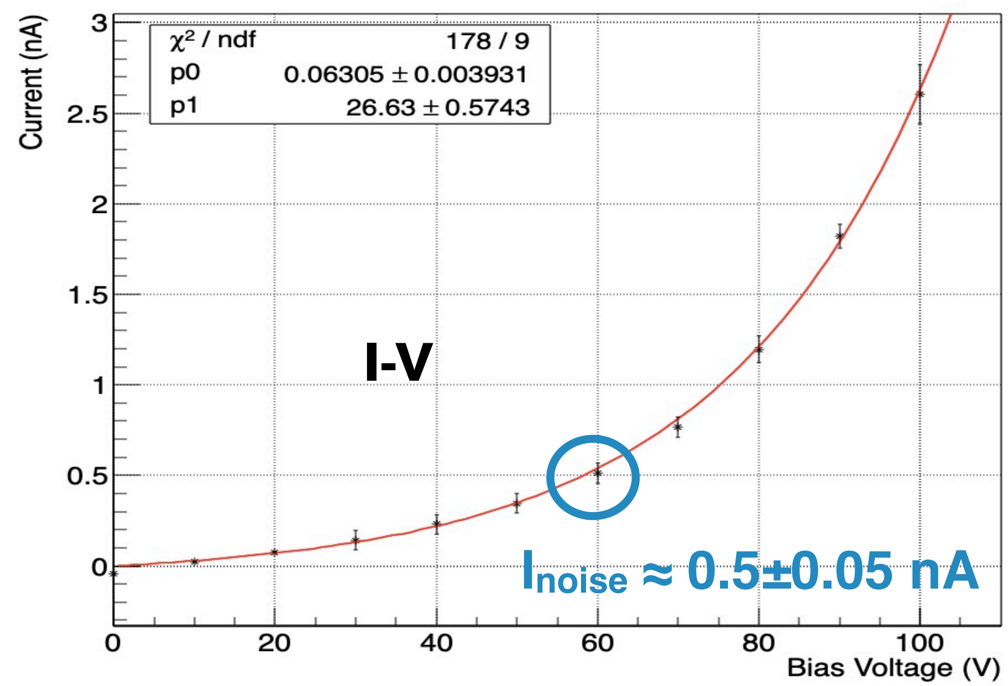
a-Si:H p-i-n Pad

d=2.5 µm; V=0.06 mm^3

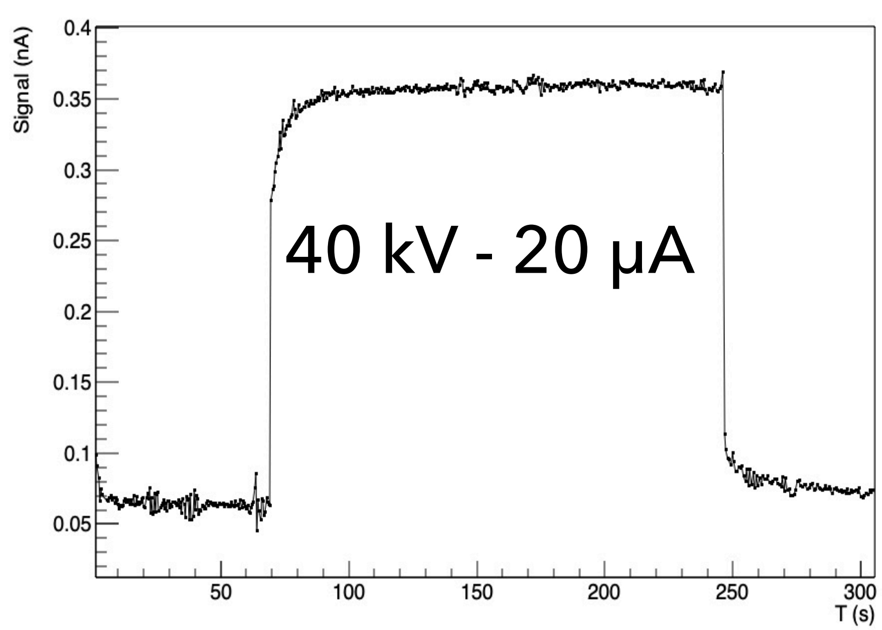
CHARACTERIZATION OF A-SI:H DETECTOR

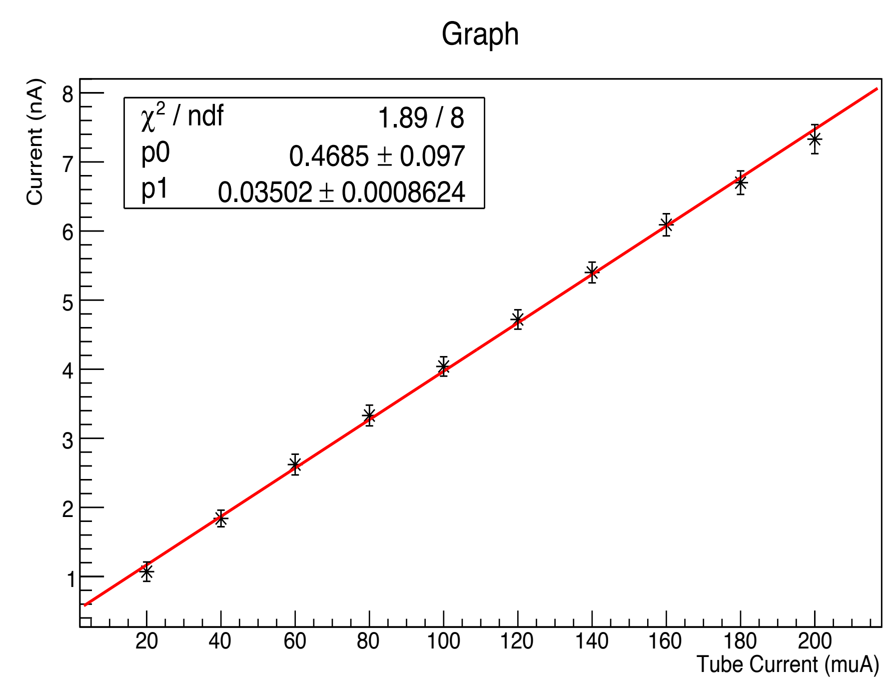
We initially studied the detector response in the absence of a signal source for different bias voltage values, to evaluate its noise.



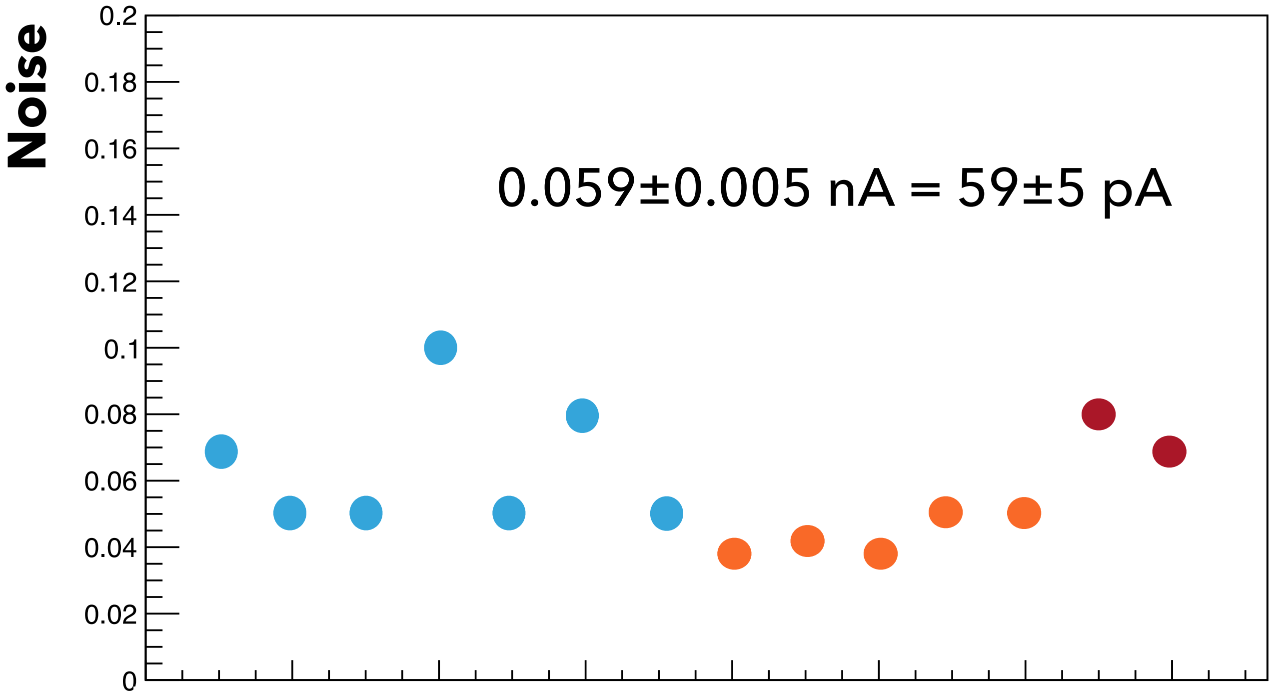


To make a first characterization of the response of the sensors to radiation we exposed the detectors to an X-ray source.

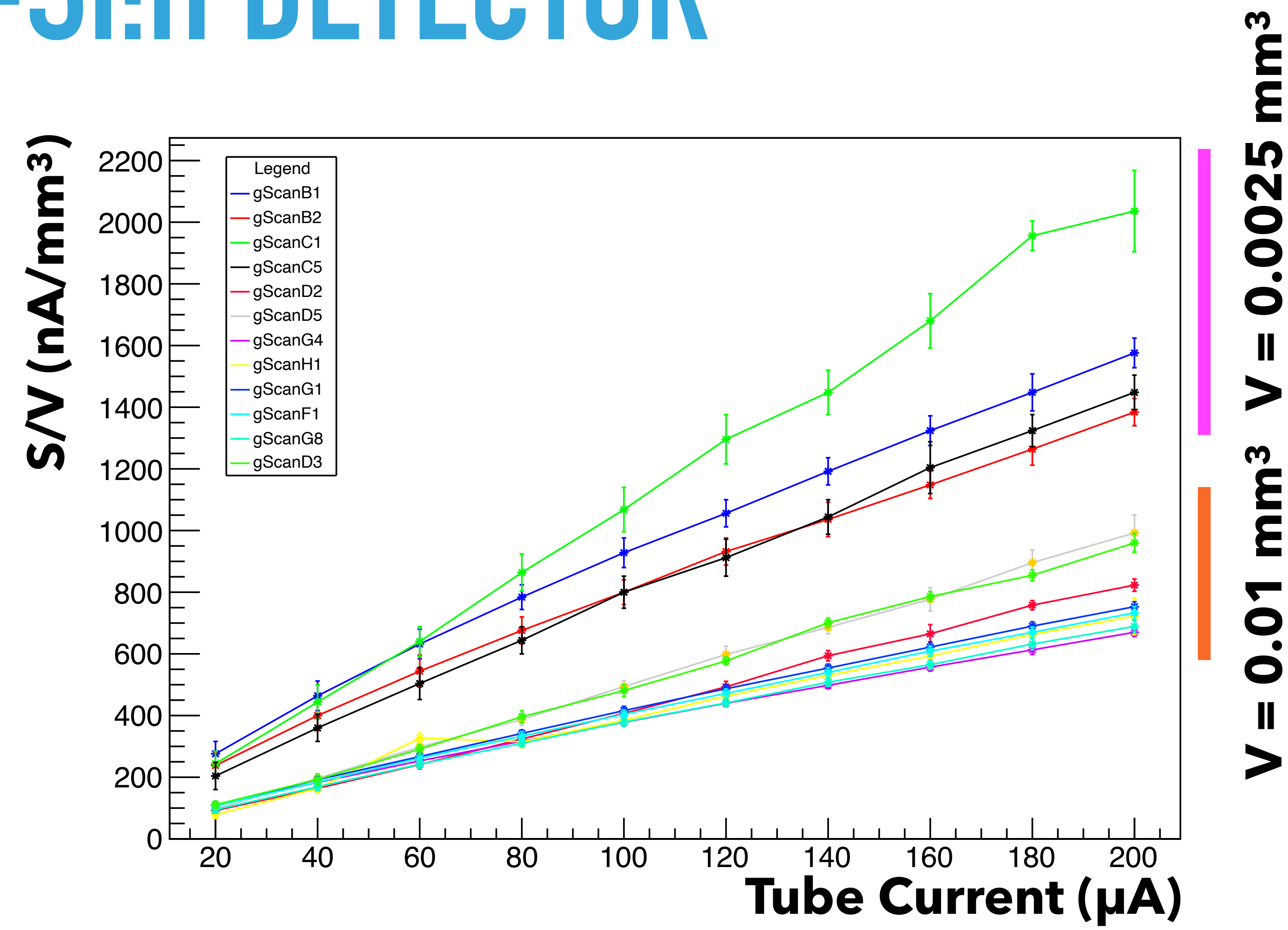




CHARACTERIZATION OF A-SI:H DETECTOR



- **Pad V=0.01mm³ & V=0.0025mm³**
- **Strip V=0.01mm³**
- **CSC V=0.13 mm³**



Response to X-ray is **linear** wrt tube current and dose rate.

Neverthless, given the higher ionization energy wrt c-Si, we have obtained typical **noise values** of the order of **50 pA**.

The first data shows that with the same **dose rate** and **thickness** the prototypes with a smaller volume appear more sensitive.

IRRADIATION TEST WITH PROTONS

We start the study of radiation resistance for the usage of this material in particle flux measurement.

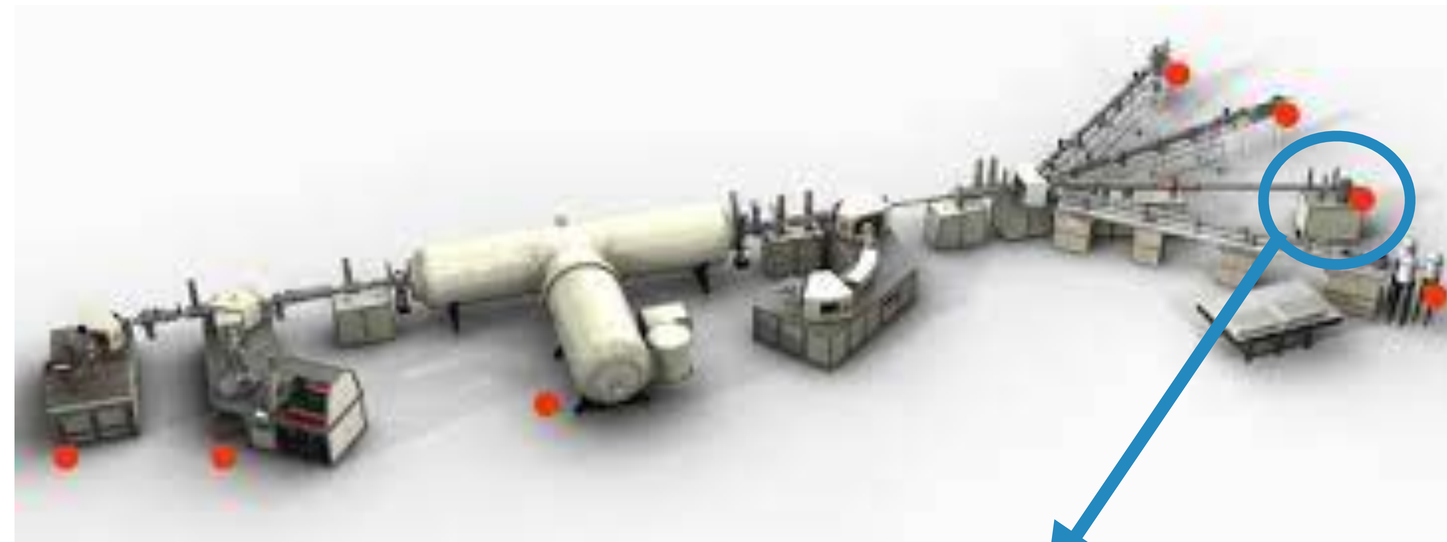
The detectors have been irradiated with proton (3 MeV) at **CEDAD** Laboratory in Lecce with a dual purpose:

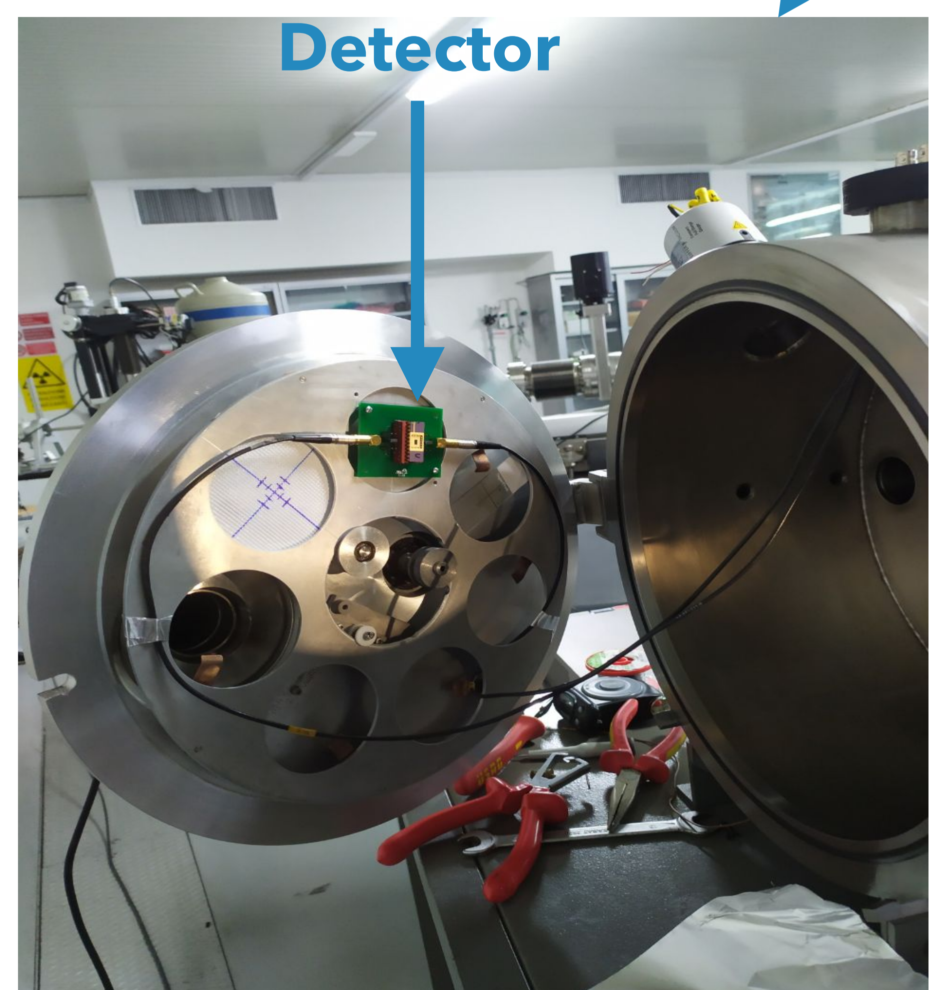
- Measure detector response under irradiation at different dose rates (dosimetric **sensitivity**).

  Flux $< 1.3 \cdot 10^{9}$ p/(s $\cdot$ cm^{2})

- Induced damage in order to evaluate **radiation resistance**

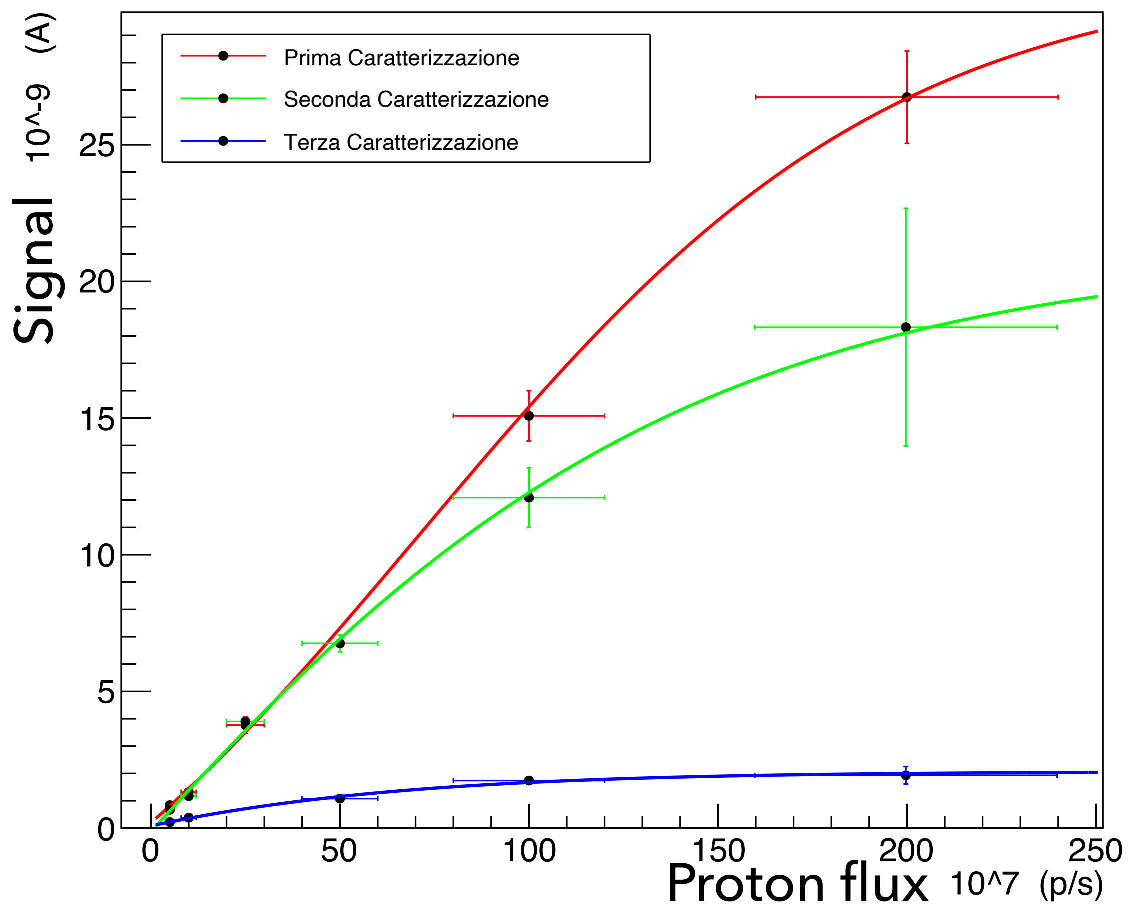
  Flux from 10^{13} to $5 \cdot 10^{16}$ n_{eq}/cm^{2}

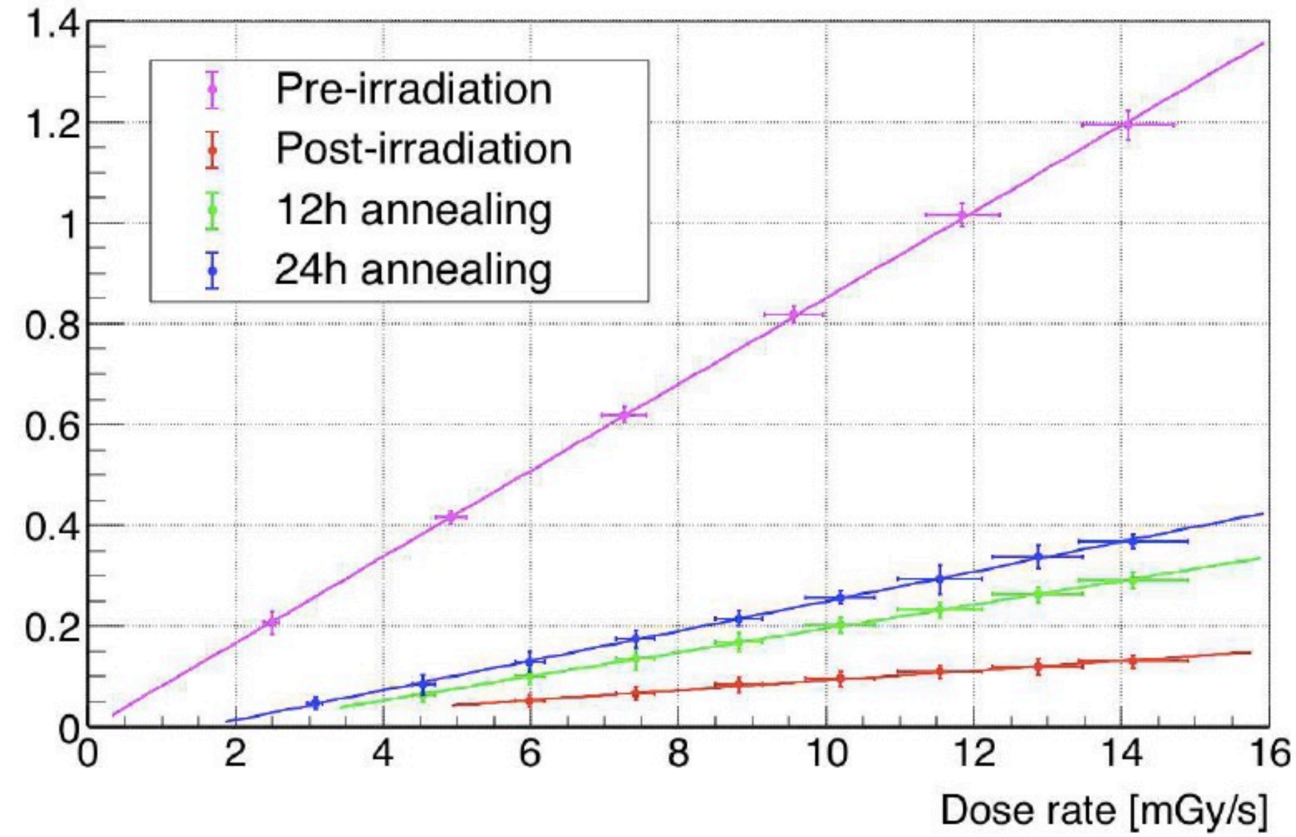




IRRADIATION TEST WITH PROTONS

After each phase of damage to the device, **the signal** generated with the same proton flux **decreases** and at the same time **the leakage current increased**.





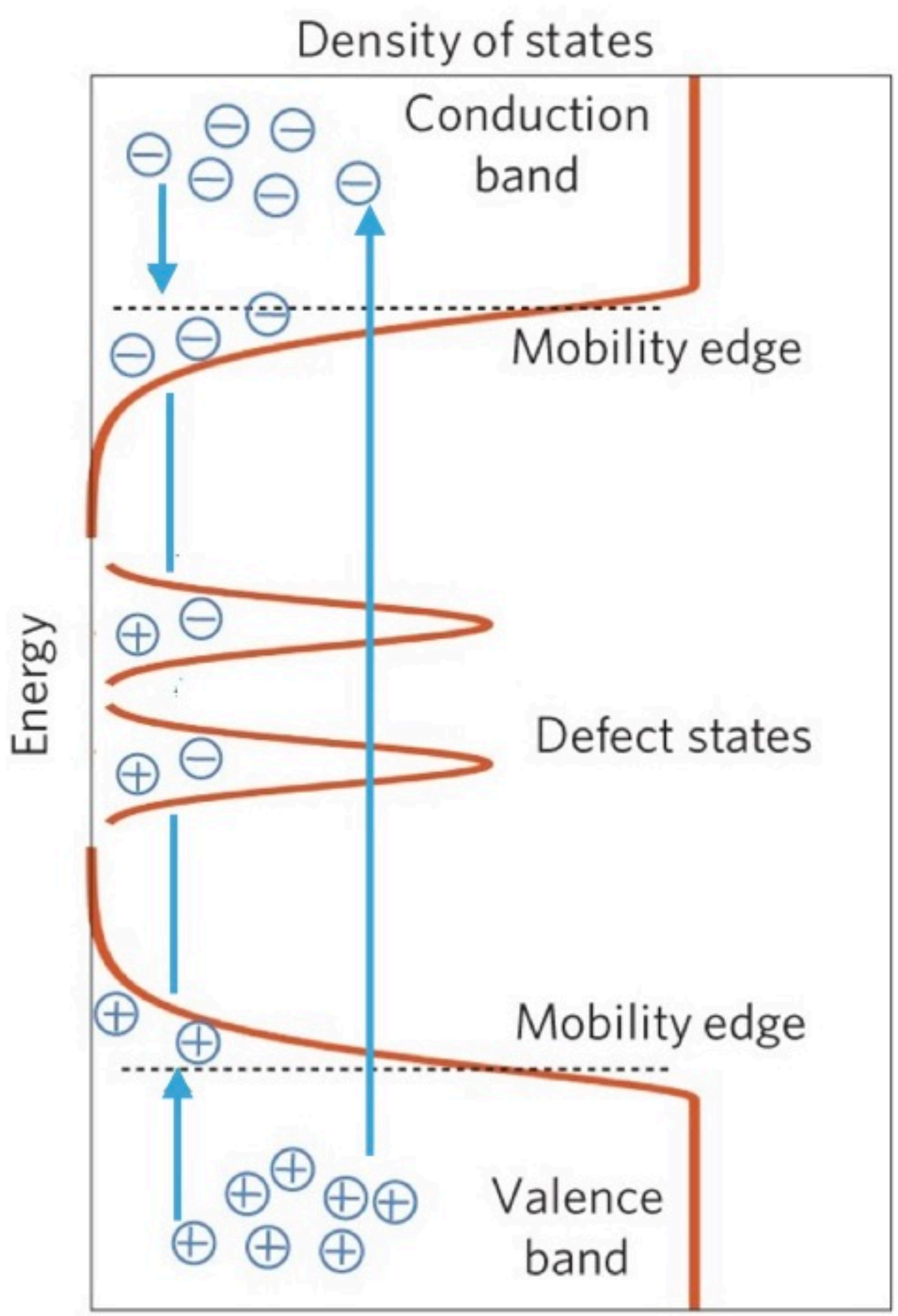
Similar results was obtained also with neutron

With neutron we also see that after annealing process **the degradation was** completely **reversed.**

All electric measurements showed that the detector's performance deteriorate after irradiation, while after the annealing process performance improves again.

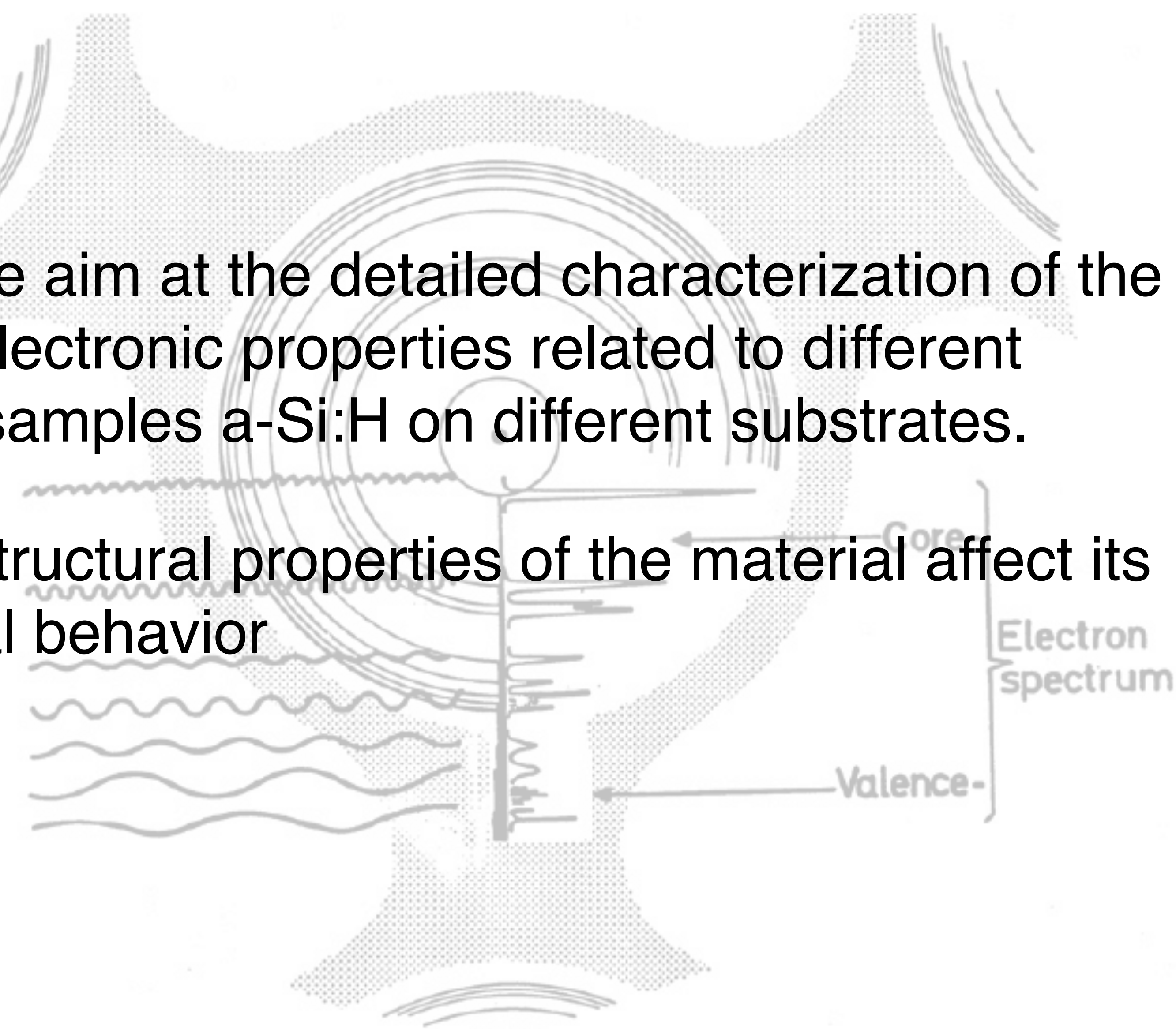
PHOTOEMISSION AND ABSORPTION SPECTROSCOPY

I investigate the radiation resistance of **p-i-n devices** based on hydrogenated amorphous silicon (a-Si:H) material with the use of high-resolution photoemission, soft X-ray absorption and Atomic Force Microscopy.

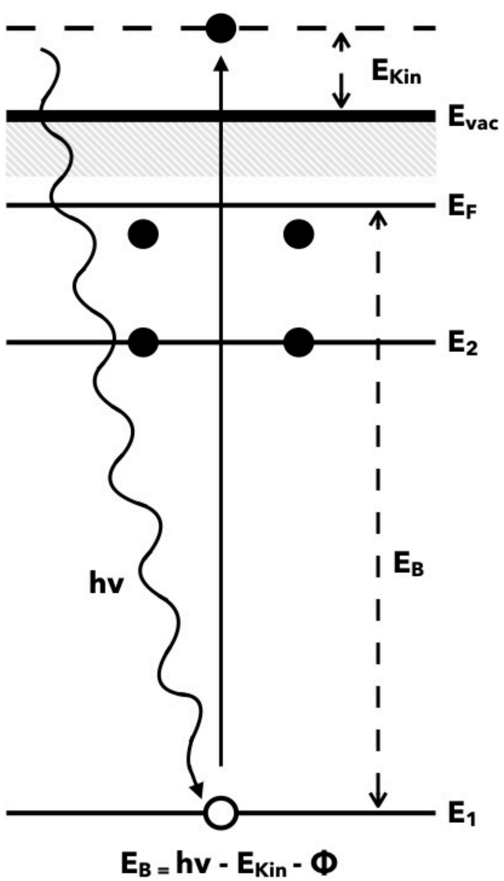


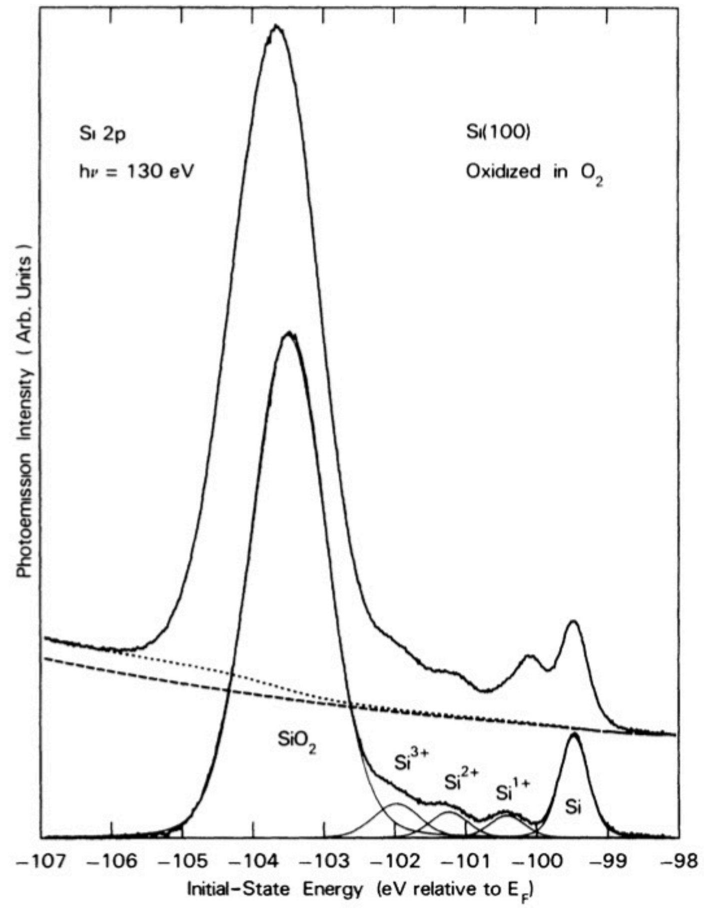
Goal: we aim at the detailed characterization of the a-Si:H electronic properties related to different growth samples a-Si:H on different substrates.

All the structural properties of the material affect its electrical behavior



CORE LEVEL PHOTOEMISSION SPECTROSCOPY

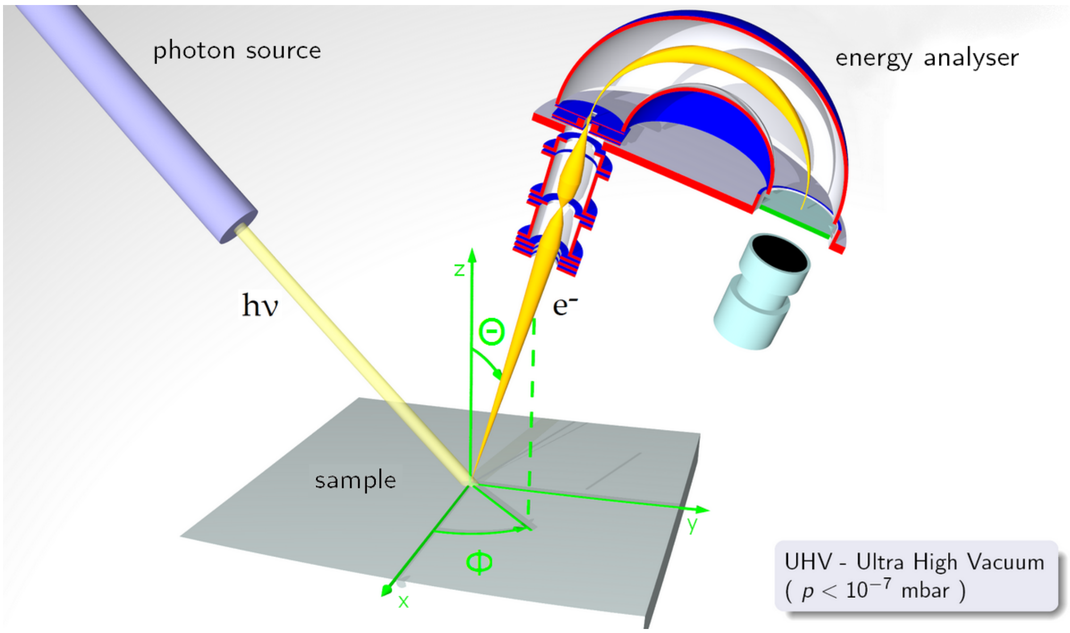




X-ray photoelectron spectroscopy (**XPS**) studies the chemical properties of solids through the photoelectric effect. In a XPS experiment a solid is irradiated with light of few tens to several hundred eV.

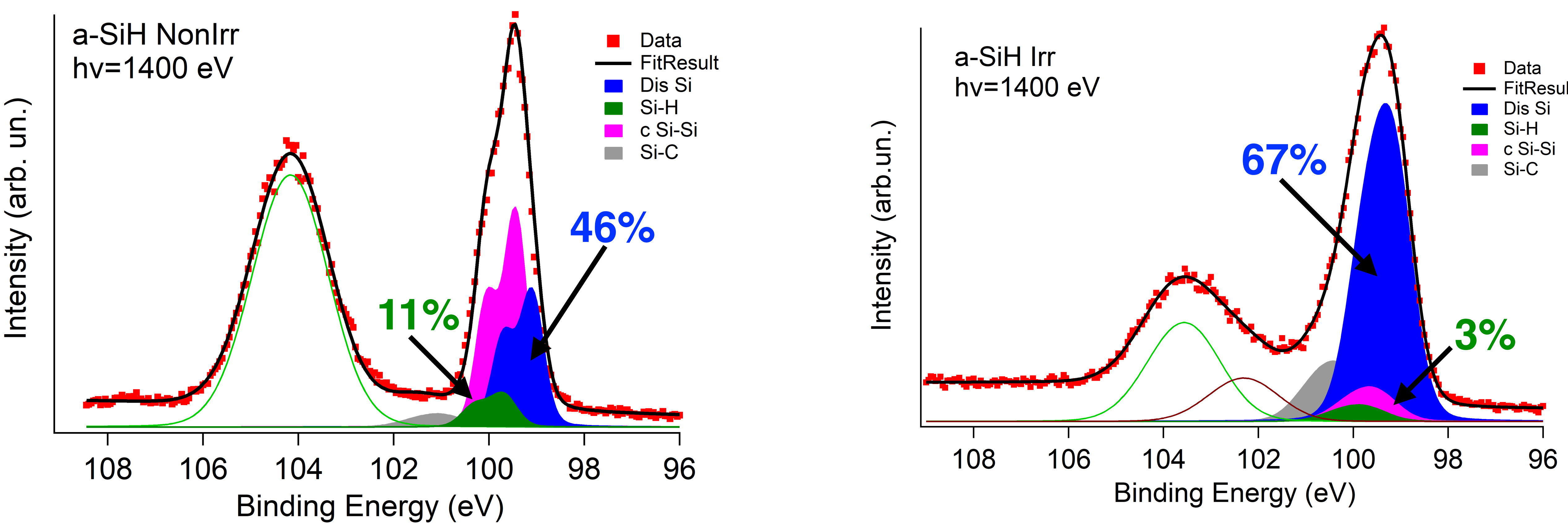
The core-level electrons emitted from the sample carry element-specific information.

We measure the kinetic energy of the photoemitted electrons. To do this, the electrons are collected by an electron analyzer, which is able to measure the energy and the number of electrons that come out of the sample surface.



CORE LEVEL PHOTOEMISSION SPECTROSCOPY

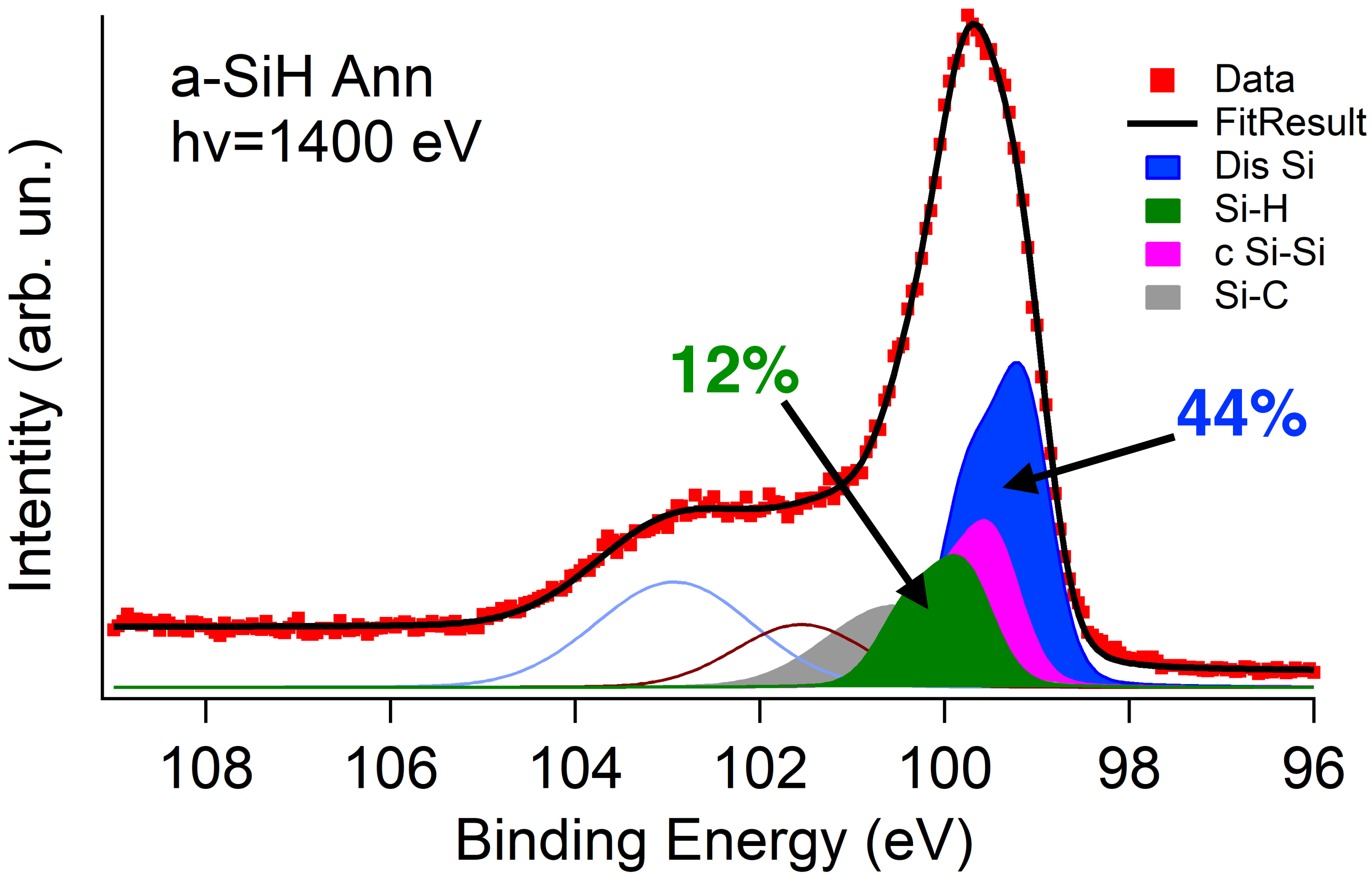
We have studied the **dangling bonds** formation in a-Si:H heterostructures after neutron **irradiation** using **core level** measurements (the measurements were made on **real devices** to get a deeper understanding of the damaging mechanism).



We observe that irradiation breaks some of the existing **Si-H** bonds, and increases the number of **dangling bonds** in the hydrogenated layers.

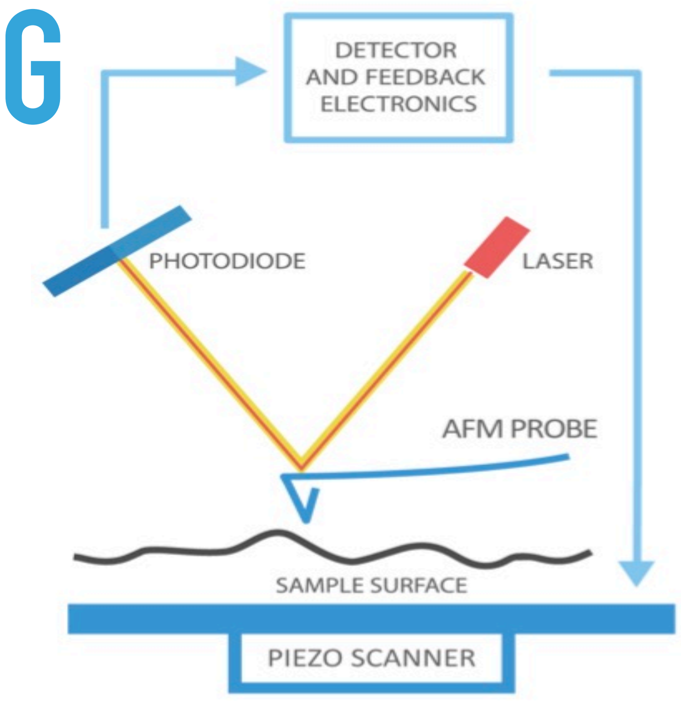
CORE LEVEL PHOTOEMISSION SPECTROSCOPY

After **annealing** a recovery of the Si-H concentration takes place up to 12%, with a decrease of the dandling bonds component practically to the value of the non-irradiated sample.

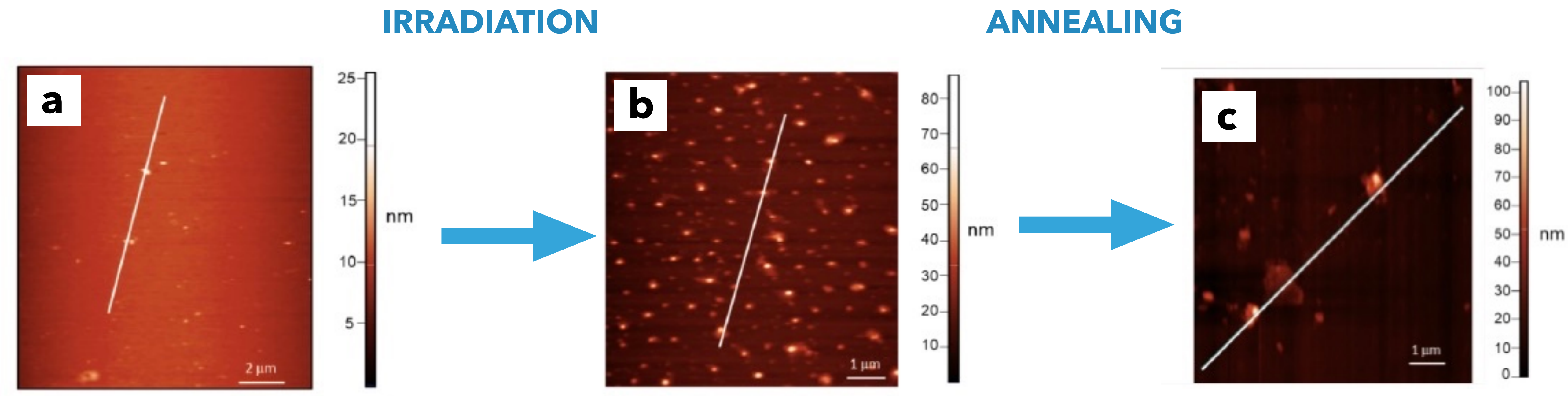


The neutron irradiation induces a reduction of **Si-H** component by more than 50%. The subsequent annealing induces **passivation of the dandling bonds** which is crucial for the device performance. **This explains the electrical behavior of the devices.**

EFFECT OF IRRADIATION ON THE COATING



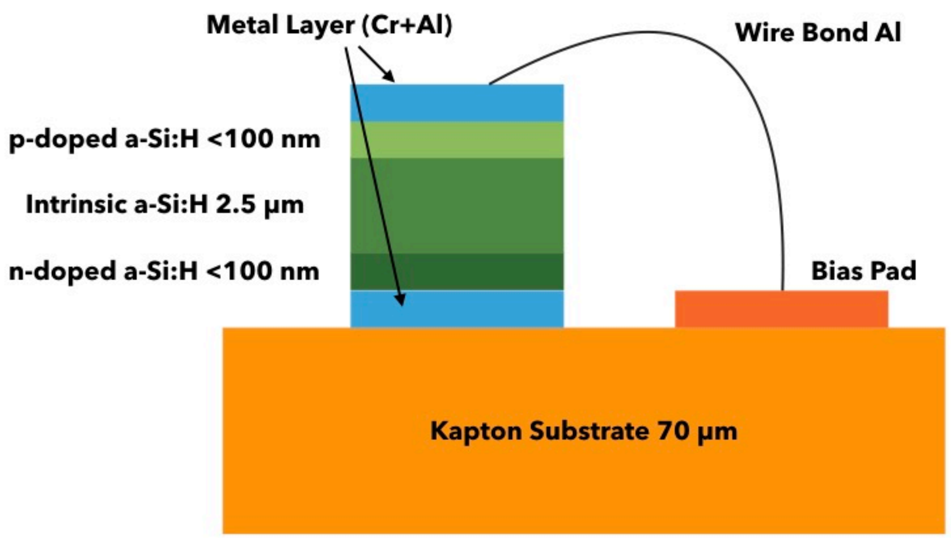
The effect of irradiation and annealing on the coating of the device samples have been characterized by AFM (Atomic Force Microscopy) an high-resolution non-optical imaging technique.

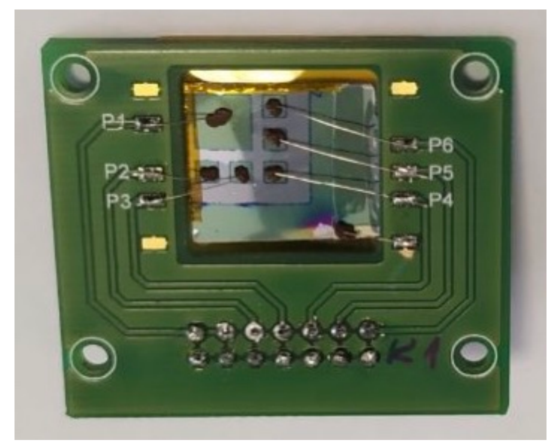


The in-plane defects of the a-Si:H sample before irradiation have an area density of about **2%(a)**, after irradiation, the area of defects results increased to about **12%(b)**, while after annealing it is reduced to **6%(c)**.

DETECTOR ON KAPTON SUBSTRATE PRLIMINARY RESULTS

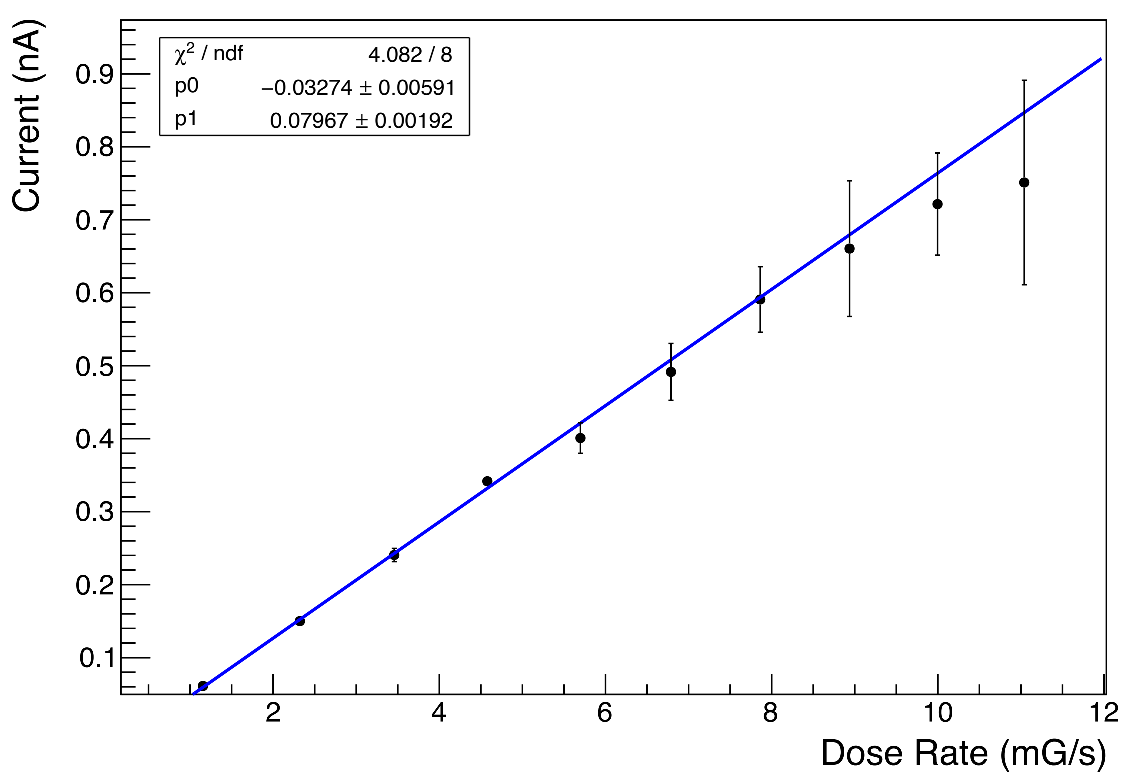
The first prototypes deposited on **kapton** were built.



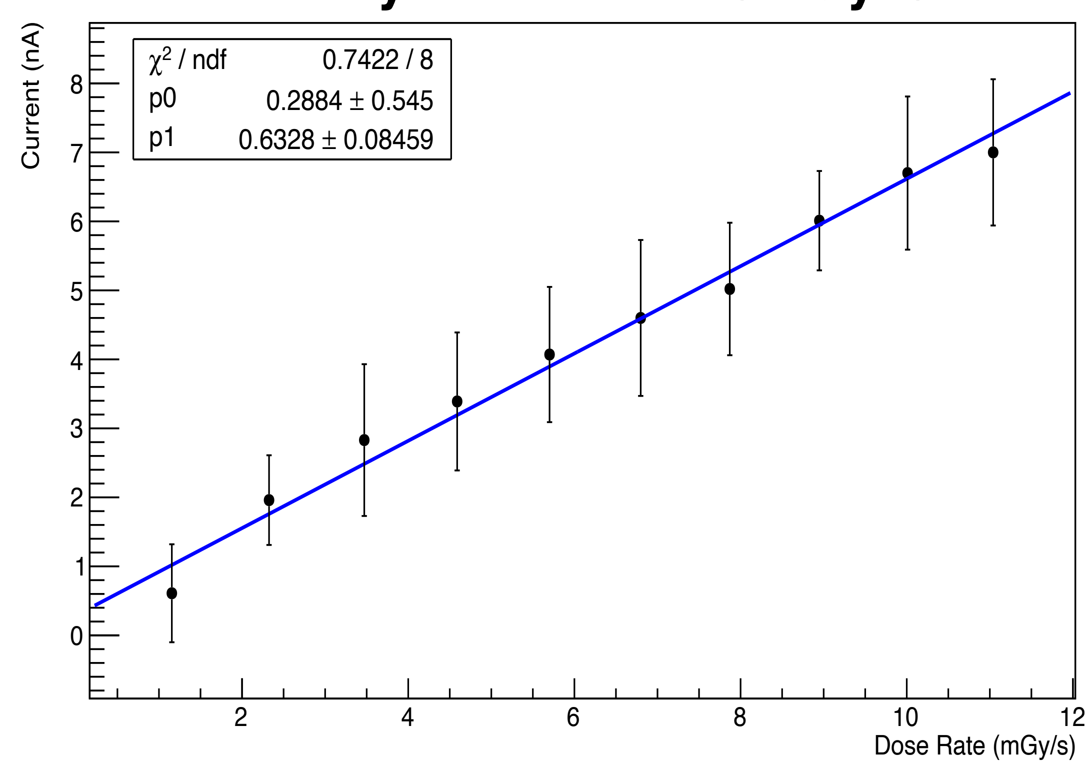


We are proceeding with their characterization here in Perugia and then proceeding with tests on a beam with different sources of ionizing radiation.

Sensitivity = 0.80 ± 0.02 nC/cGy @ 0V



Sensitivity = 6.3 ± 0.8 nC/cGy @ 8V



FIRST RESULTS

- **Preliminary** estimate of p-i-n detector charge collection **efficiency with proton source** $\epsilon = \frac{S_{measured}}{S_{estimated}} = 0.77$

- Sensor response as a function of the X-ray tube current is well approximated through a **linear** function.

- **Preliminary** estimate of detector sensitivity.

Ionizing radiation	**50 kV X-Ray**	**Protons (3 MeV)**	**40 kV X-Ray Photons**	**6 MV Photons (Clinical)**	**6 MV Electrons (Clinical)**
Sensitivity (nC/cGy)	1-20 (CSC)	0.1-0.2 (p-i-n on c-Si)	1-6 **(p-i-n on Kapton)**	0.1-1 (p-i-n on c-Si)	0.1 (p-i-n on c-Si)

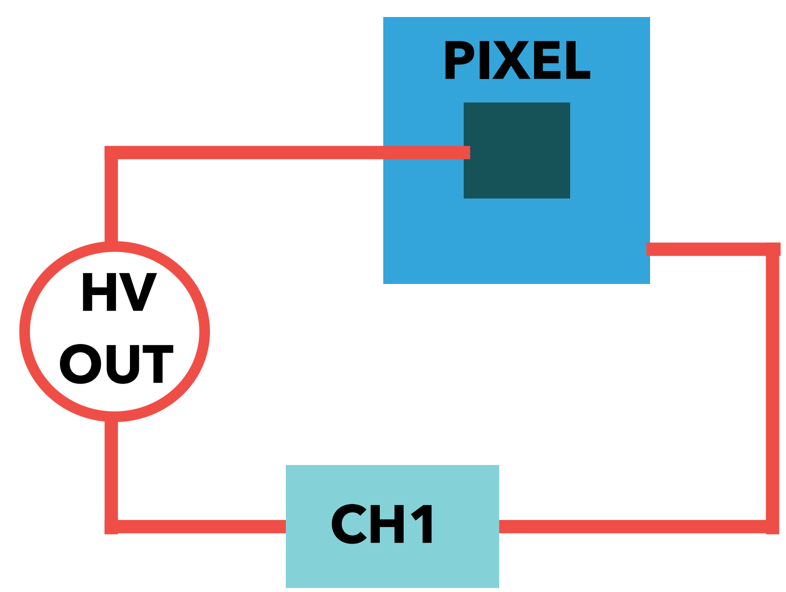
- Within the same device the different detectors show a **uniform** electronic behavior.

- The **noise** level is uniform for all type of prototypes and is around a few tens of pA (~ 50 pA)

COLLABORATION WITH BEAMIDE COMPANY

BEAMIDE, a company founded in Perugia which the main project on which the foundation of the start-up is based is the MRADSIM software, a software with a user-friendly graphic interface that allows to simulate the effects of radiation on electronic.

I started the collaboration with the BEAMIDE company, spending some time in the company to learn to use a device for the **simultaneous acquisition** of several channels at the same time.



FUTURE WORK

- Characterization on new prototype with Kapton substrate (electronic performance and quality testing)
- Quality of material testing, we want to study **a-Si:H on Kapton** electrical and transport properties (at the **ELETTRA** synchrotron, CFSYS technique).

→ The aim is to try to establish and study the differences from those deposited on c-Si

- Dosimetric measurement on small prototype on kapton in clinical environment
- Irradiation test with proton beam on small prototype on kapton at the **University of Bern** and at **CEDAD** Laboratory in Lecce
- Carry on the collaboration with the company and also participating in data collection campaigns with different types of sensors for ionizing radiation
- Start programming the stay abroad at The École polytechnique fédérale de Lausanne (**EPFL**) based in Lausanne (Switzerland)

EPFL

COURSES, SCHOOL AND RESEARCH OUTCOMES

Summer School **NDRA2022**, June 30 to July 4, 2022, 4th Summer School on Neutron Detectors and Related Applications;

UNIVERSITÀ DI TRENTO
Department of Industrial Engineering

INFN
Istituto Nazionale di Fisica Nucleare

2022 **IEEE Nuclear Science Symposium** (NSS), Medical Imaging Conference (MIC) and Room Temperature Semiconductor Detector (RTSD) - **Poster Presentation**;

MILANO
2022 IEEE NSS MIC RTSD
IEEE NUCLEAR SCIENCE SYMPOSIUM, MEDICAL IMAGING CONFERENCE AND ROOM TEMPERATURE SEMICONDUCTOR DETECTOR CONFERENCE

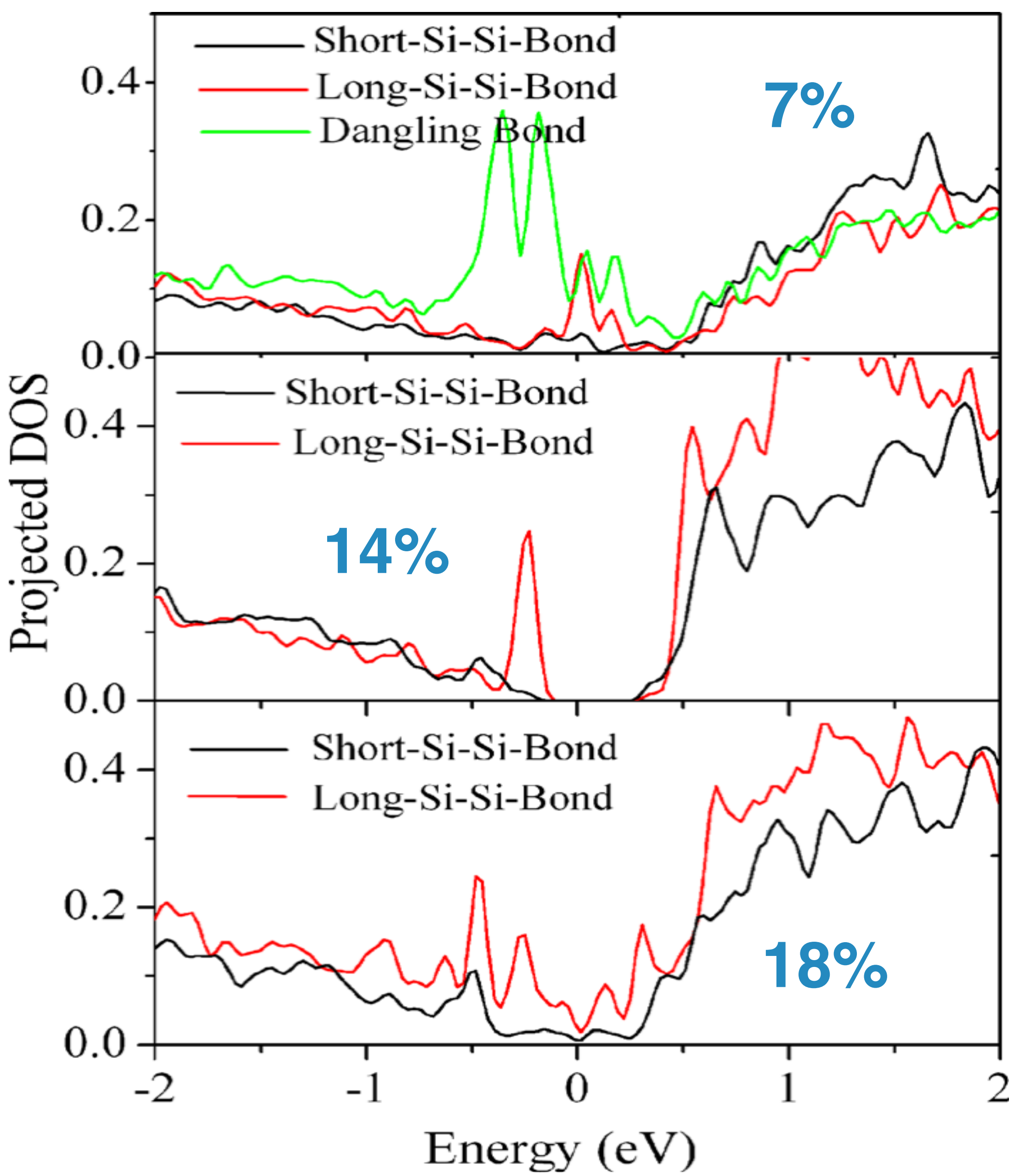
MDPI

Published paper for the **Nanomaterials Journal** (MDPI) “High-Resolution Photoemission Study of Neutron-Induced Defects in Amorphous Hydrogenated Silicon Devices”;

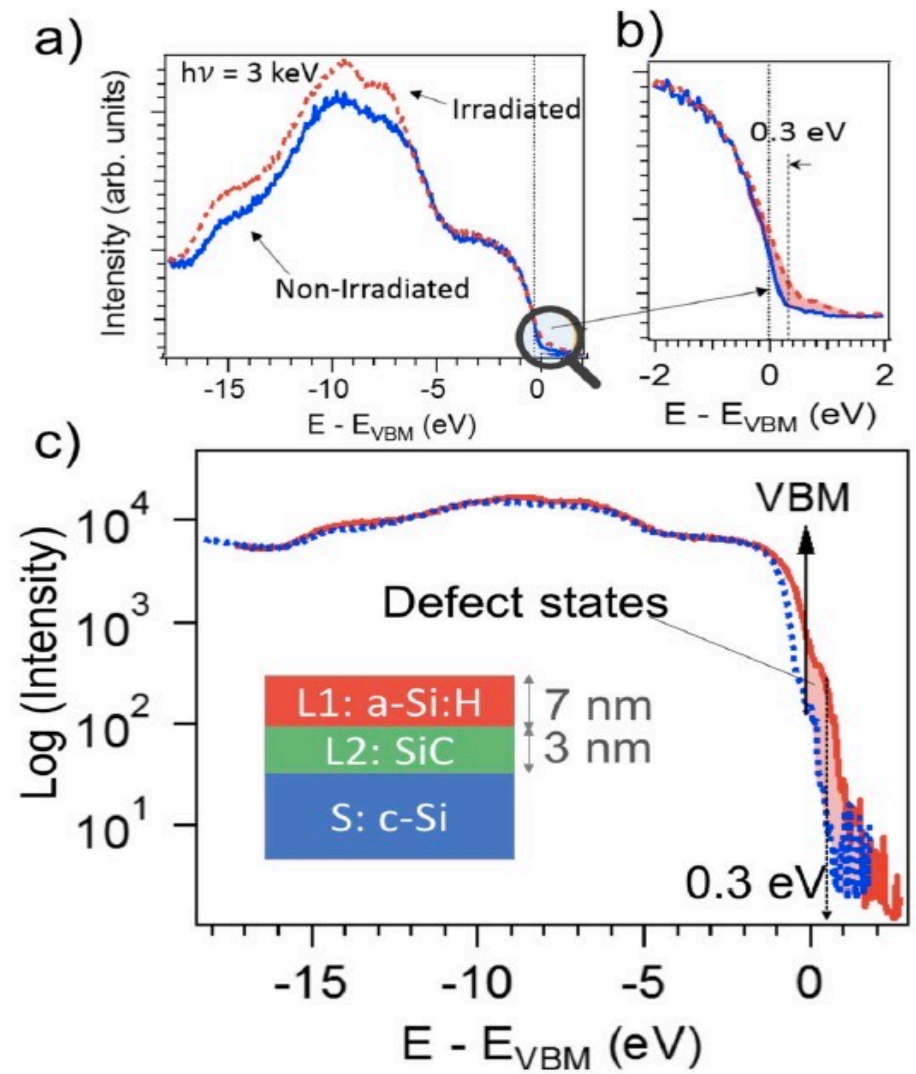
Proposal submission awarded with 18 operational shifts on the CiPo beam line at the Trieste synchrotron (**ELETTRA**).

Elettra Sincrotrone Trieste

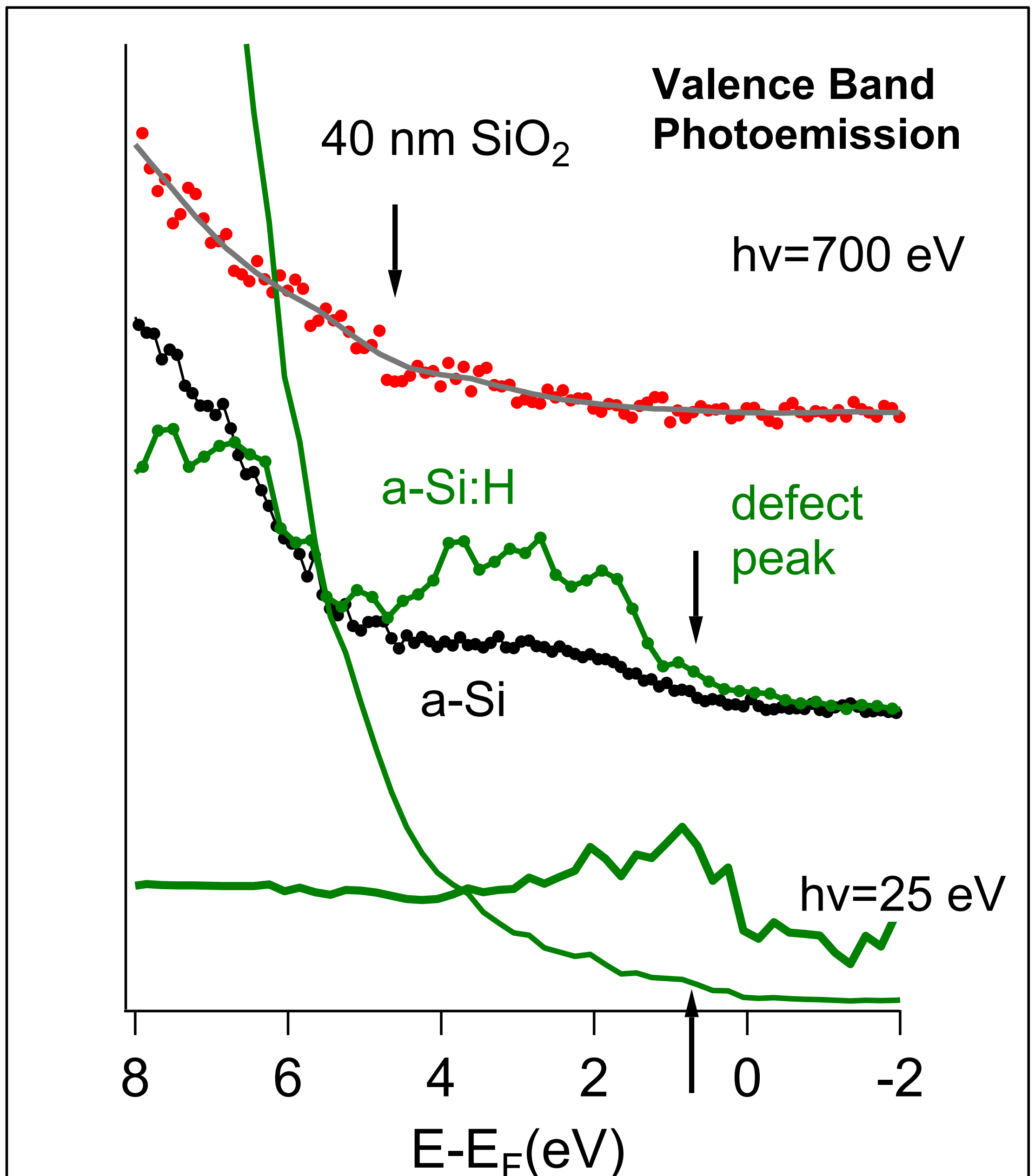
VALENCE BAND PHOTOEMISSION SPECTROSCOPY



"Defect State Analysis in Ion-Irradiated Amorphous-Silicon Heterojunctions by HAXPES" Min-I Lee, Alice Defresne, Olivier Plantevin, Denis Ceolin



VALENCE BAND PHOTOEMISSION SPECTROSCOPY



We want to acquired enough information about the valence band to be able to characterize the material to quantitatively compare the differences with the samples once irradiated.

Once the Raman and IR measurements have also been implemented, it will be possible to extract the correlation between the hydrogen content and the number of defects in the material.