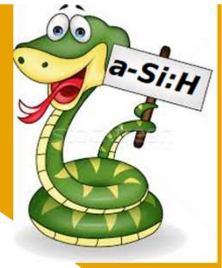
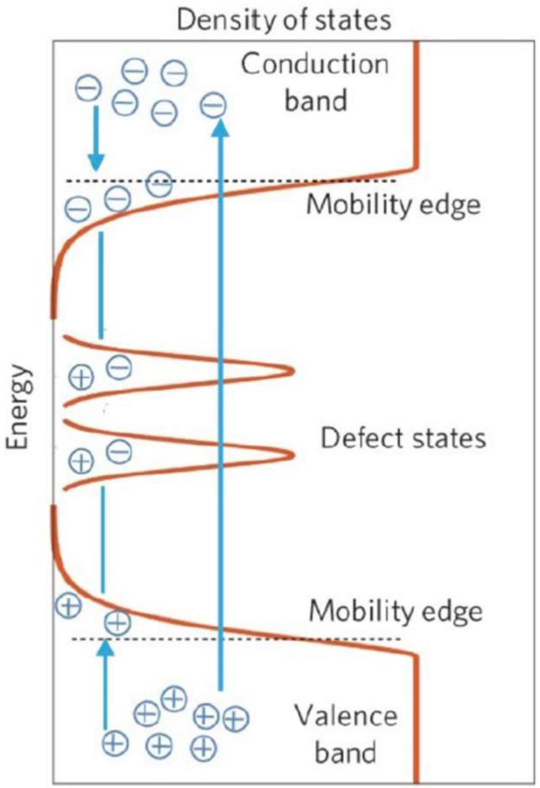
HASPIDE Spectroscopic Characterization



Hydrogenated Amorphous Silicon PIxel DEtectors for ionizing radiation

M. Pedio WP1

Spectroscopic Characterization: Why?



- To understand the radiation damage and annealing mechanism at a microscopic level
- To characterize the uniformity and hydrogen content on a-Si:H films
- To provide fundamental parameters to the simulation team, to be able to model the performance of the detector

HASPIDE STATUS: WP1

1) Spectroscopic characterization: Goals

→ *Understanding the microscopic properties of the deposited films and interrelation with electronic properties-morphology of a-Si:H films*

→ *Study of the devices*
  - → *a-Si:H/contact layers in the devices grown on: Kapton, Glass, c-Si*

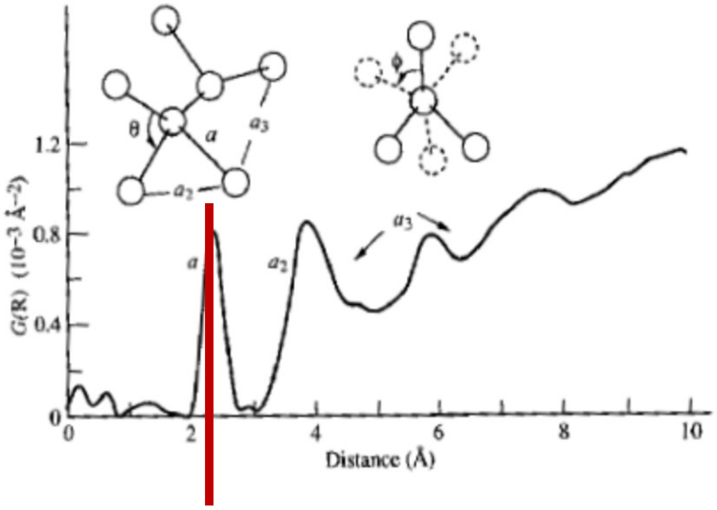
→ *Provide feedbacks to simulation and production, to enlighten the link of microscopic properties with electrical measurements*

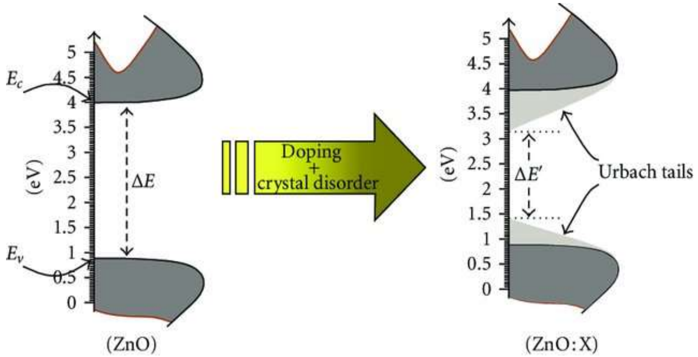
2) Spectroscopic characterization: Means

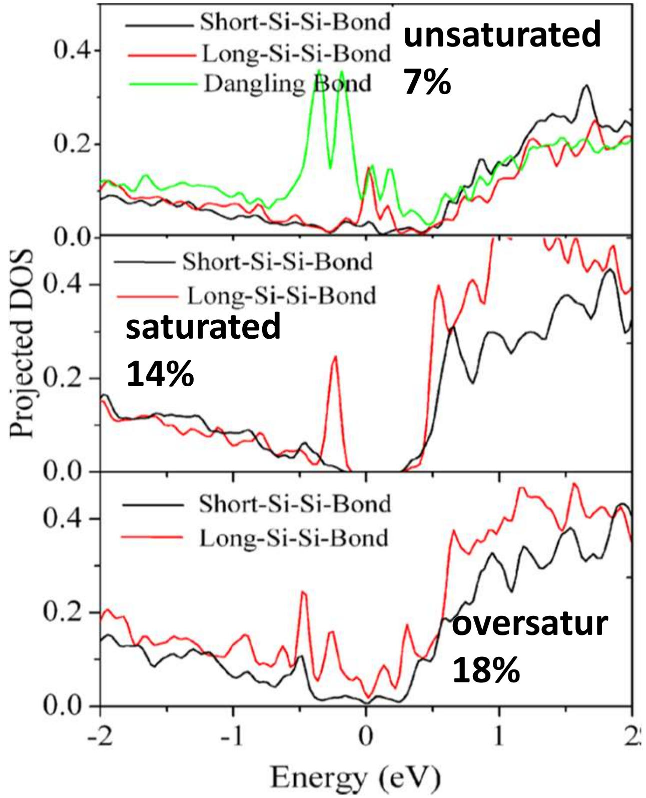
Characterization of the HASPIDE devices: Kapton, c-SiC, Glass

- → *Inverse Photoemission Measurements at the lab SIPE CNR-IOM PG*
  - → *Info on the Conduction Band*
- → *Photoemission at ELETTRA beamlines*
  - → *Info on Valence Band*
- → *New laboratory PYE: Setup of a measuring UHV system in Perugia for photon energies few eV*
  - → *Info on the gap states*
- → *MicroRaman (collaboration with Silvia Caponi CNR-IOM)*
  - → *Info on Si-H bonds and amorphous*

a-Si:H properties





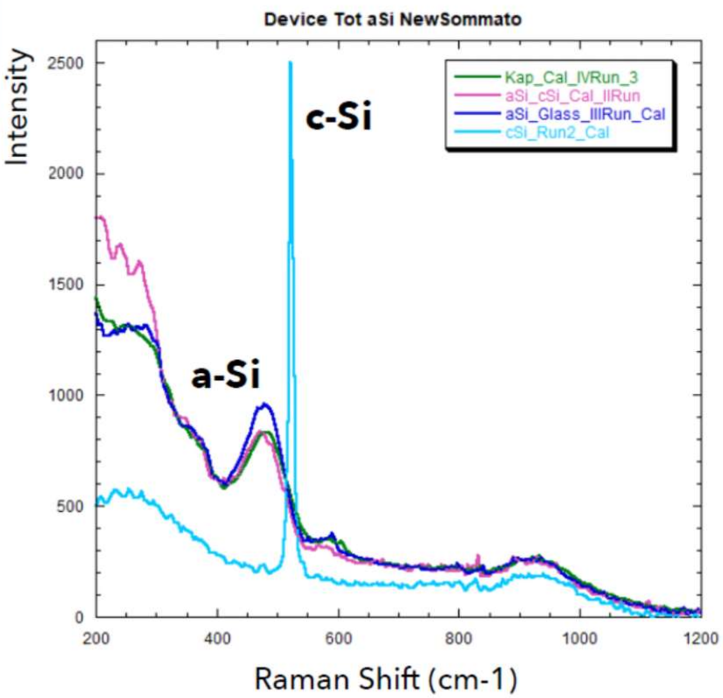


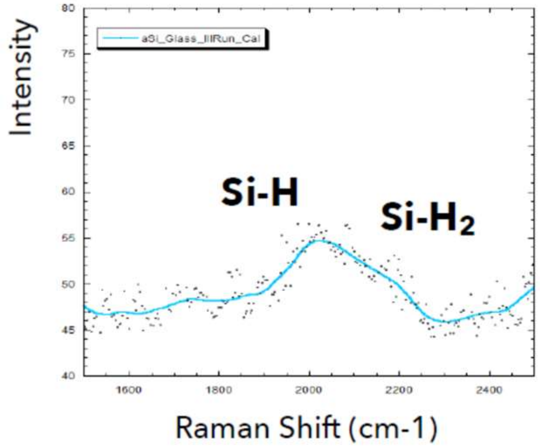
Density Functional Theory DFT calculations DOS vs Si-H bonds Legesse et al 2014

The specific band gap structure depends on the deposition conditions and film treatments (contacts, irradiation etc)

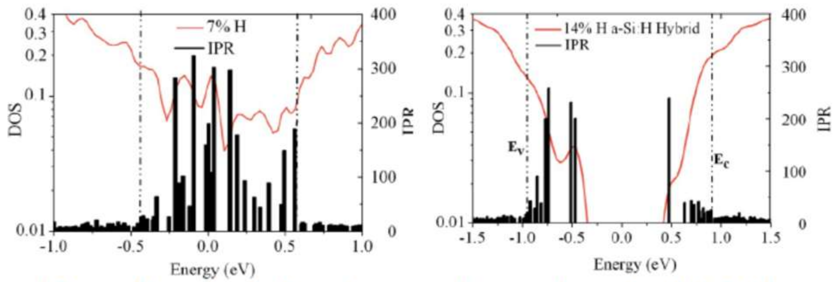
Impact on the device performance

Spectroscopic Characterization: Raman





The quantity of **hydrogen** can influence the bandgap of a-Si:H, by adjusting the hydrogen content, it is possible to tailor the material's **bandgap** to match specific applications

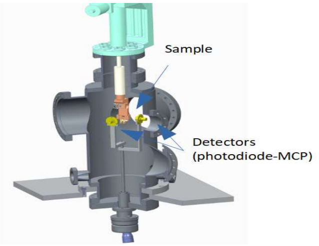


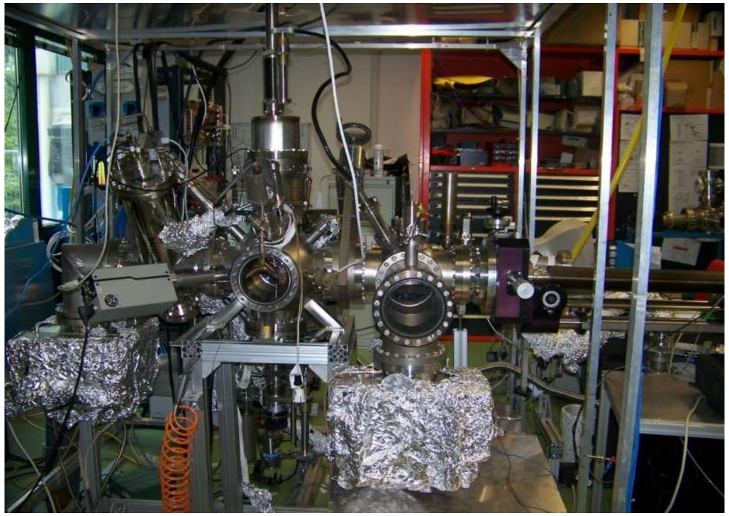
Density of states for under saturated (7%), and saturated (14%) a-Si:H.

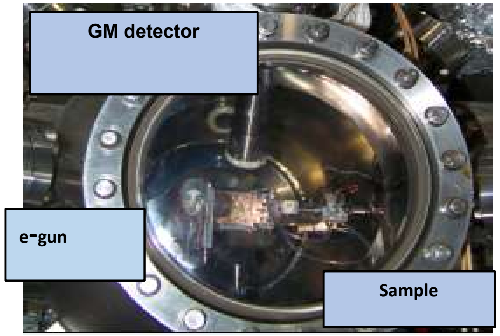
The Kapton devices show higher degree of dishomogeneities and lower H content then devices with c-Si and glass substrates

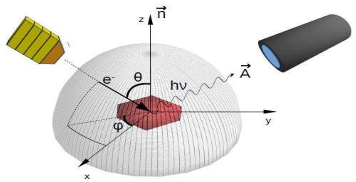
Laboratorio Spettroscopie Perugia

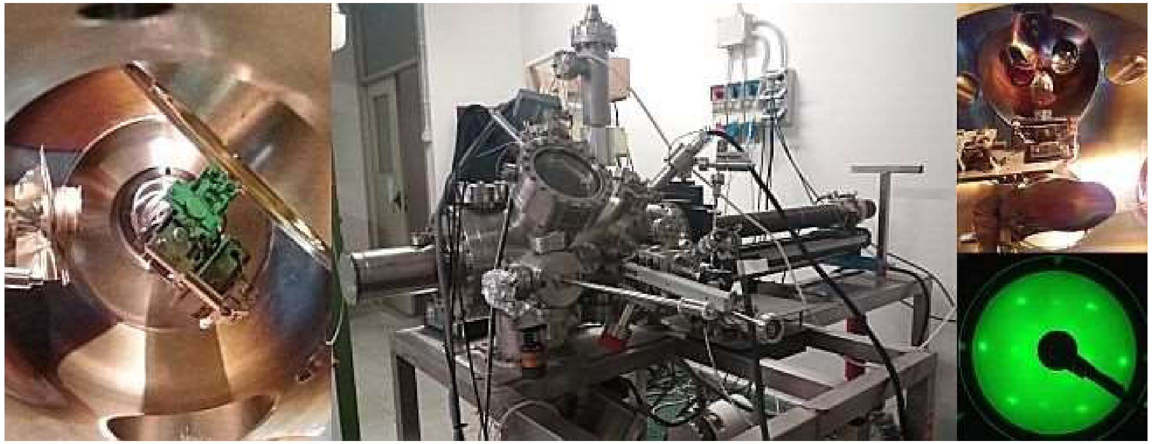
SIPE
nanoStructures Inverse Photoemission and Excitation dynamic









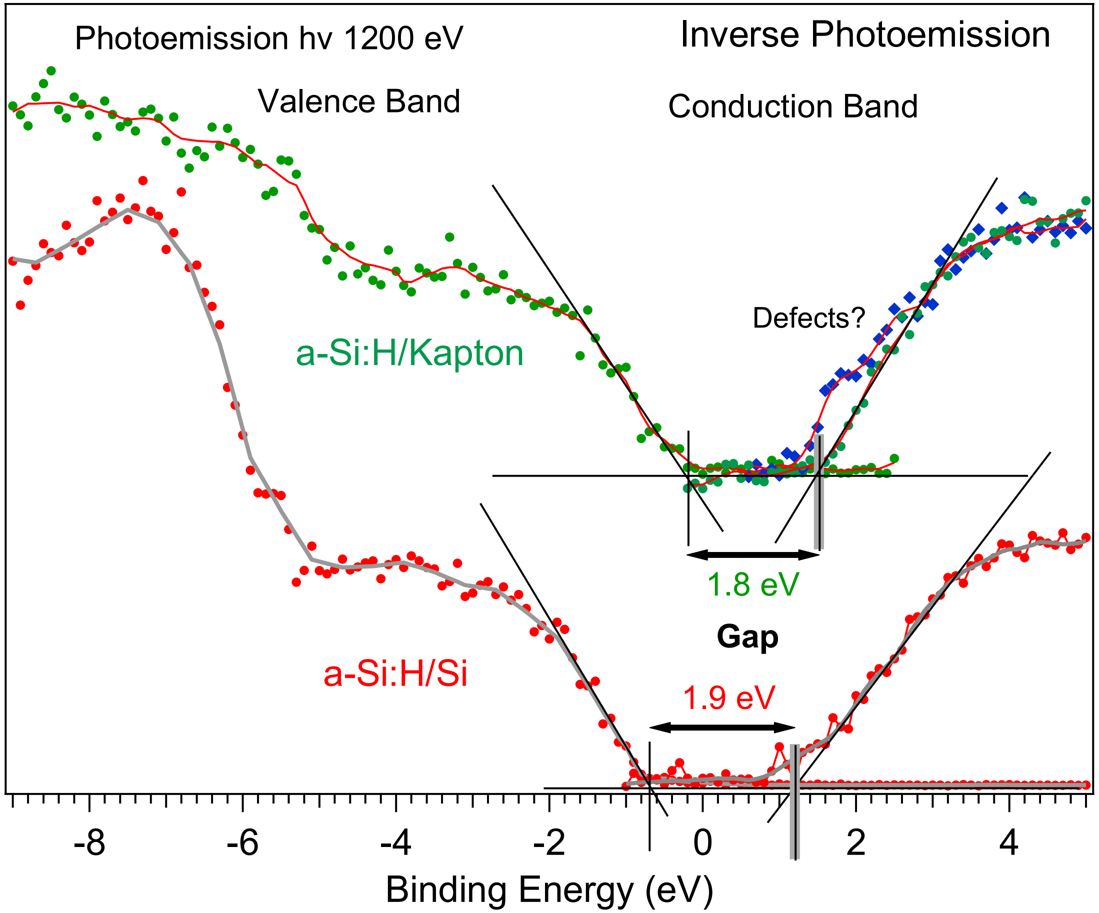


ACROSS - Advanced ChambeR fOr Surface Studies

CNR-IOM at the UniPG Physics Department.
2 Ultra High Vacuum UHV systems for photoemission and inverse photoemission spectroscopies.

Each UHV system equipped with a UHV 4-axis manipulator with a variable temperature sample holder (100-1000K), an electron energy analyser for UPS measurements and a standard surface science preparations tools (LEED, ion sputtering).

Spectroscopic Characterization: Combined Photoemission-Inverse Photoemission

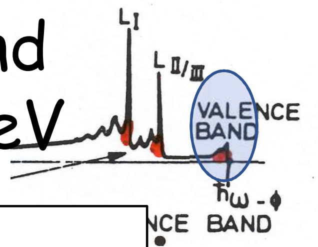


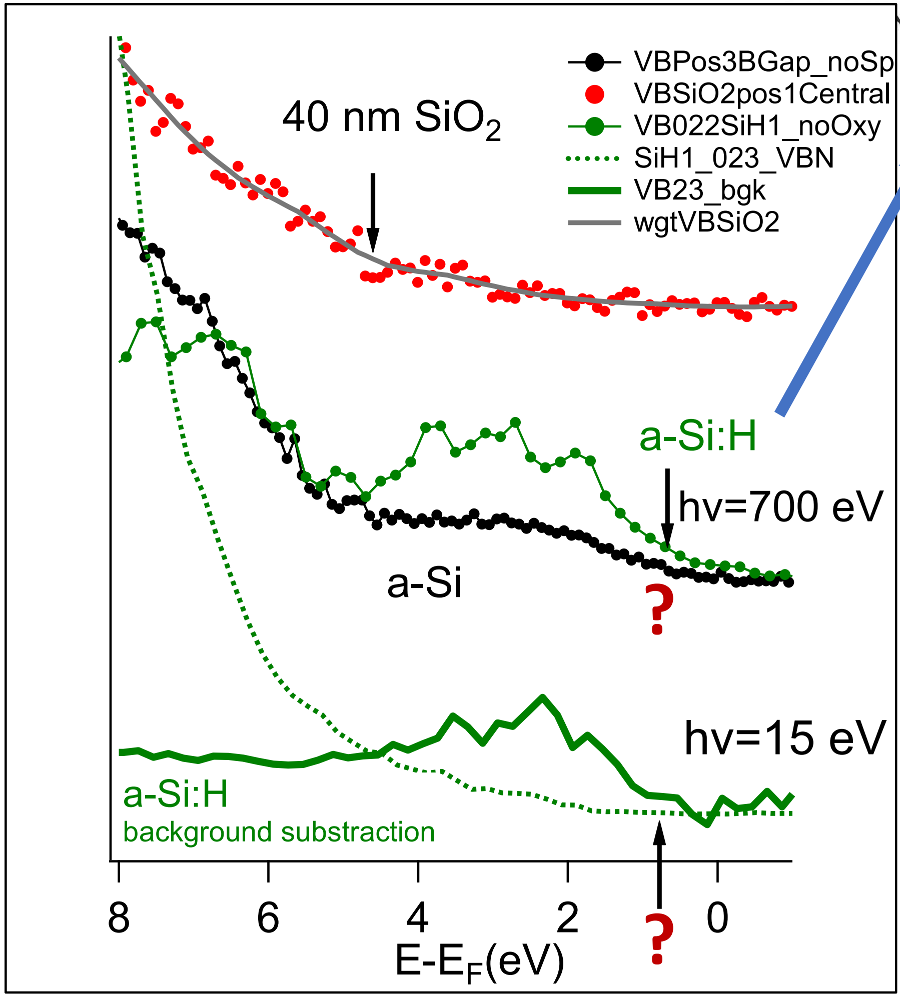
Mobility gap (extracted by standards graphical method) similar within the experimental resolution (±0.2 eV)

To be confirmed by additional future cheks

IPES peaks within the mobility gap (defects?) has higher intensities in case of strongly Dishomogein areas

Standard Valence band photoemission hv>20 eV





Why CFSYS Valence band photoemission at low photon energy < 8eV

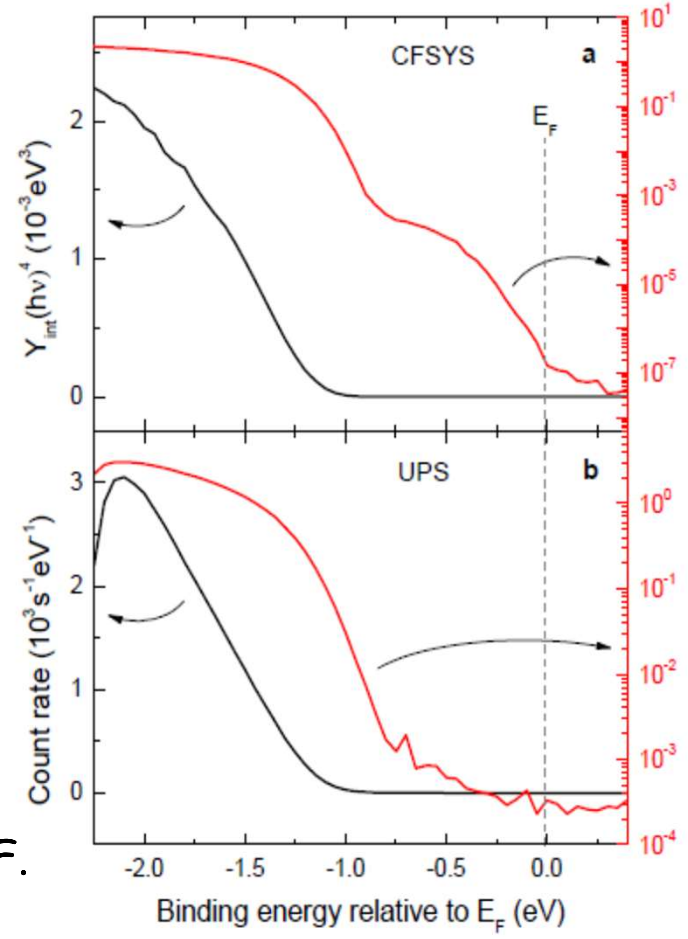
CFSYS measures and quantifies

-energy position of gap states

-density of active defect states in band gap

in a-Si:H down to 10^{15} states/cm^3

M. Sebastiani, L.D. Gaspare, G. Capellini, C. Bittencourt, F. Evangelisti, Phys. Rev. Lett.(1995)

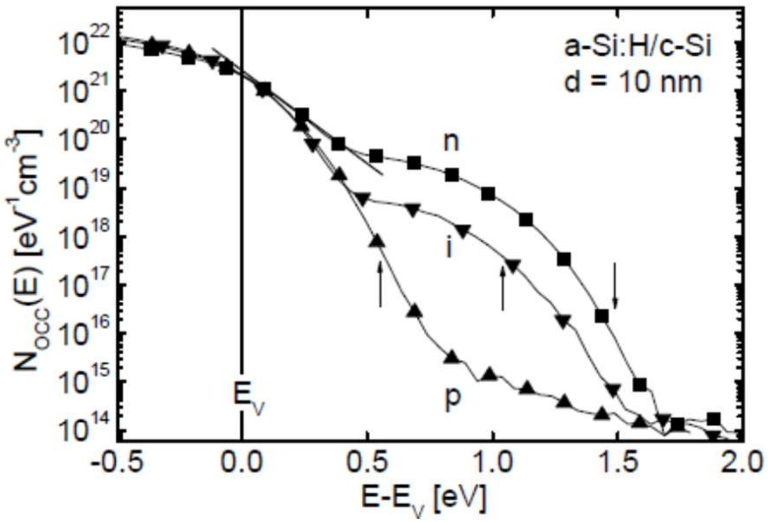


L. Korte group, Berlin

Control Defect Density in the gap

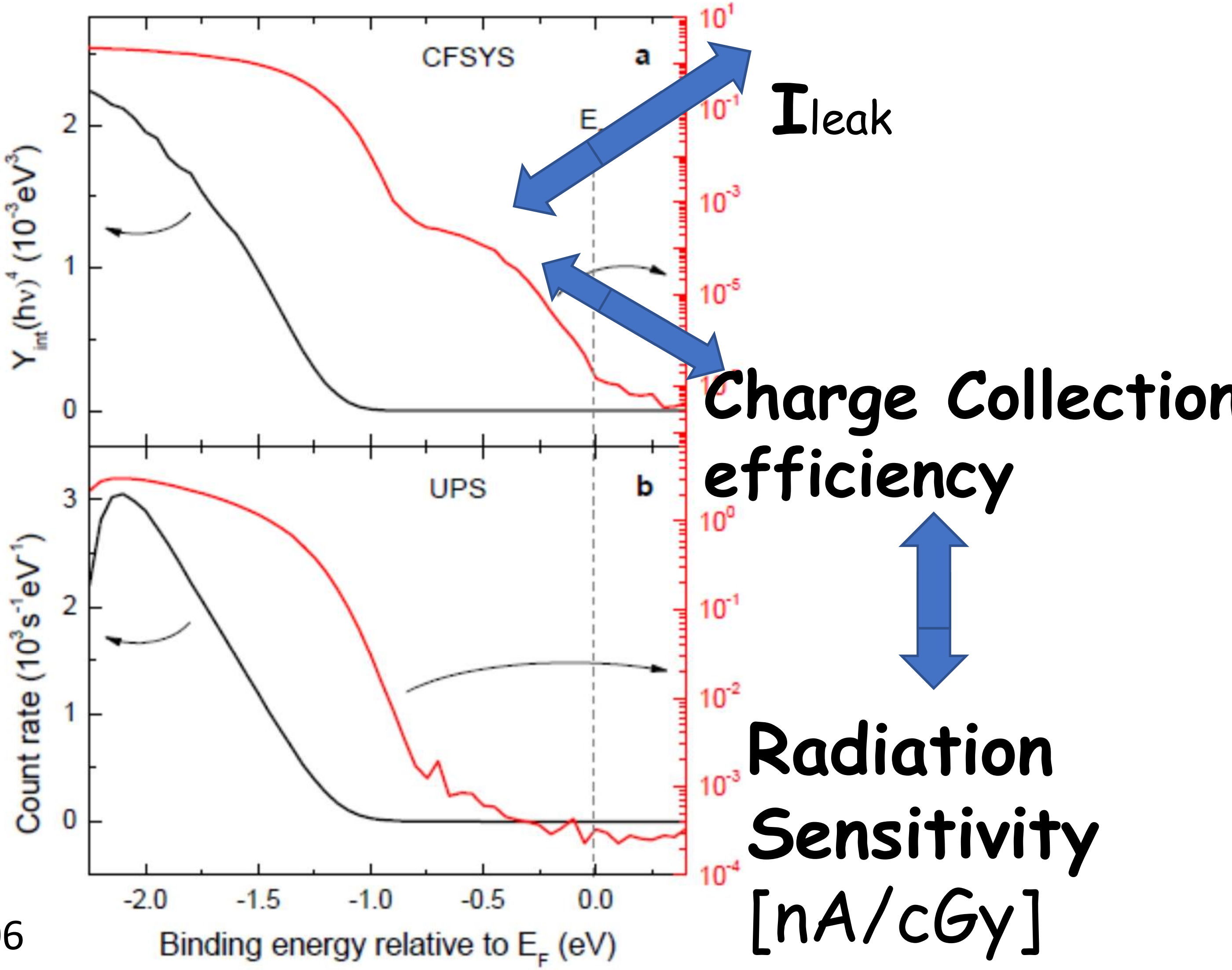
CFSYS distinguishes between **tail, shallow and deep gap states**

crucial for simulation of a-Si:H devices

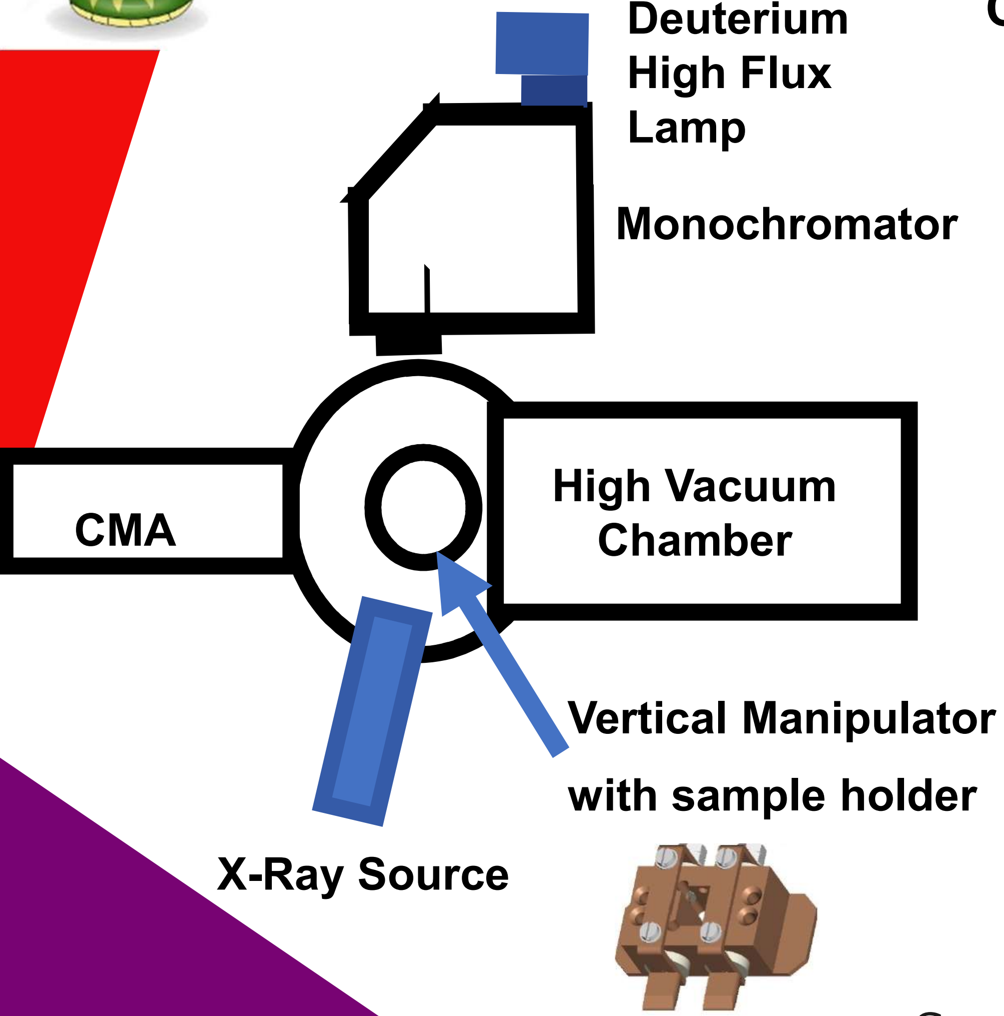


Example of measured a Si:H Density of Defects in the gap with different doping. Arrows=EF

L. Korte J. Optoelect. and Adv. Mat. 2006



New Laboratory
Partial Yield Electron spectroscopy



CFSYS or Partial Yield Photoemission

In **CFSYS**, the energy E_{phot} of the photons impinging on the sample is the variable, the kinetic energy E_{kin} where the analyser detects the electrons is the fixed quantity. Information on **Tail, shallow and deep gap states**)

Source = Deuterium lamp

Measure = Electrons Counts at fixed Kinetic energy detected by an Electron Analyser versus hv

Future additional XPS Photoemission System

In **XPS** the photon energy is fixed and the Kin energy is variable. Information on **Element Binding energies, stoichiometry**

Source = X-Ray lamp.

Measure = Electrons Counts versus Kinetic energy detected by an Electron Analyser (**Filled electronic state**) at fixed X-ray hv

New Laboratory
Partial **Y**ield **E**lectron spectroscopy

Low photons photoemission to get the defects state within the gap on the valence band side

Contributo CNR

Support design and UHV chamber

CMA Upgrade of the Electron Analyser, New power supply

Manipulator

Turbo pump

Ion pump Star cell and Power supply

Computer for the remote control/spectra acquisition

Deuterium Lamp and Hg lamp for calibration

Contributo INFN

Monochromator Horiba JY singolo HR320

Cassetto NIM

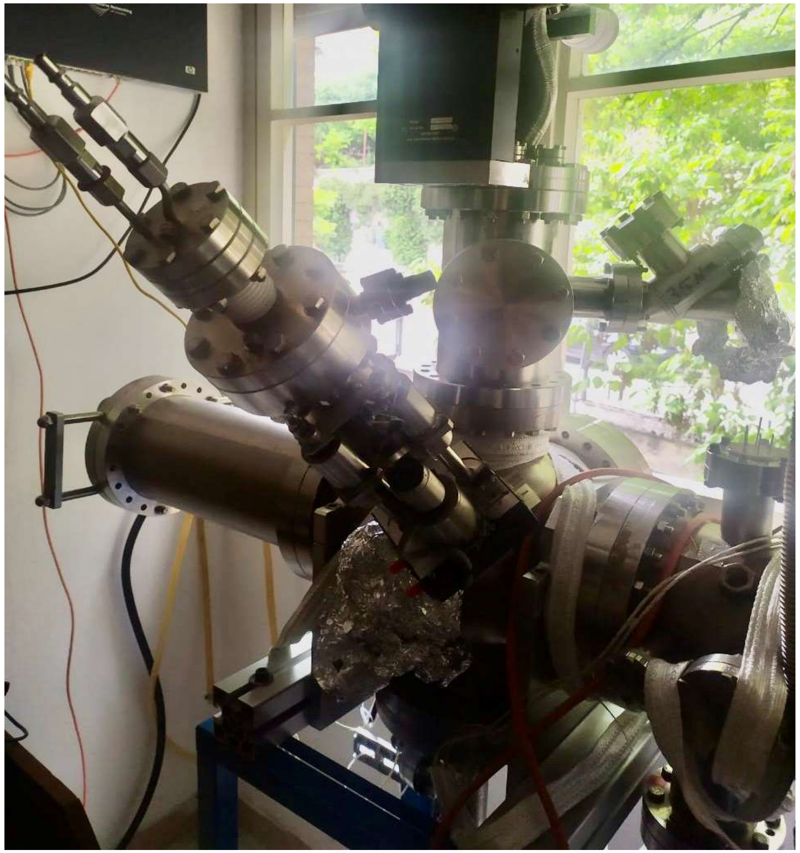
Internet tools and connection

PhD fellowship

Time schedule PYE Lab Perugia
Mounting and commissioning

Monochromator first tests	February
Support design	
Mounting at the UHV chamber	April
Optics and spot onto the sample test	
Update Acquisition code	June
CMA commissioning	December
New Laboratory IV floor	Summer 2023
Transfer lab	August-October
Internet connection still missing	
Commissioning	next 3 months

PYE Lab



Time schedule - Perugia

Monochromator arrival,
first tests

- Control check ✓
- Calibration ✓
- Acquisition code implementation ✓

Support design ✓
Mounting at the UHV chamber

Optics and spot onto the sample test ✓

Transfer of the lab ✓

Integration with previous acquisition code
On going…

People involved

Perugia

Francesca Peverini PhD student
Maddalena Pedio associated INFN
Nicola Zema associated INFN
Luca Tosti assegniista INFN

Collaboration with

Stefano Cristiani Technician CNR-IOM
Alberto Verdini CNR-IOM
Silvia Caponi CNR-IOM PG μRaman

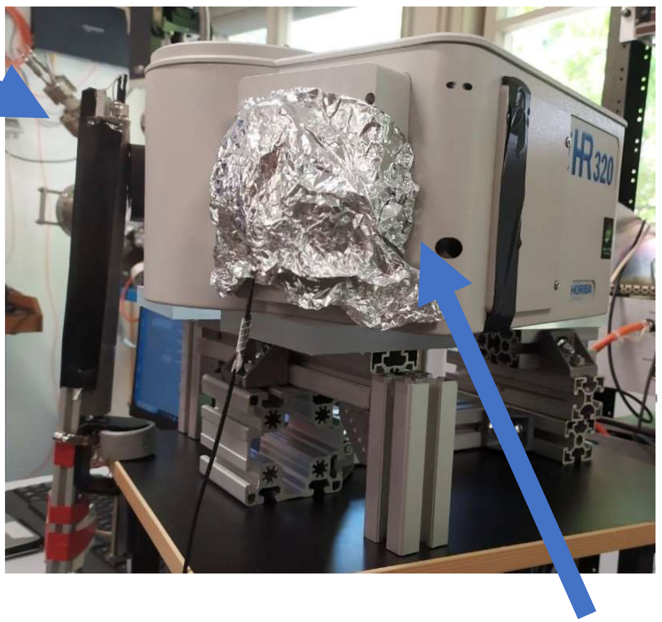
Trieste/NG

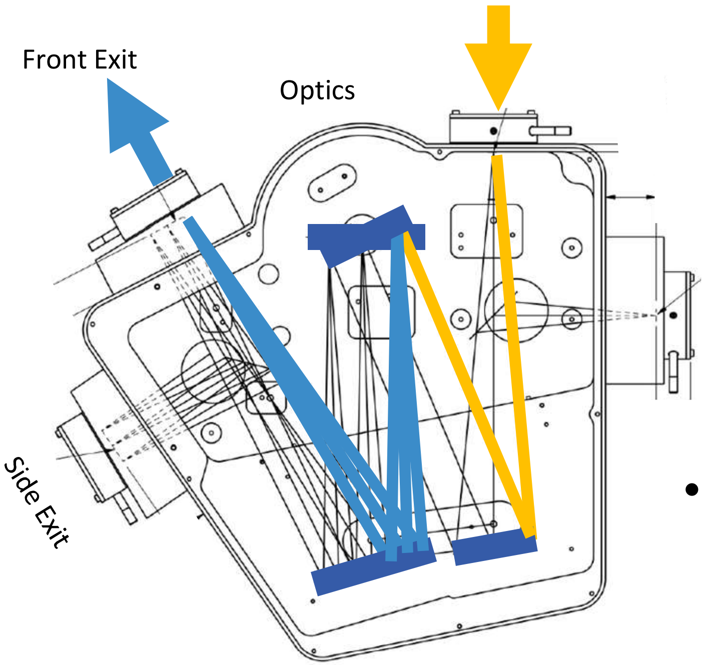
Roberto Gotter CNR-IOM
Technical services CNR-IOM

Federica Bondino,
Igor Pis, Elena Magnano BACH beamline

PYE Lab

iHR 320





- System controlled by a dedicated computer and electronics
- New acquisition program for the remote control selection of the monochromator photon energy

PYE LAB: program for monochromator scan hv

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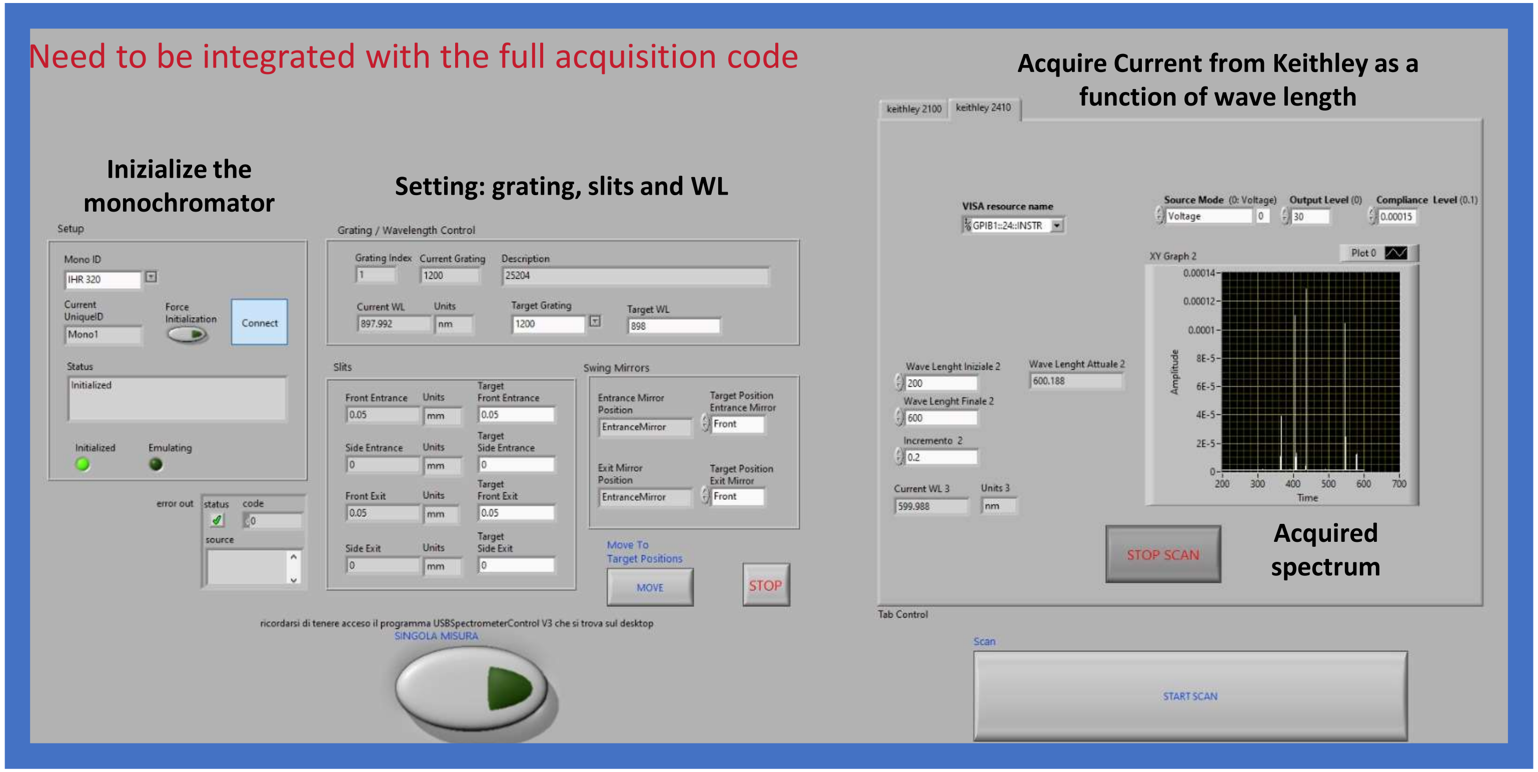
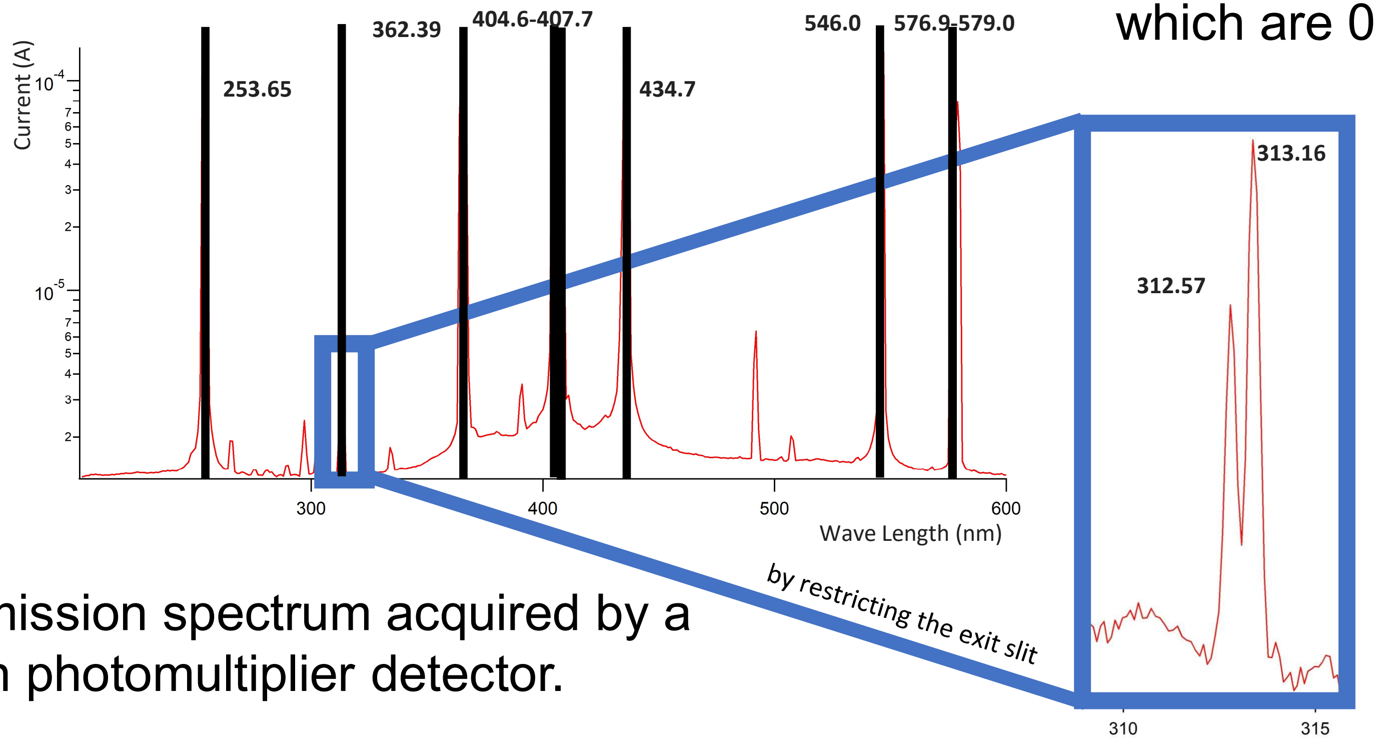


Implementation of the PYE system

Currently we are able to distinguish the two peaks which are 0.6 nm apart



The resolution can be further improved by varying the monochromator settings up to 0.06 nm.

Hg lamp emission spectrum acquired by a silicon photomultiplier detector.

We reconstructed the complete spectrum of the lamp, which we will use to calibrate.

WP1 specroscopies-WP3

WP3 TCAD Simulation Outlines

- Traps description [1] -> Introduction rate / effectiveness.
- Warning! Band Gap description: Ec + vs. Ev - ...
- Fermi's level position
- New bunch of fresh measurements
    - Effect of material activation (storage conditions...)
- Mobility model / mapping
- Devising of the model/strategy as reference (see paper in preparation) for further analysis (e.g. time varying) and optimization (charge collection, radiation damage effects)

[1] Nawaz M. Design analysis of a-Si/c-Si HIT solar cells. Adv Sci Technol. (2010) 74:131–6. doi: 10.4028/www.scientific.net/AST.74.131

Thanks you for your attention

HASPIDE 2023, WP1, spectroscopies applied to a-Si:H devices at Perugia

CFSYS (also calle Partial Yield) is a variant of conventional photoelectron spectroscopy (source He lamp, 21.2 eV) with near-UV light excitation ‘constant final state yield spectroscopy’ CFSYS (source: Deuterium lamp coupled with monochromator, photons within 3-6eV) ref [1] applied to the valence band maximum region. Using this technique, the position of the surface Fermi level E_F is obtained and the density of recombination active defect states in the amorphous hydrogenated silicon (a-Si:H) band gap down to 10^{15} states/cm^3 can be detected and quantified, ref [2].

Low-energy photoelectron spectroscopy measurements can be used to obtain directly the energy position of gap states. This technique allows for distinguishing between tail, shallow, and deep gap states, a crucial information for the optimization of a-Si:H devices, before and after irradiation at high dose.

Part of the experimental set-up needed for CFSYS measurements has being bought and/or ordered by CNR. The Ultra High Vacuum experimental chamber mounts a Cylindrical Mirror Analyser in commissioning. Feasibility test by conventional photoemission on a-Si:H films and devices has been performed recently, in other CNR laboratories.

1 M. Sebastiani, L.D. Gaspare, G. Capellini, C. Bittencourt, F. Evangelisti, Phys. Rev. Lett. 75 (1995) 3352
2 L. Korte & M. Schmidt, J. Non-Cryst. Sol. **354** (2008) 2138-43

Paper

Electronic properties of Hydrogenated Amorphous Silicon films related to morphology and its influence on electrical performance

- The paper is focused on the electrical performance and spectroscopic characterization of the first prototypes of a-Si:H on Kapton devices compared with glass and c-Si. The electric measurements show differences among the three cases.
- We highlighted differences by Raman technique, in the a-SiH films' morphology in the three cases. The morphology differs. The glass device present a good homogeneity and a concentration of Si-H bonds close to the optimal (in the literature is about 11-12%). In the Kapton case, even though the concentration of Hydrogen is similar to that of c-Si (8-9%), a reduced amount of Si-H bonds with respect to Si-H2 bonds is detected, and the Si-H distribution is not as homogeneous and in the other cases.
- The mobility (transport) gap obtained by combined Photoemission and Inverse Photoemission data, results slightly reduced in the case of Kapton device.
- These are key measures to enlighten the link of microscopic properties with electrical measurements, which are critical to optimize the a-Si:H application, because the specific band structure can impact significantly the device performance.
- Simulations are in progress to rationalize the detected differences.

Figures

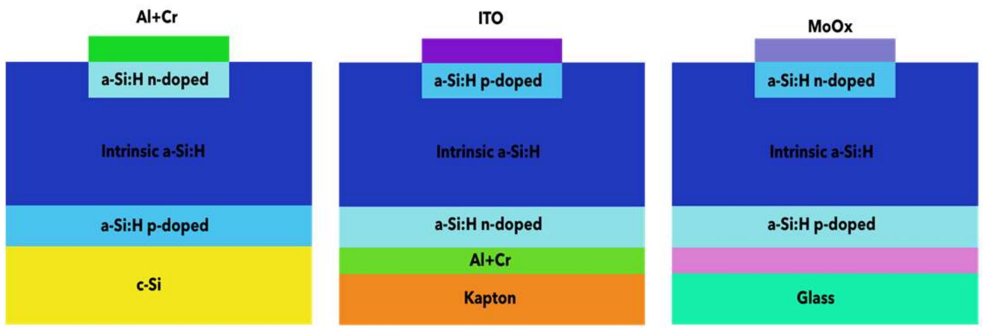
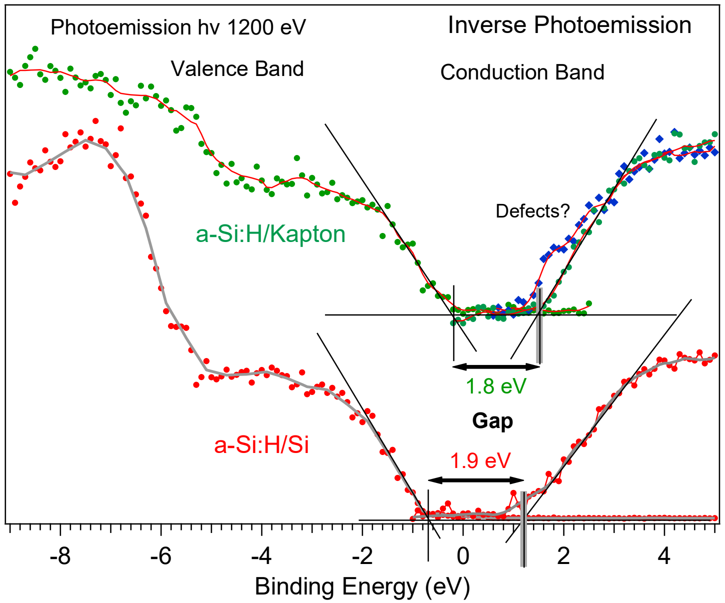
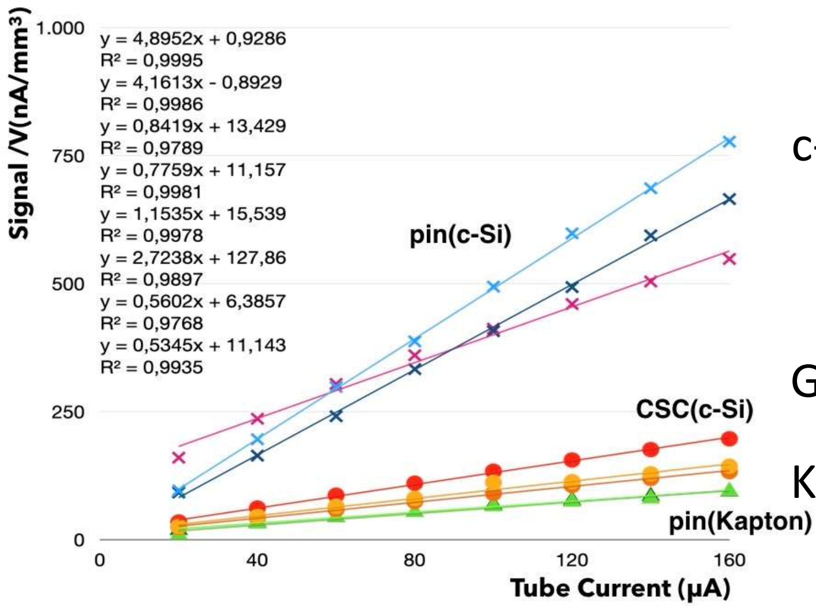


Figure 1: side view of the two p-i-n diode: (a) deposited on crystalline silicon and (b) deposited on kapton, (c) deposited on glass.

c-Si Kapton Glass





c-Si

Glass

Kapton