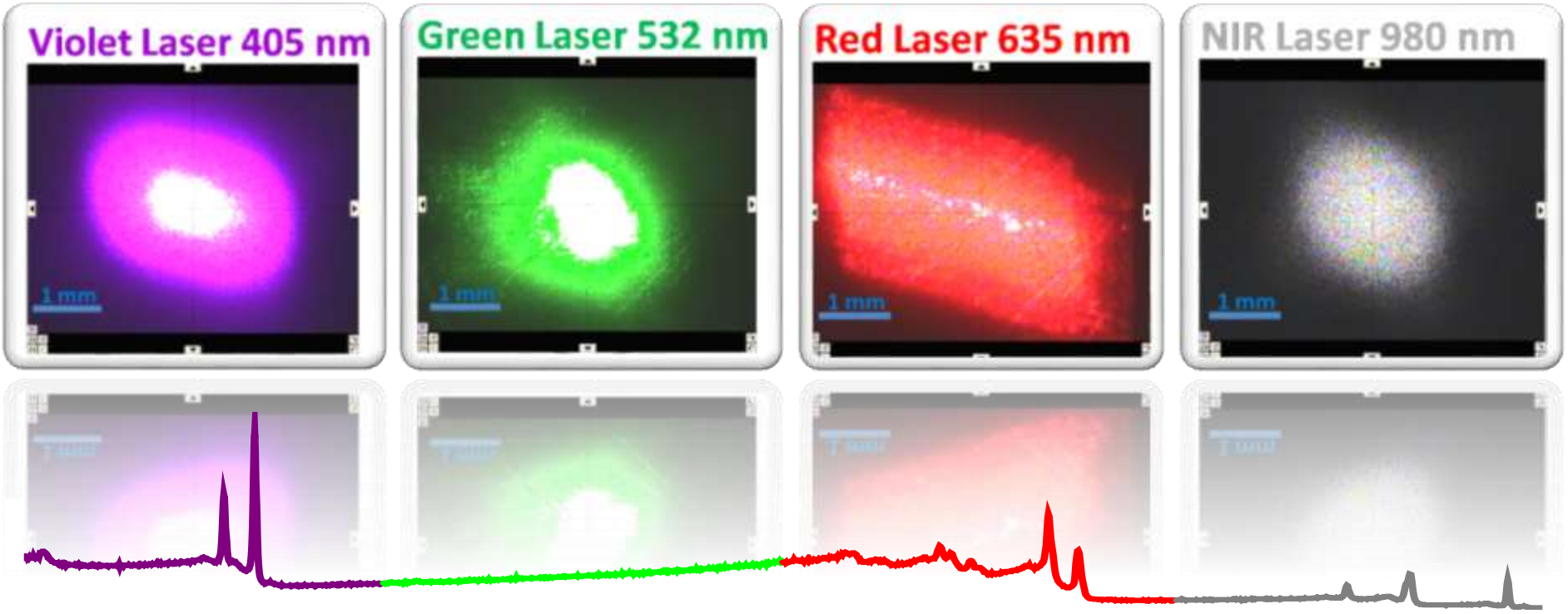


Dynamic XPS for Photoinduced Voltage Changes on Semiconducting Materials

Hikmet Sezen

Chemistry Department

Karlsruhe Institute of Technology
Institute of Functional Interfaces (IFG)

May *15, 2013*
Karlsruhe

Outline:

- **Part I(2009-2011):**
  - **Introduction**
    - ❑ **X-ray Photoelectron Spectroscopy (XPS)**
      - ❖ Controlled Surface Charging
        - ➢ *DC, SQW, Model*
    - ❑ **Photoconductivity**
  - **Our Motivation**
  - **Results & Discussions**
    - ❑ **np-Si and np-Si/SiO_x**
    - ❑ **CdS**
    - ❑ **np-GaN**
  - **Conclusions**

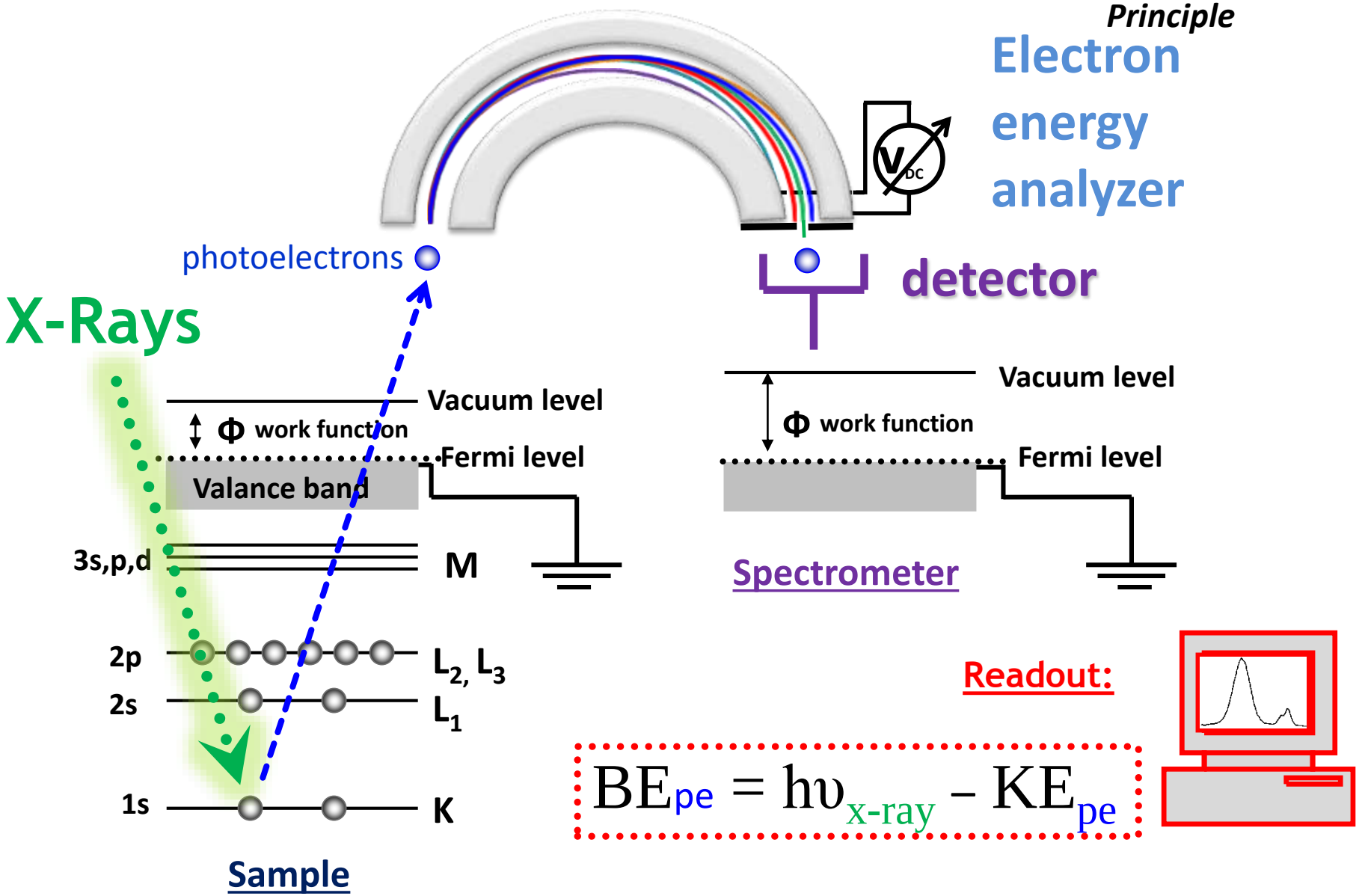
- **Part II(2012-):**
  - ❑ **Instrument: Theo**
    - ❖ **TiO_2**

Ankara/Turkey, **Prof. Şefik Süzer**

Karlsruhe/Germany, **Prof. Christof Wöll**

X-ray Photoelectron Spectroscopy:

Principle



X-ray Photoelectron Spectroscopy:

- Provide Chemical/Elemental Information
- Capable to Separate Chemical States of Elements
- Highly Surface Sensitive : 1-20 nm
- Quantative Analysis:
  - Stoichiometric, Thickness, and Depth Profile

....

Instrument *(Part I*

Cracking Hardware

Customized Sample Holder

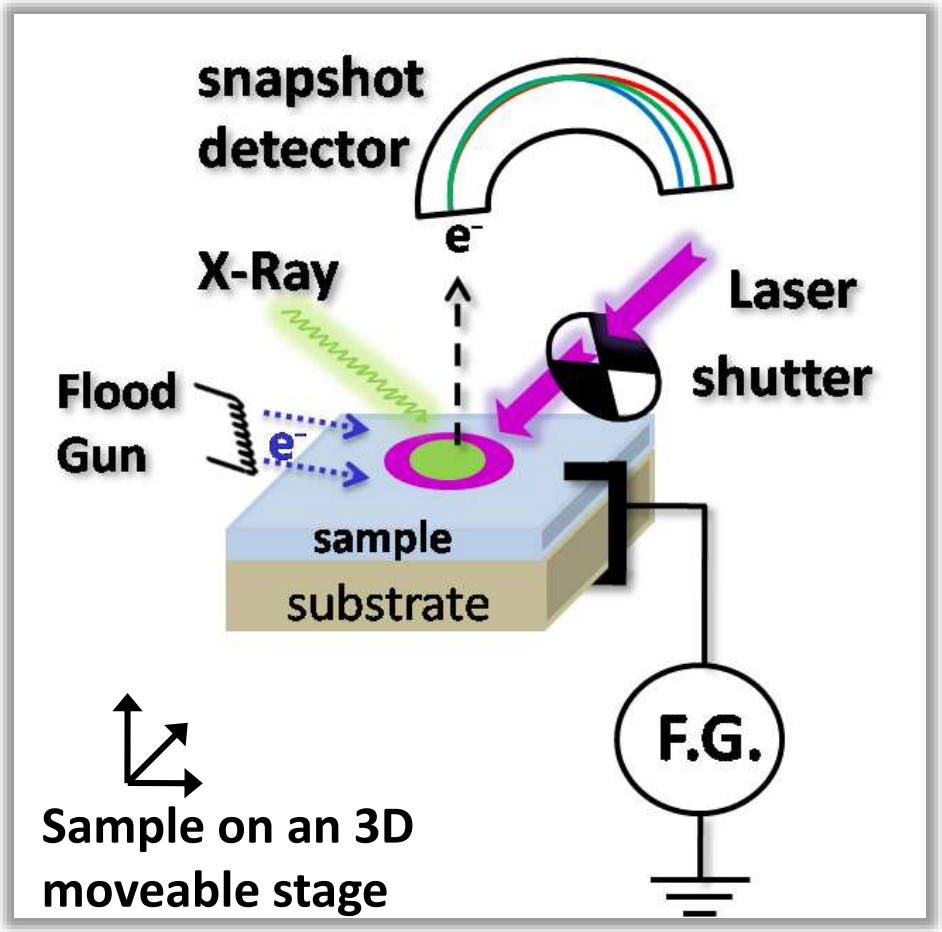
Optics Board

Cracking Software

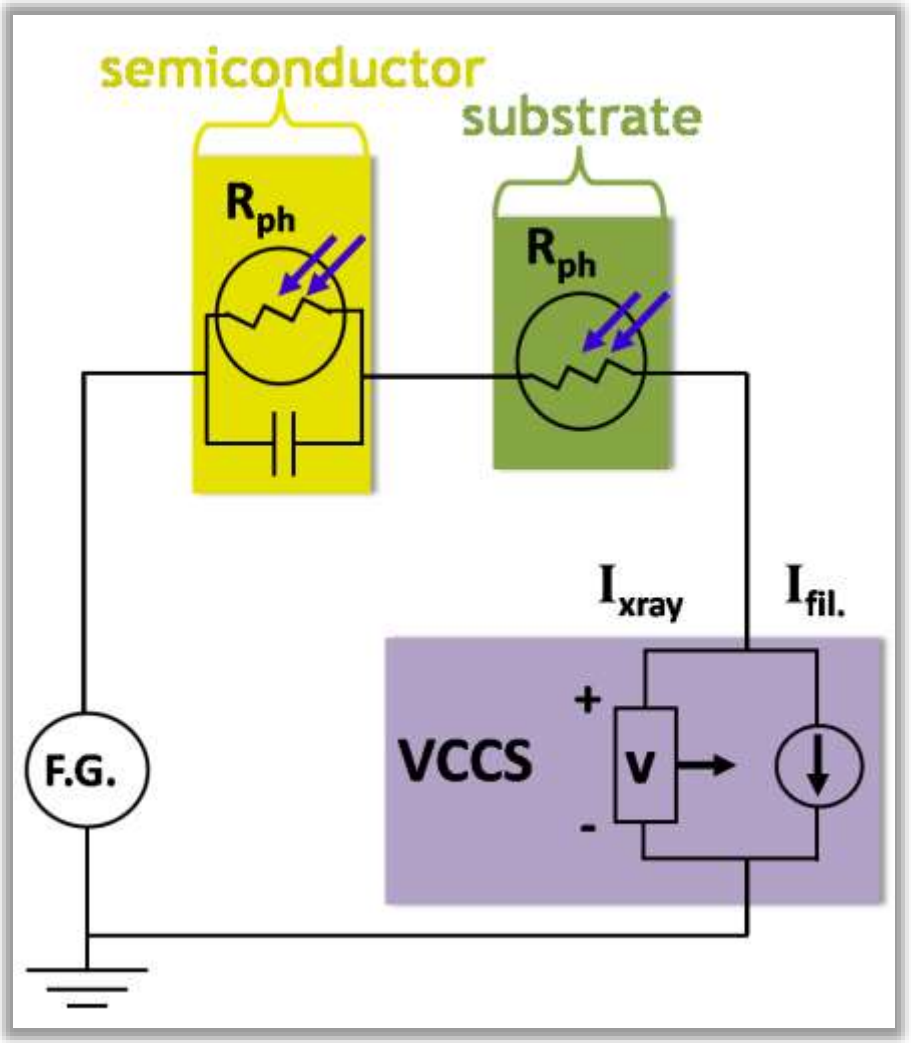
Specifications:

- Monochromatic Al K-α (1486.68 eV) X-ray source
- X-ray spot 400-30 µm
- ~100 msec snapshot with an 128 channel detector

Method:



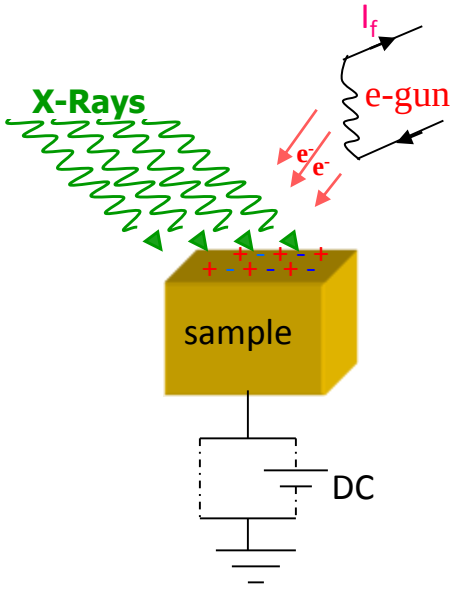
Model:



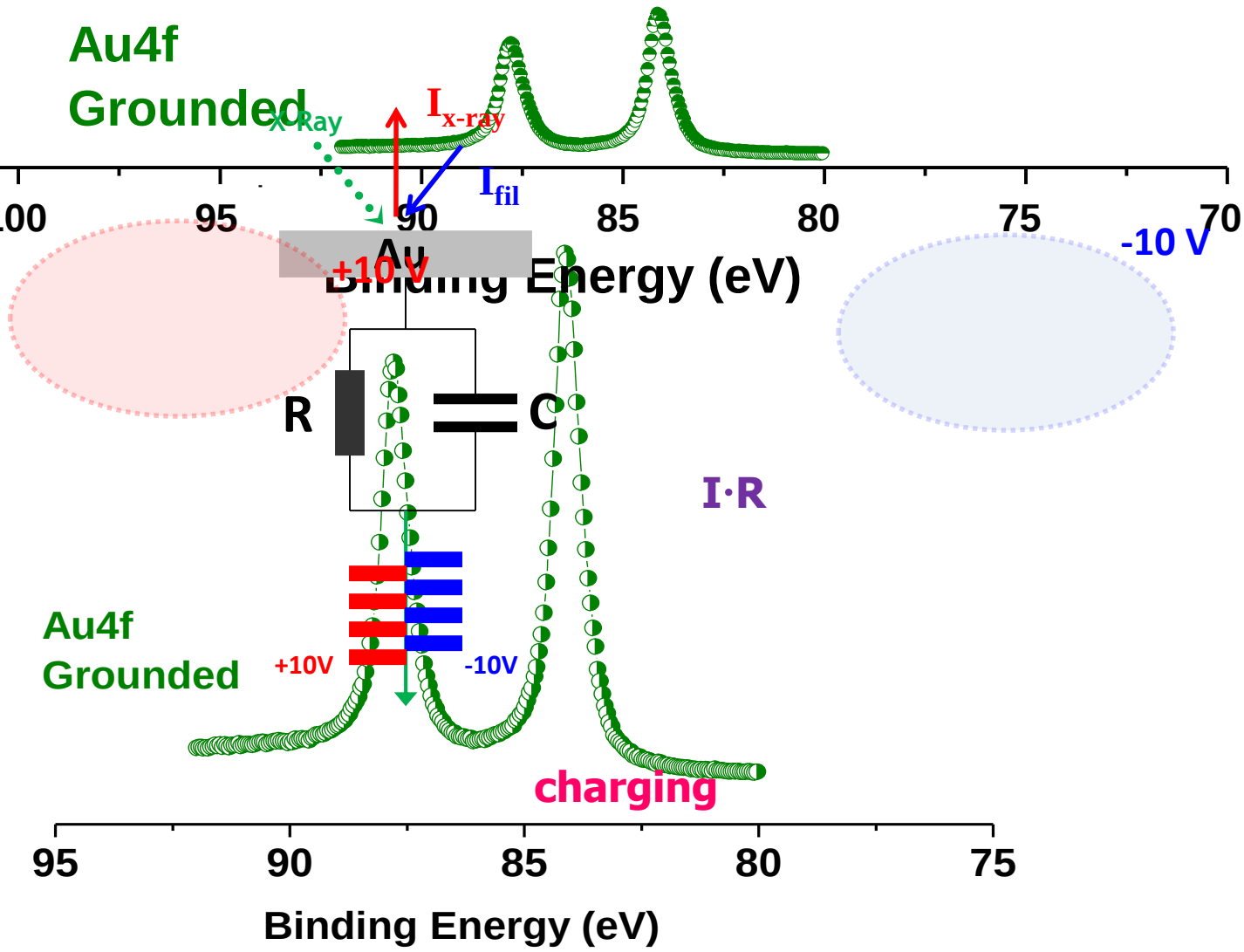
$$BE_{pe} = h\upsilon_{x\text{-}ray} - KE_{pe}$$

Controlled Surface Charging (DC):

Surface Charging:



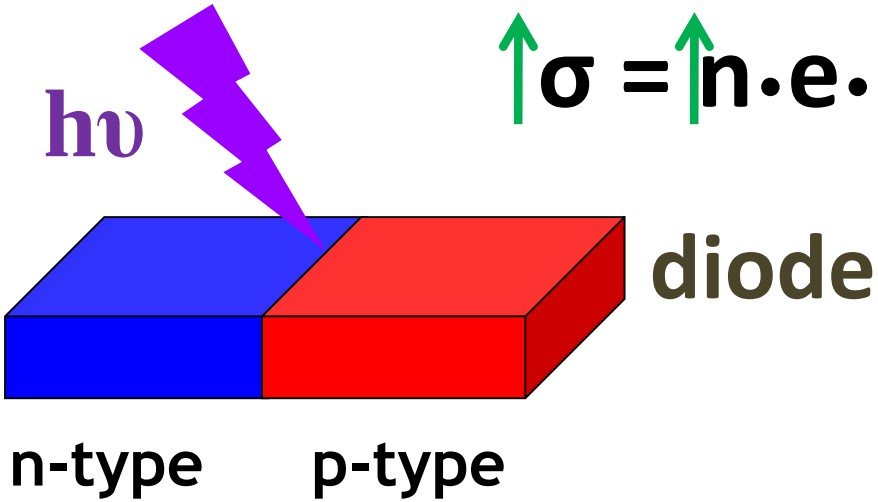
Controlled Surface Charging (SQW):

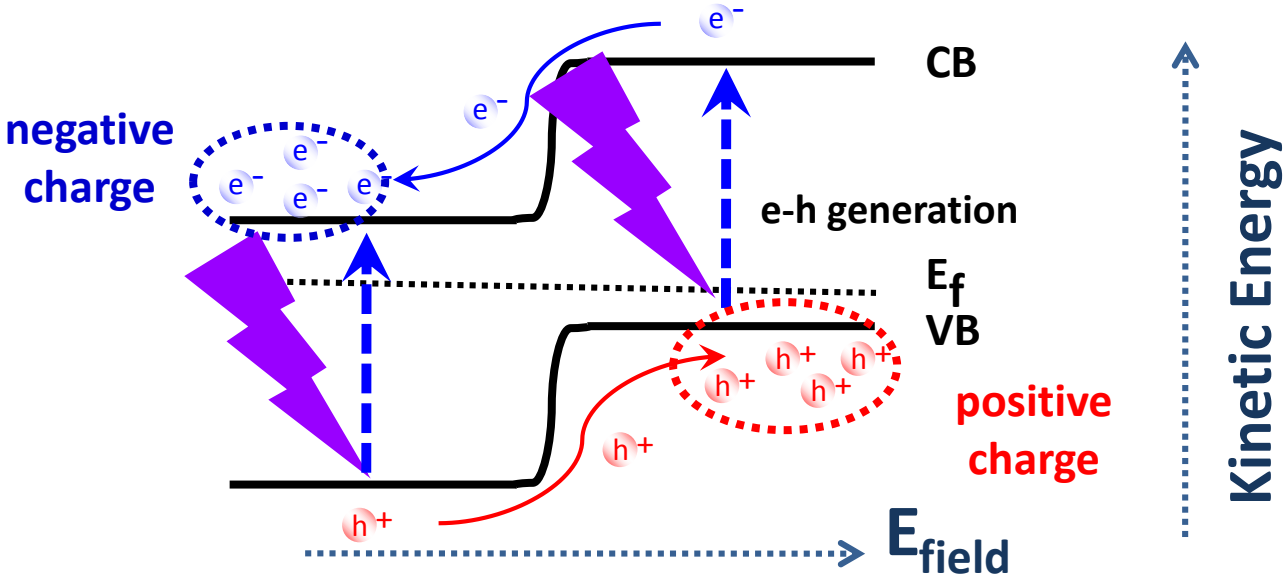


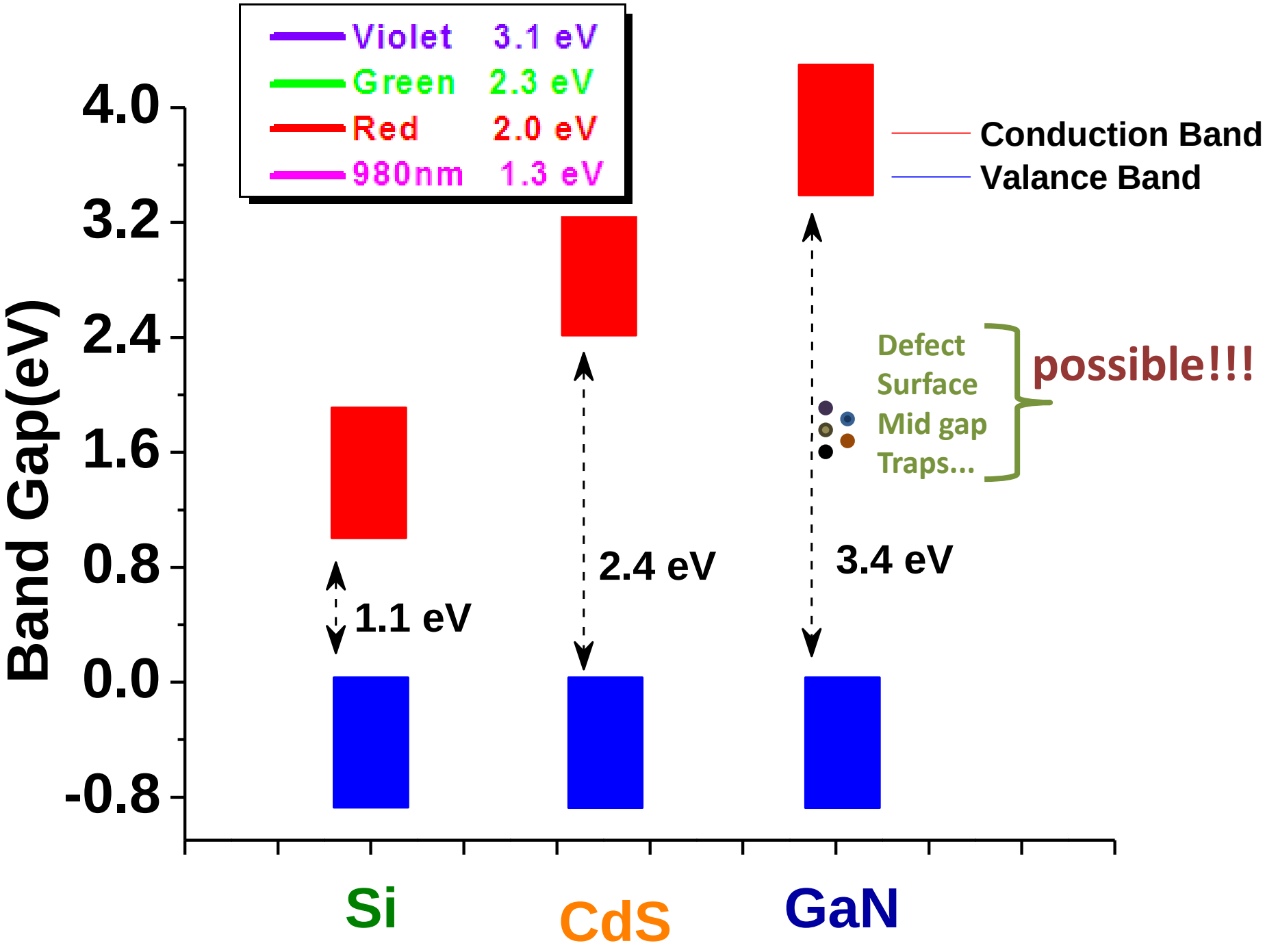
Photoconductivity:

Charge Separation

$\uparrow\sigma = \uparrow n \cdot e \cdot \mu$






Violet 3.1 eV
Green 2.3 eV
Red 2.0 eV
980nm 1.3 eV
Band Gap(eV)
4.0
3.2
2.4
1.6
0.8
0.0
-0.8
Conduction Band
Valance Band
Defect
Surface
Mid gap
Traps...
possible!!!
1.1 eV
2.4 eV
3.4 eV
Si
CdS
GaN

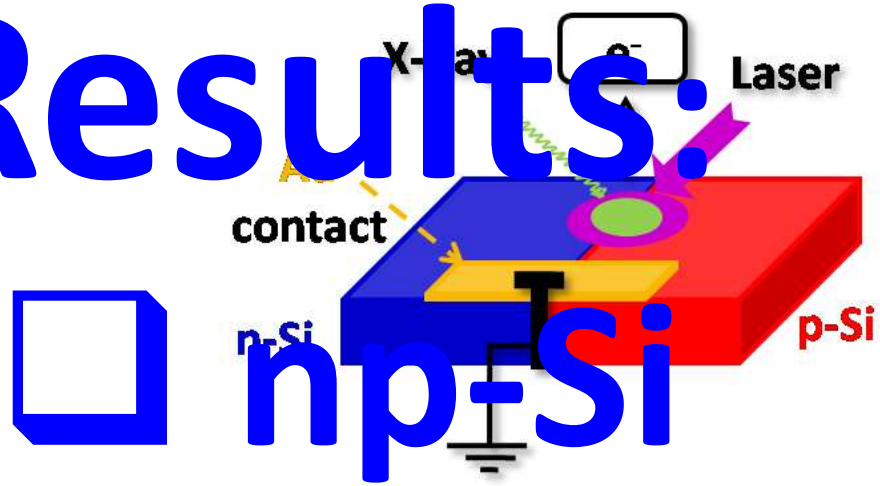
Band Offset Measurement

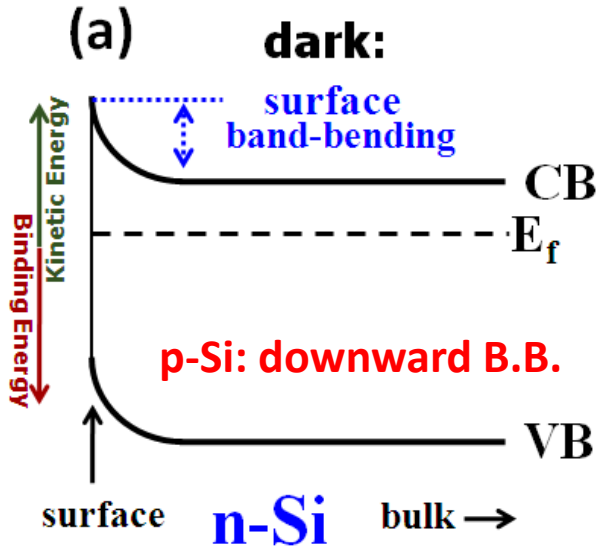
Surface Photovoltage:

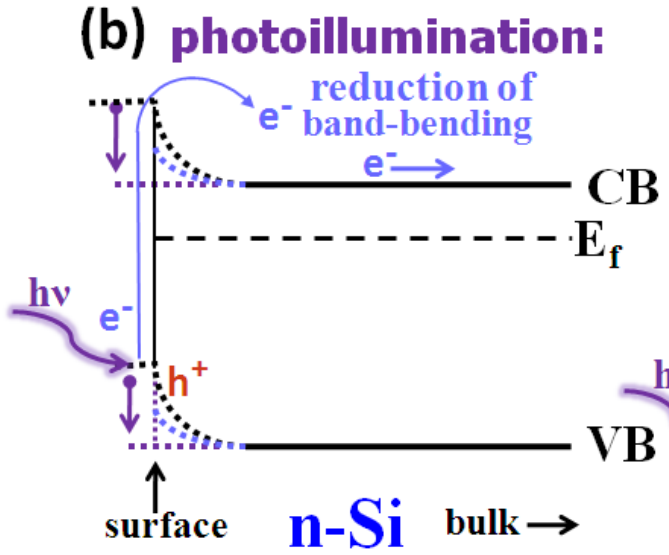
Between n-type and p-type Si

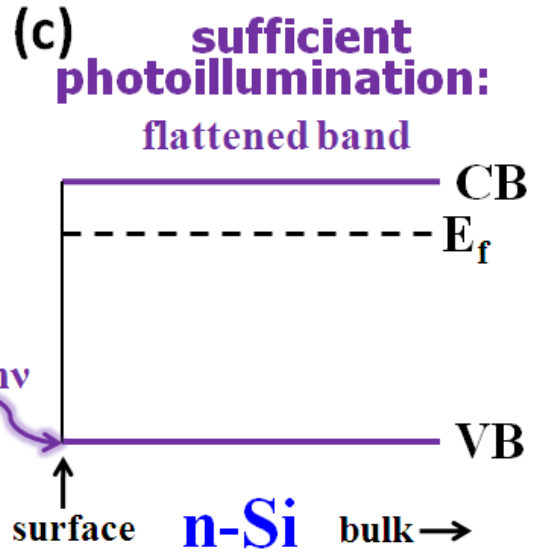
Results:

- np-Si

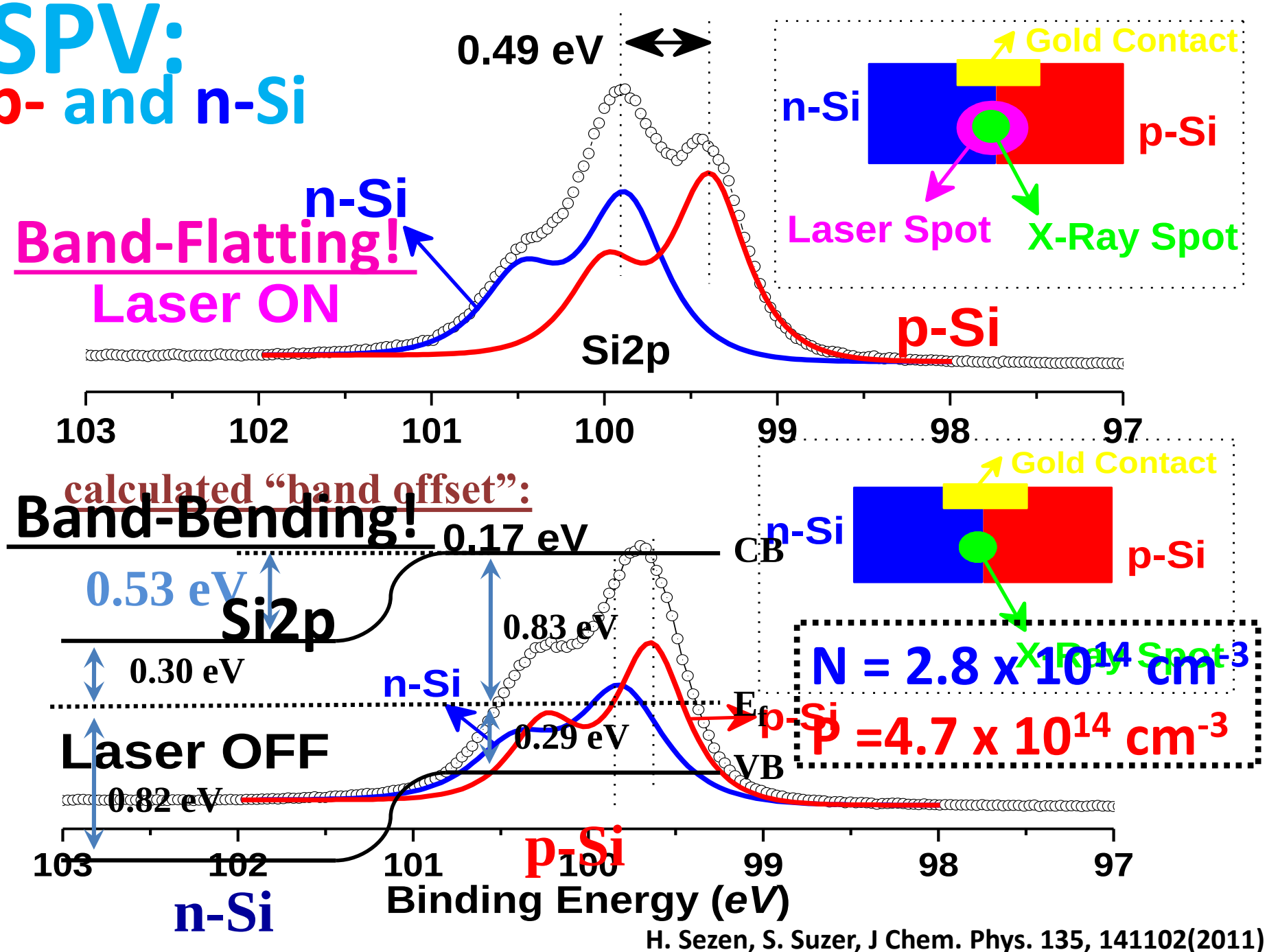






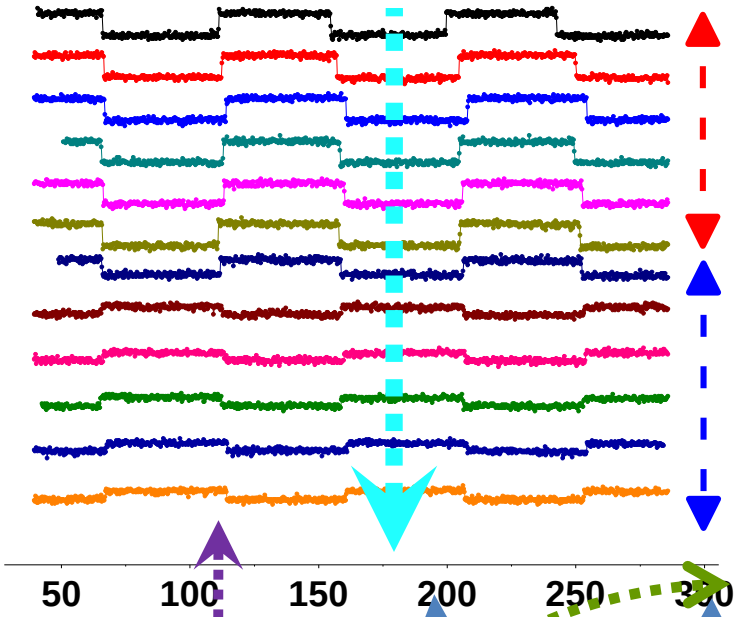


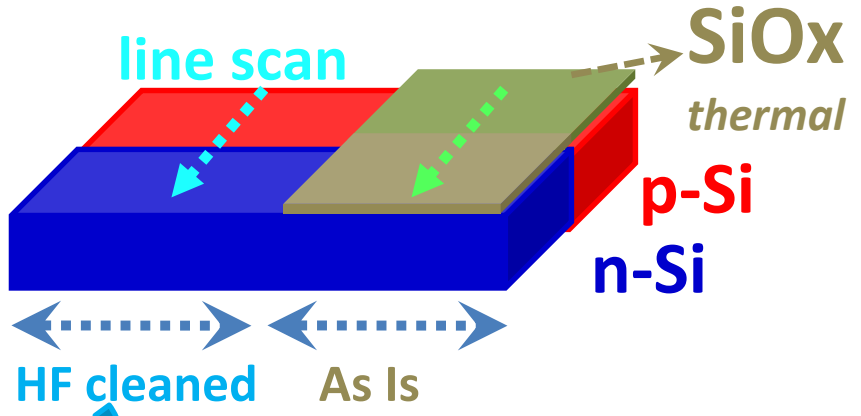
SPV:
p- and n-Si



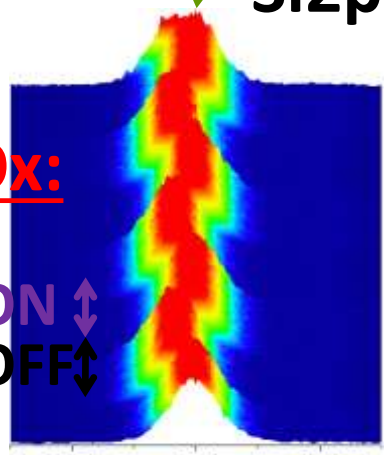
H. Sezen, S. Suzer, J Chem. Phys. 135, 141102(2011)

Band Bending / Inversion of SiOx/p- and n-Si





Si2p

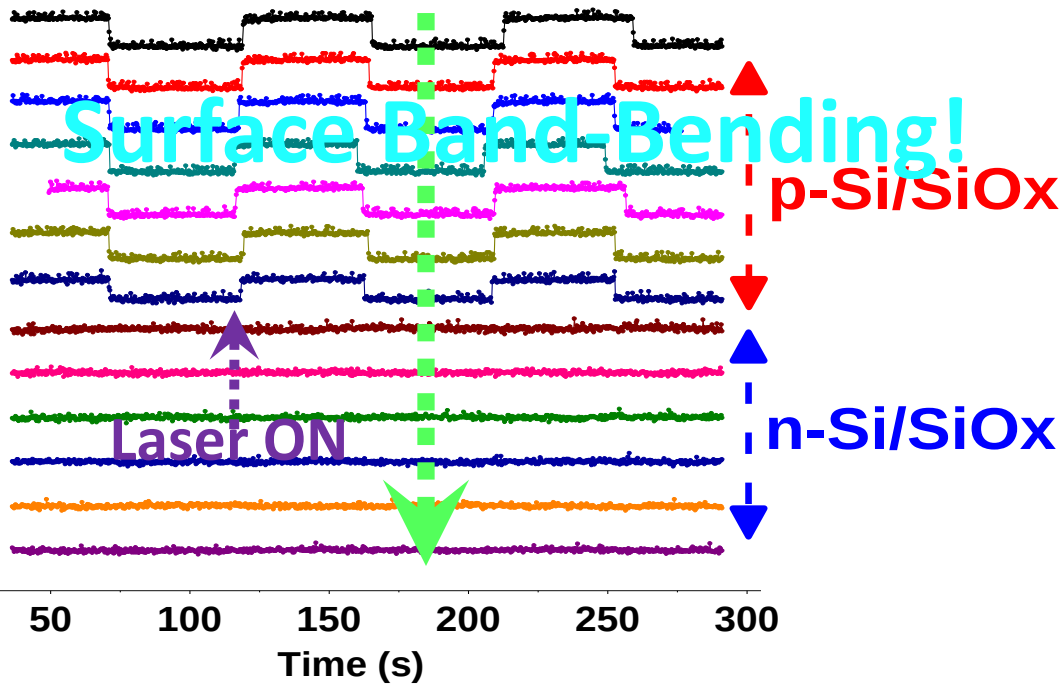


p-SiSiOx:

Laser ON

Laser OFF

Surface Band-Bending!

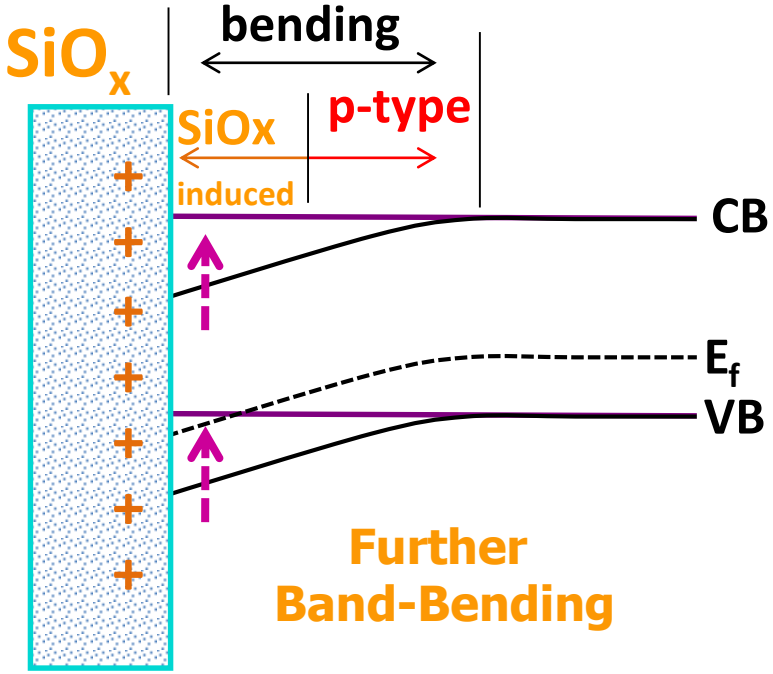


H. Sezen, S. Suzer, J Chem. Phys. 135, 141102(2011)

Band Bending / Inversion of SiOx/p- and n- Si

Possible band diagram:

SiOx/p-Si



Inversion of
Band-Bending

H. Kobayashi et al. Appl. Phys. Lett. 73 933(1998)
C. Munakata, et al. Jp. Appl. Phys. 23, 1451(1984)
H. Sezen, S. Suzer, J Chem .Phys. 135, 141102(2011)

Photo-Dynamic XPS with p-Si:

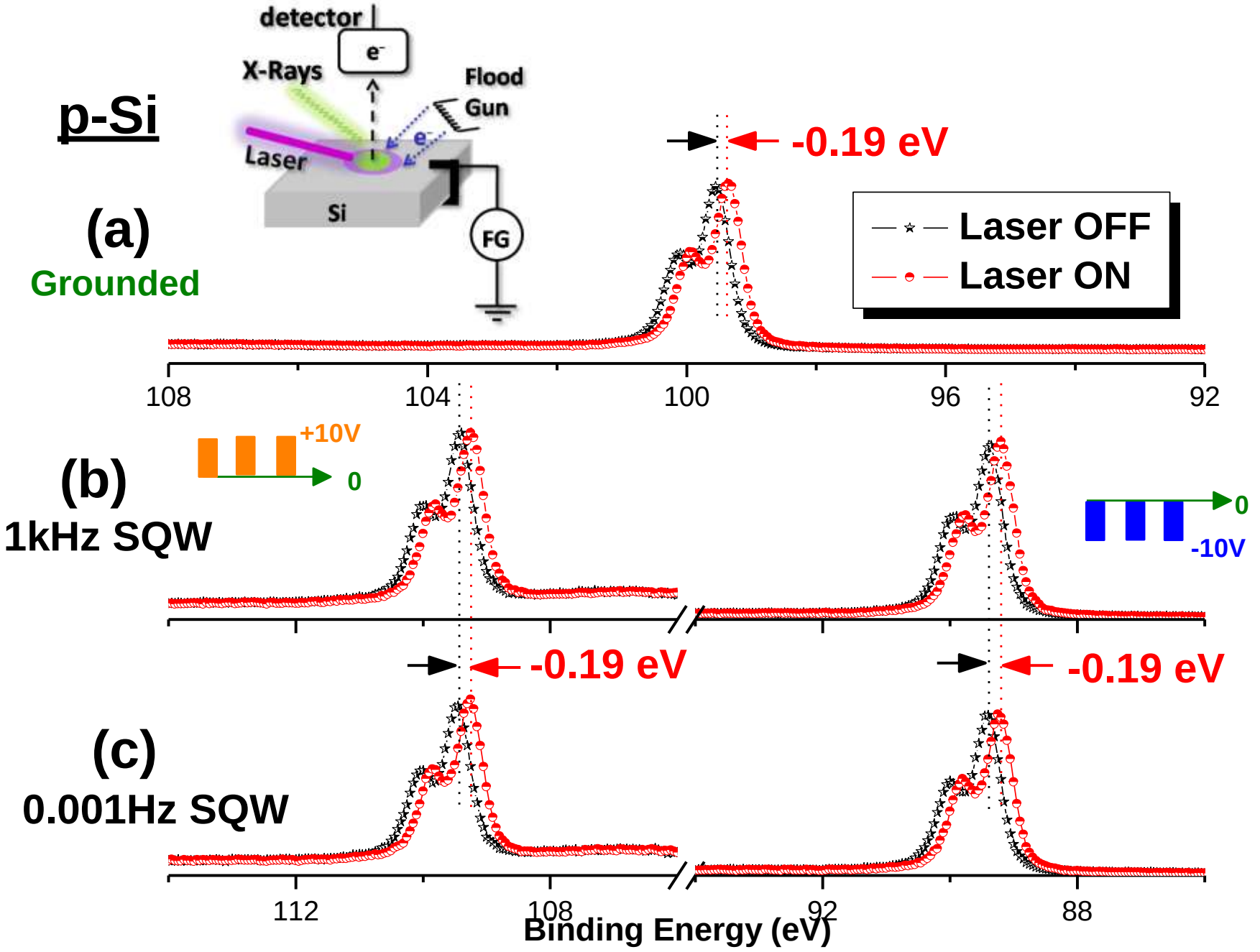
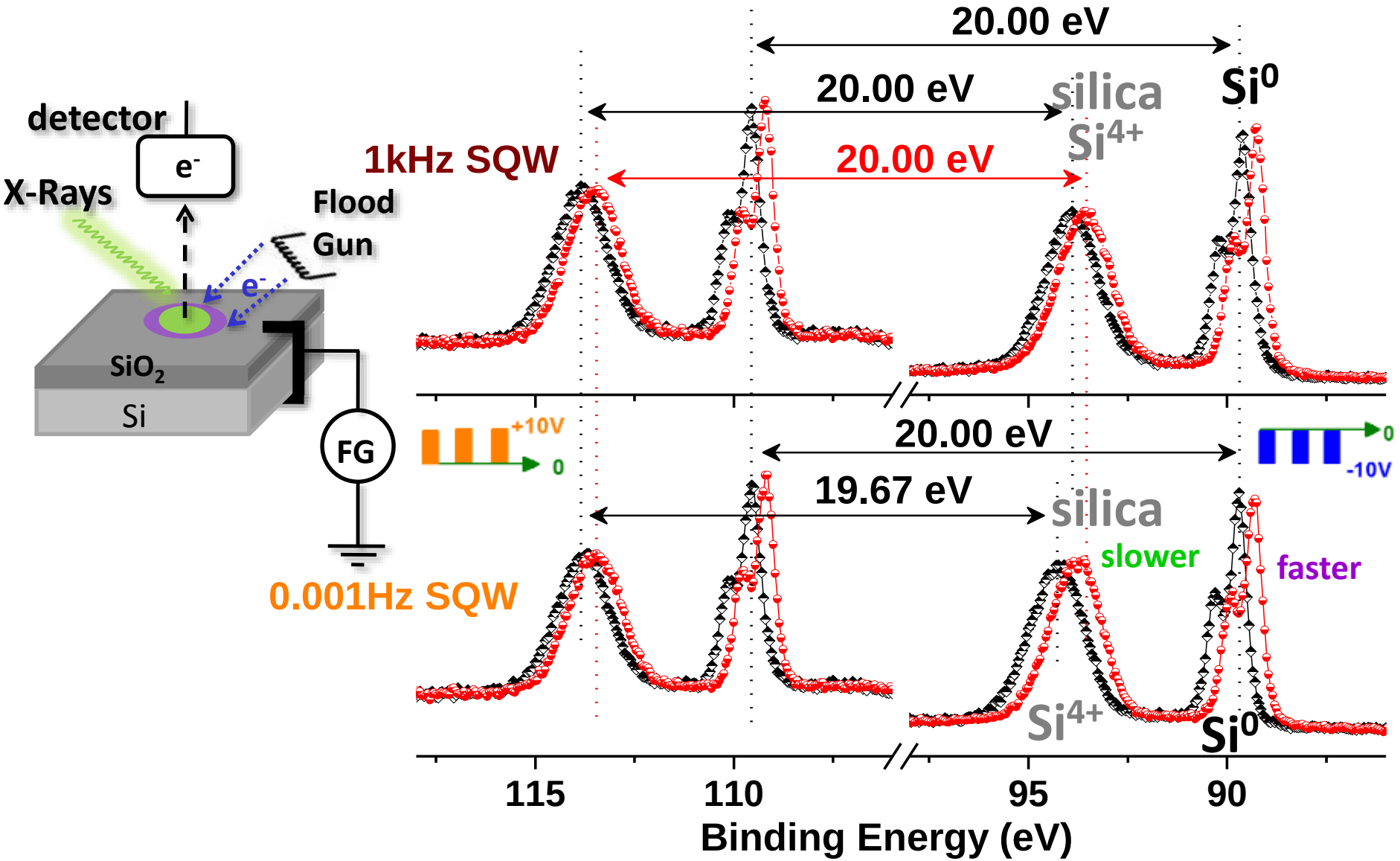


Photo-Dynamic XPS with SiOx/p-Si:



H. Sezen, S. Suzer Thin Solid Films 534, 1(2013)

SPV:

CdS

n-type shift

+0.2eV

SPV or photoconductivity?

Violet 3.1 eV
Green 2.3 eV
Red 2.0 eV
980nm 1.3 eV

CdS

Laser OFF

Violet Laser ON

Band gap 2.4 eV

Grounded

$Cd3d_{5/2}$

407 406 405 404

Binding Energy *(eV)*

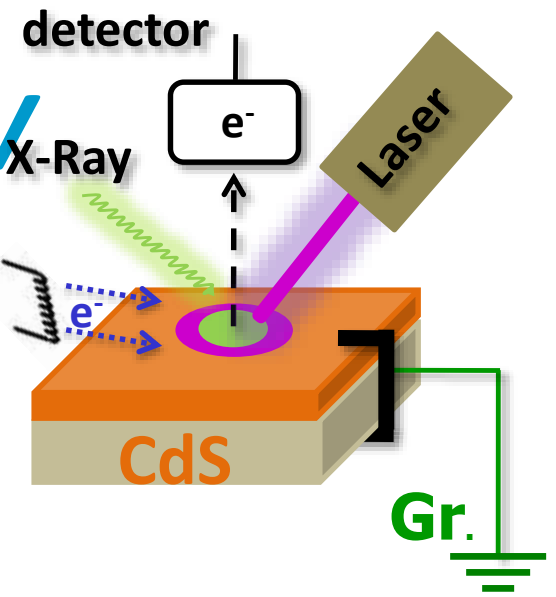
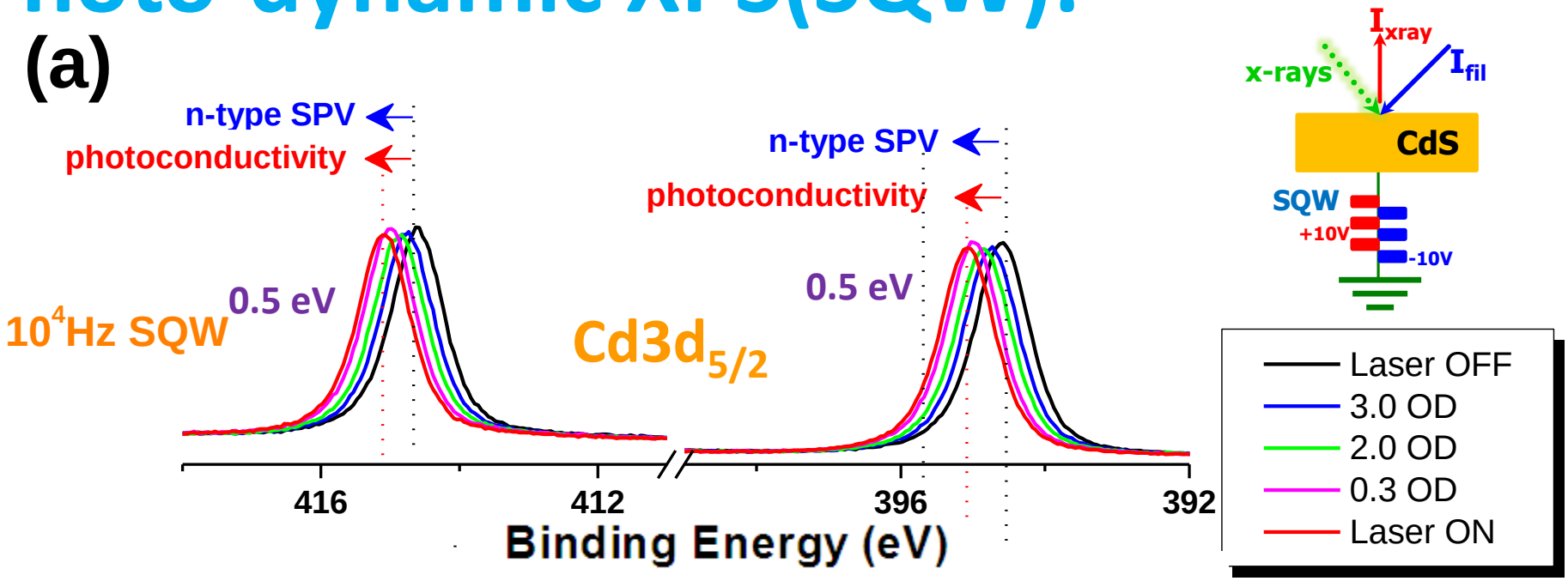


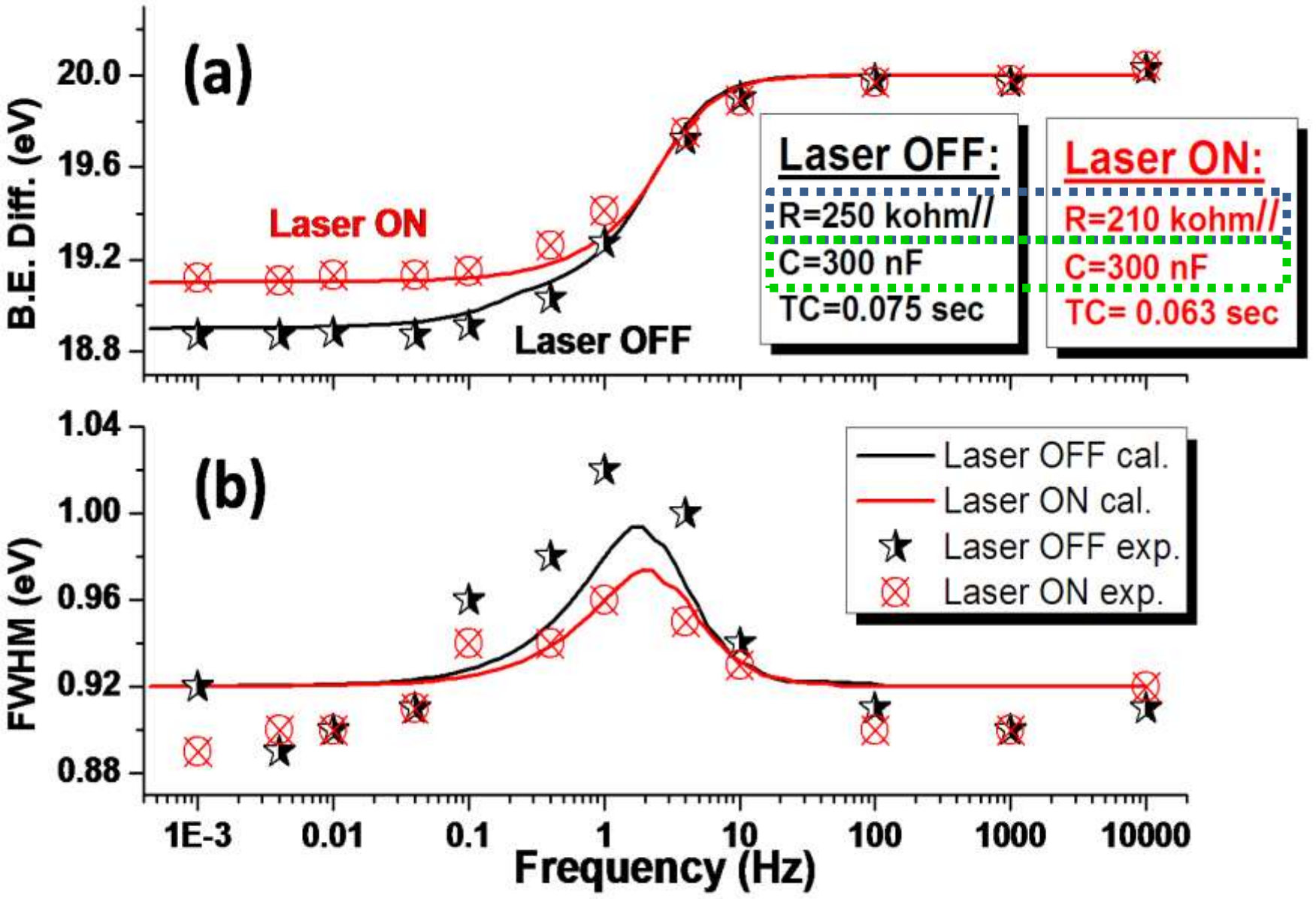
Photo-dynamic XPS(SQW):



Resolved different phenomena

H. Sezen, S. Suzer Surf. Sci. 604, L59(2010)

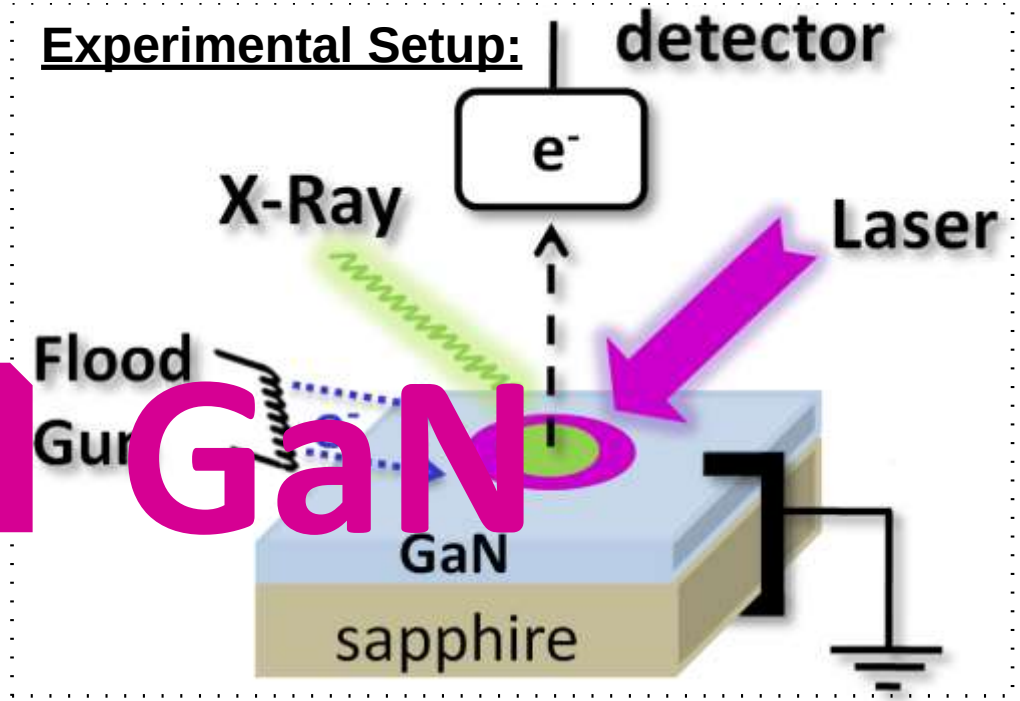
The electrical parameters of CdS film

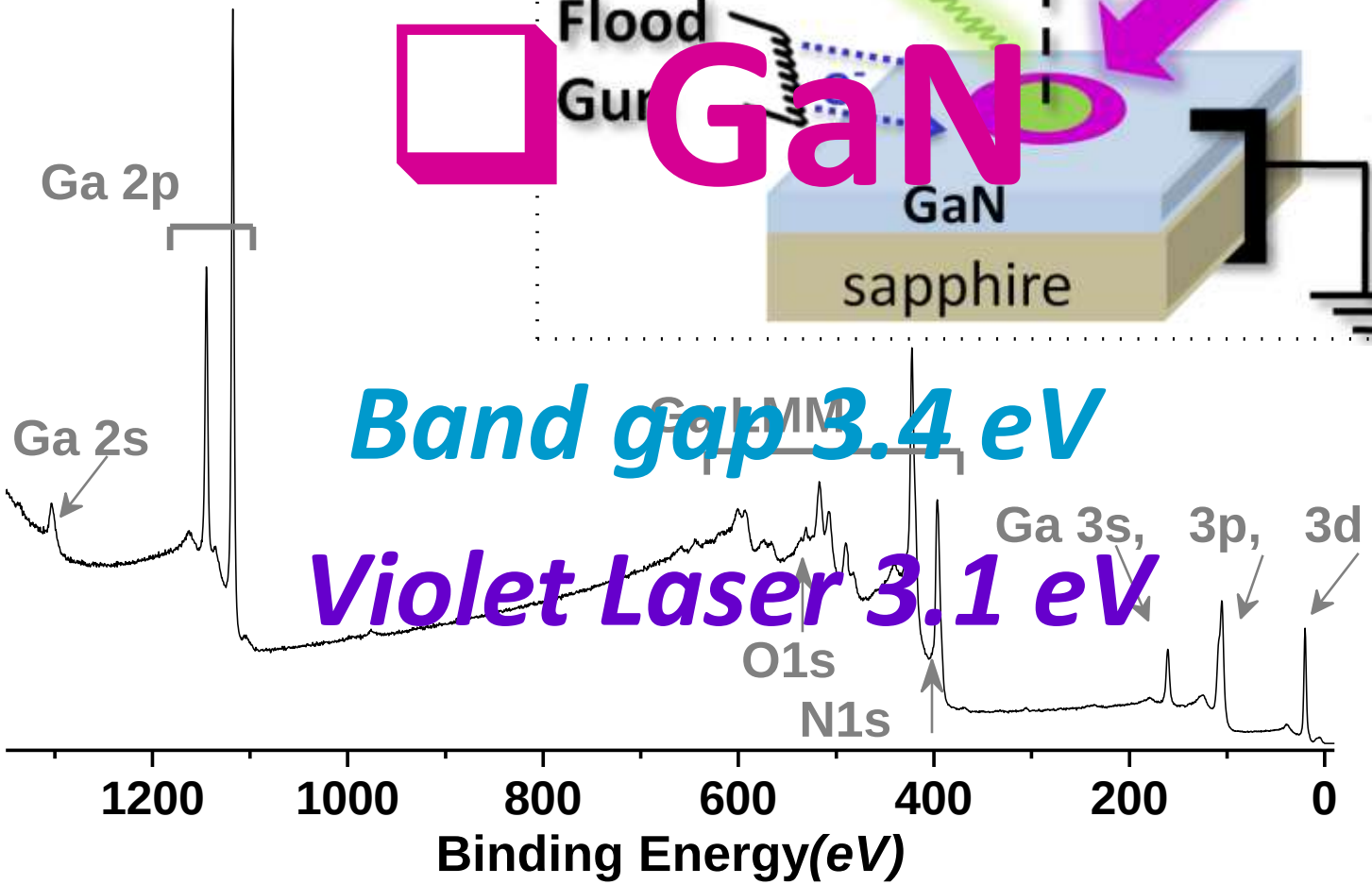


H. Sezen, S. Suzer Surf. Sci. 604, L59(2010)

p-GaN

Band gap 3.4 eV

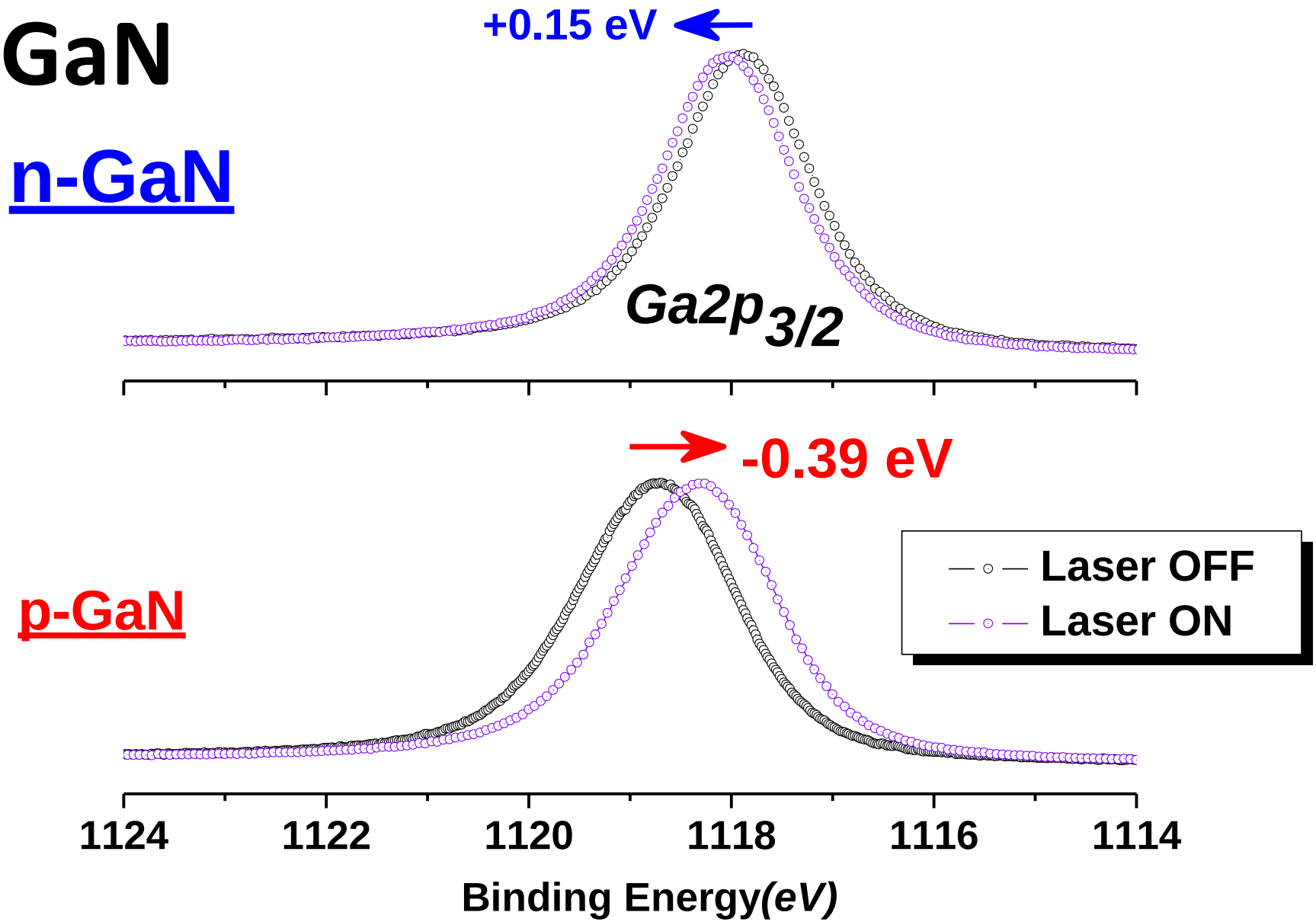




Band gap 3.4 eV

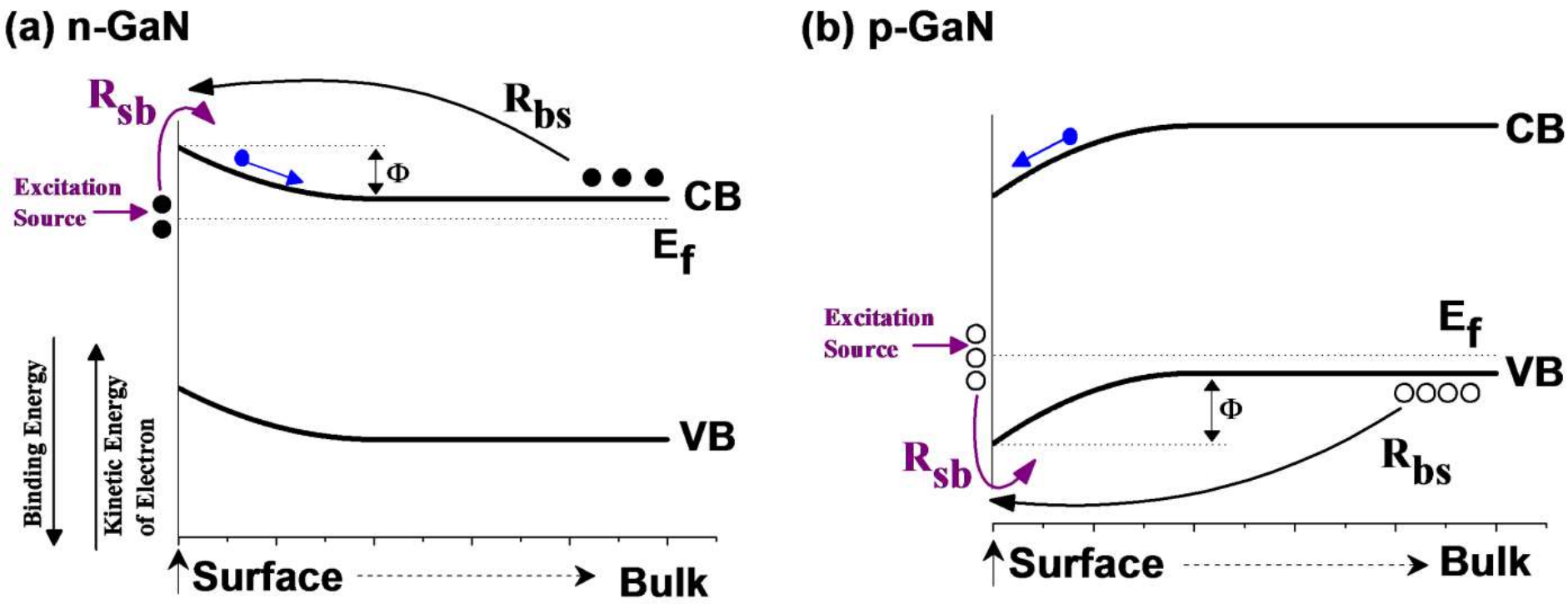
Violet Laser 3.1 eV

Static SPV :



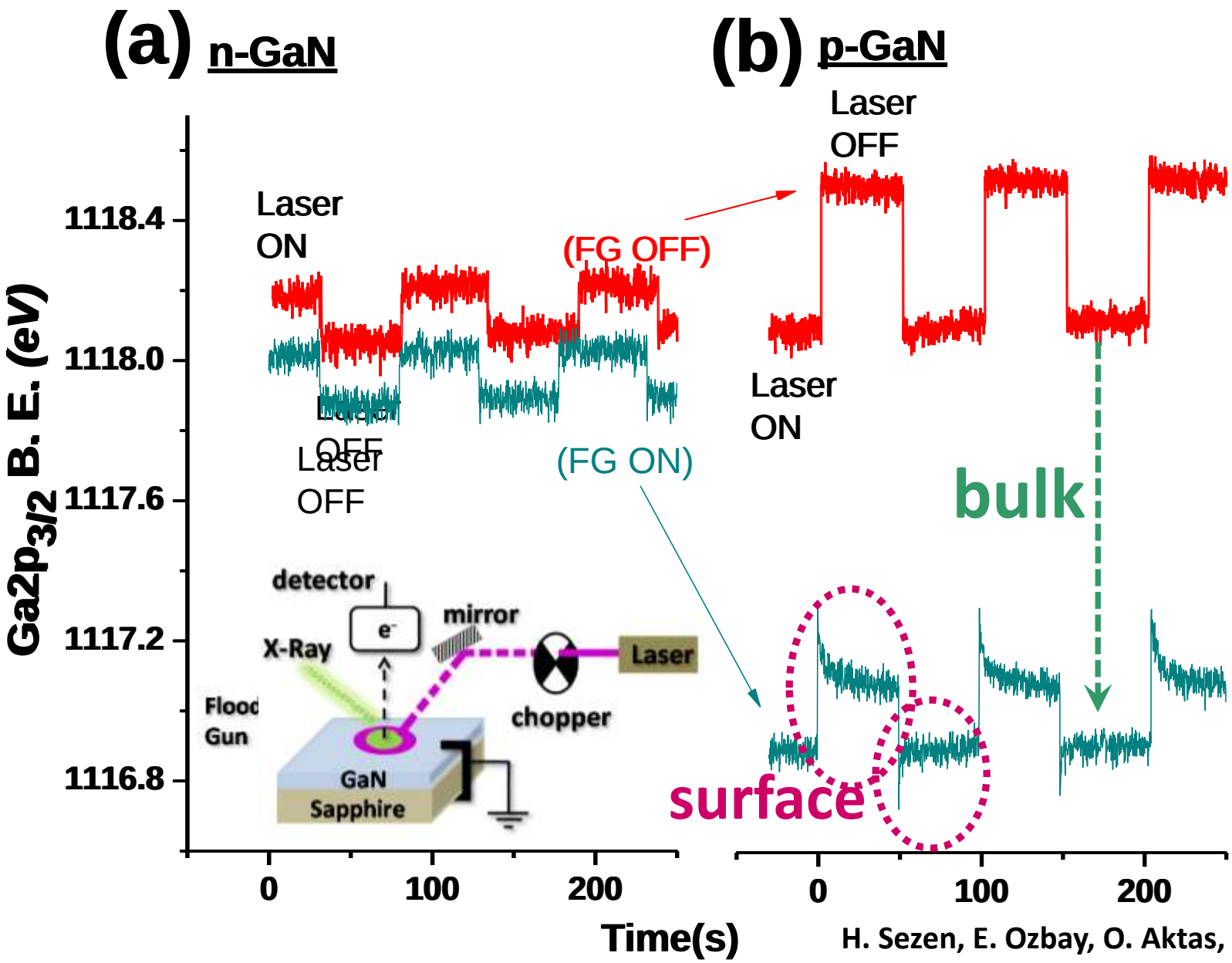
H. Sezen, E. Ozbay, O. Aktas, S. Suzer Appl. Phys. Lett. 98, 111901(2011)

SPV Mechanisms:

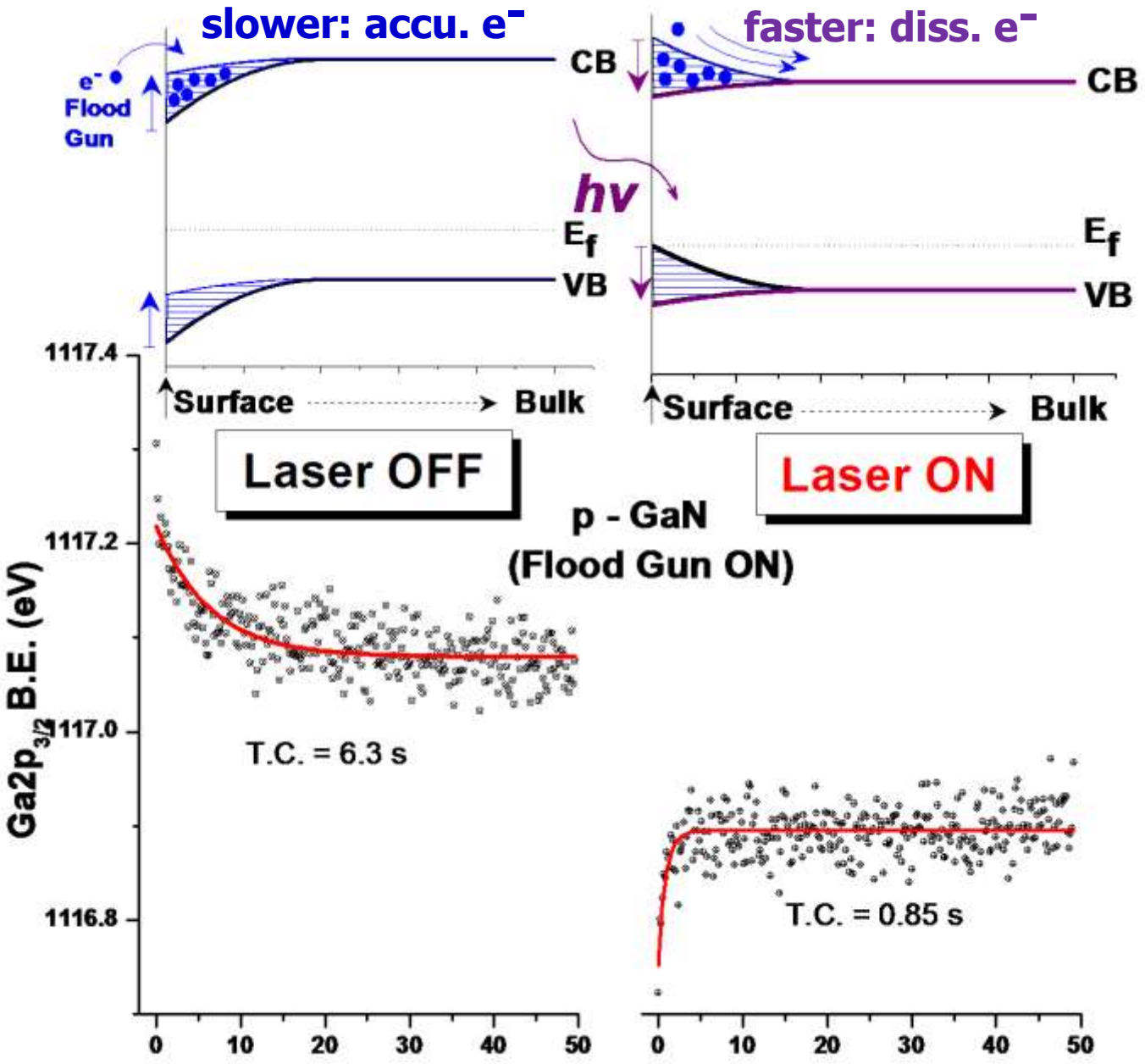


H. Sezen, E. Ozbay, O. Aktas, S. Suzer
Appl. Phys. Lett. 98, 111901(2011)

Dynamic SPV Transients:



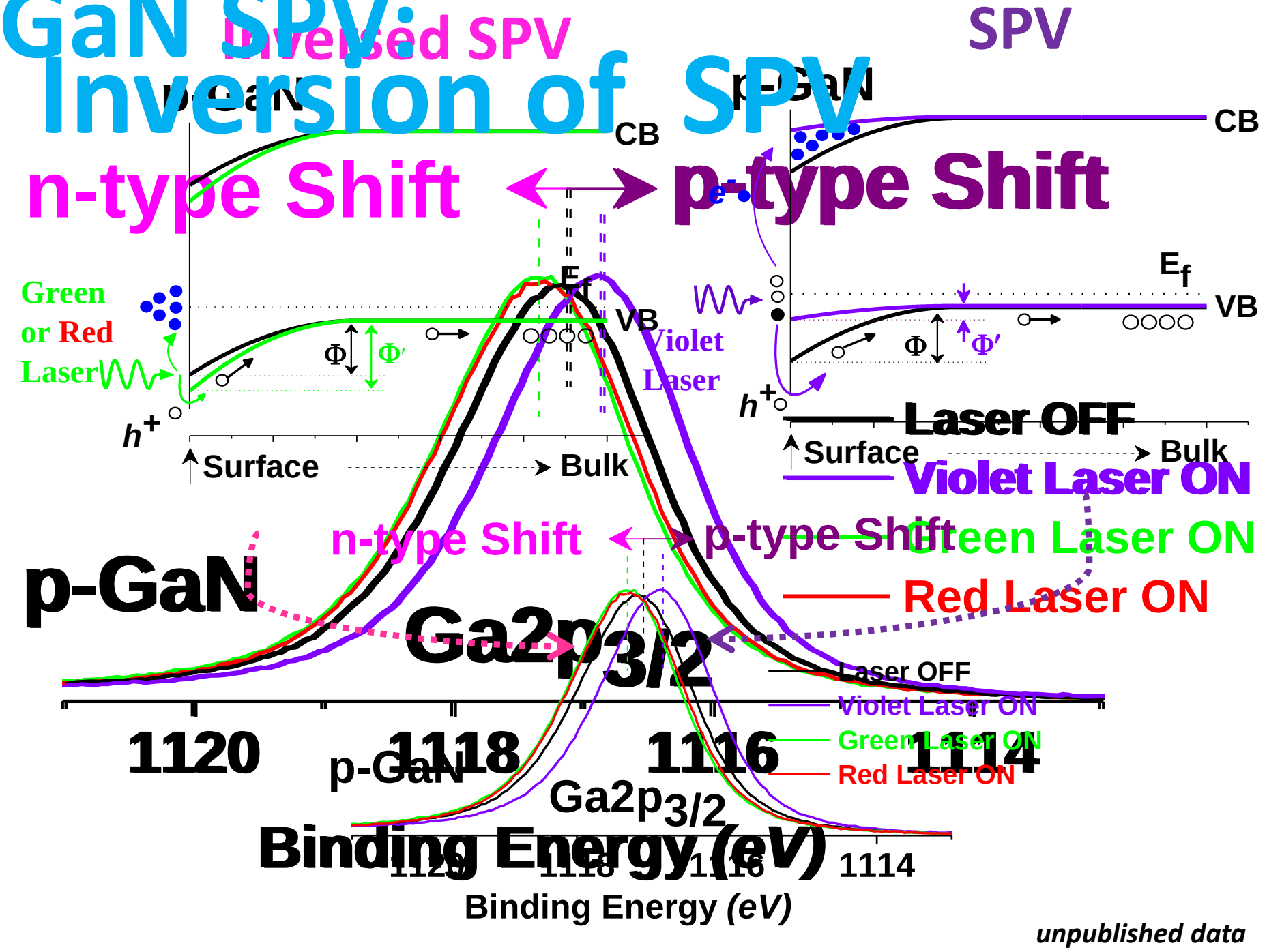
H. Sezen, E. Ozbay, O. Aktas, S. Suzer
Appl. Phys. Lett. 98, 111901(2011)



H. Sezen, S. Suzer J. Spectrosc. Dyn. 2, 3(2012)

H. Sezen, E. Ozbay, O. Aktas, S. Suzer Appl. Phys. Lett. 98, 111901(2011)

GaN SPV: Inversion of SPV



unpublished data

Conclusions

"Photo „Dynamic" XPS„

rest of the world:

$BE_{pe} = h\upsilon_{x\text{-}rays} - KE_{pe}$

but we:

$BE_{pe} = h\upsilon_{x\text{-}rays} - KE_{pe} \pm eV \pm e\Delta V \pm e\Delta V_{ph} \pm e \cdot SPV$ ....

Thin Solid Films 534 (2013) 1–11

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journal homepage: www.elsevier.com/locate/tsf

Critical review

XPS for chemical- and charge-sensitive analyses

Hikmet Sezen, Sefik Suzer *

Bilkent University, Chemistry Department, 06800 Ankara, Turkey

H. Sezen, S. Suzer Thin Solid Films 534, 1(2013)

Organic species: E. Yilmaz, H. Sezen, S. Suzer Angew. Chem. Inter. Ed. 51, 5488(2012).

Acknowledgement

Thanks to

Prof. Şefik Süzer *(advisor)*	***Chem., Bilkent U., TR***
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Prof. Ekmel Özbay	***Phys, Bilkent U., TR***
Prof. Mehmet Erbudak	***Phys, ETHZ, CH***
Prof. Oğuz Gülseren	***Phys, Bilkent U., TR***
Asst. Prof. Ömer İlday	***Phys, Bilkent U., TR***
Asst. Prof. Özgür Aktaş	***EE Eng., Bilkent U., TR***
Asst. Prof. Aykutlu Dana	***Phys, Bilkent U., TR***
Asst. Prof. Özgür Birer	***Chem., Koç U., TR***

Dr. Tim Nunney and crew of the Surface Analysis

Department of Thermofisher, UK

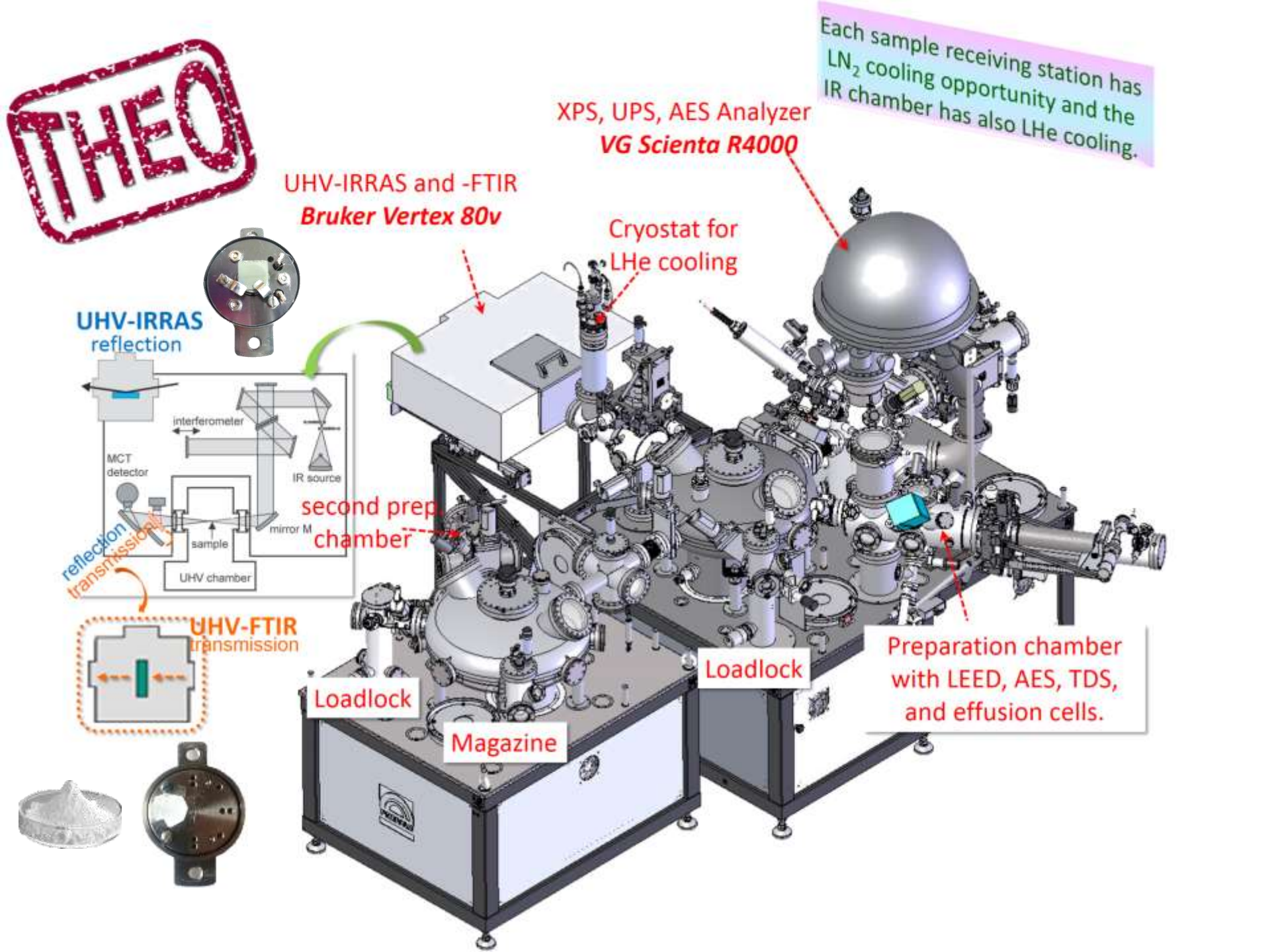
Probing Shallow trapped electrons of TiO_2 with UHV-IRRAS

Hikmet Sezen, Carsten Natzeck, Alexei Nefedov, Christof Wöll

Institute of Functional Interfaces (IFG)

Chemistry of Oxydic and Organic Interfaces

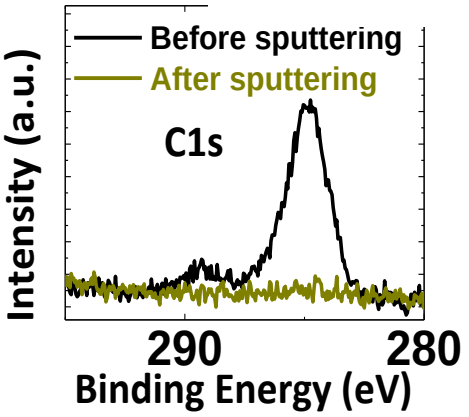
Part II (2012):


THEO
Each sample receiving station has LN_2 cooling opportunity and the IR chamber has also LHe cooling.
XPS, UPS, AES Analyzer
VG Scienta R4000
UHV-IRRAS and -FTIR
Bruker Vertex 80v
Cryostat for LHe cooling
UHV-IRRAS
reflection
interferometer
MCT detector
IR source
mirror M
sample
UHV chamber
reflection
transmission
second prep. chamber
UHV-FTIR
transmission
Loadlock
Magazine
Loadlock
Preparation chamber with LEED, AES, TDS, and effusion cells.

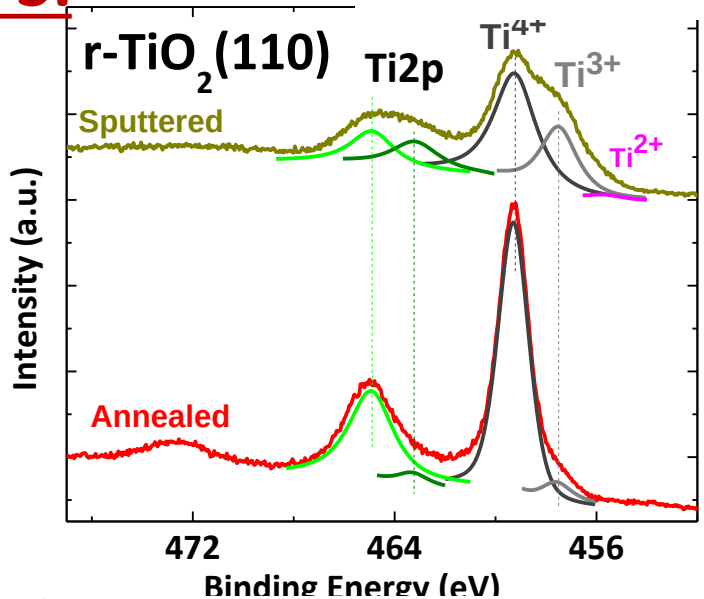
TiO_2 single crystal:

Sample Preparation:

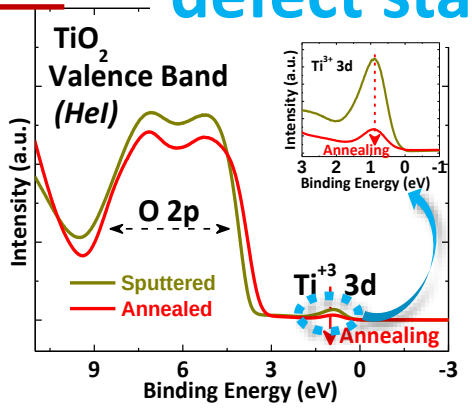
cleanness ✓



XPS: oxidation state ✓



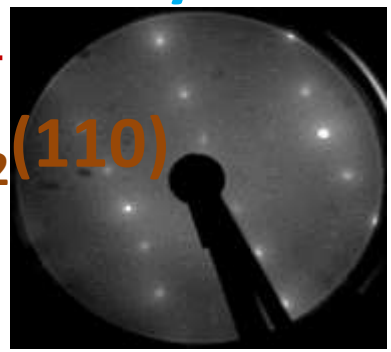
UPS: defect state ✓



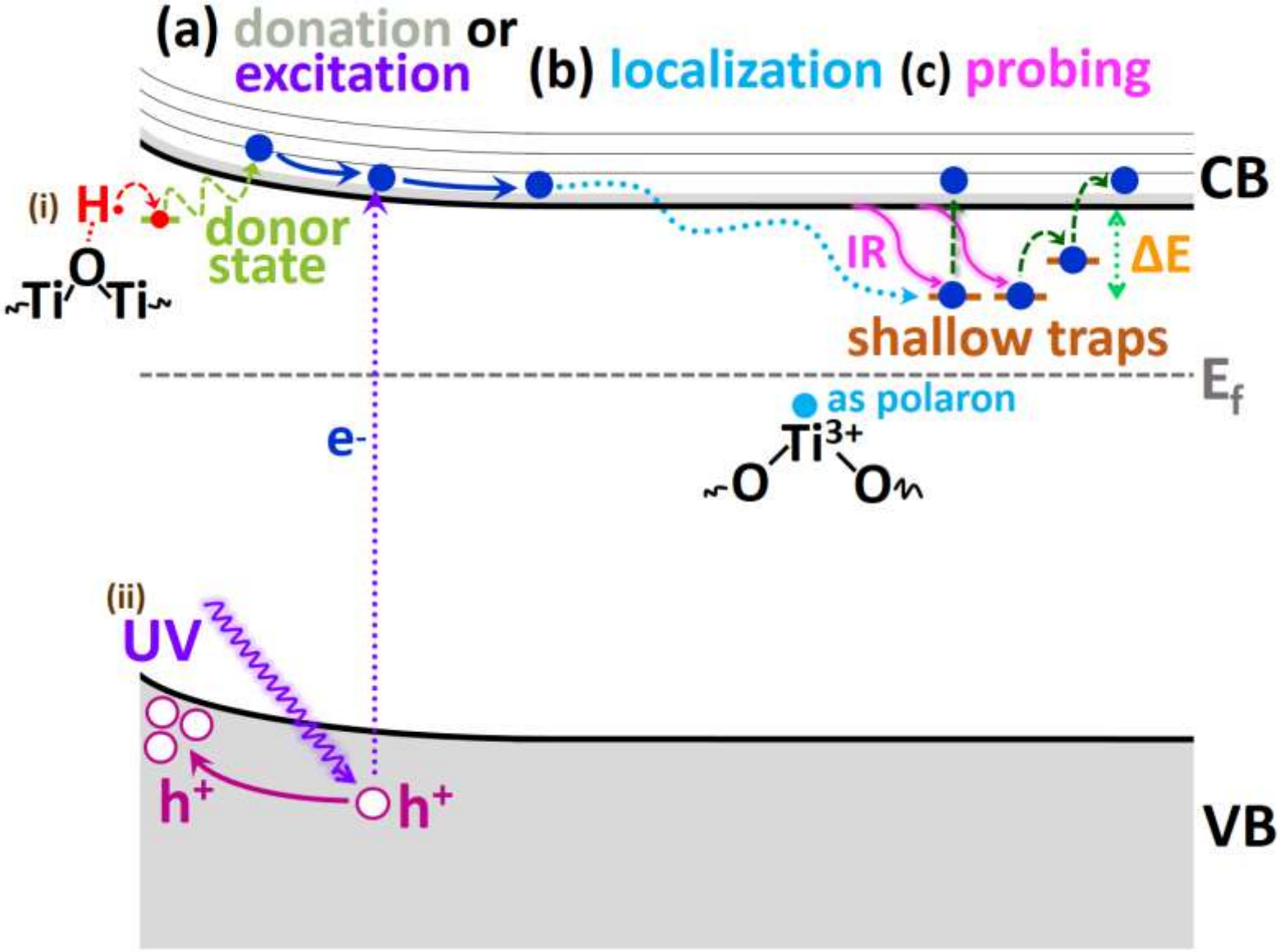
surface crystal structure ✓

LEED:

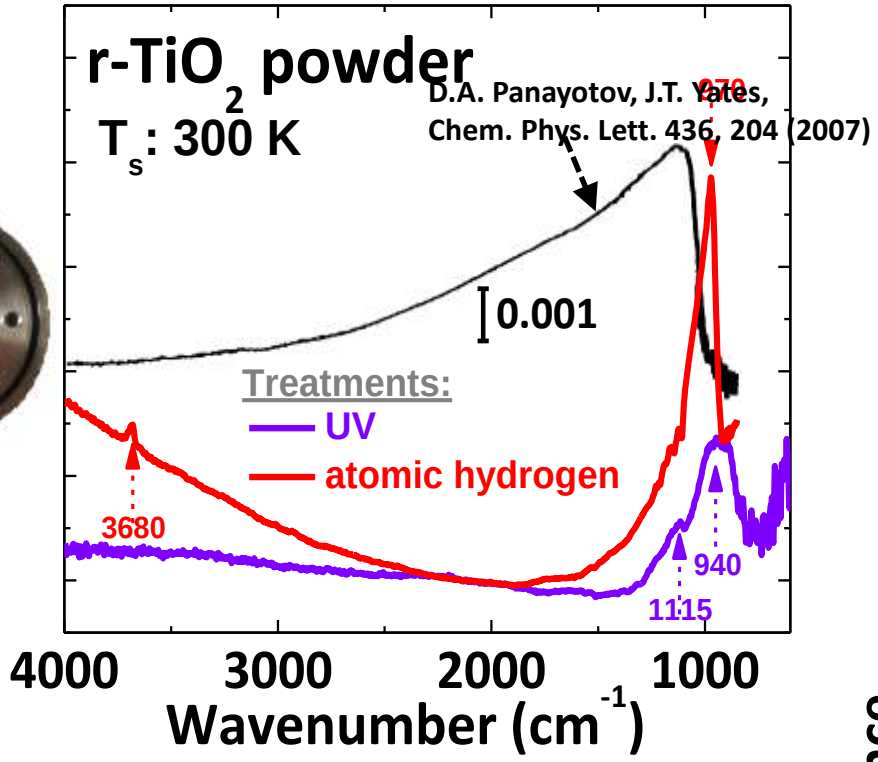
$R\text{-}TiO_2(110)$

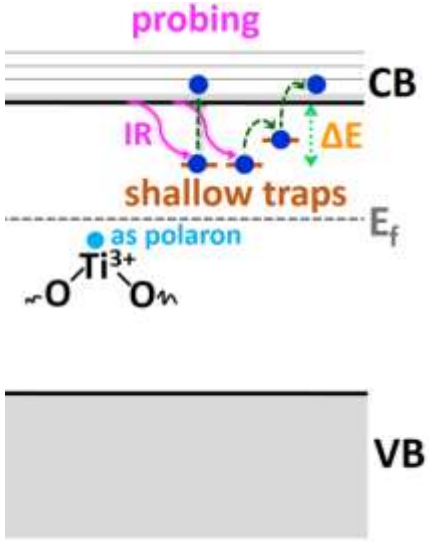


TiO_2 Band structure: shallow state

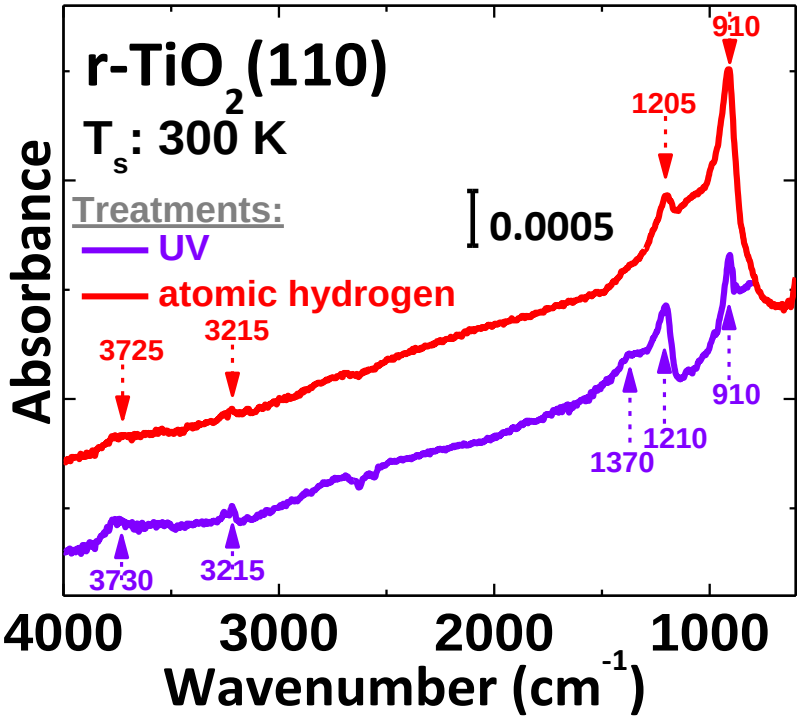


powders:





single crystal:



Thank you for your attention!..