

**Wavelength selective UV detector
heterostructures based on p -ZnO
fabricated
by Molecular Beam Epitaxy**

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Why Zinc Oxide?



Future

- Excitation lasers
- Exciton-polariton lasers

- Quantum physics
- Quantum devices

Single crystal films
On ZnO crystals

Minority carrier devices

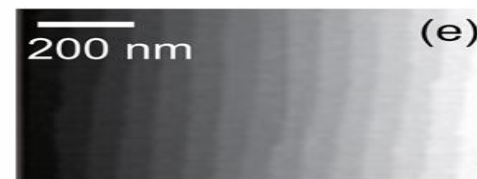
- UV emitters
- UV photodetectors

Majority carrier devices

- Field-effect transistors
- Two-dimensional electron gas

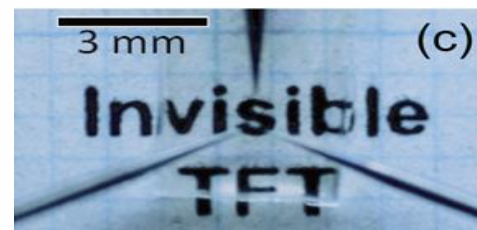
Key technologies

- Surface treatment of substrates
- Mass production of ZnO crystals
- Film growth techniques
- Interface engineering



Poly-crystalline
thin films on
glass

- Transparent conducting films
- Transducers
- Gas sensors
- Transparent transistors

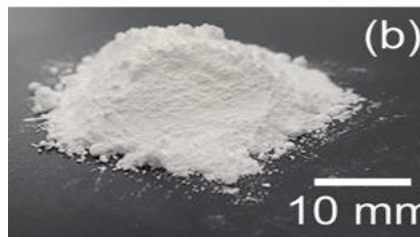


Bulk



Ceramics

- Varistors
- Gas sensors
- Actuators



Powder

- Chemical ingredient
- Cosmetic powder



„The key to making UV-emitting (and detecting) devices is likely to be ZnO: it’s a better material than GaN for making these devices, because it naturally emits (and absorbs) at those wavelengths more efficiently. Plus it is cheap and abundant — zinc is used in drugs and sunscreens — and is easy to grow into wafers that are virtually defect-free. ”

(from IEEE Spectrum - Prachi Patel Predd)

MBE Laboratory for GaN/ZnO



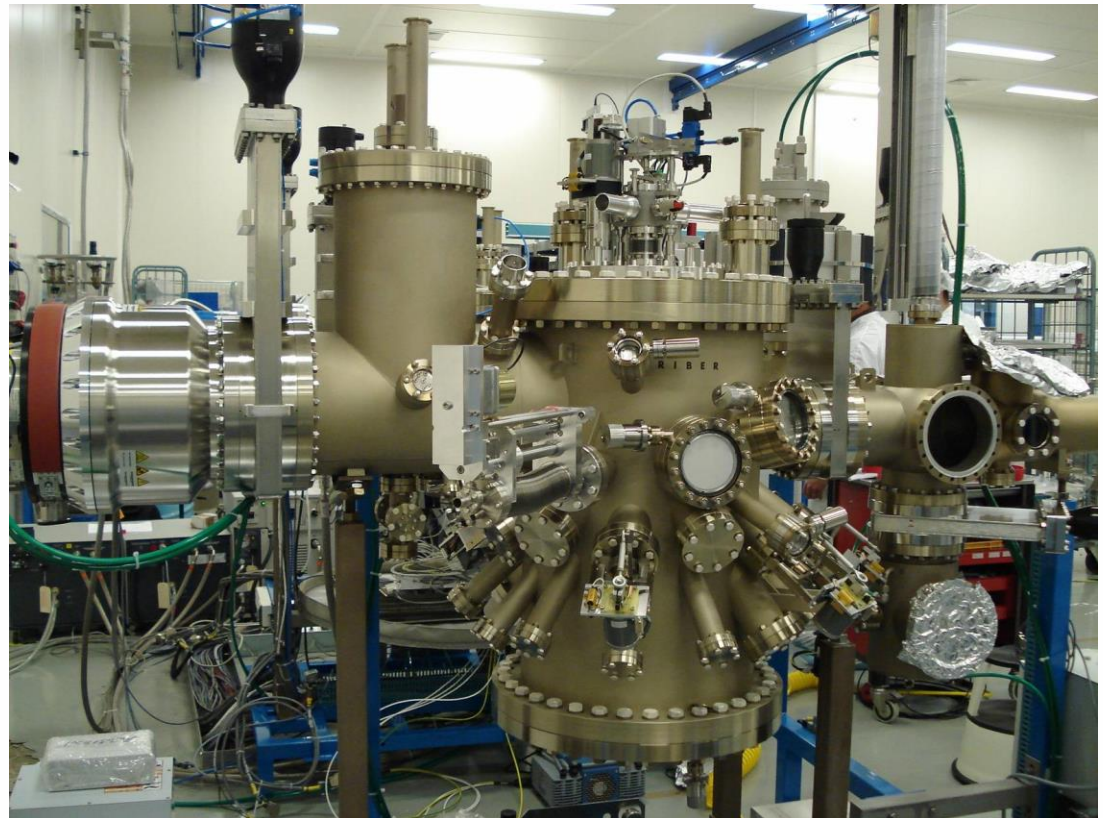
Molecular Beam Epitaxy (MBE) system for ZnO

Installed sources

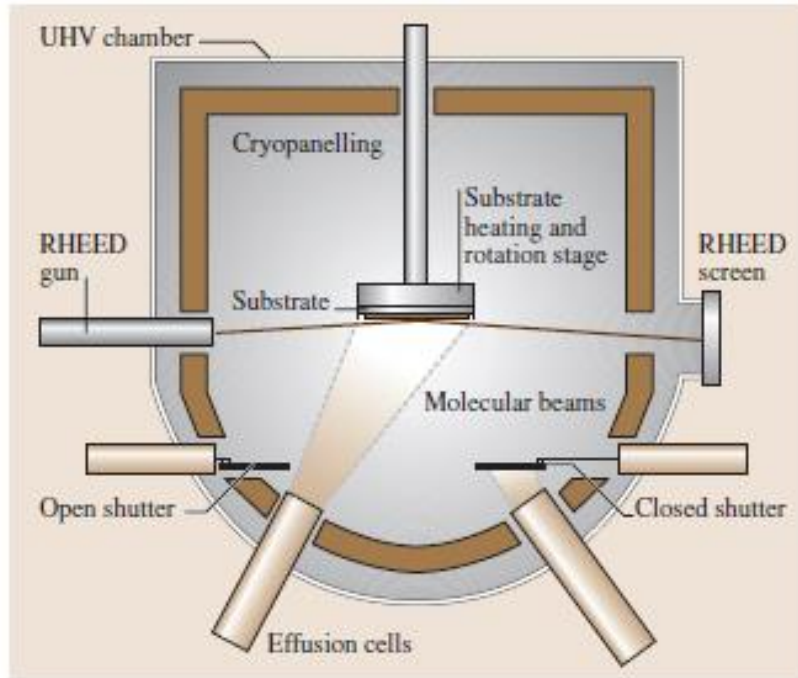
- Zn
- Mg
- *rf* plasma – oxygen

Dopant cells:

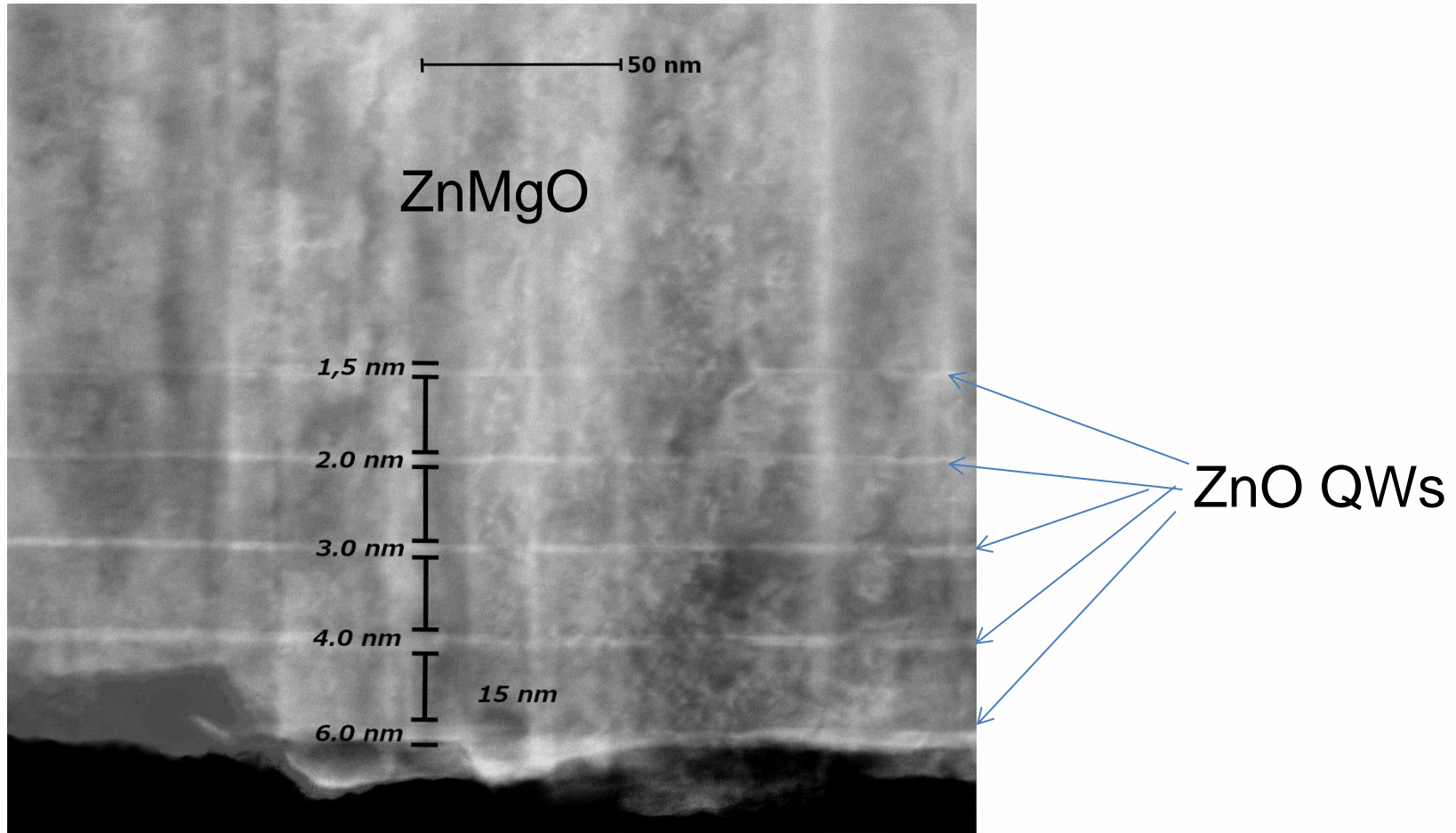
- *rf* plasma - nitrogen
- Sb
- As
- Al



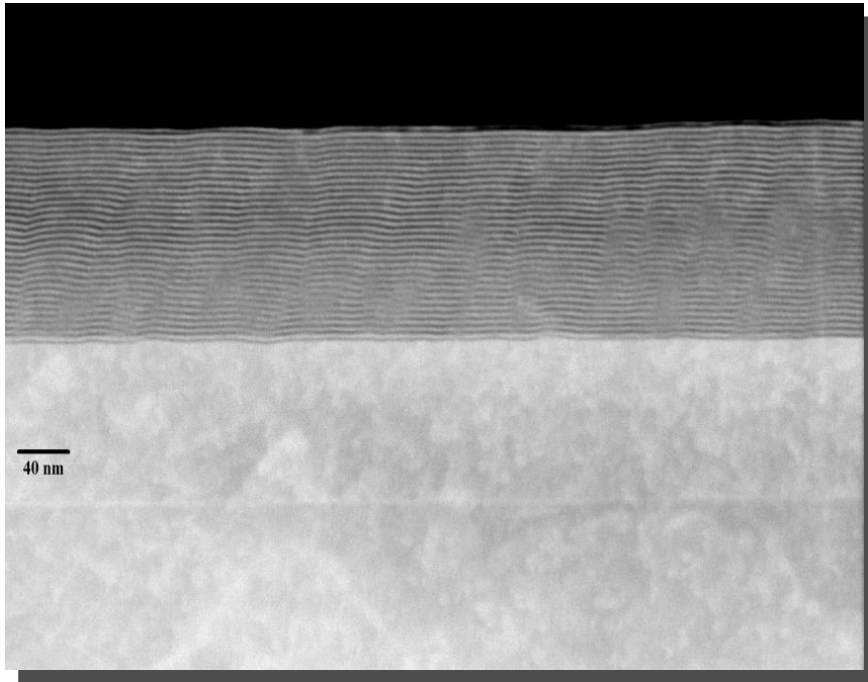
Growth of ZnO/ZnMgO quantum structures



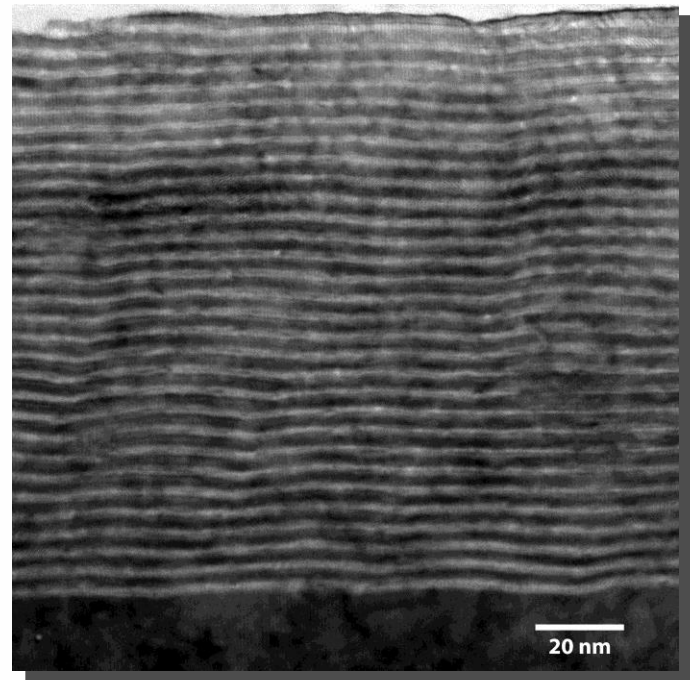
Examples of ZnMgO/ZnO/ZnMgO Quantum Well structures



Z08 superlattice ZnO/MgO, 30/30 layers 2 nm/2nm



STEM



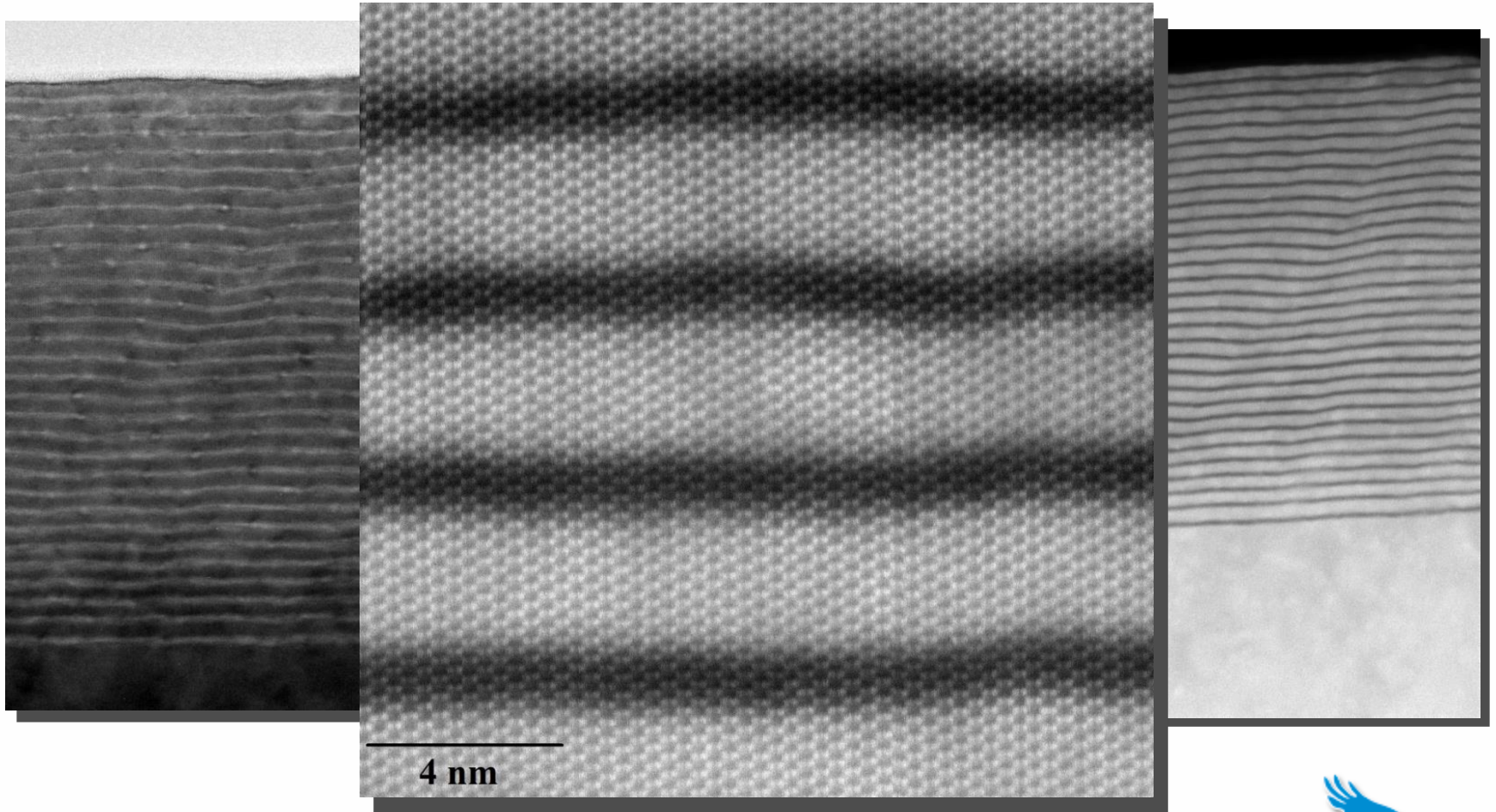
TEM

D. Jarosz, M. Pietrzyk

P. Dłużewski

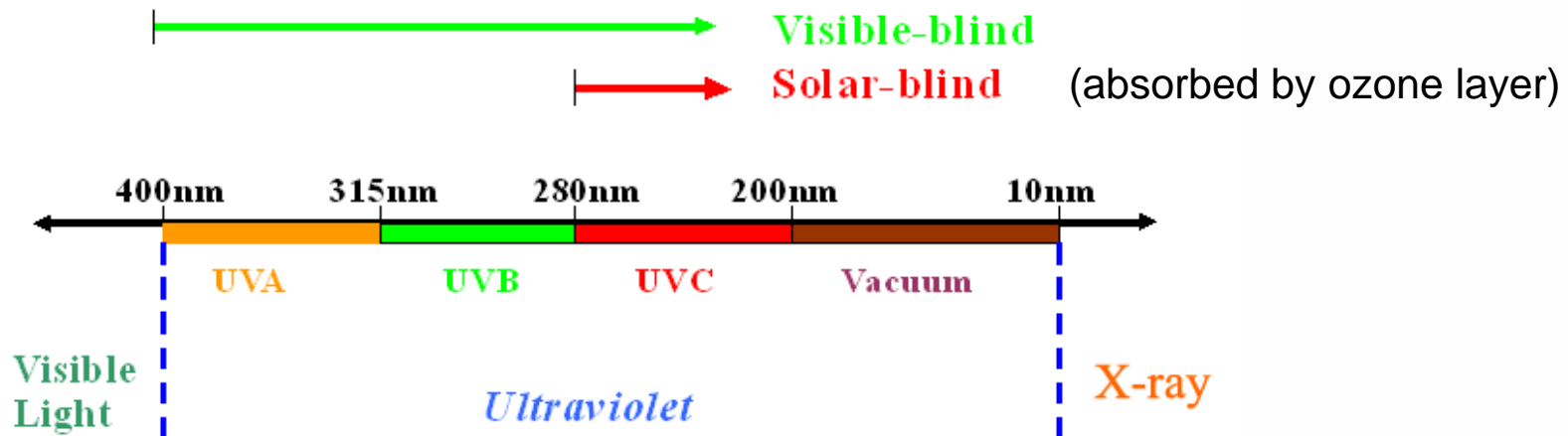


Z07 superlattice ZnO/MgO 2,5 nm/1nm

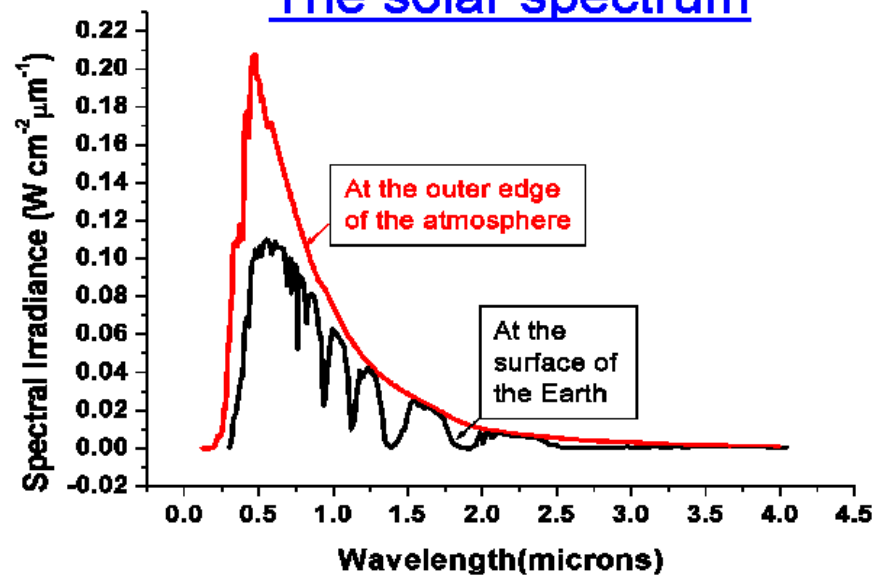


Wavelength selective UV detector heterostructures





The solar spectrum



Applications of UV detectors

- chemical and biological analysis and monitoring
- flame and radiation detection
- astronomical studies
- environmental contaminations monitoring
- missile launch detection and anti-aircraft missile guidance systems
- research applications

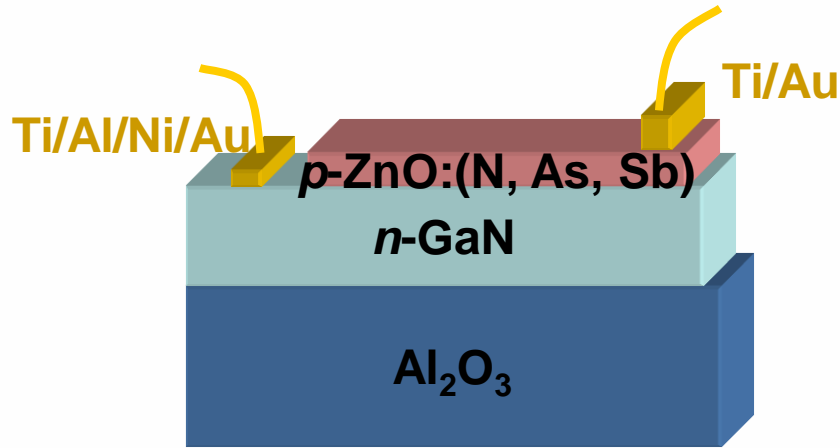


The **5S** requirements for high performance UV detectors:

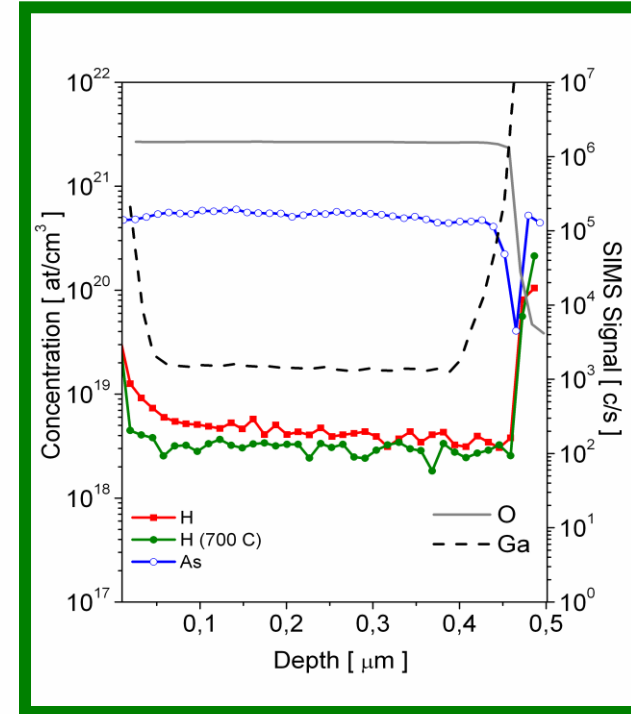
- high ***sensitivity***
- high ***signal-to-noise*** ratio
- high ***spectral selectivity***
- high ***speed***
- high ***stability***



The structure of a p-n heterojunction:



Dopant concentrations by SIMS



Processing:

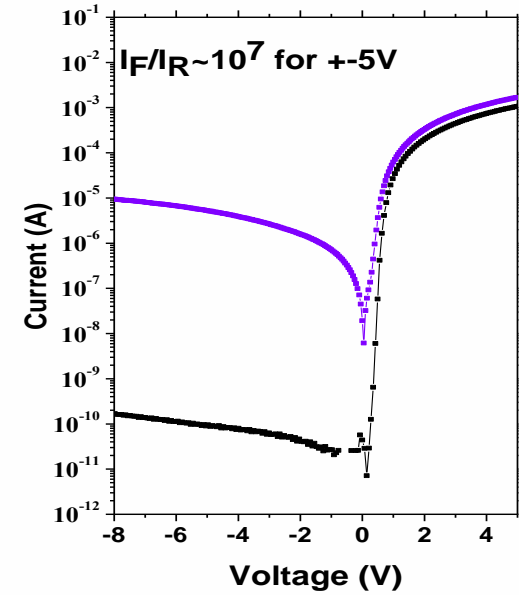
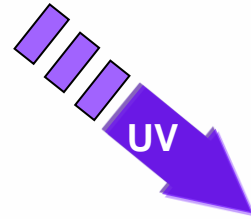
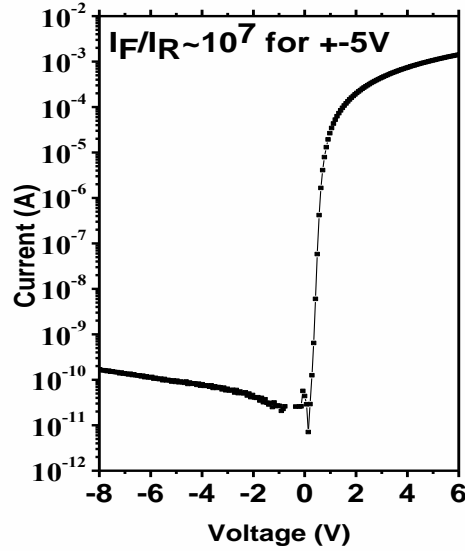
RTA - rapid thermal annealing for activation of acceptors
 Electrical contacts – e-beam evaporation

Electrical parameters of the layers:

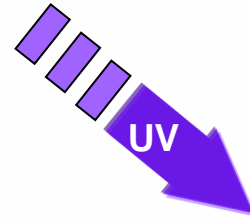
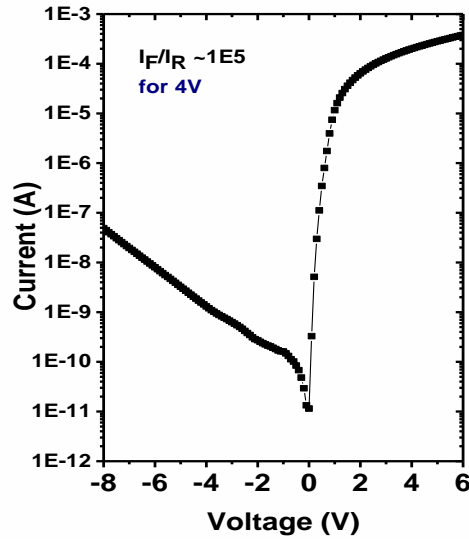
Layer	Doping	Concentration (cm ⁻³) Van der Pauw; RT	μ (cm ² /Vs)	Resistivity (Ω)
ZnO	N	p~1e17	5	2e5
ZnO	As	p=8e15-2e16	17-26	1e5-1e6
GaN	-	n=7e17	45	7e3

Current-voltage characteristics of the *p-n* junctions

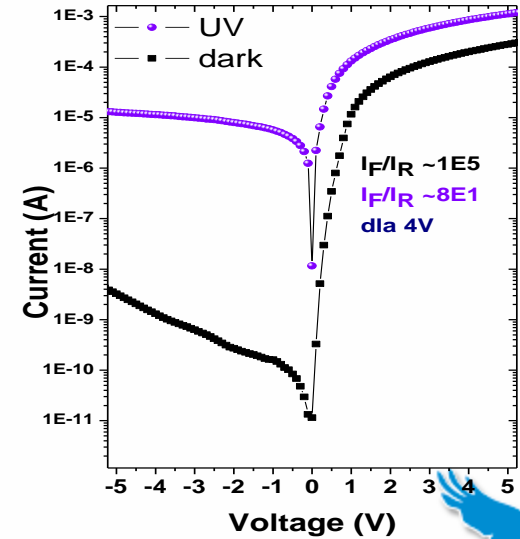
Nitrogen doping



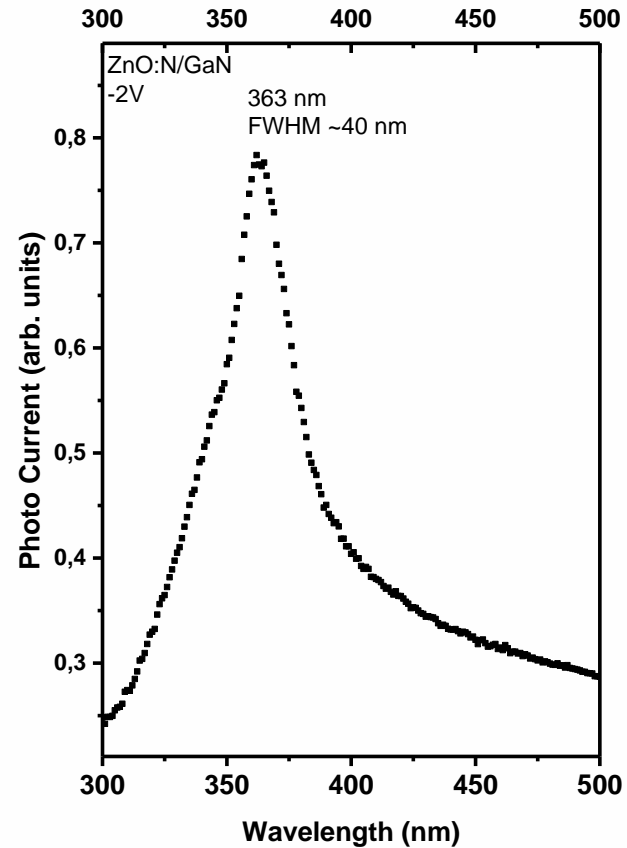
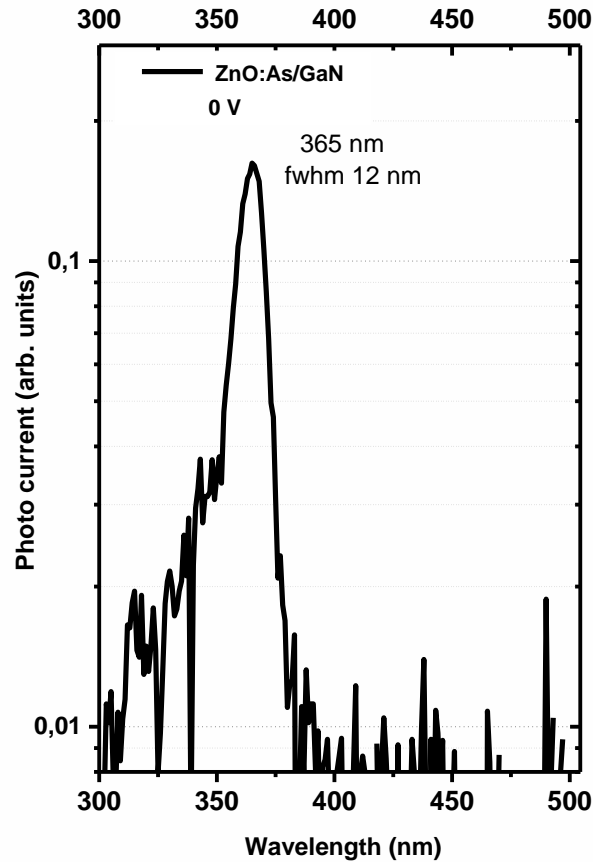
Arsenic doping



$$I_F/I_R = I_{\text{Forward}}/I_{\text{Reverse}}$$



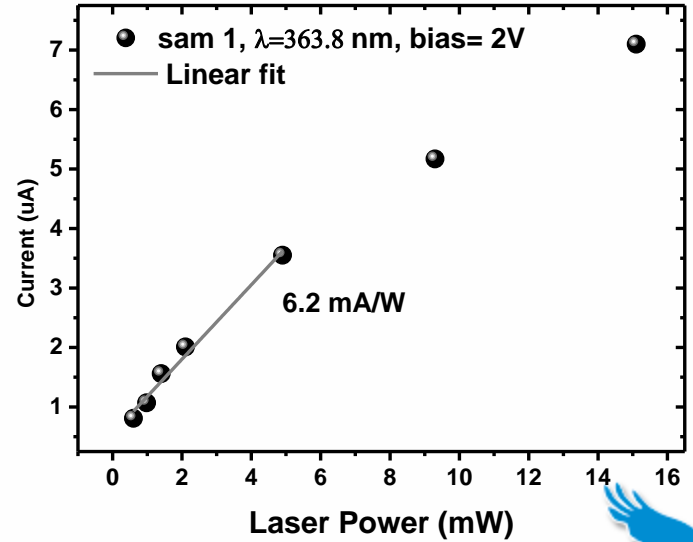
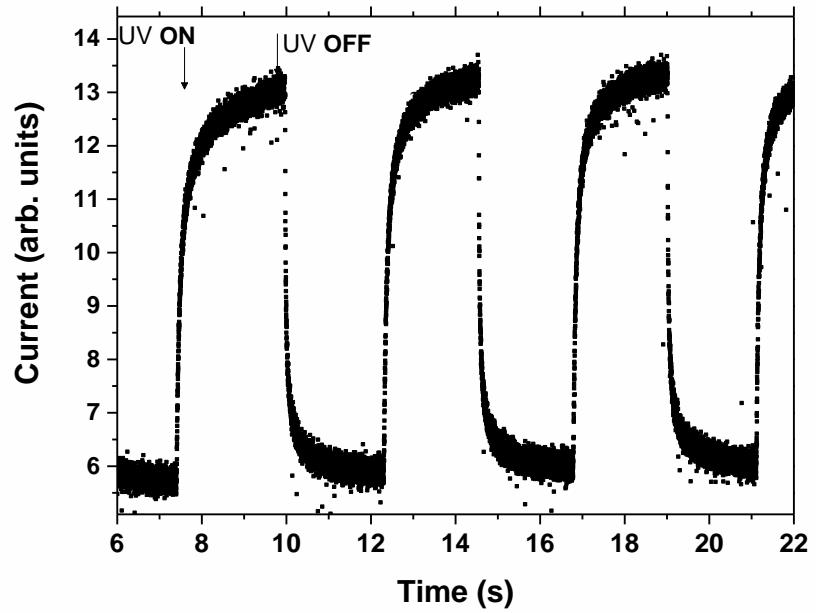
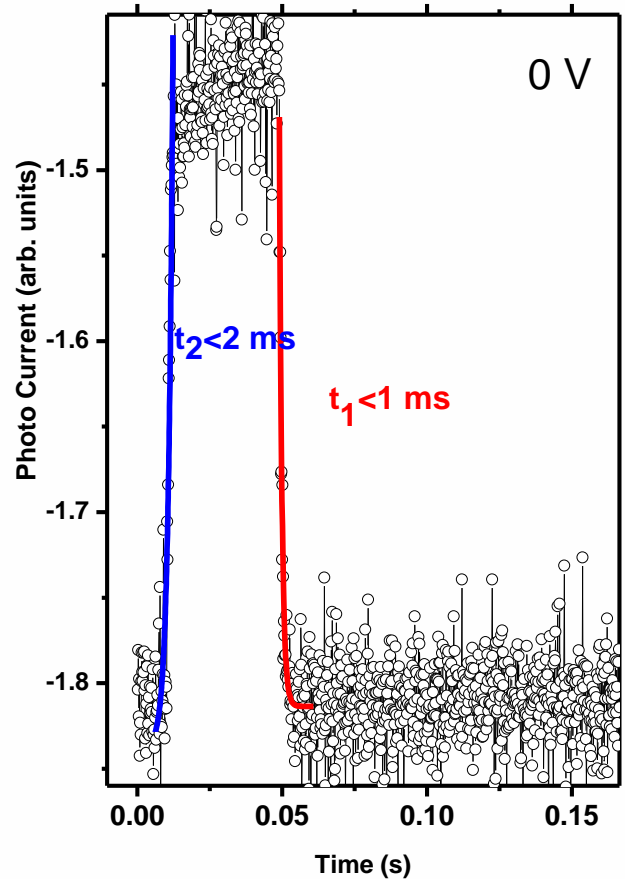
Spectral range of the detectors



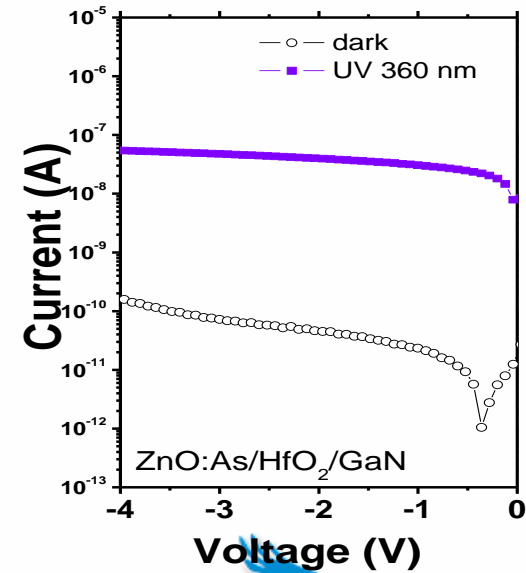
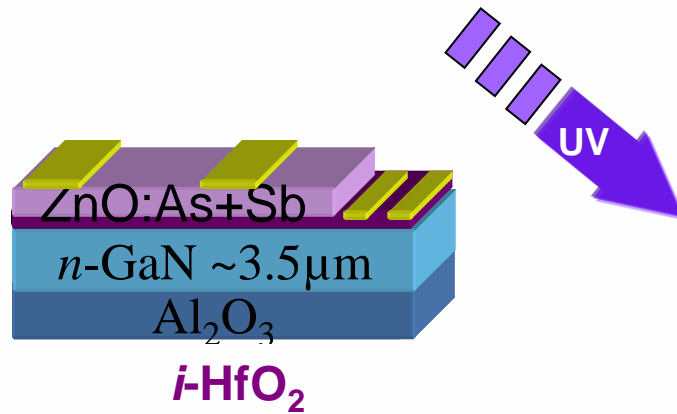
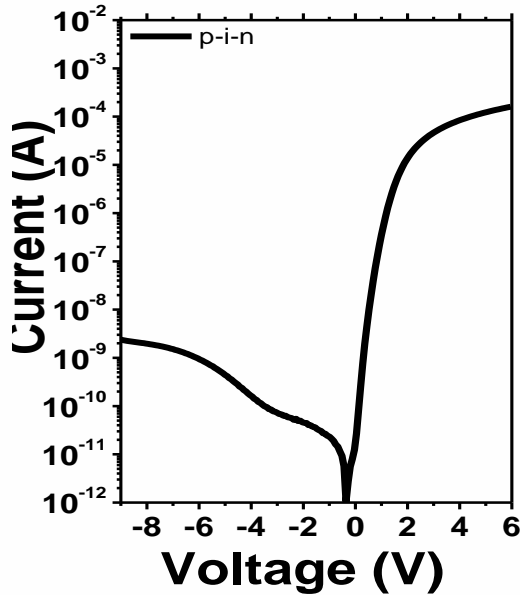
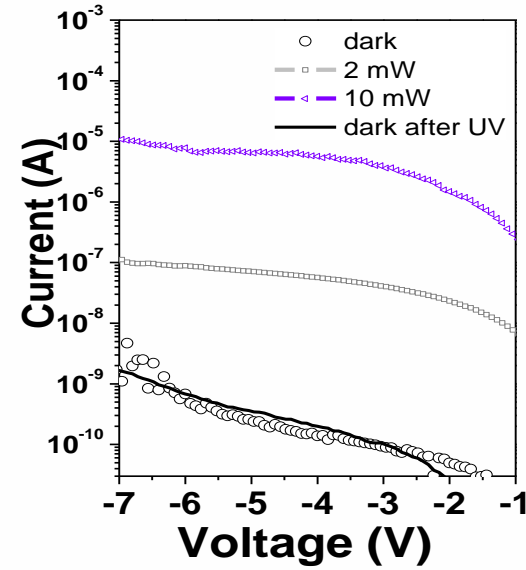
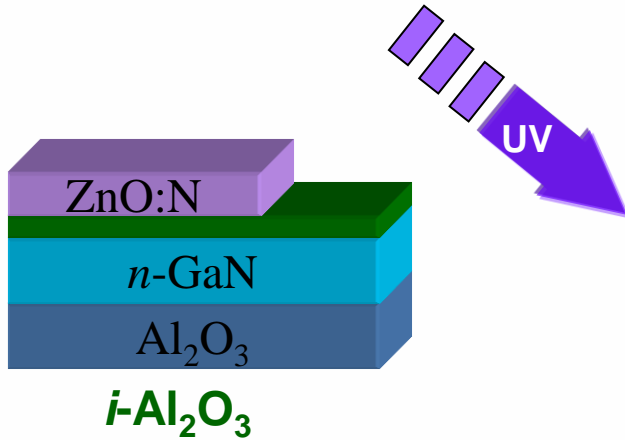
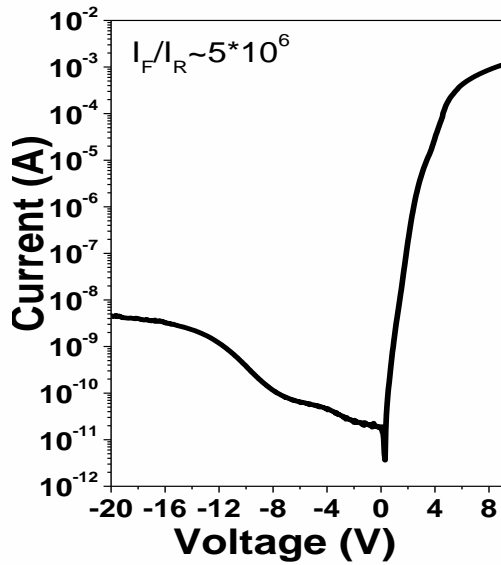
High selectivity in the UV spectral range !

Detector kinetics

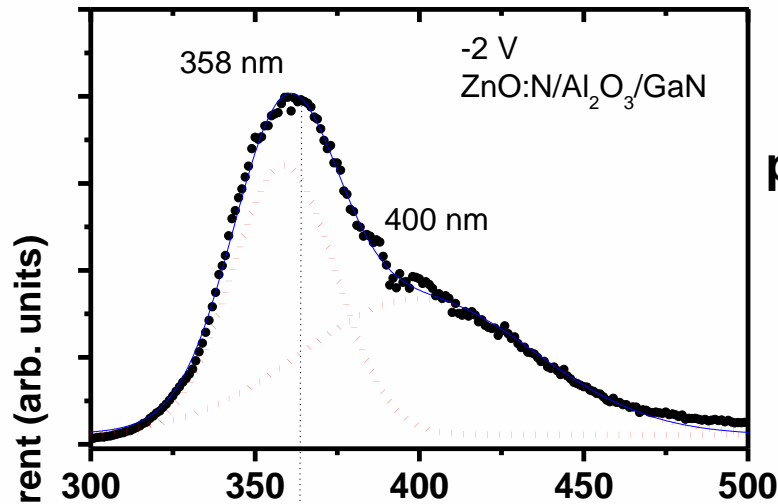
Returns to its initial state in <2 msec!



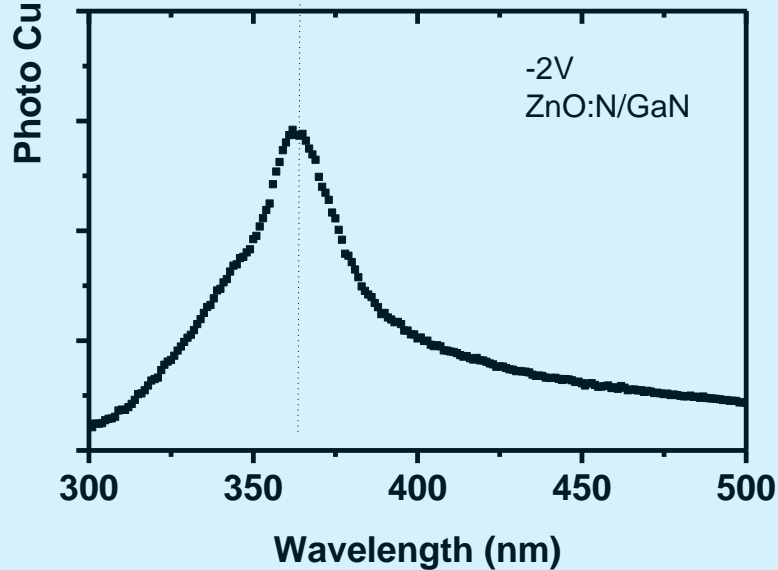
Current-voltage characteristics of *p-i-n* heterostructures



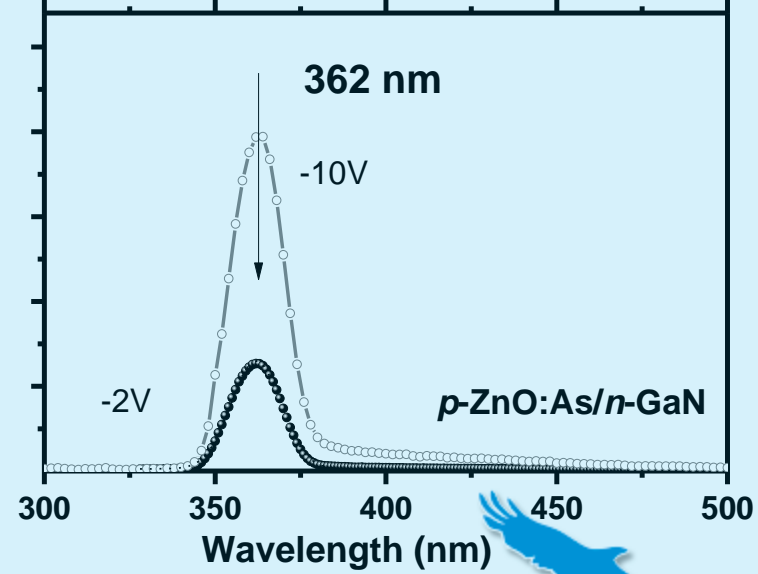
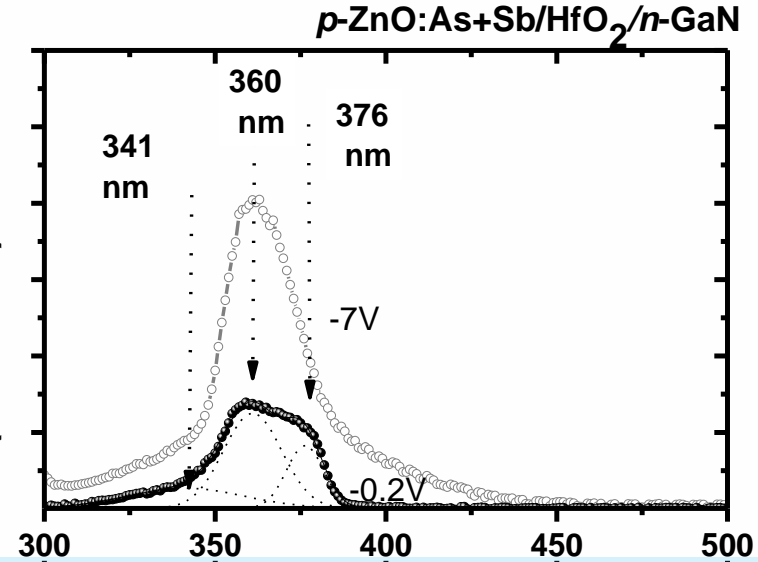
Spectral ranges of the detectors:



p-i-n junction



p-n junction

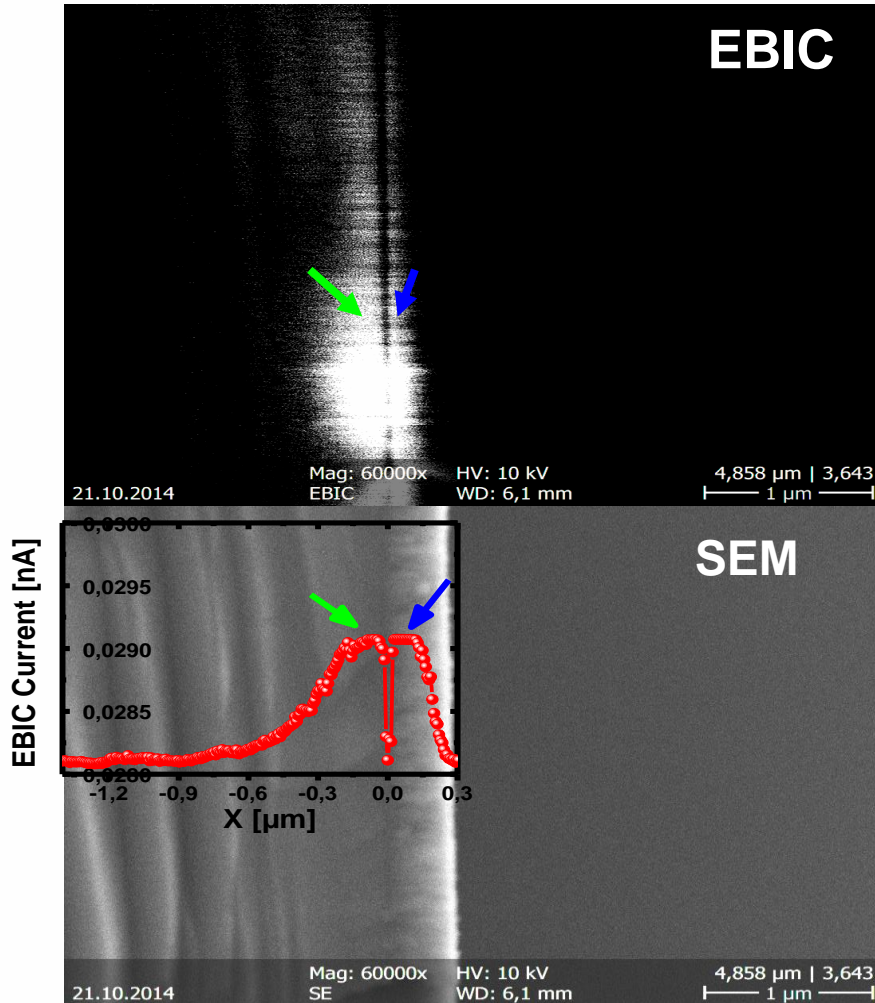


EBIC

EBIC = Electron Beam Induced Current

p-i-n junction at ZnO/Al₂O₃/GaN.

An insulating layer is very well seen!



Summary - main results:

- UV wavelength-selective detection: *p-n* and *p-i-n* heterostructures
- Low dark current
- Large difference between white I_w and dark current I_d

$$I_w / I_d \sim \text{up to } 10^4$$

- The response time less than 2 msec
- *p-i-n* structures - lower leakage current, noise, and better wavelength selectivity

Summary

At least 3 requirements out of the **5S** rule are satisfied

1. high *sensitivity*
2. high *spectral selectivity*
3. high *speed*

We work on:

high *signal-to-noise* ratio and high *stability*

Other results:

1. Two patent applications in Poland

2. Publications:

- E Przeździecka *et al.* *J. Phys. D: Appl. Phys.* 46, 035101 (2013)
Characteristics of ZnO:As/GaN heterojunction diodes obtained by PA-MBE
- E Przeździecka *et al.* *Sensors and Actuators A: Physical* 195, 27 (2013)
Spectrum selective UV detectors from an p-ZnO:As/n-GaN diodes grown by Molecular Beam Epitaxy,
- E. Przeździecka *et al.* *physica status solidi (a)* 211, 2072 (2014)
Dual-acceptor doped p-ZnO:(As,Sb)/n-GaN heterojunctions grown by PA-MBE as a spectrum selective ultraviolet photodetector
- E Przeździecka *et al.* *Key Engineering Materials*, 605, 310, (2014)
PA-MBE Grown p-n (p-ZnO:(As+Sb)/n-GaN) and p-i-n (p-ZnO:As/HfO₂/n-GaN) Heterojunctions as a Highly Selective UV Detectors
- E Przeździecka *et al.* *Appl. Phys. Lett.* 106, 062106 (2015)
Electron beam induced current profiling of the p-ZnO:N/n-GaN heterojunction



Thank you
for your attention

