Photonics & Nanotechnology at Wrocław University of Technology

Faculties at Wrocław University of Technology

(active in photonics & nanotechnology in red)

- Faculty of Architecture
- Faculty of Civil Engineering
- Faculty of Computer Science and Management
- Faculty of Chemistry
- Faculty of Electronics
- Faculty of Electrical Engineering
- Faculty of Enviromental Engineering
- Faculty of Fundamental Problems of Technology
- Faculty of Geoengineering, Mining ang Geology
- Faculty of Microsystem Electronics and Photonics
- Faculty of Mechanical Engineering
- Faculty of Mechanical and Power Engineering

Research in nanotechnology & photonics stimulated and coordinated by:

Centre of Advanced Materials and Nanotechnology

Key groups:

- **Laboratory of Nanotechnology and Semiconductor Structures,** *Faculty of Microsystem Electronics and Photonics*
  prof. Marek Tłaczała (3 professors, 14 research associates, 4 PhD students)

- **Laboratory of Optical Spectroscopy of Nanostructures,** *Faculty of Fundamental Problems of Technology*
  prof. Jan Misiewicz (1 professors, 8 research associate, 4 PhD students)

- **Laboratory of Nonliner Optics,** *Institute of Physical and Theoretical Chemistry, Faculty of Chemistry*
  prof. Andrzej Miniewicz (2 professors, 5 research associate, 2 PhD students)

- **Laboratory of Physics and Chemistry of Molecular Solids,** *Institute of Physical and Theoretical Chemistry, Faculty of Chemistry*
  prof. Juliusz Sworakowski (2 professors, 5 research associate, 2 PhD students)

Key groups:

- **Laser and Fiber Electronics Group,** *Faculty of Electronics*
  prof. Krzysztof Abramski (2 professors, 8 research associates, 8 PhD students)
- **Fiber-Optic Laboratory,** *Faculty of Fundamental Problems of Technology*
  prof. Waclaw Urbanczyk (1 professors, 3 research associates, 2 PhD students)
- **Laboratory of Metrology of Micro- and Nanostructures,** *Faculty of Microsystems Electronics and Photonics*
  prof. Teodor Godszalk (3 professors, 10 research associates, 7 PhD students)
- **Photonics Group,** *Faculty of Microsystems Electronics and Photonics*
  prof. Sergiusz Patela (1 professors, 2 PhD students)
- **Photonics Group,** *Faculty of Microsystems Electronics and Photonics*
  prof. Sergiusz Patela (1 professors, 2 PhD students)
- **Group of Theoretical Modelling of the Physical Phenomena in Nanostructures and Devices,** *Faculty of Fundamental Problems of Technology*
  prof. Lucjan Jacak

Key groups:

Staff overall: 14 professors, 53 research associates, 31 PhD students

- 250 journal publications in last 5 years
- 24 patents
- 18 PhD theses completed in last 5 years

Teaching of Photonics and Nanotechnology:

Materials Engineering	- 200 students
Optocommunications	- 120 students
Optoelectronics	-150 students
Microsystems	- 120 students
Applied Physics and Photonics	-160 students

Overall about 140 MS students each year

New opportunities :

Erasmus Mundus Masters, *Molecular nano- and bio-photonics for telecommunication and biotechnologies* – **MONABIPHOT**

International collaboration:

- ZODIAC „Zero order dimension based industrial components applied to telecommunications” – 6th FP of EU
- NEMO „Network of Excellence on Microoptics”-6th FP of EU
- BIMORE - 6th FP of EU
- GIFT „GaAs-based emitters for fibre-optical data and telecommunication” – 5th FP of EU
- CERION 2 „Canadian European Research Initiative on Nanostructures -2” – 5th FP of EU
- IST Nanoelectronics Network „PHANTOMS”, – 5th FP of EU
- SQID Semiconductor-based quantum information device – 5th FP of EU
- Quantum information processing network of excellence – 5th FP of EU
- Optical and electronic properties of nanoscale systems – Nato Collaborative Linkage Grant

International collaboration:

- ADAPTOOL - 5th FP of EU
- COST ACTIONS: 299, 291, P11
- „NATO Collaborative Linkage Grant" – „Synthesis of luminescent xerogel films embedded in porous anodic alumina", cooperation with University of Manchester, UK and Belarusian State University of Informatics and Radioelectronics, Belarus
- Collaboration with Japan:

  - *Development of intelligent materials and devices based on CT complexes with nano-structure*, grant from the New Energy and Industrial Technology Development Organization (NEDO)

  -*Dynamics of photo-induced collective transformations in molecular materials*, collaboration founded by governments of Japan, France, and Poland.

International collaboration:

Center of Advanced Materials and Nanotechnology (WUT) is a member of:

EPIC
European Photonics Industry Consortium

and

ACCORD

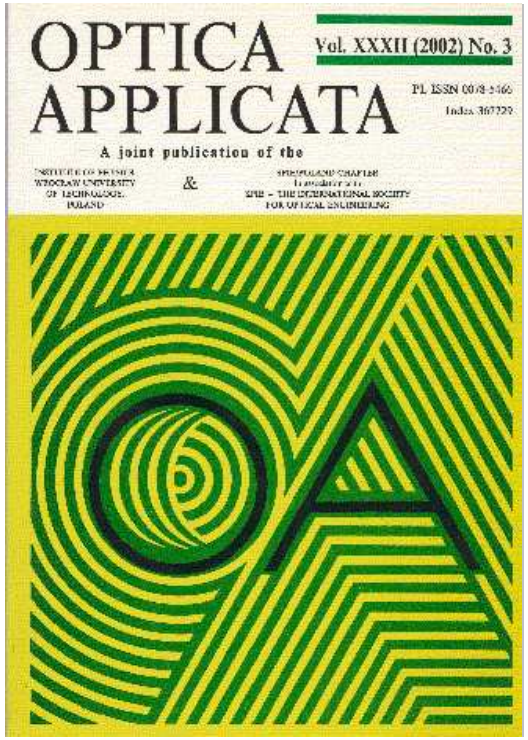
Advanced Components Cooperation for Optoelectronics Research and Development

2006 – 2009, 6th FP of EU

Scientific journals indexed by SCI:

Materials Science

an interdisciplinary Journal of Physics, Chemistry and Technology of Materials



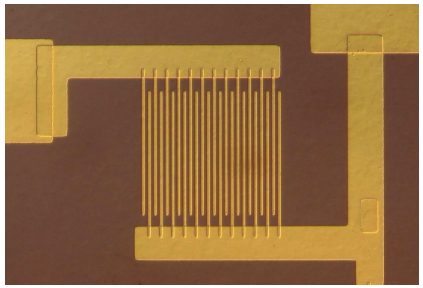
Wrocław University of Technology

Laboratory of Nanotechnology and Semiconductor Structures

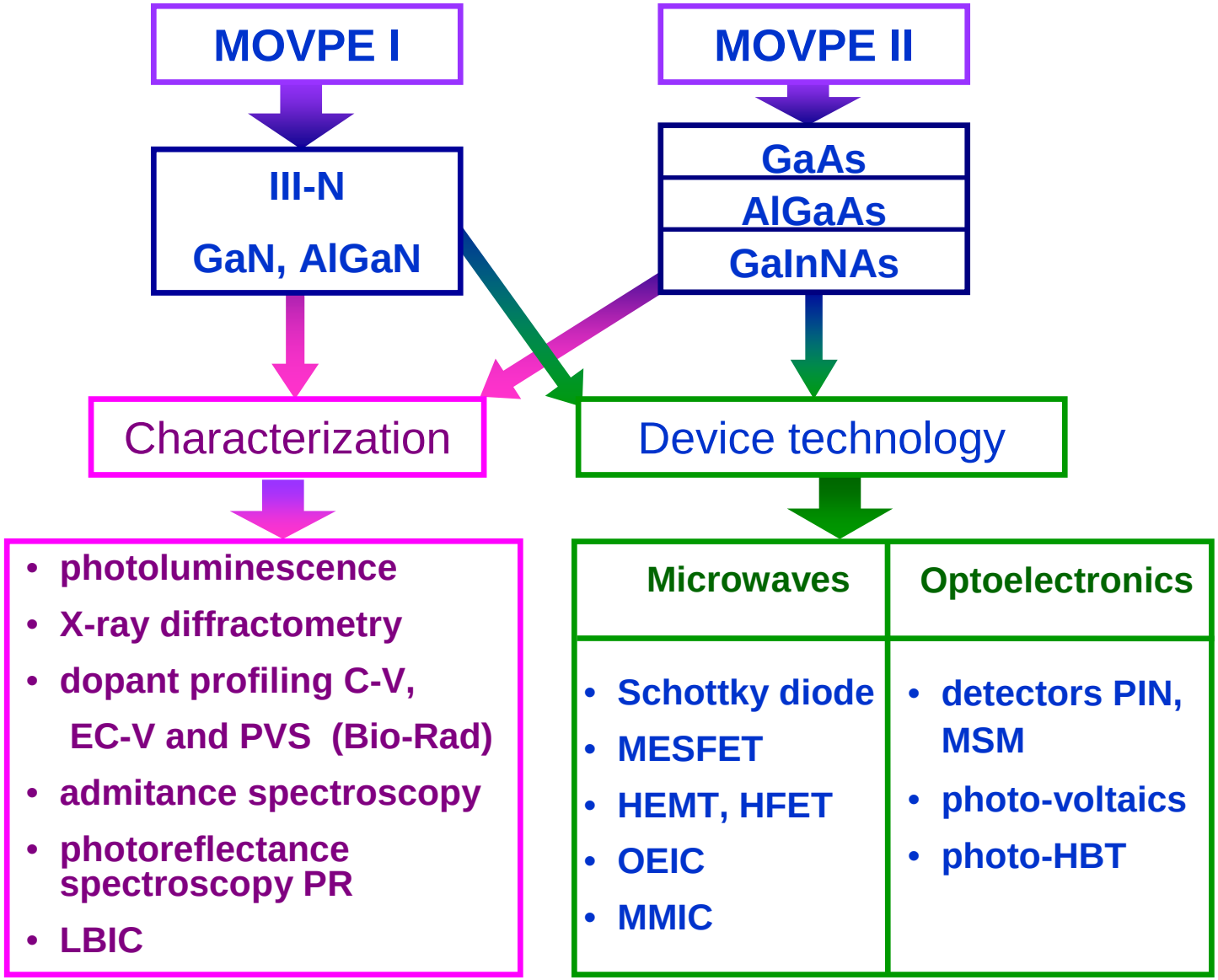
Faculty of Microsystem Electronics and Photonics

http://www.wemif.pwr.wroc.pl/zpp

head: prof. Marek Tłaczała, *marek.tłaczała@pwr.wroc.pl*



Main research interests



Wrocław University of Technology

Laboratory of Nanotechnology and Semiconductor Structures

clean room: 200 m²; class < 10 000

clean room: 15 m²; class 100

MOVPE epitaxial systems

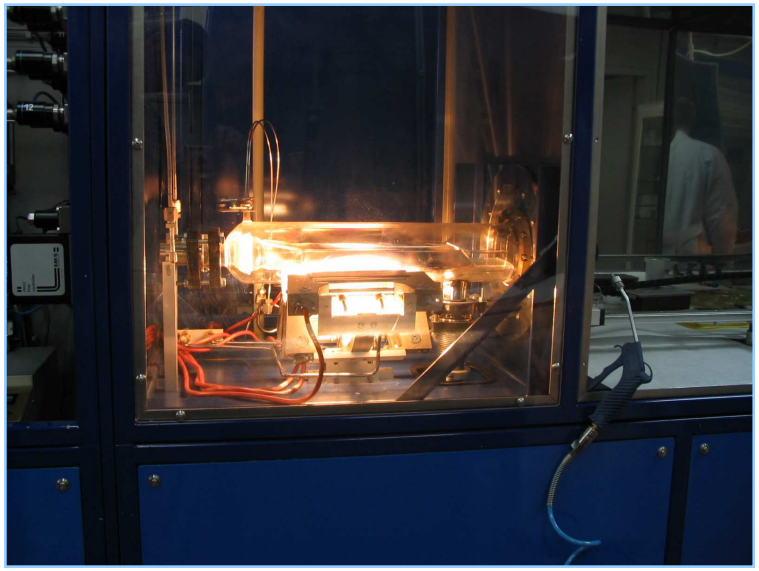
Plasma etching

Metallic contacts evaporation system

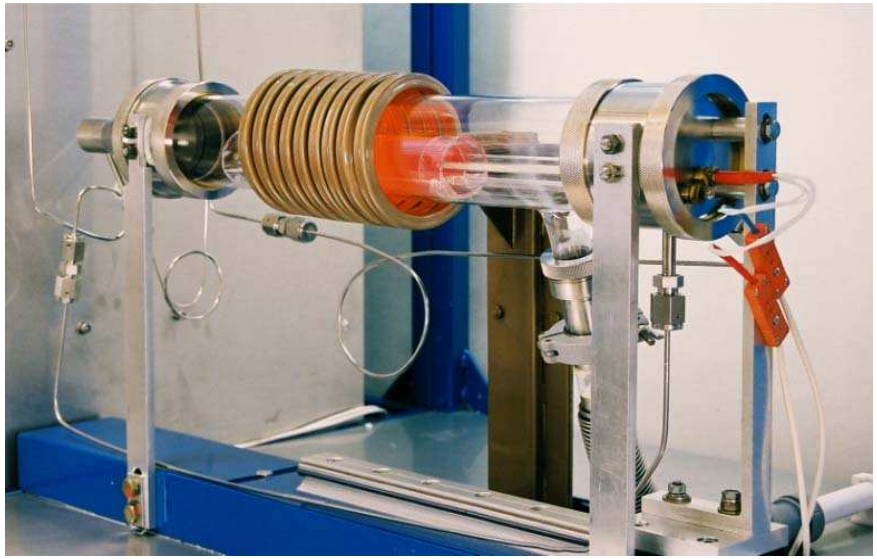
Millipore ultrapure water system

Safety system

MOVPE technique

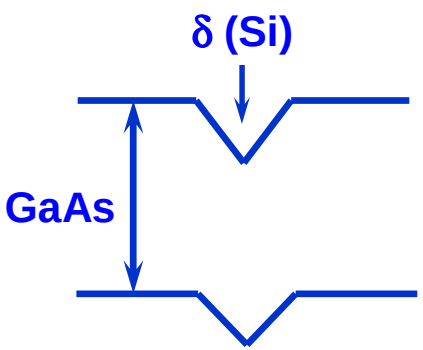


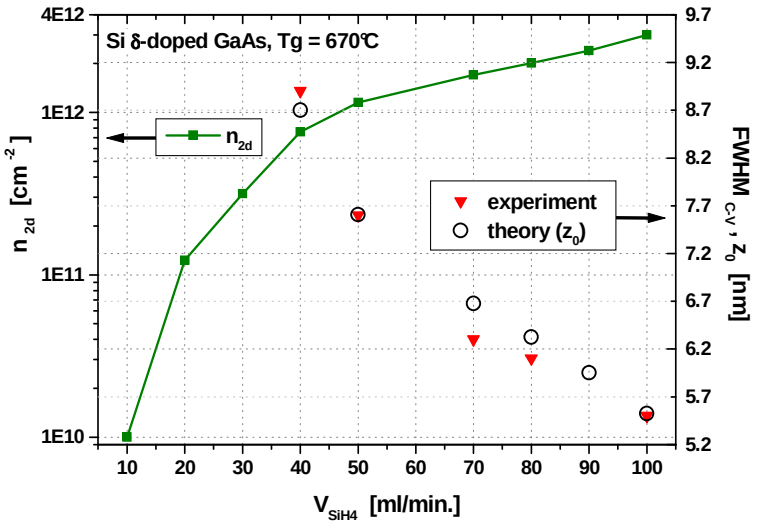
(Ga,Al,In) (As,N)
on GaAs substrate



(Al,Ga,In) N
on sapphire, SiC, Si substrates

Delta (δ) - doped structures



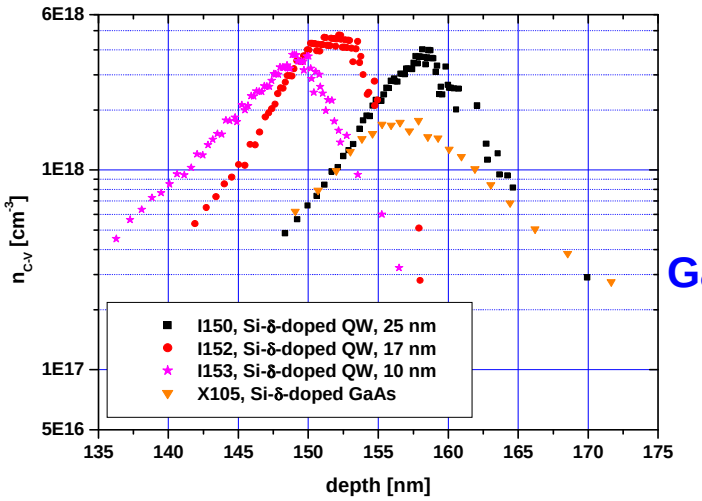


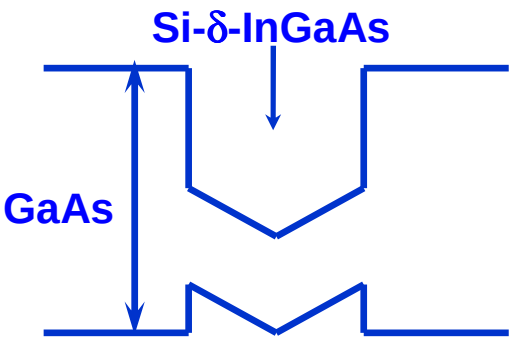
Si (n) and Zn (p) δ-doped GaAs:

- **$FWHM_{C\text{-}V}$ ~ 5 nm (Si)**
- **$FWHM_{C\text{-}V}$ ~ 8 nm (Zn)**

Si-δ-doped InGaAs/GaAs SQW

($FWHM_{C\text{-}V}$ < 3 nm)





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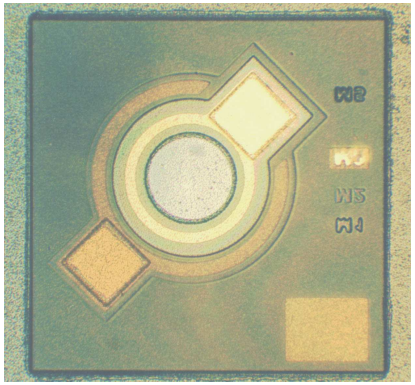
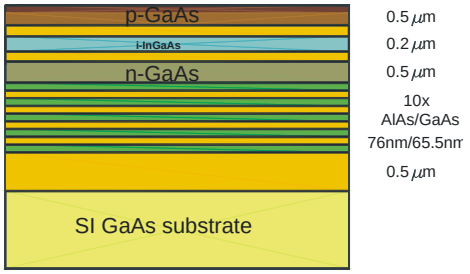
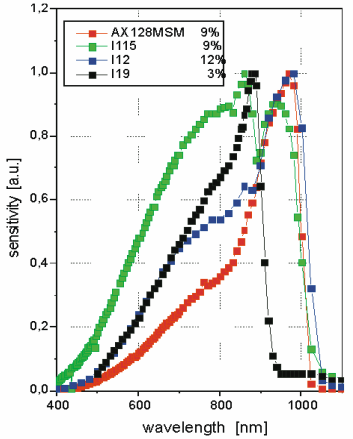
MSM and PIN photodetectors





The epitaxial structure of RCE PIN detector



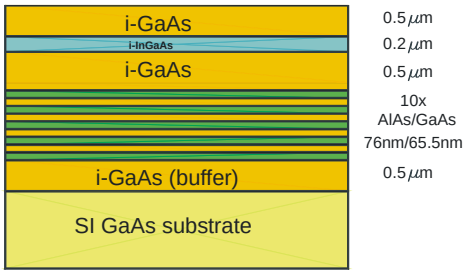
Spectral characteristic
of MSM and PIN detectors

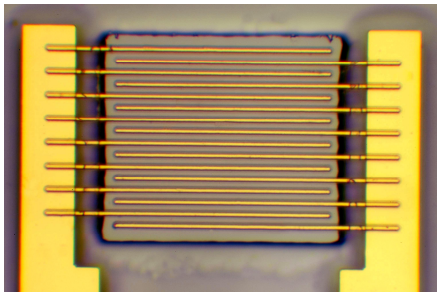
	PIN	MSM
dark current	1 nA at 20V	100 nA at 5V
capacitance	5 pF at 10V	0.2 pF
responsitivity	0.3 A/W	0.35 A/W
active surface dimensions	diam.= 150 um	80 um x 50 um

InGaAs/AlGaAs/GaAs growth by MOVPE technique

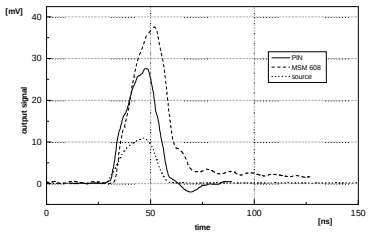
Ohmic contacts: AuGe/Ni/Au for n-type
Ti/Ni/Au for p-type

Schottky contacts: Ti/Pd/Au or Ti/Pt/Au



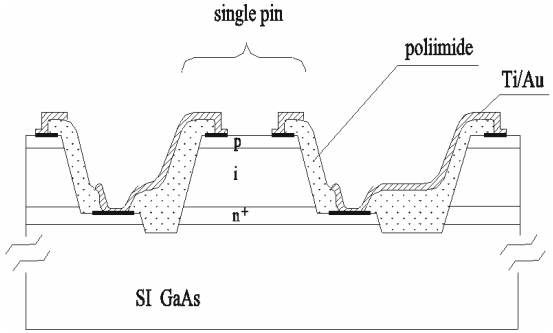


The epitaxial structure of RCE MSM detector

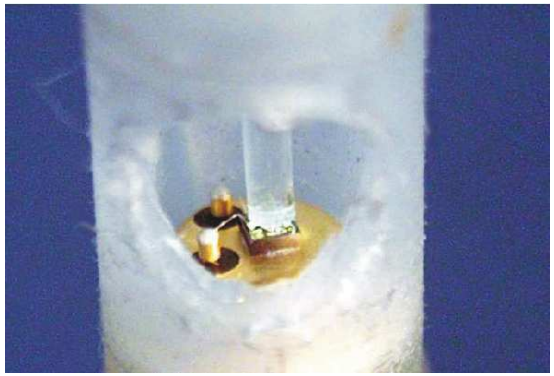


Optical pulse response
of the MSM and PIN detectors

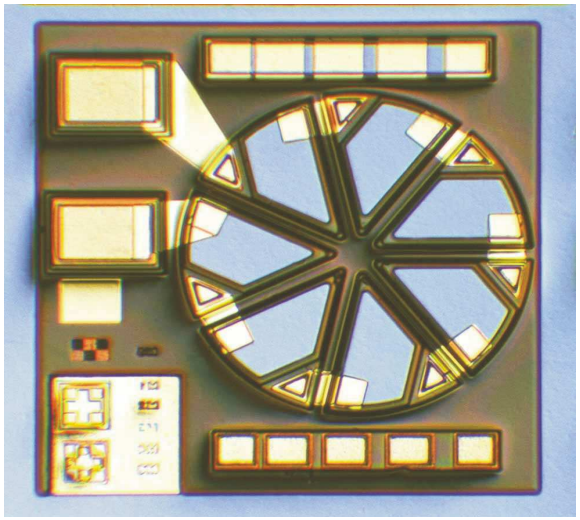
GaAs photovoltaic micro-array



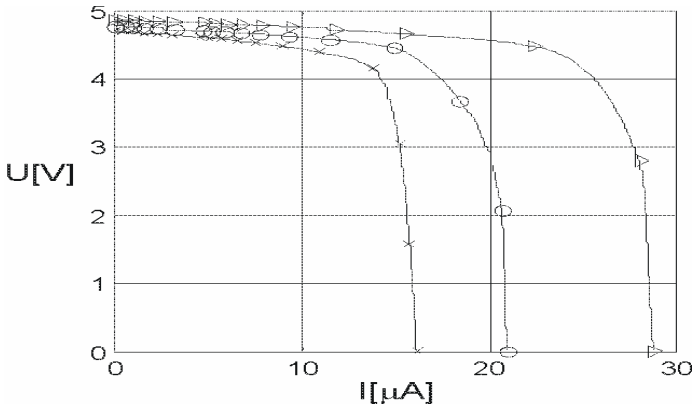
Schematic cross-section of a single p-i-n photovoltaic structure



Photovotaic cell coupled to a plastic optical fibre



Top view of the planar photovoltaic array



I-V characteristics of the array

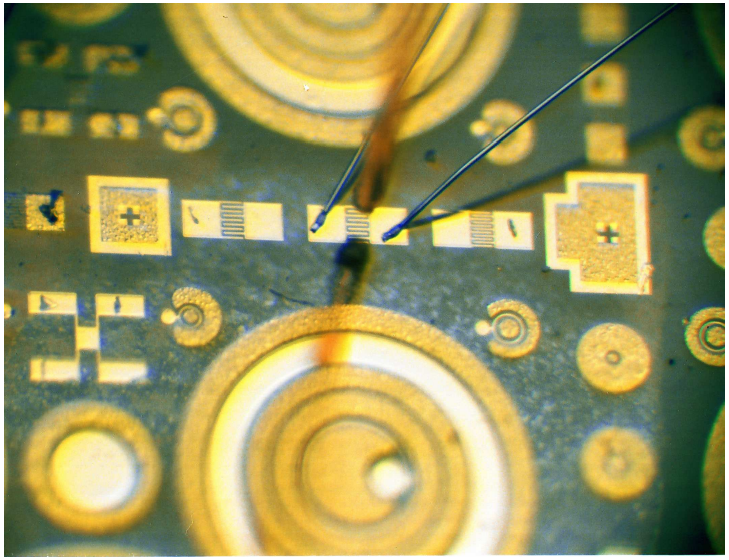
Electrical parameters :

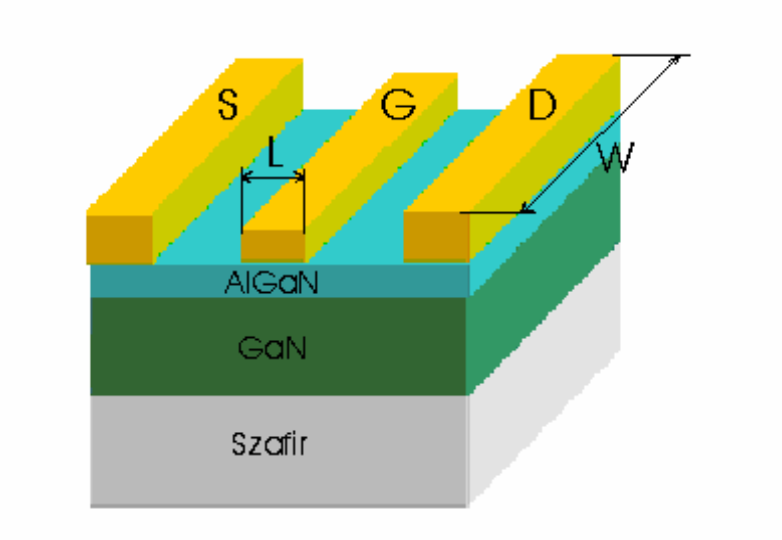
open circuit voltage: 4.6V

zero bias capacitance: 3pF

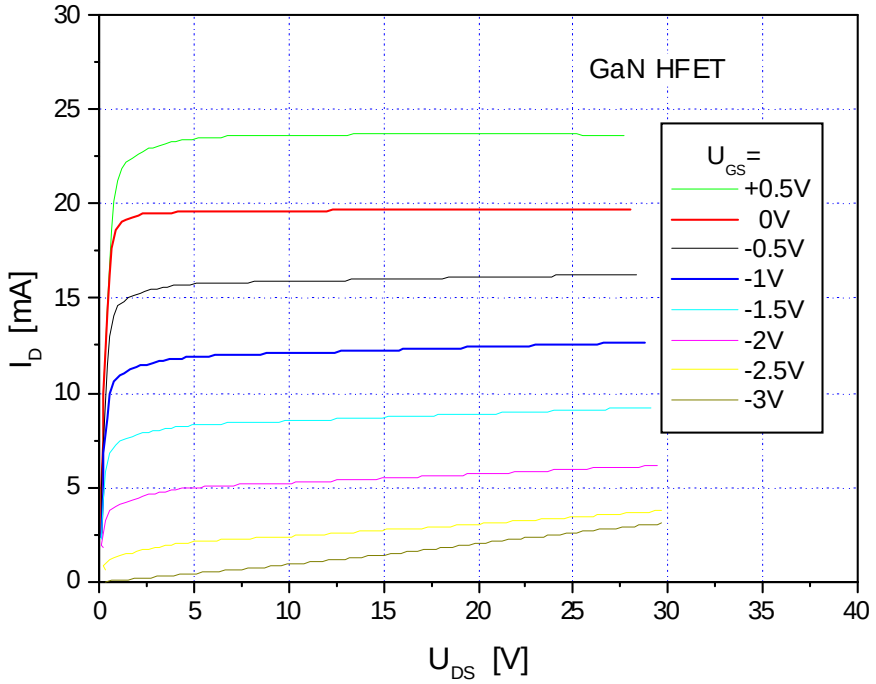
Application: remote power supply - fibre light activated

GaN devices: Schottky diodes, HFETs

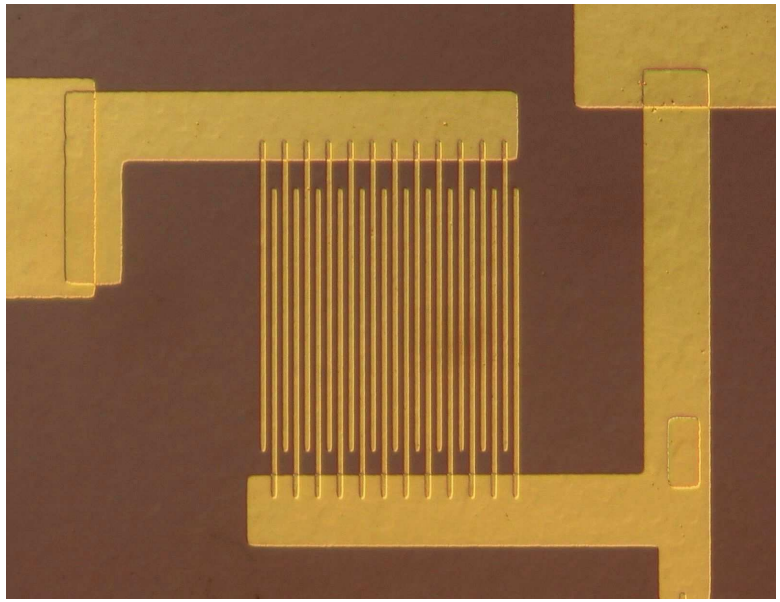




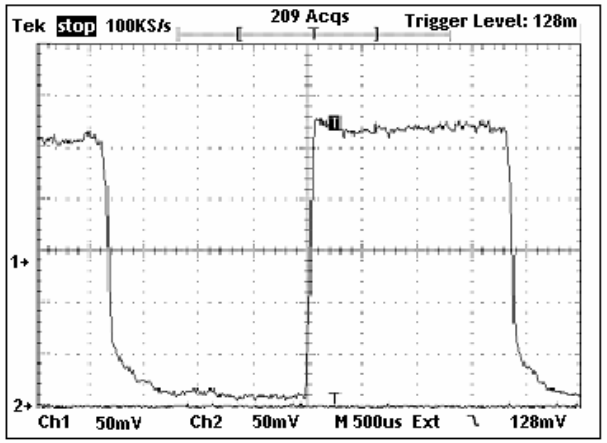
AlGaN/GaN HFET



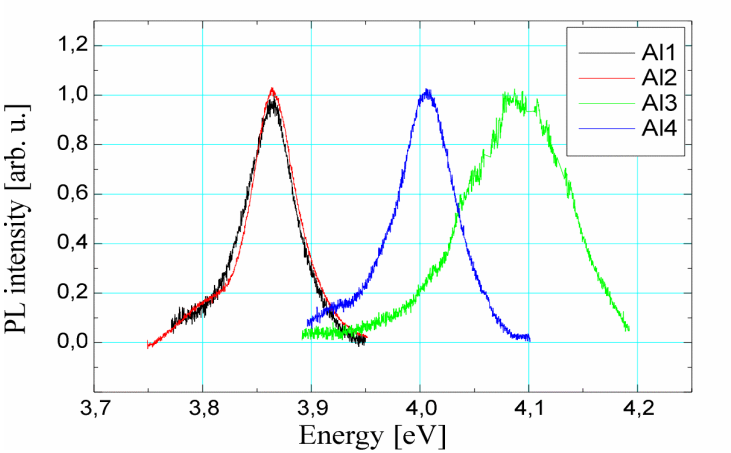
GaN MSM UV photodetectors



Pt/Au Schottky contacts,
3 μm finger geometry

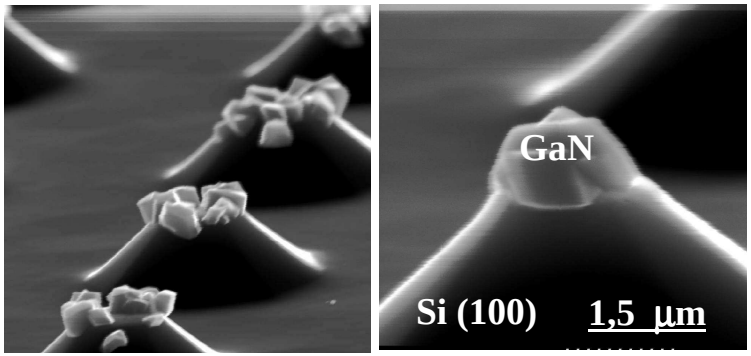


P_{opt} =70 μW ; 305nm laser pulse
Responsivity 0.1 A/W

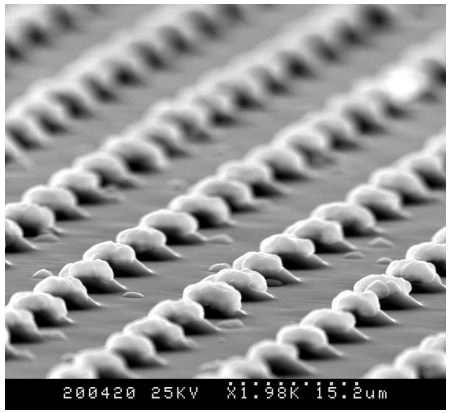


Photoluminescence spectra for
different AlGaN compositions

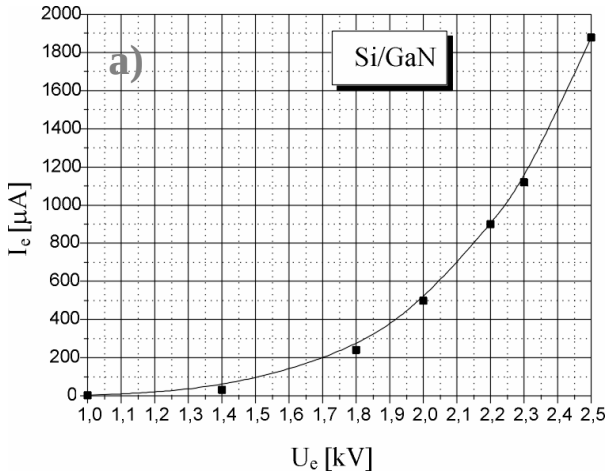
GaN-Si tips for field emitters

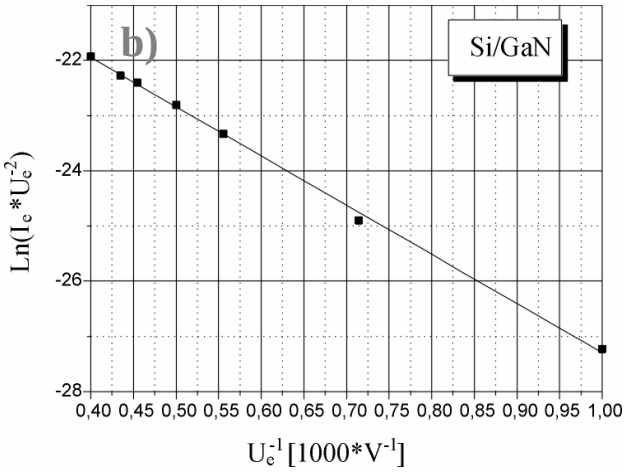


Si tips covered with GaN



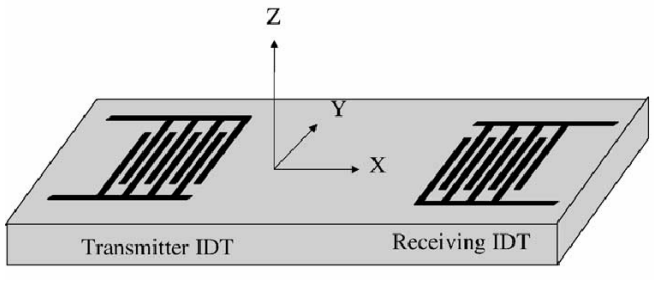
The array of 42x42
Si/GaN emitters



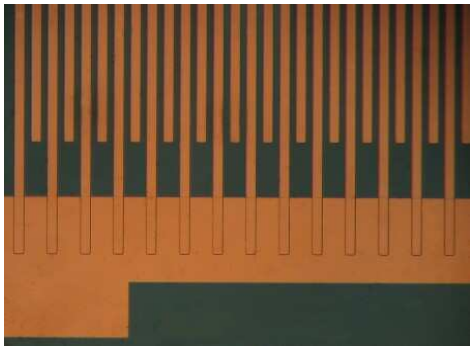


I-V characteristic (a) and
the Fowler – Nordheim plot for
the array of GaN/Si emitters (b)

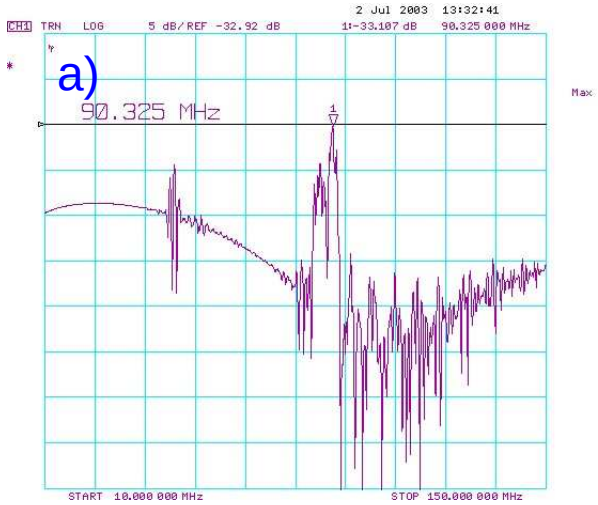
GaN SAW (Surface Acoustic Wave) transducers for high temperature piezoelectronic and sensor applications

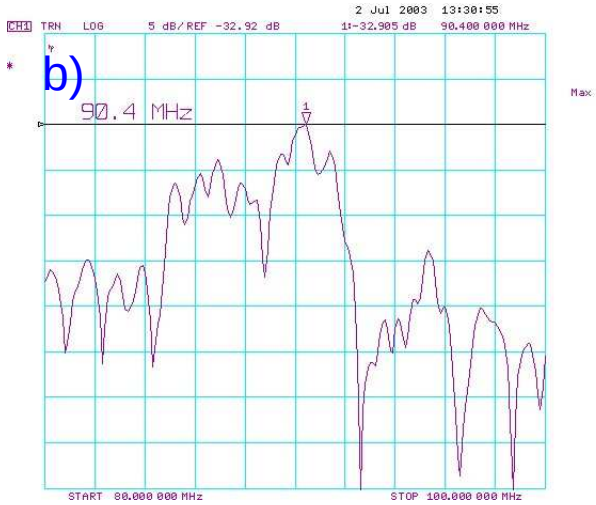


Surface acustic wave interdigitated transducer



A detail of the fabricated SAW transducer





Frequency response characteristics of the GaN/$Al_{0,147}Ga_{0,853}N$/sapphire transducer measured: in 10-150MHz range (a), near the fundamental frequency 90,4 MHz (b)

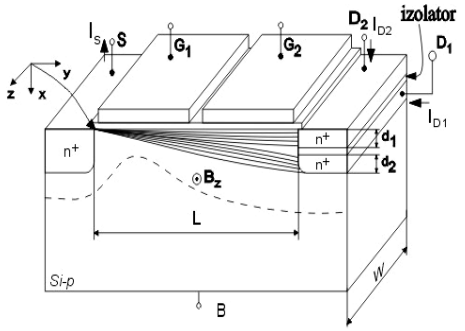
New magnetic field sensor – HSD MAGFET

Theoretical and experimental studies of a new magnetic field sensor

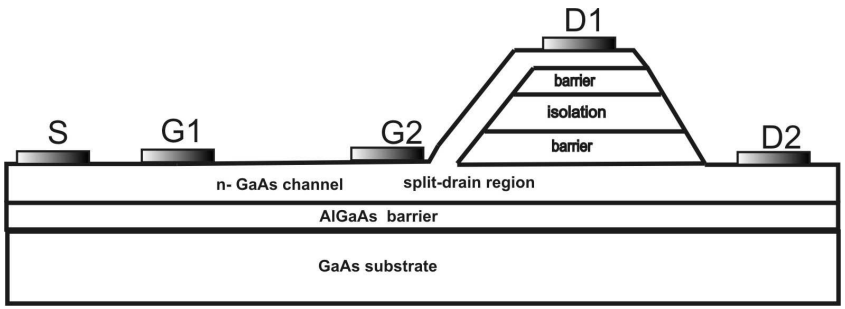
- Horizontaly Split-Drain Magnetic field-sensitive Field Effect Transistor – HSD MAGFET

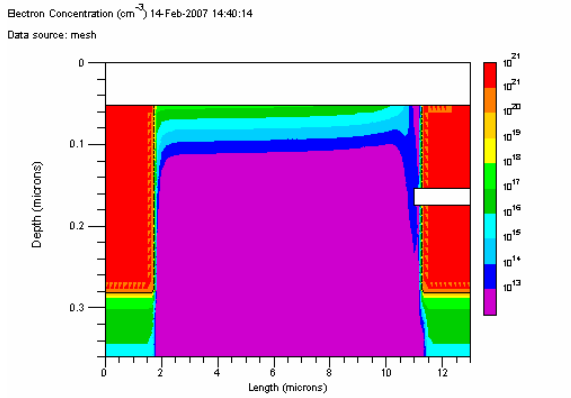
- GaAs MESFET-based HSD MAGFET

  sensor advantages:
  - high magnetic field spatial resolution
  - very high sensitivity



- Si MOS-based HSD MAGFET

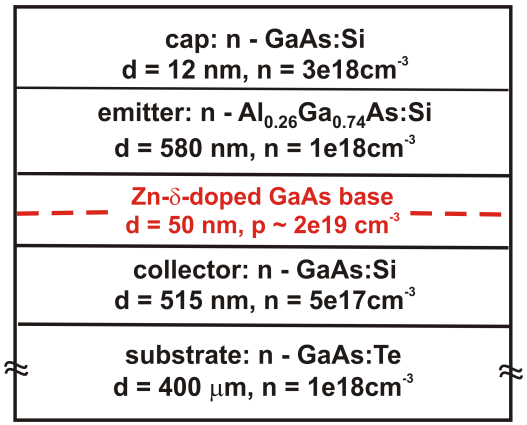




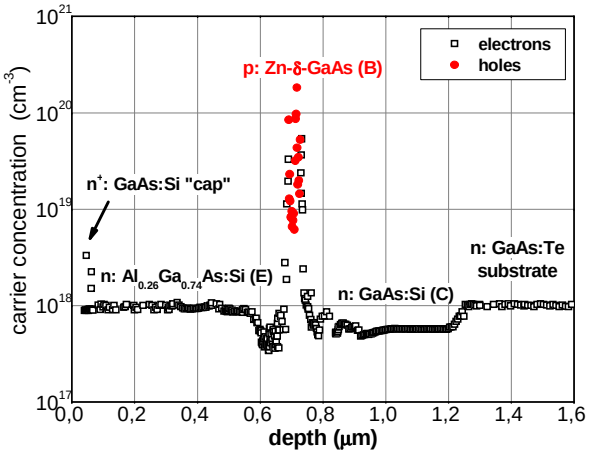
W. Kordalski, B. Boratyński, I. Zborowska-Lindert, M. Panek, B. Ściana, M. Tłaczała: *A new magnetic field sensor MagFET*, Patent pending, 2007.

Wrocław University of Technology

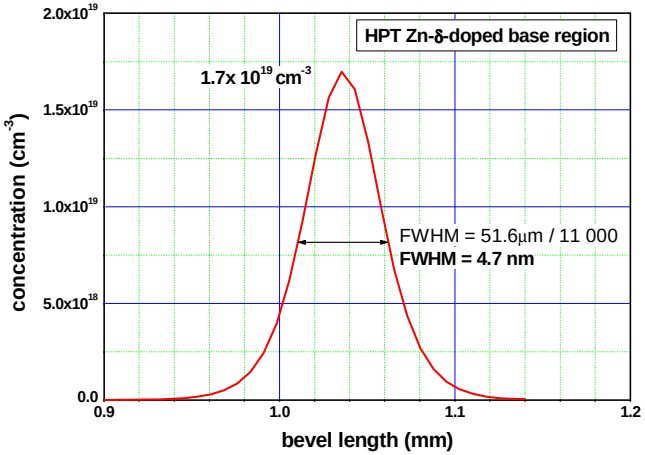
Heterojunction Bipolar Phototransistor - HPT



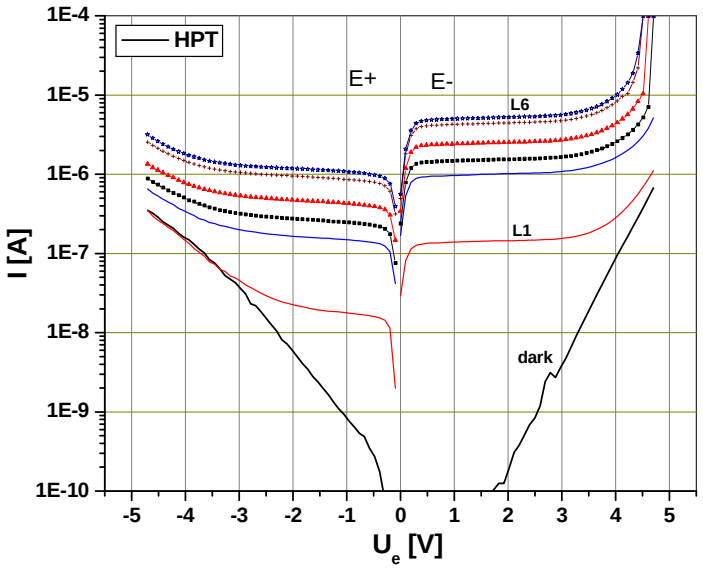
Epitaxial structure of HPT transistor



EC-V profile of HPT transistor



Zinc distribution inside the base region estimated by micro-Raman spectroscopy



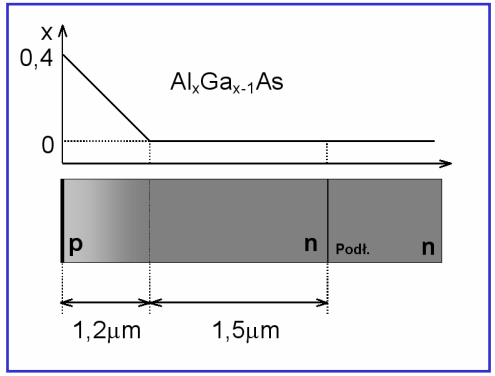
DC I-U dark and light (white) characteristics of HPT transistor

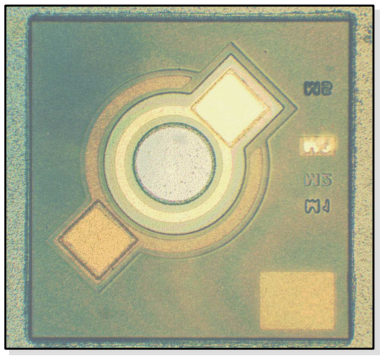
The work is focused on:

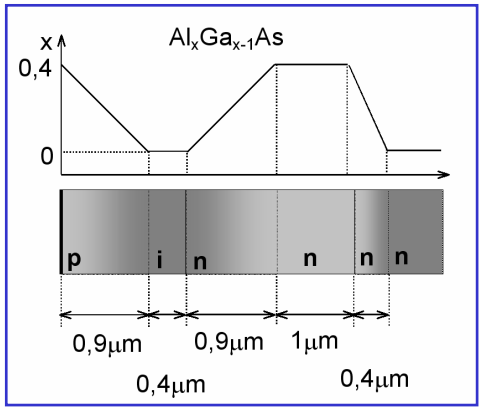
- investigation of the influence of delta doping introduced into base region on HPT characteristics,
- optimisation of delta doping processes and the base thickness to increase the gain and speed of HPT (APMOVPE technique),
- investigation of the influence of base material and configuration on the device performance,
- optimisation of the technological processes (epitaxy, surface shaping, passivation processes, metalisation, light introduction),
- fabrication of the HPT transistor model,
- measurements of time response, gain and current responsivity of the HPT test structures.

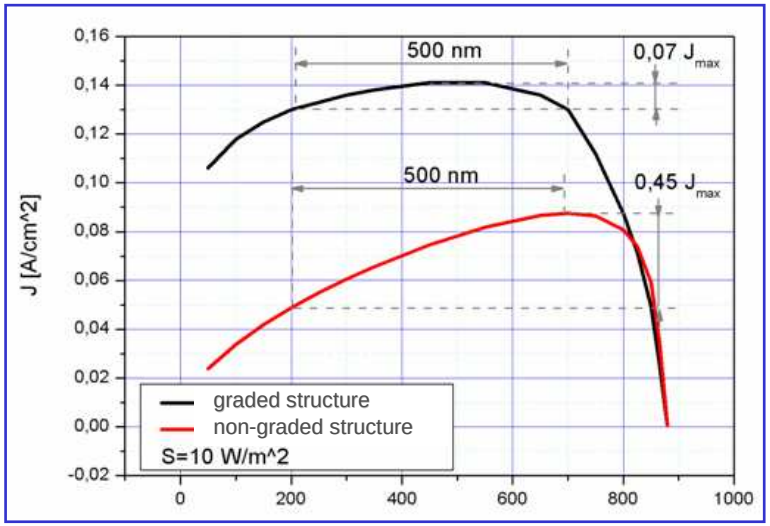
Ministry of Scientific Research and Information Technology grant No. N 515 002 31/0239: "Construction and technology of heterostructures for phototransistor application"

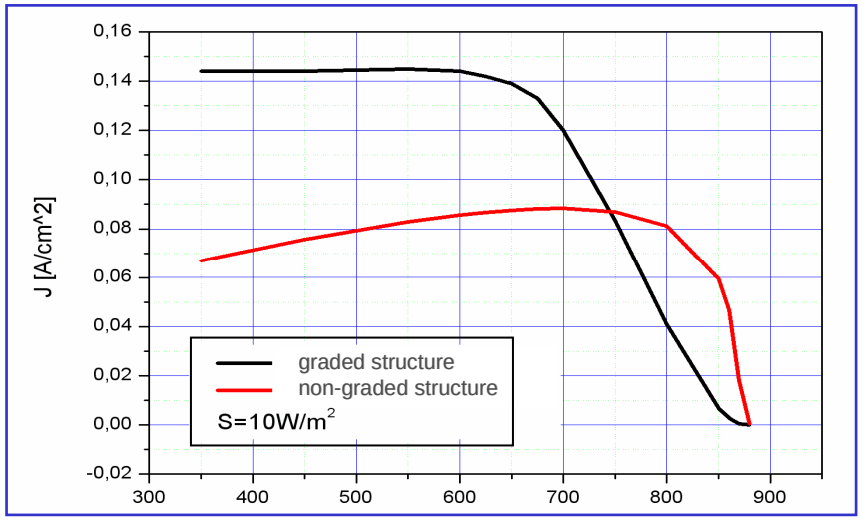
p-n detector with functionally graded active area











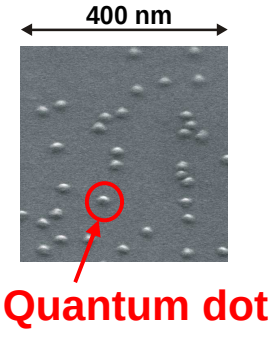
- **Spectral characteristic of photodetector can be formed by: material selection, modification of the profile of compositional gradient and changing the device geometry**
- **FGM (Functionally Graded Materials) are potential candidates for high sensitive photonic devices which could operate in a wide spectral range and for voltage tunable photodetectors**

Wrocław University of Technology

Laboratory of Optical Spectroscopy of Nanostructures

Institute of Physics
Faculty of Fundamental Problems of Technology

head: prof. Jan Misiewicz, ***jan.misiewicz@pwr.wroc.pl***

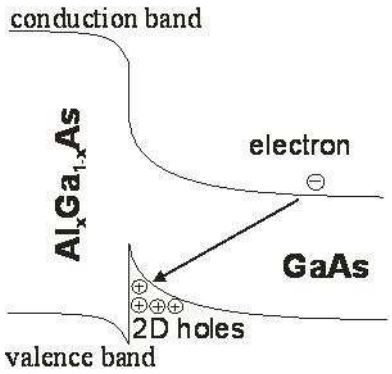


Main research interests

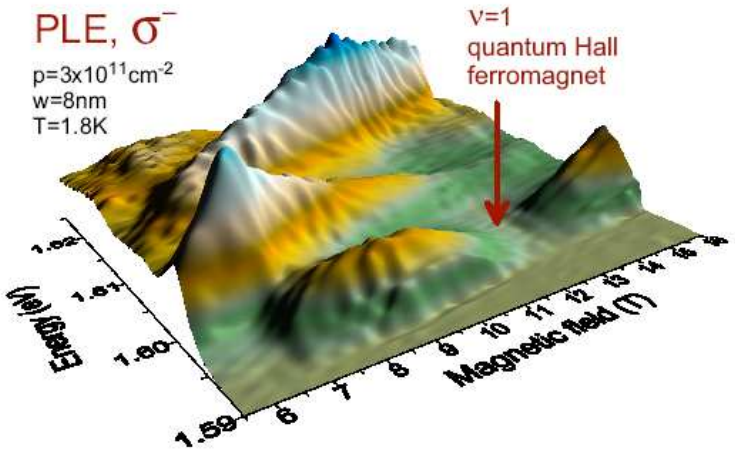
The GAOS includes the use of modulation techniques, such as photoreflectance (PR), contactless electroreflectance (CER), photoluminescence (PL) and photoluminescence excitation (PLE) in:

- ✓ **spectroscopy studies of many body interactions in 2D systems (skyrmions, trions)**
- ✓ **optical properties of low-dimensional semiconductor systems: quantum wells, quantum dots and dashes, superlattices, heterojunctions, etc.**
- ✓ **spectral characteristics of semiconductor optoelectronic devices: lasers, infrared photodetectors, Bragg reflectors, resonant cavities**
- ✓ **optical properties of group III nitrides and HEMT structures based on AlGaN/GaN**
- ✓ **properties of group III-V diluted nitrides and other N-containing multinary compounds**
- ✓ **semiconductor nanocrystals properties**
- ✓ **investigations of the photoluminescence of rare earth and transition elements in sol-gel on various films**

Magnetoptics of quantum structure in quantum Hall regime

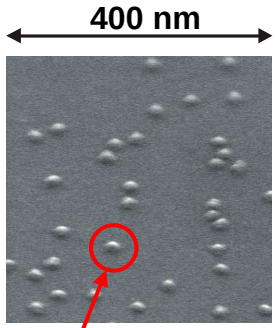


Spatial separation of optically excited carriers reduces Coulomb interaction between electrons and holes which allows studies of two dimensional holes.



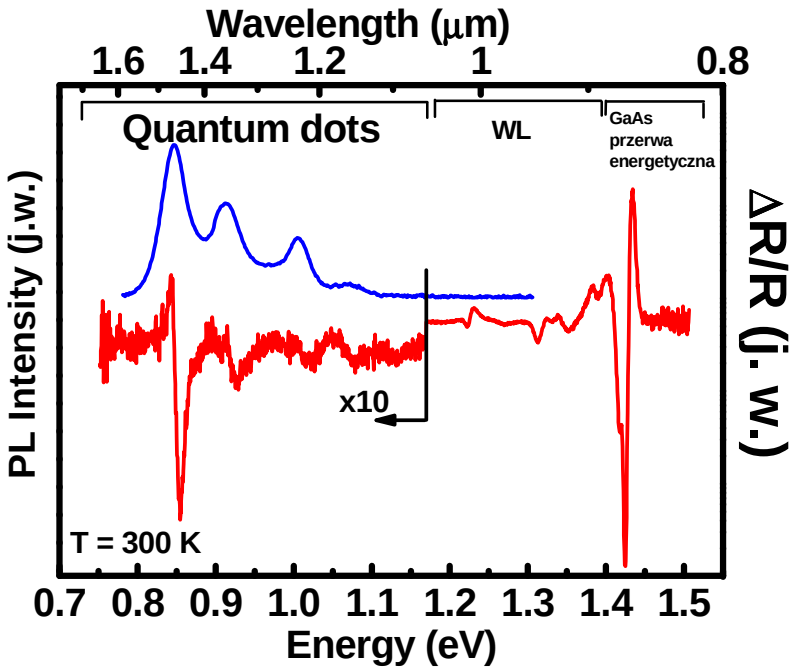
Quantum Hall skyrmions in a hole gas with Large Spin Gap

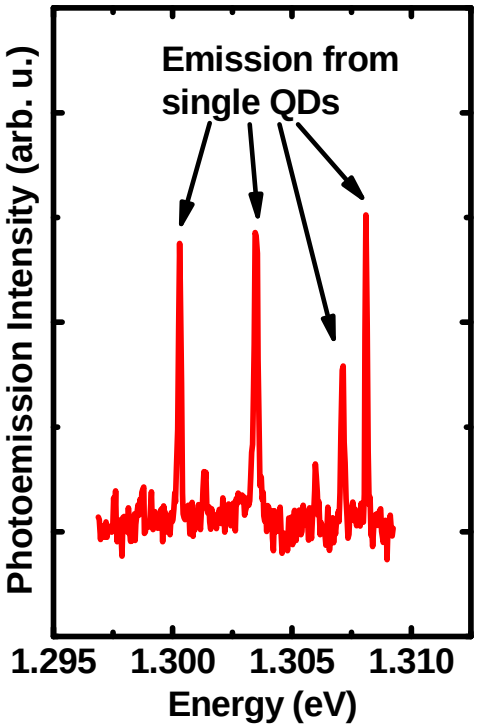
Optical modulation spectroscopy of semiconductor quantum dots



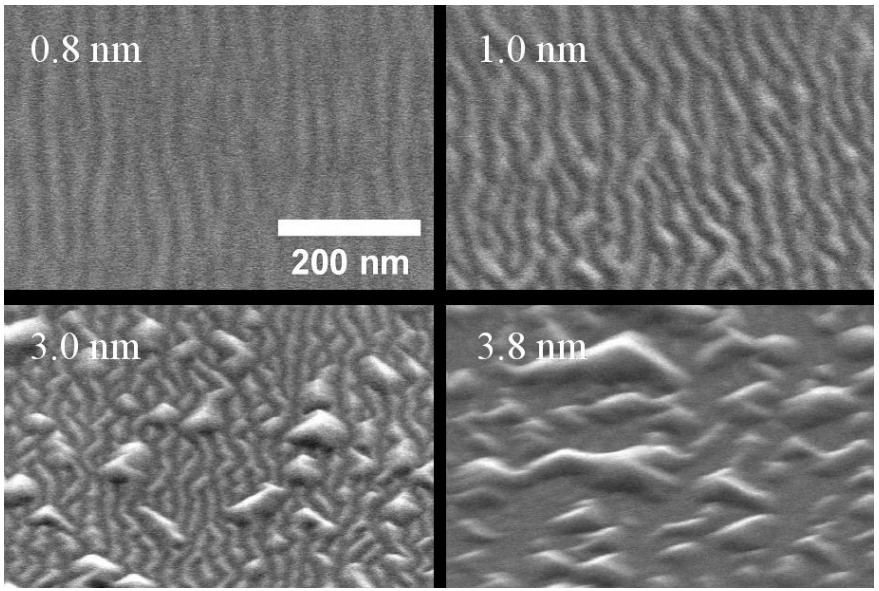
Quantum dots – nanometer scale objects confining electrons and/or holes in three dimensions

QDs as artificial atoms - offer atomic-like properties in solid state system



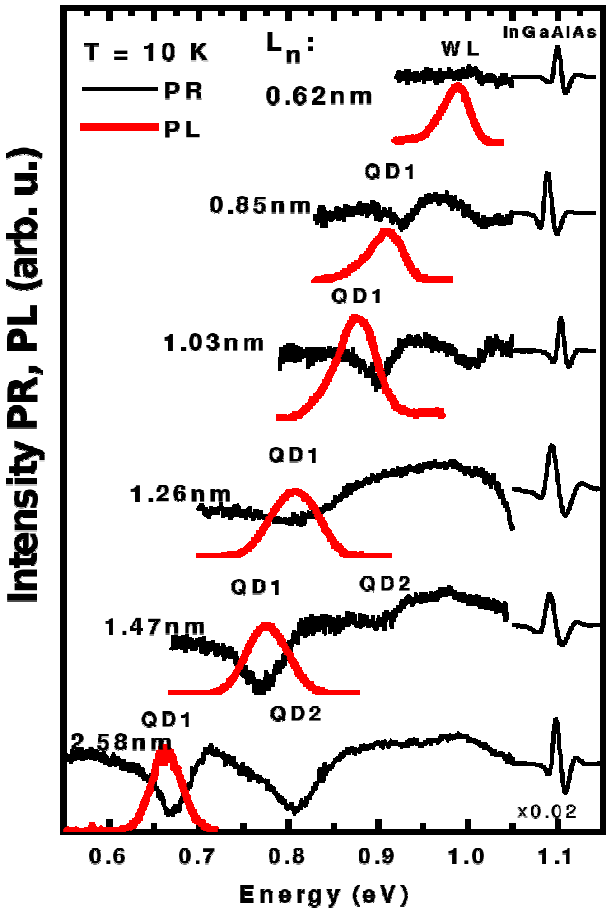


Optically probed InAs/InGaAlAs/InP quantum-dash structures



Quantum dashes – elongated dots, growing along one of crystallographic axis, suitable as emitters for 1.55 micron telecommunication window

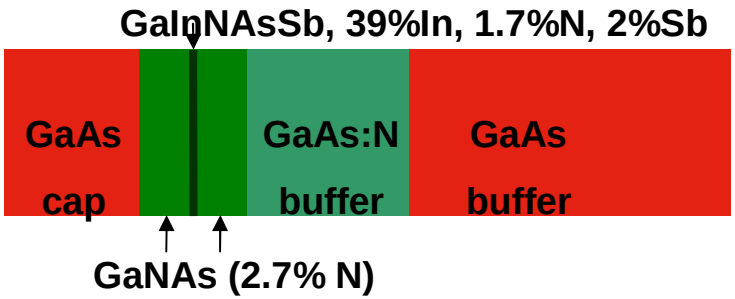
Photoreflectance probes the excited states of Quantum Dash structures, giving the information on confined states, useful for laser structure design and modeling



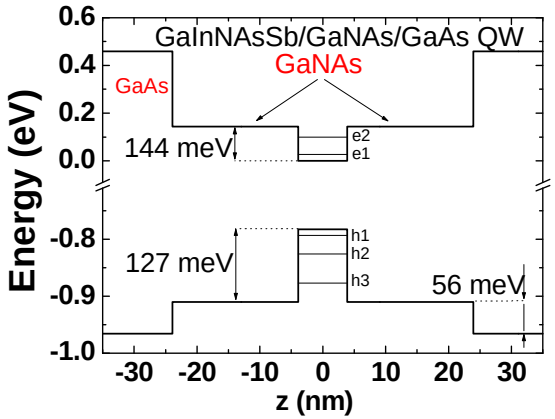
Optical modulation spectroscopy of semiconductor quantum wells

Semiconductor quantum well operating in the 1.55μm wavelength range

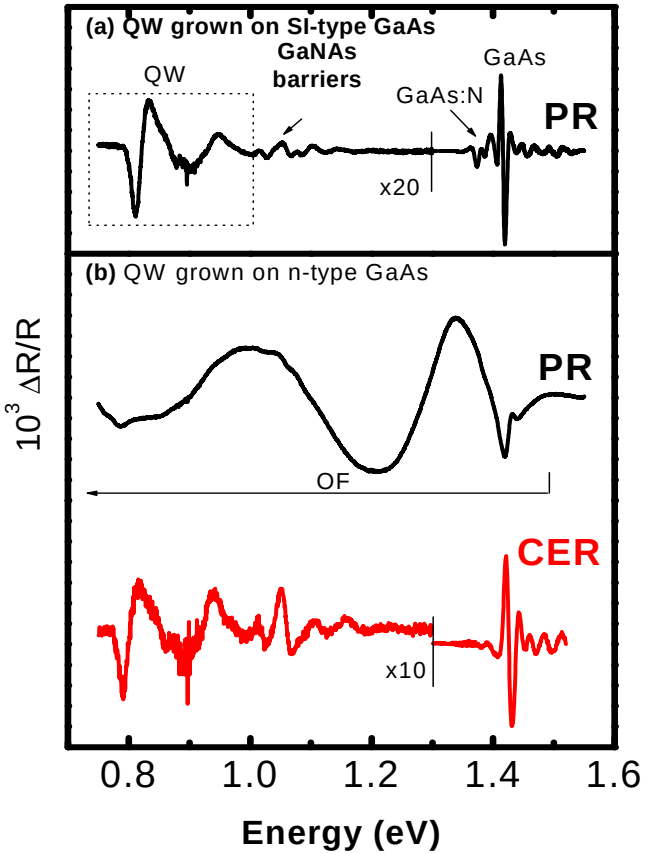
Step like quantum well structure



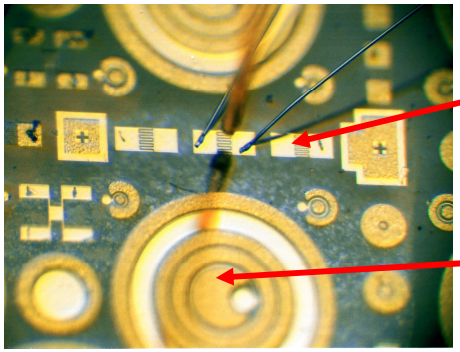
Energetic profile

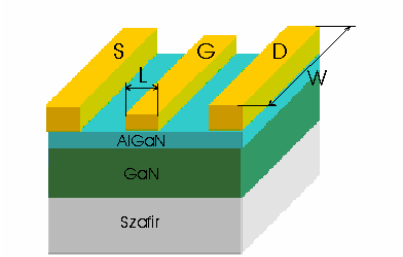


Electro modulation spectra

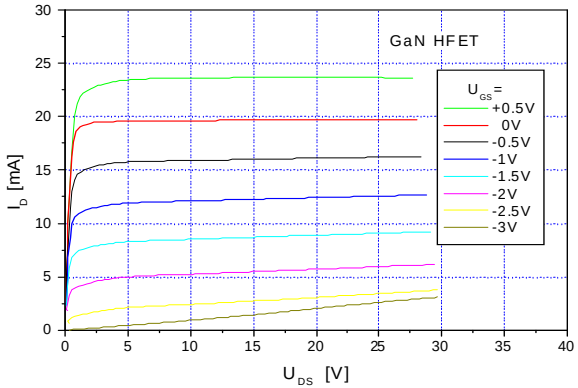


GaN devices: Schottky diodes, HFETs, MSM photodetectors

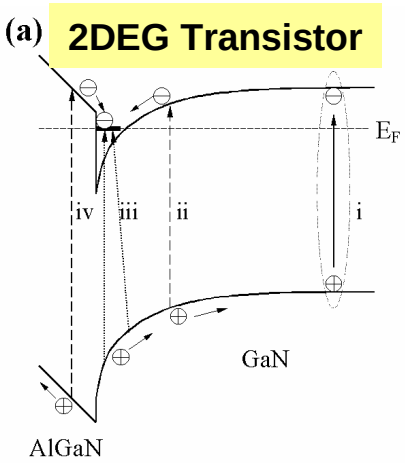




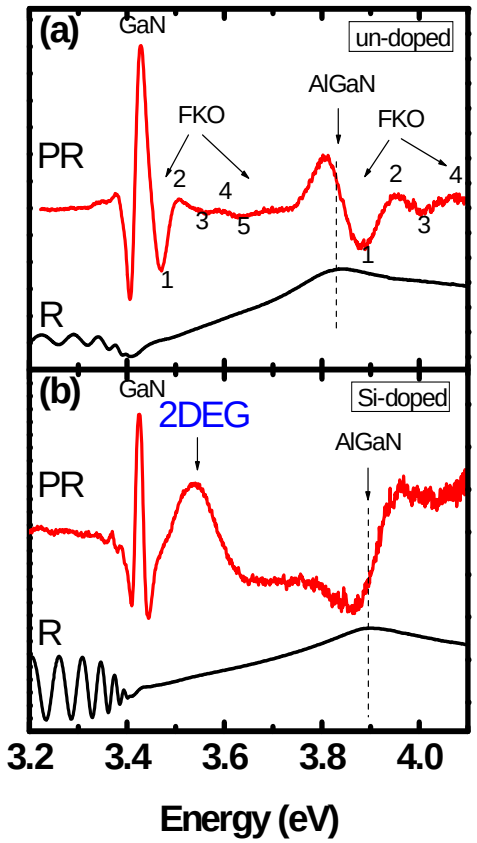
AlGaN/GaN HFET



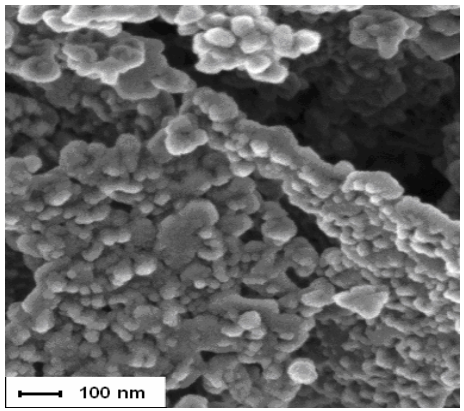
2DEG Transistor



Optical spectra

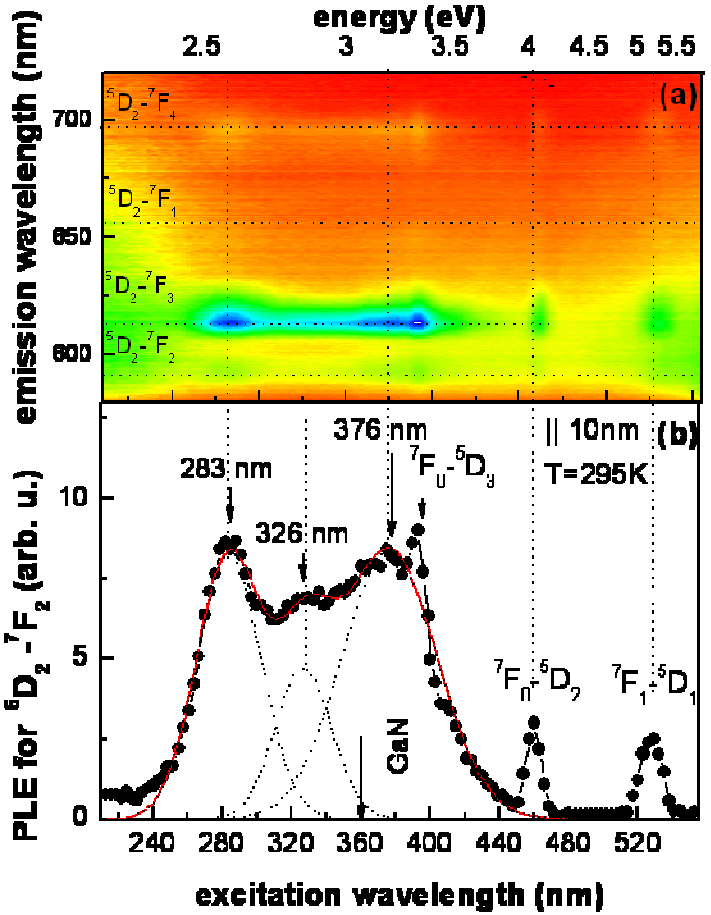


Optical investigations nanocrystals doped by rare earth (Eu, Tb, Er,...)



GaN:Eu3+ nanocrystals (ϕ~9nm)

Emission from Eu3+ ions is enhanced by energy transfer from the GaN nanocrystals and related defects.

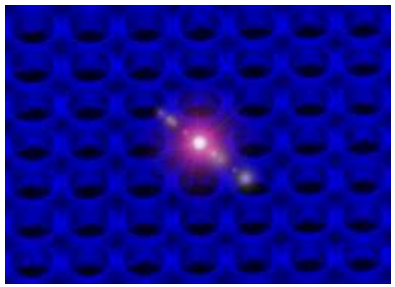


Wrocław University of Technology

Nonlinear Optics Laboratory

Institute of Physical and Theoretical Chemistry
Faculty of Chemistry

head: prof. Andrzej Miniewicz, *andrzej.miniewicz@pwr.wroc.pl*

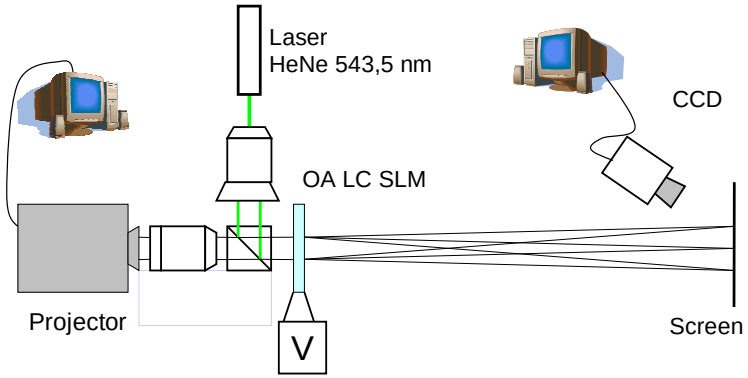


Main research interests

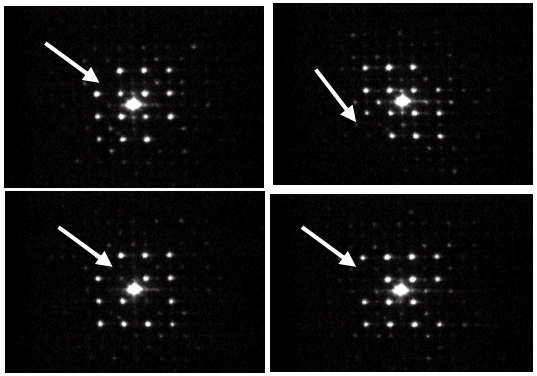
- ✓ **Organic materials for photonics**
- ✓ **Optical information processing and storage**
  - **Photorefractive liquid crystals**
  - **Azo-functionalized photochromic polymers**
  - **Bio-inspired (DNA-based) photonic materials**
  - **Development of optically addressed liquid crystalline spatial light modulators for real-time holography**
  - **Manipulation of molecules with light - surface relief gratings, polarization gratings in photochromic polymers**
  - **Simple photonic devices**

Nonlinear Optics Laboratory

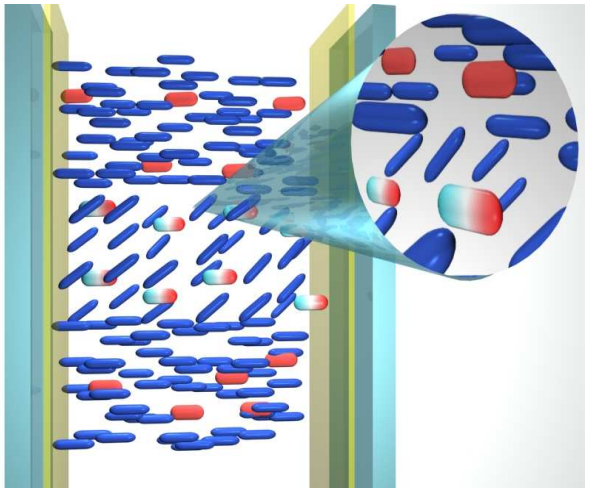
Optical retrieval of holograms projected on optically addressed liquid crystalline spatial light modulators



Holographic optical interconnects

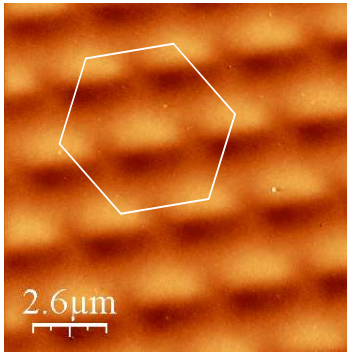


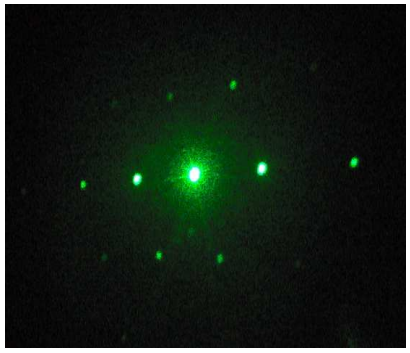
Development of photorefractive liquid crystal panels

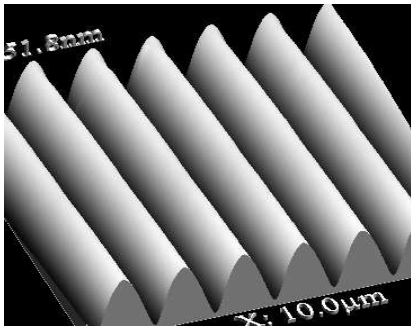


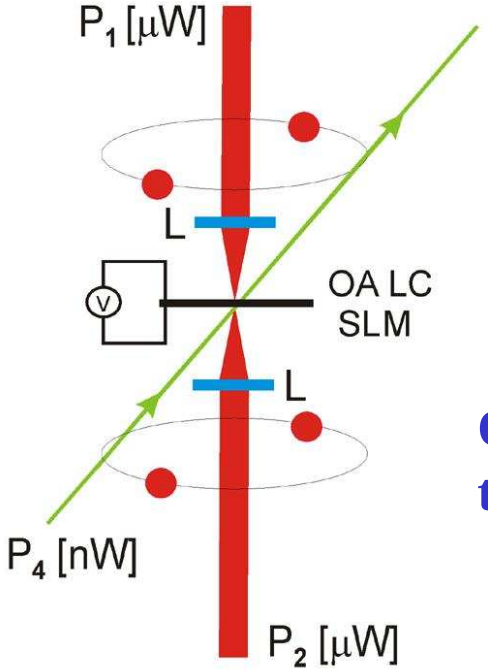
Nonlinear Optics Laboratory

Photofabrication of relief structures in photochromic polymers using laser light interference









Optical transistor

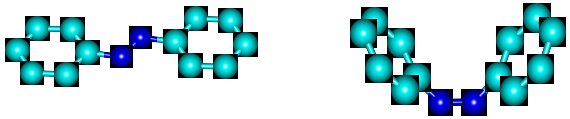
Wrocław University of Technology

Laboratory of Physics and Chemistry of Molecular Solids

Institute of Physical and Theoretical Chemistry

Fafulty of Chemistry

head: prof. Juliusz Sworakowski, juliusz.sworakowski@pwr.wroc.pl



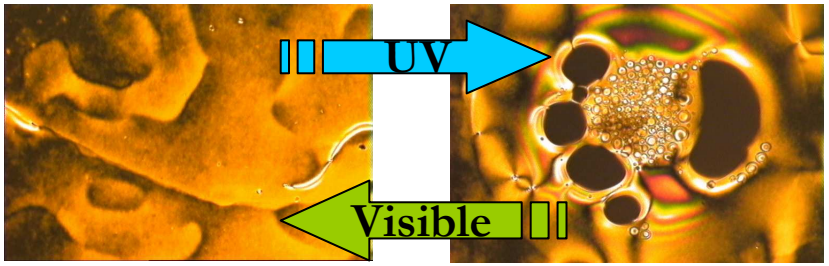
Main research interests

- ✓ **Photoactive molecular materials:**
  - **Effect of molecular constraints on kinetics of photochromic reaction in azobenzene derivatives**
  - **Effect of photochromic reaction on the phase stability in dye-doped liquid crystals (photoinduced phase change)**
- ✓ **Molecular switches**
- ✓ **Luminescence**

Wrocław University of Technology

Laboratory of Physics and Chemistry of Molecular Solids

Effect of photochromic reaction on the phase stability in dye-doped liquid crystals (photoinduced phase change)



Nematic phase

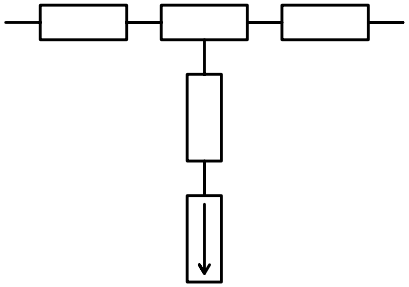
Co-existing nematic and isotropic phases

MOLECULAR SWITCH

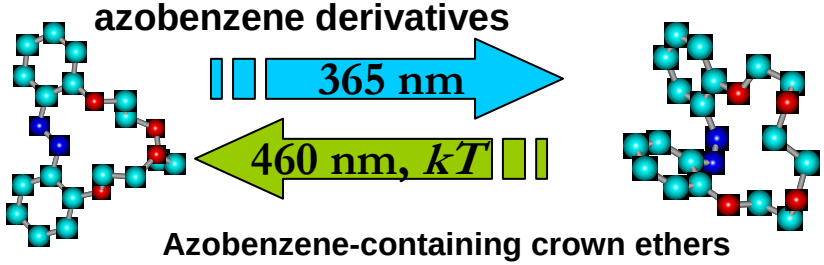
'Molecular wire' ⟶
(conjugated polymer chain)

Spacer ⟶

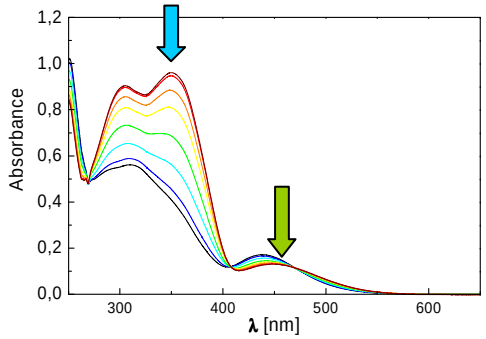
Bistable dipolar species ⟶
(photochromic molecule)

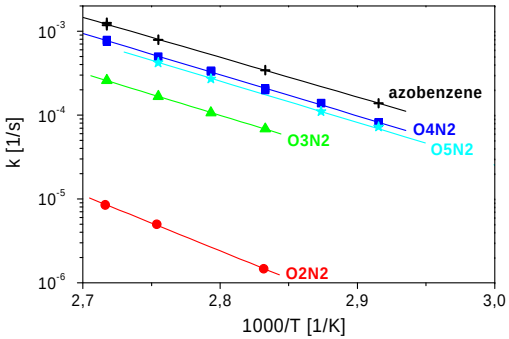


Effect of molecular constraints on kinetics of photochromic reaction in azobenzene derivatives



Azobenzene-containing crown ethers





Laser and Fiber Electronics Group

Faculty of Electronics

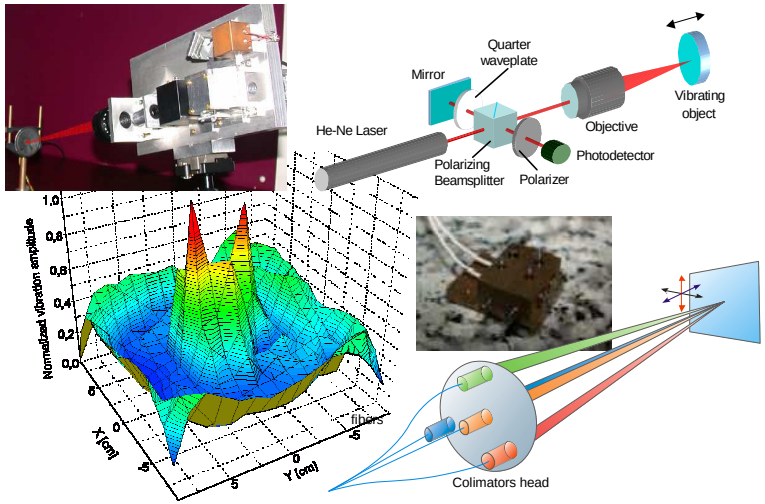
head: prof. Krzysztof Abramski *krzysztof.abramski@pwr.wroc.pl*

Main research interests

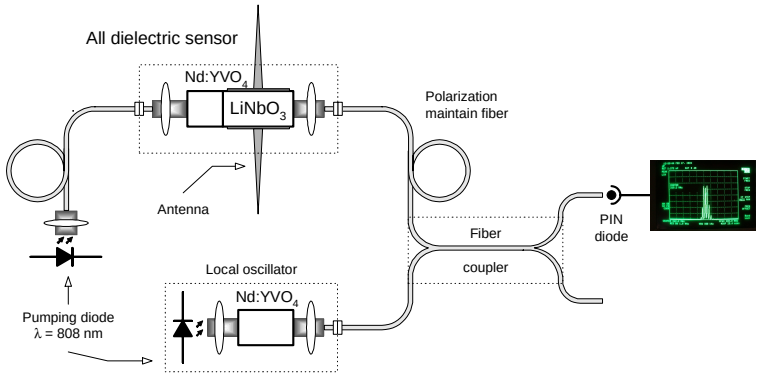
- ✓Optical fiber amplifiers, fiber lasers (cw, mode-locked, femtosecond):
- ✓Applications optical fibers in metrology and medicine;
- ✓Laser and fiber interferometry (laser/fiber vibrometry and velocimetry, laser radar);
- ✓Fiber-into-free-space telecommunications;
- ✓OFDR (optical frequency division reflectometry);
- ✓Fiber sensors (cardiodiffuser for intravascular illumination);
- ✓Microchip lasers (1064nm: Nd:YAG, Nd:YVO4, 532nm: Nd:YVO4/KTP);
- ✓Microchip heterodyne laser systems (EMF sensors based on microchip lasers);
- ✓RF excited CO2 slab, waveguide and multiwaveguide lasers;
- ✓Frequency stabilization of gas, microchip and semiconductor lasers.

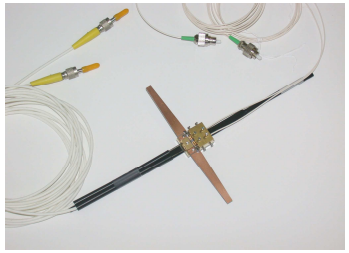
Wrocław University of Technology

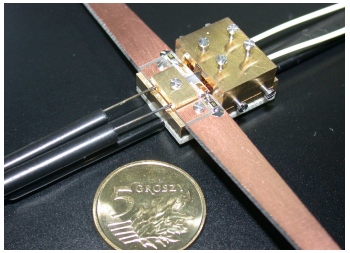
Laser and Fiber Electronics Group



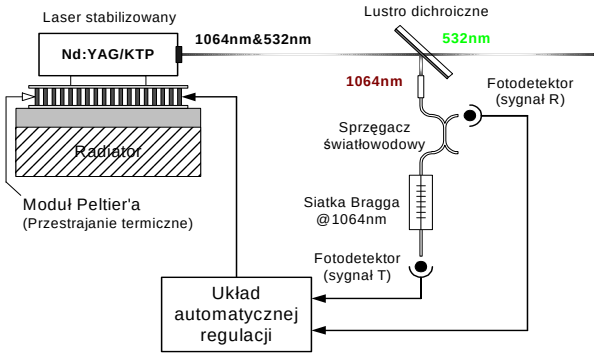
Multipoint laser/fiber vibrometry

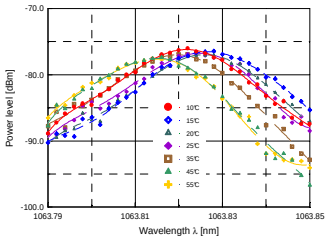


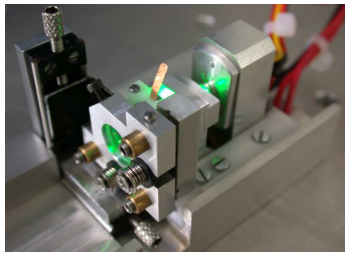


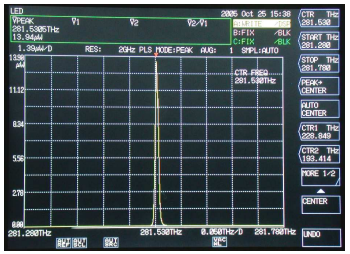


EMF sensors based on microchip lasers





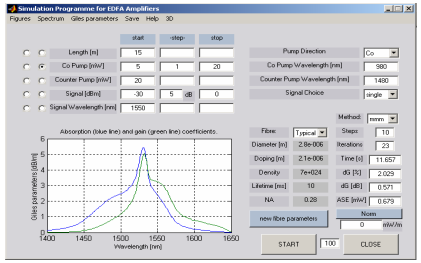


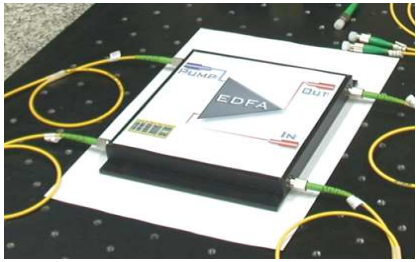


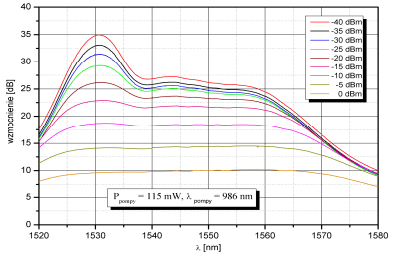
Single frequency microlaser Nd:YAG/KTP stabilized with fiber Bragg gratting

Wrocław University of Technology

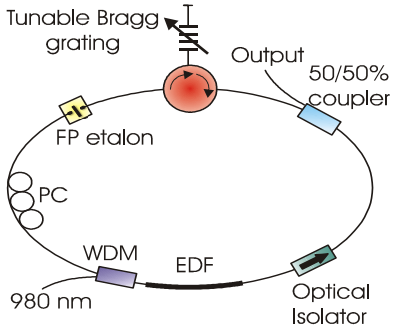
Laser and Fiber Electronics Group

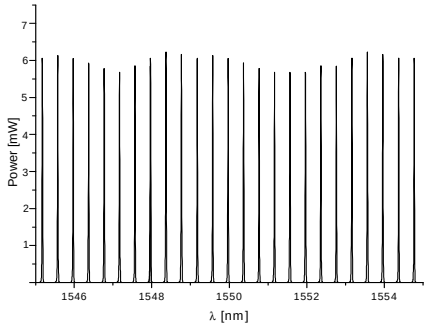


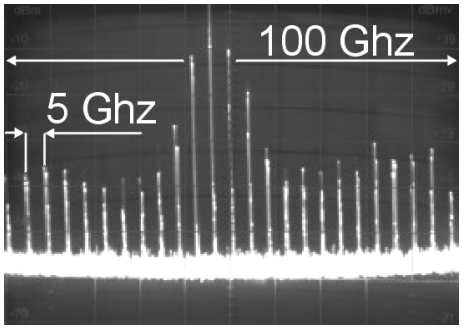




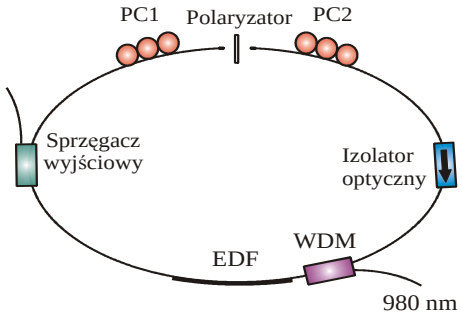
Erbium Doped Fibre Amplifier simulation and measurements

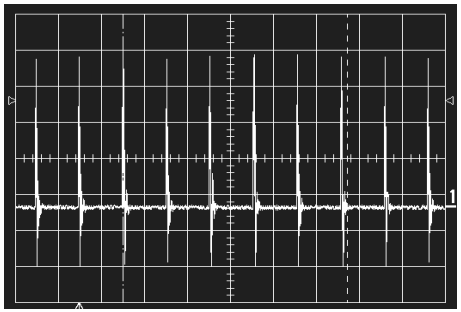


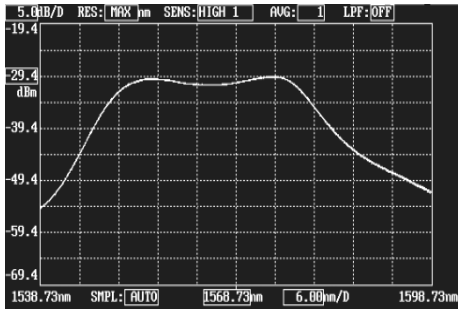




Tuneable erbium doped fibre laser







Passively mode locked erbium fibre laser

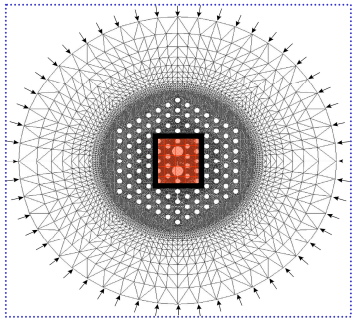
Wrocław University of Technology

Fiber-Optic Laboratory

Institute of Physics

Faculty of Fundamental Problems of Technology

head: prof. Waclaw Urbanczyk , ***waclaw.urbanczyk@pwr.wroc.pl***



Main research interests

- ✓Modeling and characterization of specialty fibers, including photonic crystal fibers;
- ✓Experimental techniques for characterization of photonic crystal fibers;
- ✓Modeling and characterization of Bragg gratings for sensing applications;
- ✓Architecture of single point and mutiplexed systems of fiber-optic sensors;
- ✓Low coherence interferometry

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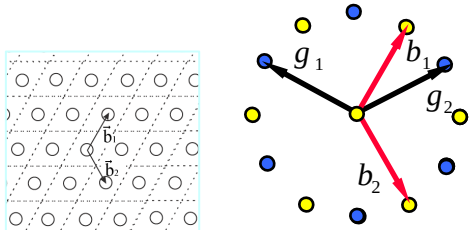
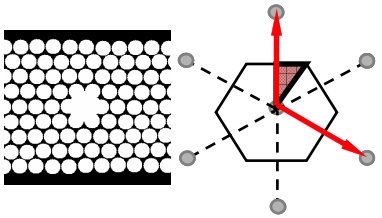
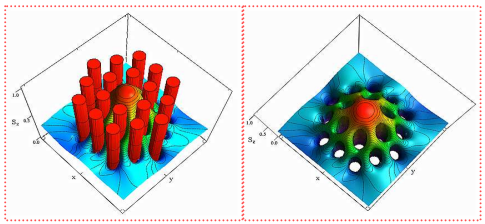
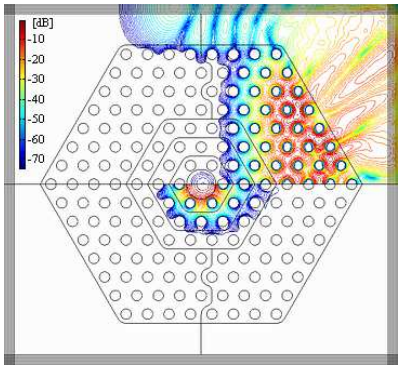
Simulation methods:

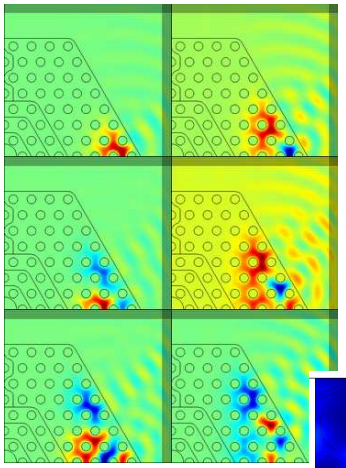
- **Plane-wave method**
  - Index Guiding Fibers
  - Photonic Bandgap Fibers (PBG)
- **Multi-pole method**
- **Finite element method**
  - Mechanical: stress/deformation analysis
  - Electromagnetic
- **Beam propagation method**
- **Finite difference time domain method**
- **Coupled mode method**
  - Fiber Bragg gratings

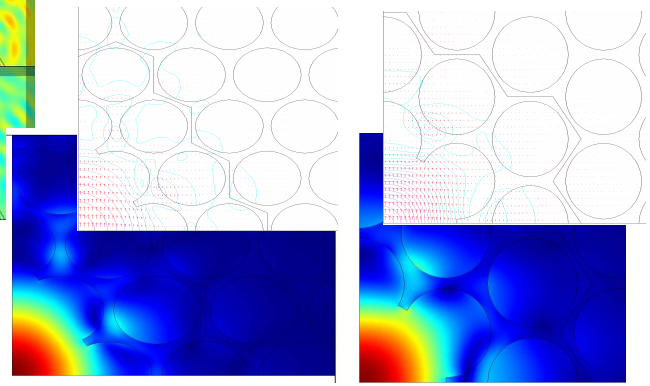




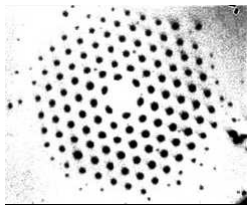




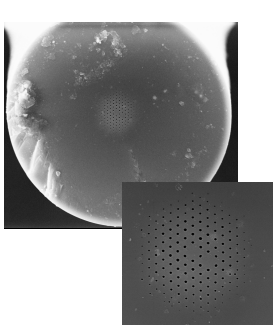




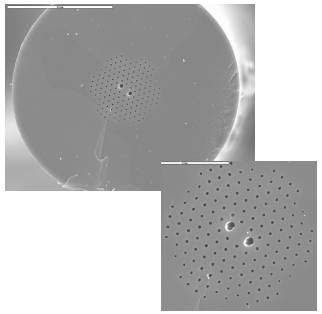
Fiber-Optic Laboratory: Designed Microstructured Fibers



Single mode

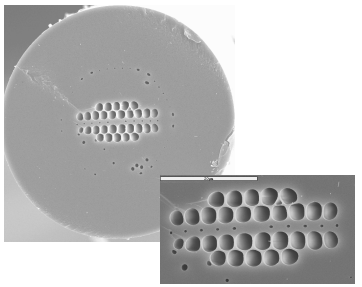


Dual core

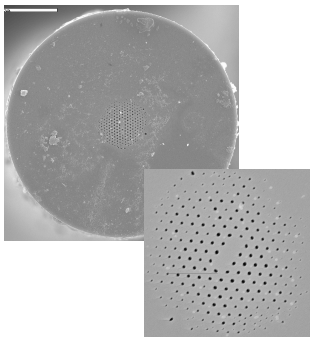


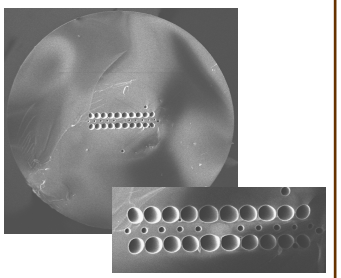
Polarizing

Manufactured by UMCS, Lublin, Poland



Highly birefringent





Manufactured by UMCS, Lublin, Poland

Parameters to analyze and design:

- **Modal analysis (effective index, field distribution)**
- **Photonic bandgap**
- **Phase and group birefringence**
- **Polariation properties**
- **Dispersion properties**
- **Confinement losses**
- **Bending losses**
- **Sensitivities of birefringence and dispersion to temperature, stress, strain, pressure etc.**

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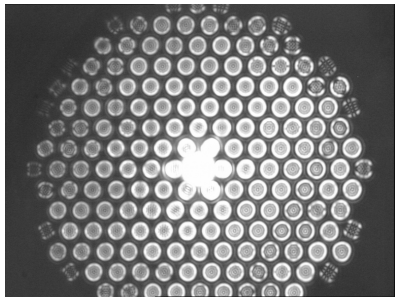
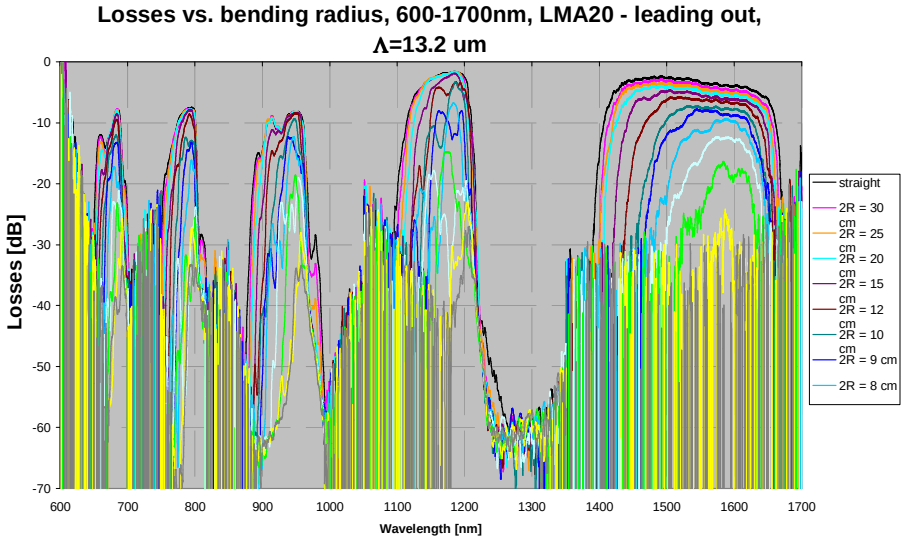
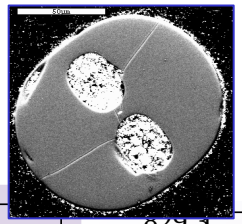
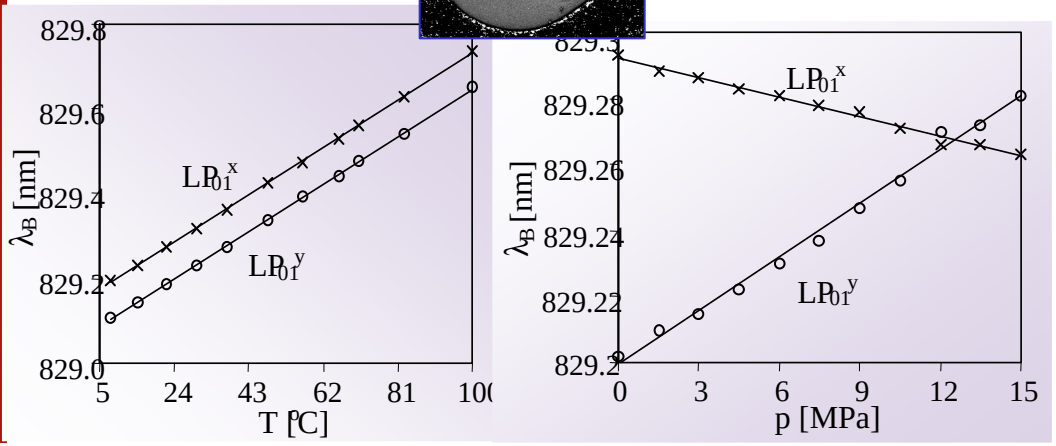
Solid bandgap PCF



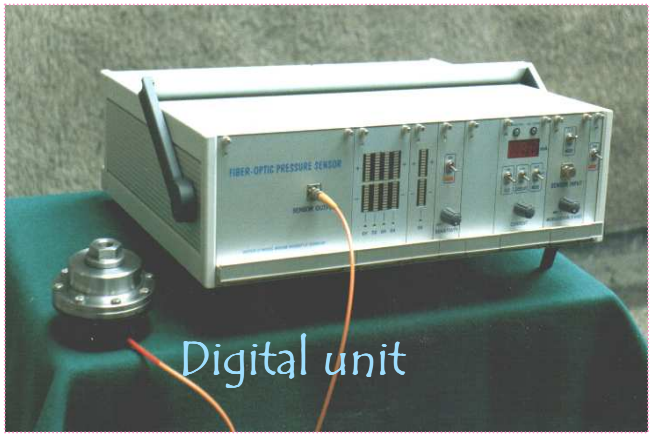


Characteristics of the Bragg grating inscribed in the side-hole fiber





Fiber-optic pressure sensor



Wrocław University of Technology

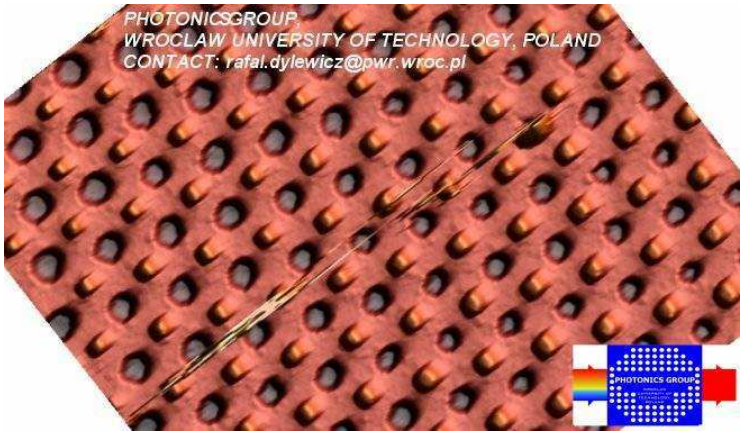
Photonics Group

Faculty of Microsystems Electronics and Photonics

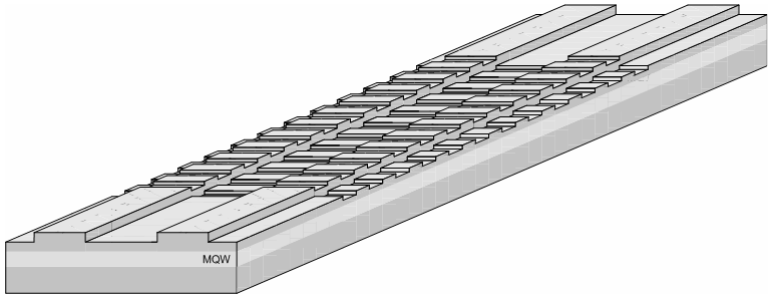
head: prof. Sergusz Patela, ***sergiusz.patela@pwr.wroc.pl***

Main research interests

- ✓Analysis, design and fabrication of advanced photonics devices including photonics crystals:
- ✓Integrated-optic modulators and switches;
- ✓Nonlinear optical devices and materials.



2-D photonic crystal waveguide



A model of grating assisted directional coupler modulator