Institute of Physics – Center for Science and Education
Silesian University of Technology, Gliwice, POLAND

A RESEARCH EXCELLENCE STRUCTURE

LAYERS (L1…L4) and PACKAGES (P1…P13)

The short scheme as a response to H2020 Programme – ver. 1b

☒ L1 – New concepts and innovations:

P1 – Simulation and modeling:

- software: COMSOL, Matlab, Mathematica, Magpar, Embarcadero RAD Studio XE7, GiD meshing software, Windows and Linux systems,
- hardware: 16-cores, 4 x i7-processors, MPI-based computing cluster,
  16-cores, 2 x Xeon-processors workstation,
  8-core, 2 x Itanium-processors workstation.

P2 – Physics of complex systems, econophysics and extreme events analysis

P3 – Basic investigations of nanomaterials:

- Contactless photoelectromagnetic investigations of graphene - In the Institute we developed the contactless method of photoelectromagnetic (PEM) investigations of graphene. It is used for determining diffusion length of minority carriers in graphene. If a graphene is illuminated by a circular spot of electromagnetic radiation, excess carriers (electrons and holes) are photogenerated in a circular region from which they diffuse in all directions in the sample. When a magnetic field is applied perpendicularly to the sample surface, diffusing carriers are deflected owing to the Lorentz force and flow in circles around the illuminated region. The circulating PEM current causes the so-called PEM magnetic flux. It depends on the external magnetic field induction, and is stronger for higher mobilities and concentrations of the photogenerated electrons and holes (it increases with the photogeneration rate, i.e., with product of illumination intensity, absorption coefficient of light, and quantum coefficient of photogeneration of free carriers). The PEM magnetic flux decreases with the increase of recombination rate, i.e. with the decrease of carrier lifetime). Under amplitude-modulated illumination of a sample the PEM circulating current varies, and consequently the changing magnetic flux caused by this alternating current can induce a measurable voltage in suitably placed pick-up coils.
- Investigations of electrical and photoelectrical quantum effects in single nanowires - all around the world a great deal of attention is focused on one-dimensional nanostructures because of their properties related to quantum effects, which may be promising for various electronics and optoelectronics applications. In our Institute we perform investigations of electrical and photoelectrical quantum effects in single nanowires of semiconducting and ferroelectric antimony sulfoiodide (SbSI). These measurements are possible due to ultrasonic welding of nanowires to the metal microelectrodes on appropriate substrates. We use ultrasonic generator ADG70-100P-230-NO (Rinco Ultrasonics) with working frequency 70 kHz and max power 120 W, transducer C 70-2 (Rinco Ultrasonics) and a special sonotrode made by ourselves with SiC single crystal end. The microelectrodes are connected with the TO-5 and TO-8 packages using HB05 thermosonic wire bonder (TPT Wire Bonder).

☒ L2 - Technology:

P4a – Sonochemical preparation of nanowires:

- Recently, in the Institute the ultrasound irradiation was applied to induce the 1D growth of nanowires of ternary and quaternary chalcohalides formed from the group 15-16-17 elements. Antimony sulfoiodide (SbSI) is one of the best piezoelectric crystals with high volume piezoelectric modulus and extremely high electromechanical coupling coefficient. It is photoferroelectric material characterized by very high fotosensitivity.
  The experimental setups for sonochemical preparation of nanomaterials consist of: an ultrasonic processor Sonics VCX-750 13TIP (firma Sonics & Materials) with the

frequency of 20 KHz and automatic tuning, ultrasonic electrical power 750 W and different sonotrodes, two ultrasonic reactors InterSonic IS–UZP–2 with the frequency of 35 kHz, electrical power 75 W, ultrasound power density 2.6 W/cm^2, HAAKE DC30-K20 (Thermo Scientific) compact refrigerated circulator, 830-ABC/EXP Compact Glove Box, One-Station EA (Plas-Labs Products), - the MPW-223e centrifuge (MPW Med. Instruments), the CP-401 pH-meter (Elmetron) with ERPt-13 and ERH-11S electrodes (Hydromet) for Eh and pH measurements, spectrophotometer HR-4000 (Ocean Optics Inc.) with integrating sphere ISP-REF (Ocean Optics Inc.).

P4b – Sonochemical fulfilling of carbon nanotubes with nanowires:

- One approach leading to new features of carbon nanotubes (CNTs), i.e. directional action on their versatile electronic characteristics, is based on filling them with condensed substances from a wide range of materials. Recently, in our Institute the ultrasound irradiation was applied to fill CNTs with ternary chalcohalides formed from the group 15–16–17 elements, i.e. antimony sulfoiodide (SbSI) and antimony selenoiodide (SbSeI) known as SbSI-type materials that are semiconducting ferroelectrics.
  The experimental setups for sonochemical fulfilling of the CNTs consist of: an ultrasonic processor Sonics VCX-750 13TIP (firma Sonics & Materials) with the frequency of 20 KHz and automatic tuning, ultrasonic electrical power 750 W and different sonotrodes, two ultrasonic reactors InterSonic IS–UZP–2 with the frequency of 35 kHz, electrical power 75 W, ultrasound power density 2.6 W/cm^2, HAAKE DC30-K20 (Thermo Scientific) compact refrigerated circulator, 830-ABC/EXP Compact Glove Box, One-Station EA (Plas-Labs Products), - the MPW-223e centrifuge (MPW Med. Instruments), the CP-401 pH-meter (Elmetron) with ERPt-13 and ERH-11S electrodes (Hydromet) for Eh and pH measurements, spectrophotometer HR-4000 (Ocean Optics Inc.) with integrating sphere ISP-REF (Ocean Optics Inc.).

P4c - Growth of photoferroelectric single crystals from vapor phase:

- The class of ferroelectric semiconductors of $A^{V}B^{VI}C^{VII}$ type, wherein antimony sulfoiodide (SbSI) is the most outstanding representative, is of principal interest. SbSI has an unusually large number of interesting properties. Among them there are pyroelectric, pyrooptic, piezoelectric, electrooptic, and nonlinear optical effects. Due to these properties, SbSI is an attractive and suitable material for many applications. In our Institute the single crystals of SbSI are grown from vapor phase in closed termisil ampoules placed in a two-zone furnaces. Temperature of every zone is programmed and controlled independently.

P4d – Fabrication of textured policrystalline antimony sulfoiodide:

- Antimony sulfoiodide (SbSI) has an unusually large number of interesting properties. Among them there are pyroelectric, pyrooptic, piezoelectric, electrooptic, and nonlinear optical effects. This makes SbSI an attractive and suitable material for many applications. Unfortunately, due to its specific inherent characteristics of the SbSI growth rate anisotropy, the needle morphology is found to be predominant; accordingly, there is the difficulty in growing device quality large single crystals or films. To avoid these drawbacks, in our Institute the textured polycrystalline SbSI is fabricated by rapid quenching of the melted SbSI eutectic in liquid nitrogen.

P4e – Laser preparation of photoferroelectric heterostructures:

- There is a great demand for actuators and sensors for practical applications. Antimony sulfoiodide (SbSI) is one of the best piezoelectric crystals with high volume piezoelectric modulus and extremely high electromechanical coupling coefficient. It is photoferroelectric material characterized by very high fotosensitivity. Heterojunctions based on SbSI single crystal have just been fabricated in Institute of Physics SUT. It was done by done by applying laser beam that evokes melting and chemical decomposition of one or a few selected sections of the crystal. Treated sections are composed of amorphous or crystalline antimony (III) sulphide (Sb2S3) with energy gap 0.3 eV smaller than that of SbSI. Devices with one heterojunction (diodes), two heterojunctions (transistors) and multi heterojunctions can be created. Fabricated heterostructures are characterized by very high fotosensitivity. Nowadays, we irradiate separate sections or ends of SbSI single crystals with radiation emitted from molecular CO_2 laser with wavelength λ = 10,6 μm (LTG70626G laser from LaserTechGroup equipped with LPZ1000 PZT driver with maximum output power 5 W as well as LM–100 laser from Elektrometal Żary with maximum output power 100 W). The set up contains goniometer table model Chirana 41Y313, power meter PM5200 with an air-cooled power meter probe PM150 (Molectron).

P4f – Preparation of opals, opals infiltrated with SbSI, and inverted SbSI opals:

- Research on materials for photonic crystals is actual and important topic for many investigations all over the world. The proposed paper presents morphology and structure of ferroelectric and semiconducting antimony sulfoiodide used for fabrication of inverted opals.
  Experimental set up for synthesis of SiO_2 nanospheres and their gravitational sedimentation to obtain opal matrices. Owens for sintering the opals at 1000 ºC and for infiltration of the sintered opals with melted SbSI at 490 ºC. Sonoreactor for cleaning the opals infiltrated with SbSI. Experimental set up for etching the photonic crystals to obtain inverted SbSI opals.

P5 – Thin-layer technologies:

- Multi-chamber ultra-high vacuum experimental setup with the base pressure 4x10-9 mbar allowing deposition and investigation of thin and ultra-thin layers of organic materials. The setup is equipped with intro chamber which allow on substrate annealing prior deposition.The technological chamber is equipped with physical vapor deposition (PVD) method based on low temperature (Tmax~500°C) effusion cell. The deposited layer thickness control is performed by means of quartz crystal microbalance with theoretical accuracy 0.1Å. The setup allows controlling both: the deposition rate (resolution 0.1 Å/s) and the substrate temperature during deposition (within the range 293K to 500K). The investigation part of the setup is equipped with quadrupole mass spectrometer (Stanford Research RGA 100) allowing Temperature Programmed Desorption (TDS) measurements. Additionally, TDS measurements may be enhanced with kinetics of gas adsorption investigation thanks to leak valves of high accuracy. The setup is also equipped with Photoemission Yield Spectroscopy (PYS) method which allow on determination of electronic properties (like work function and ionization energy) of sample's subsurface region. In case of the layers deposited in technological part of the setup the TDS and PYS measurements can be done in-situ, i.e. without evacuating the sample.

☒ L3 – Measurement capabilities:

P6 – Optical methods:

- Luminescence (optically stimulated luminescence OSL, thermoluminescence TL) measurements (Automated TL/OSL reader Daybreak 1150, Automated OSL/TL reader Daybreak 2200, single photon counting system with dead time equals 50 ns, temperature range: ambient-700ºC, visual light stimulation: high power halogen lamp with the filter set giving 20 mW/cm^2 at 514 (FWHM 7) nm, high power blue LEDs with the filter set giving max 49,7 mW/cm^2 at 486(FWHM 20) nm, infrared stimulation: high power IR LEDs with the filter giving 45-129.9 mW/cm^2 at 880 (FWHM 20) nm,
- Irradiations exciting luminescence (alpha, beta or soft X radiation) (Automated alpha/beta irradiator Daybreak 801 with two controlled sources of beta and alpha rays beta or soft X ray excitations are made in the luminescence readers - mentioned above),

- Measurements of photoluminescence spectra in UV-VIS range (He-Cd laser, 325 nm; spectrometer, power meter, optical setup),
- Optical diffuse reflection and transmittance spectroscopy (DRTS) measurements using the spectrophotometer PC-2000 (Ocean Optics Inc.), two integrating spheres ISP-REF (Ocean Optics Inc.), R2205 Cryogenic Microminiature Refrigeration II-B System with K7701 temperature controller (MMR Technologies, Inc.), Vacuum: TSH 071E turbomolecular drag pumping station and the standard WS-1 (Ocean Optics Inc.) reference,
- Specular reflectivity and transmittance measurements in temperature range 80 K to 343 K and in spectral range from 380 nm to 1000 nm (the optical cylindrical chamber, GUR-5 (LOMO) goniometer, R2205 Cryogenic Microminiature Refrigeration II-B System, K20 temperature controller (MMR Technologies, Inc.). Vacuum: TSH 071E turbomolecular drag pumping station, the PC2000 (Ocean Optics Inc.) spectrophotometer with master and slave cards with 600 lines grating (blazed at 500 nm and 400 nm, respectively), the deuterium–halogen light source DH2000-FHS from Ocean Optics GmbH,
- Photoreflectivity investigations of the nanomaterials using for excitation the Ar laser (448 nm) in the spectral range from 600 nm to 1100 nm at room temperature (monochromator SPM-2 (Zeiss Jena), Ar laser (448 nm) Reliant 50s (Laser Physics), He-Ne laser (633 nm), 25-LHP-121-230 (Melles Griot), acoustooptical modulator TEM-85-2 (Brimrose), mechanical modulator SR540 (Stanford Research Systems), neutral density filter (Lot Oriel), the photodiode S2387 (Hamamatsu), the lock-in current-voltage converter in EG&G 5100 nanovoltmeter,
- Measurements of photoluminescence spectra in UV-VIS range will be performed using He-Cd Omnichrome 374XM laser (325 nm), GDM_1000; monochromator (Zeiss Jena),
- Measurements of elastic properties of thin layers using Brillouin light scattering from surface phonons (Sandercock Inc. Tandem Interferometer).
- Magnetic properties od ferromagnetic nanostrures are measured with the use of Magneto-Optic Kerr Effect (MOKE). A system is equipped with the HP34970A universal multimeter, a power supply (Kepco), a self-made photo-diodes (Si, Siemens) bridge. All work in GPIB standard.

P7 – Electrical and photoelectrical methods:

- Impedance spectroscopy of unilluminated and illuminated nanomaterials in vacuum and in various gases at different temperatures (Hioki 3532-50 and 3522-50 LCR meters. Vacuum: (Oerlikon Leybold vacuum PT50 pumping station, Alcatel ACC 1009, ADS 1001 and ADS 1004 gauges, ACM 1000 controller, Peltier thermoelectric cooling modules controlled by PRG RS H100 (Peltron GmbH), circulator HAAKE DC30, bath Kessel HAAKE K20 (Thermo Scientific), Keithley 196, humidity of atmosphere measured by the SHT15 sensor (Sensirion AG), ES-1530 meter (Elektro-System s.c.), Ar laser (448 nm) Reliant 50s (Laser Physics), He-Ne laser (633 nm), 25-LHP-121-230 (Melles Griot),
- Advanced scanning Kelvin probe system package (SKP5050) by KP Technology,
- Enhanced electrostatic force microscopy and scanning capacitance microscopy modules to scanning probe microscope PSIA XE-70,
- Investigations of quantum efficiency of photogeneration of free carriers in nanomaterials (R2205 cryogenic microminiature refrigeration II-B system (MMR Technologies), K7701 (MMR Technologies) temperature controller; Vacuum: (TSH 071E turbomolecular drag pumping station; Photoconductivity: (Keithley 617 electrometer, SPM2 monochromator (Carl Zeiss), 750 W halogen lamp, Reliant 50S argon laser (Laser Physics), neutral filters UV–NIR-FILTER-250–2000 nm (Quartzglas-Substrate, Oriel), S-2387 silicon photodiode (Hamamatsu), PM 150 laser beam detector, Powermax 5200 meter (Molectron-Coherent),
- Investigations of ambipolar difussion length and surface recombination velocity of free carriers in nanomaterials - the same experimental set up as the described for investigations of quantum efficiency of photogeneration of free carriers in nanomaterials,

- Determination of electric conductivity and activation energies of dc electric conductivity in nanomaterials (Keithley 6517A electrometer, R2205 cryogenic microminiature refrigeration II-B system (MMR Technologies), K-20 (MMR Technologies) temperature controller. Vacuum: (TSH 071E turbomolecular drag pumping station).

P8 – Morphology and chemical analysis:

- Atomic force microscopy in contact and non-contact modes (scanning probe microscope XE-70, PSIA Inc. with signal access module SAM),
- Scanning Auger microscopy (SAM PHI 600, Physical Electronics),
- Scanning electron microscopy using Phenom proX (Nano Science Instruments) with fully embedded EDS elemental analysis.

P9 – Thermal measurements:

- Thermal diffusivity determination of bulk samples and thin layers based on dynamic mesurements utilizing IR radiometry (solid-state laser DPSS 532nm, Shanghai Dream Lasers Technology Co., Ltd., acousto-optic modulator MDD-P80L-1.5, Isomet Co., IR detector MCT-13-0.50, InfraRed Associates, Inc., lock-in voltmeter EG&G 7625, Signal Recovery), and mirage effect (He-Ne laser - 7672 type, LASOS, laser diode F-840-500C-50-SM-M, Coherent, silicon position detector DL400-7PCBA, Pacific Silicon Sensor Inc., lock-in voltmeter EG&G 7625, Signal Recovery),
- Highly localized thermal measurement in temperature contrast mode and conductivity contrast mode (scanning probe microscope XE-70, PSIA Inc. with scanning thermal microscopy SThM module).
- Micorcalorimentric measurement in temperature range from -170°C to 600°C (DSC 3500 Sirius, Netzsch).

P10 – Radioisotope measurements:

- Liquid Scintillation Counting (LSC) suited for measurements of ultralow radioactivity of beta radiation from radiocarbon decay and can be performed using: automated LSC spectrometers of beta radiation Quantulus 1220 (Quantulus 1 and Quantulus 2), Liquid scintillation spectrometers of beta radiation ICELS 1 and ICELS 2,
- Accelerated Mass Spectrometry (AMS) and graphitization systems – suited for preparation of samples to the form of pure graphite for ultra-low radiocarbon concentration measurements by AMS system and can be performed using: Automated AGE-3 system, Vacuum line for production and graphitization of CO_2 - manual system.

☒ L4 - Sensors:

P11 – Gas sensors – gas analysis using surface acoustic waves:

- Surface acoustic waves (SAW) are used in gas analysis because of in a proper configuration sensor structure – gas molecules one can obtain very high sensitivity. Even for a very low gas concentrations (ppm, ppb level) the changes in SAW velocity and attenuation can be very easy measurable by means of dedicated oscillator circuits. The new possibilities of SAW gas sensors investigated in Institute of Physics SUT are bilayers sensor structures which can be realized in thin film technology. The bilayer structures of various materials (semiconductor –metal, dielectric – metal and the reverse ones) can obtain better “work point” and consequently higher sensitivities. Nowadays, we can test various sensor materials in the form of thin film and bilayer thin film structures on the lithium niobate substrates (~43 MHz) and on the new 205 MHz quartz substrates (SAW Components Dresden Germany) bouth in dual – delay line configuration. The three channel OWLSTONE gas generator device (OFC,OVG – 4,OHG, UK) is used for creating very precise concentrations of various gases and vapours (i.e. DMMP – stimulant of warfare agent) in air or nitrogen.

P12 – Nanowires, nanotubes, and photonic crystals as gas sensors:

- All around the world a great deal of attention is focused on one-dimensional nanostructures because of their properties related to gas sensing. SbSI (being a semiconducting ferroelectric) is a promising material due to a large number of interesting properties, e.g., pyroelectric, pyrooptic, piezoelectric, and electrooptic. Recently, SbSI nanowires are prepared sonochemically. DC electric field of $5 \cdot 10^5$ V/m is applied between electrodes during the deposition of SbSI sol on IAME--co-IME2-1AU substrates to align the nanowires perpendicularly to the electrodes. SbSI nanowires are welded ultrasonically to the metal microelectrodes. We use ultrasonic generator ADG70-100P-230-NO (Rinco Ultrasonics) with working frequency 70 kHz and max power 120 W, transducer C 70-2 (Rinco Ultrasonics) and a special sonotrode with SiC single crystal end. The morphology of SbSI nanostructures is studied using scanning electron microscope Phenom ProX (Phenom-World). The electrical connections between gold electrodes and the measurement board are made using HB05 thermosonic wire bonder (TPT Wire Bonder). The quantum effects in conductivity and photoconductivity of single SbSI nanowires are investigated in controlled vacuum or various gas environment in optical vacuum chamber. The measurement chamber is equipped with mass spectrometer UMS 200 (Prevac) with quadrupole gas analyzer RGA200 (Stanford Research Systems), PT50 Oerlikon Leybold turbomolecular vacuum pump, vacuum gauge controller ACM 1000 with gauges Alcatel ACC 1009, ADS 1001 and ADS 1004, two Mass Flow Controllers SLA 5850 (Brooks Instruments), temperature sensors with 211 temperature controller (Lake Shore), and humidity sensor SHT15 (Sensirion AG) with humidity meter ES-1530 (Elektro-System s.c.). The DC electric measurements are performed using the Model 6430 Sub-Femtoamp Remote SourceMeter (Keithley) or Keithley's electrometers 617 and 6517A, as well as with Keithley 224 programmable current source or Keithley 2410-C High Voltage SourceMeter. The photoelectrical investigations are performed using the Reliant 50S (Laser Physics) argon laser with λ=488 nm wavelength. Neutral filters UV–NIR-FILTER-250–2000 nm (Quartzglas-Substrate, Oriel) are used to change the light intensity. Acquisition of the data and control of the radiation wavelengths, temperature, gas flow and pressure are realized using a PC computer with GPIB bus and appropriate programs in LabView 8.5 (National Instruments).

P13 - UV-radiation sensors:

- Gallium nitride and related compounds (InGaN, AlGaN) have wide bandgap (in visible and ultraviolet range) and have very good thermal and chemical stability. Also, they are promising materials for light sources and photodetectors. Metal/insulator/AlGaN/GaN structures with capacitance-based detection of UV light seem to be an especially interesting candidate for a sensitive solar-blind detector. The designed UV photodetector is based on metal/insulator/AlGaN/GaN structure with transparent gate electrode and thin insulating layer (in nm range). The technology of device fabrication will be developed in other co-operating research centers. In our laboratory, we measure electrical characteristics (capacitance-voltage, current-voltage etc.) under controlled illumination and to characterize the surfaces and chemical composition of the devices by atomic force microscopy (AFM) and by Auger electron spectroscopy and microscopy (AES/M), respectively. One of our goals is the optimization of insulator/AlGaN interface to obtain thermal stability of the photodetector, its high sensitivity, and blindness to solar light background.