XIII Symposium of PhD Students

IF PAN ◦ CFT ◦ MagTop ◦ UNIPRESS

Abstract Book

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1. SEMICONDUCTOR TECHNOLOGY

1.1. Sushma Mishra (IF PAN)

The relationship between Structure and conductivity of thin ZnO films grown by ALD: differences between Si and a-Al2O3 substrates

Versatile ZnO semiconducting films with well-defined structural qualities, tunable electrical and optical properties are needed for device applications. However, unintentional structural and point defects and impurities present in ZnO films are main obstructions in achieving controllability, repeatability, and carrier transport in this material. The aim of the present study was to find out relationship between structure and conductivity of thin polycrystalline ZnO films grown under O- or Zn-rich conditions. Two series of ~100 nm thick ZnO films were grown by Atomic Layer Deposition on Si and a-Al2O3 substrates at growth temperature (Tg) range of ~100-300oC. RT-Hall measurements revealed that resistivity increased with Tg and also after rapid thermal annealing (RTP) for both ZnO/Si as well as ZnO/a-Al2O3 films. SIMS experiments found that the content of unintentional H impurity in both as grown and annealed films is higher than the carrier concentrations, showing that not all H atoms play a role of a donor. There exist a certain Tg range of ~160-200oC where preferred orientation showed switching phenomenon influencing conductivity of the films. Strain, dislocation density, and Urbach energy calculations showed that films formed at Tg~160oC had better crystalline quality and higher electrical conductivity, as well as the carrier mobility (25-29 cm2/Vs) for both series. Overall, when compared to ZnO/a-Al2O3, the ZnO/Si films showed lower strain and lower dislocation density.

1.2. Monika Ożga (IF PAN)

Memristive effect observed in CuO thin films grown by hydrothermal method

Thin films of copper (II) oxide are obtained by a new modified hydrothermal method in an open system. The developed technology is characterized by i.a. an extremely fast growth rate and low process temperature. Comprehensive investigation on material properties was carried out. In order to determine its properties numerous methods, like SEM, AFM, XRD, EDX, UV-vis were used as well as many electrical measurements. The results forced further work on the technology, consisting of sequencing the growth processes and rapid thermal annealing. Electrical measurements of so prepared CuO thin films showed the occurrence of switching and memristive effects, what makes our material suitable for potential applications in memory devices. The main steps of conducted research on obtaining, characterization and applications of the obtained CuO layers will be presented.

1.3. Abinash Adhikari (IF PAN)

Structural and optical Investigation of CdO-MgO quasi and random ternary oxides

The bandgap engineering through alloying of semiconductor materials is a well-established phenomenon. But still, growing a stable structure based on oxide semiconductors for better device performance is a challenging task and yet to be explored. In this project, I am focusing on group II-VI binary oxides i.e., CdO, ZnO, and MgO. Despite having the same crystal structure of both CdO and MgO (cubic rocksalt structure; $Fm\bar{3}m$), CdO-MgO heterostructures are one of the least studied aspects in the group II-IV oxides family. Again, the bandgap tunability of CdO from 2.3 to 7.5 eV, by alloying with MgO increases the perspective applications for CdO-MgO based heterostructures as it enables light emission over a wide range of spectra. Additionally, I expect that the heterostructures will allow quantum wells and energy barrier formation to provide significant quantum efficiency and effective quantum confinement.

1.4. Abdul Khaliq (IF PAN)

Spin-glass like magnetic ordering in $Ge_{1-x-y}(Sn_xMn_y)Te$ diluted magnetic semiconductors

Compound semiconductors (SCs) doped with magnetic elements unveil new prospects for possible spintronic applications. Forbye magnetic features, magnetically doped IV-VI SCs possess spontaneous ferroelectric polarization making them favorable to develop non-volatile memory materials. In this work, we report structural, magnetic and magnetotransport studies of ferroelectric α-GeTe doped with Sn and Mn in the range $0.18 \leq x \leq 0.79$ and $0.02 \leq y \leq 0.086$. The $\chi AC(T)$ graphs of $Ge_{1-x-y}(Sn_xMn_y)Te$ crystals indicate a spin-glass like magnetic ordering for $x \approx 0.2$, 0.4 and $y = 0.047$, 0.052 with critical temperature values, TC of about 6 and 8 K respectively. Furthermore, zero field cooled-field cooled (zfc-fc) plots of the crystals displaying a spin-glass like behavior show a shift in freezing temperature, TF towards lower values at high applied field. We show that the shift in TF at high applied field indicates these crystals follow de Almeida-Thouless Line $\delta T_F \propto H^{2/3}$ for spin-glasses in which an ordered system changes into a paramagnetic state at high temperatures and applied field. The magnetization hysteresis M(B) of the crystal $x \approx 0.2$, $y = 0.061$ manifested anomaly in coercivity and remanence near the critical temperature, $TC \approx 13$ K. We attribute such anomalous behavior in coercivity to the presence of disorder in spin-glass like ordering. Moreover, the off-diagonal resistivity measured B = 1.4 T demonstrates anomalous Hall effect below $B \approx 0.2$ T

The research was financed by the National Science Centre, Poland under the project number 2018/30/E/ST3/00309.

2. QUANTUM COMPUTING AND ASTRONOMY

2.1. Rafael Freitas Dos Santos (CFT)

Self-testing of Qubit Graph States based on Temporal Noncontextuality Inequalities.

To realize the power of quantum computers, it is important to certify their quantum components such as the quantum states and measurements. Self-testing of quantum devices provides a device-independent characterization of quantum states and measurements, i.e., it can be used to certify the relevant quantum state and measurements without making strong assumptions on the internal functioning of the quantum devices. In this work, we propose self-testing schemes based on temporal noncontextuality inequalities to certify Qubit graph states. Unlike the schemes based on Bell inequalities, our device-independent scheme does not require a spatial separation between the subsystems, does not rely on the assumption of compatibility of measurements, and doesn't assume the dimension of the Hilbert Space. As a special case of our device-independent scheme, we propose a semi-device-independent scheme designed to certify non-isomorphic graph states. Our schemes are desirable for certifying the graph states and might be useful for implementing quantum computation on the physical set-ups that do not have a spatial separation between the subsystems.

2.2. Shubhayan Sakar (CFT)

Certification of quantum systems using quantum steering

Device-independent certification schemes have gained a lot of interest lately. In this regard, we explore quantum steering for certifying higher-dimensional quantum systems in a one-sided device-independent way. I would discuss our proposal of a one-sided device-independent protocol that could certify any bipartite entangled state using minimal number of measurements possible, that is, two per subsystem. Using the certified state, we were able to certify every extremal POVM which in turn can be used to certify randomness of amount 2logd bits, which is the maximum amount that can be achieved using quantum systems of dimension d.

2.3. Lorenzo Mattioli (CFT)

Universality Problem in Quantum Computing

I describe a few ways to decide whether a finite set of quantum gates is universal, i.e., we can approximate any other quantum gate by composing such gates.

2.4. Filip Maciejewski (CFT)

Reducing measurement noise on quantum devices

Quantum computers have potential to drastically improve multiple fields of science and industry, however they are currently in an early development stage. Existing prototypes are affected by significant amount of noise of various types, which motivates development of methods for errors' characterization and mitigation. I will discuss some of the techniques that we proposed for characterizing and countering effects of measurement noise on quantum devices. To confirm practical effectiveness of our methods, we will present results of experiments on 15- and 23-qubit quantum processors from IBM and Rigetti.

2.5. Suhani Gupta (CFT)

Halo mass function as a probe of gravity

In my presentation, I will talk about the halo mass function statistics in cosmology and how it can be used to test the underlying theory of gravity. I have studied the standard Lambda CDM cosmological model, along with two models, that go beyond the standard theory.

2.6. Susane Calegari (CFT)

Contextuality and memory cost of simulation of Majorana fermions

Contextuality has been reported to be a resource for quantum computation, analogous to non-locality which is a known resource for quantum communication and cryptography. We show that the presence of contextuality places new lower bounds on the memory cost for classically simulating restricted classes of quantum computation. We apply this result to the simulation of a model of quantum computation based on the braiding of Majorana fermions, namely topological quantum computation (TQC) with Ising anions, finding a saturable lower bound in log-linear in the number of physical modes for the memory cost. TQC model lies in the intersection between two computational models: the Clifford group and the fermionic linear optics (FLO), a framework analogous to bosonic linear optics. We extend our results and prove that the lower bound in the memory required in an approximate simulation of the FLO model is quadratic in the number of physical modes.

3. PROTEIN PHYSICS

3.1. Michał Białobrzewski (IF PAN)

Studies of Hydrodynamic Properties and Interactions of Ordered and Intrinsically Disordered Proteins Involved in Regulation of Gene Expression by Fluorescence Correlation Spectroscopy (FCS)

Fluorescence correlation spectroscopy (FCS) is one of biophysical methods used to determine hydrodynamic and photophysical properties of fluorescently labelled molecules that diffuse in aqueous solutions. This technique makes it possible to perform in vitro and in vivo observations of intermolecular interactions by measuring of fluctuations in the fluorescence intensity signal. In every living organism, protein production i.e., gene expression is a fundamental process regulated at many different levels. One of the mechanisms responsible for the regulation is strictly dependent upon interactions between disordered and structured proteins. In my talk, I will discuss our recent biophysical results that contribute to understanding of molecular mechanisms of these interactions.

3.2. Quyen Vu Van (IF PAN)

Non-native Self-entanglements are Kinetic Traps in Physics-based All-atom Protein Folding Simulations

Protein self-entanglements, in which a protein backbone segment threads through a loop formed by another portion of the protein, are present in one-third of the native structures of globular domains. Native-centric coarse-grained models predict (i) that such self-entanglements can also form in misfolded states during the process of protein folding, (ii) these states can be long-lived kinetic traps, (iii) they can have similarity to the native state. Here, we test these predictions using long-time-scale, physics-based all-atom simulations of protein folding and find that indeed these misfolded states due form, are long-lived, and are similar in size to the native state. These results support the emerging theoretical perspective that many proteins can exhibit subpopulations of misfolded, self-entangled states that can explain long-time-scale changes of protein structure and function in vivo.

4. X-RAY AND ELECTRON MICROSCOPY

4.1. Zeinab Khosravizadeh (IF PAN)

Band crossing evidence in $Pb_xSn_{(1-x)}Te$ observed by SIMS measurements

For the first time SIMS measurement was used to observe a direct evidence of band inversion. The material studied was Pb1-xSnxTe topological crystalline insulators (TCI). The SIMS signal ratios of $Sn^{\pm}$ /$Te^{\pm}$ and $Pb^{\pm}$ /$Te^{\pm}$ were analyzed in the MBE grown layers. By using the ionization parameters like work function (ϕ), electron affinity (A) and ionization potential (I) the variation in ionization probabilities ($P^{\pm}$) were described. The changes of $P^{\pm}$ depend on the behavior of band gap and electron affinity for different x values. Using the deviation in SIMS signal ratio the band crossing was determined.

4.2. Houri Sadat Rahimi Mosafer (IF PAN)

Structural properties of Ca10.5-xTMx(VO4)7 orthovanadates

Orthovanadates attract researchers' attention because of opportunity of their application in various fields, especially in optoelectronics, biomedicine and in chemistry in connection with their catalytic properties. Calcium orthovanadate and orthophosphate, Ca3(XO4)2, X = V or P, are known to crystallize in R3c space group, with Ca atoms residing at five inequivalent cationic sites. We report an X-ray diffraction study of the structure properties of novel calcium orthovandates Ca3(VO4)2 with Ca atoms partially substituted by transition metals, investigated at room and high temperature.

4.3. Dorota Janaszko (IF PAN)

The structure and oxidation mechanism of Pb1-xSnxTe nanowires

SnTe and Pb1-xSnxTe narrow gap semiconductors are interesting because of their thermoelectric and optoelectronic applications and recently identified topological crystalline insulator properties. Transmission Electron Microscope (TEM) studies of Molecular Beam Epitaxy (MBE) and Physical Vapor Deposition (PVD) -grown IV-VI nanowires (NWs) were performed. Both processes were metal- catalyzed in case of SnTe nanowires, whereas the catalytic droplet, mainly gold, determined the size of the NWs. The growth mechanism was VLS (vapor- liquid-solid) in both methods, additionally some VS growth directly on the nanowire's sidewalls occured in PVD, what caused some NW's asymmetry. Crystal structure of both groups of NWs was rock salt and the crystal growth direction was always [001] independently of inclination for both MBE an PVD NWs. The length of PVD- grown SnTe NWs ranges from 0.8 µm to even over 12 µm with golden

droplet on the top and width of the structures ranges between 50- 200 nm. In case of the MBE grown nanowires, the structures are uniform, and their dimensions are about 0.5 μm length and 40nm width. In both cases oxidation process occurred and the protective ability of gold in terms of preventing oxidation was observed.

5. QUANTUM PHYSICS

5.1. Soheil Arbabi (IF PAN)

Multiscale Simulation of Surfactant-Laden Droplets

Providing a fundamental microscopic description of the coalescence of Surfactant-Laden Droplets. Based on the analysis of the Molecular dynamics (MD) trajectory of coalescence I describe different properties of the process (e.g., dominant mass transport of surfactant molecules, changes in the shape, formation of the surfactant aggregates and the properties of the liquid bridge formed during coalescence).

5.2. Filip Gampel (IF PAN)

Quantum Zeno dynamics for a moving particle

We introduce a model of repeated position and momentum measurement of a single quantum particle. The particle is considered an open system in an environment of detectors, described by a Lindblad equation. Using the Monte Carlo wavefunction method allows us to predict single trajectories. In the talk I will discuss the emergence of different types of such trajectories: classical and Zeno-like dynamics.

5.3. Maciej Bartłomiej Kruk (IF PAN)

Quantum droplets at zero temperature

I will present my work on quantum droplets in three dimensions at zero temperature as well as results for an effective low dimensional theory. Stability of the droplets, critical numbers and finite size effects will be discussed.

5.4. Jan Głowacki (CFT)

Relative observables

Anytime a quantity is being measured, in both classical and quantum physics, it happens through an interaction with a reference system. This is easily accounted for in classical case by introducing a reference frame with respect to which all the observable quantities are defined. The situation differs quite dramatically, however, if we want to treat both the system and the reference as quantum objects. I will briefly introduce one of the formalisms that makes the idea of a quantum reference system and a quantum relative observable precise.

6. TOPOLOGICAL MATERIALS RESEARCH

6.1. Pradosh Kumar Sahoo (MagTop)

Quasi-ballistic transport study of topological materials: SnTe and NbP Hall bars

Recently, topological materials have gained huge attention due to their exciting properties and potential device applications. Here we present the sample fabrication steps to obtain the Hall bar patterns of different dimensions from MBE grown SnTe thin films and NbP single crystals grown by chemical vapour transport method. We use electron beam lithography and subsequent etching processes to obtain the Hall bar patterns for the MBE grown SnTe thin films. The NbP Hall bar is prepared by using focused ion beam (FIB) technique from the single crystal. The transport measurements are performed using physical property measurement system.

6.2. Alam Md Shahin (IF PAN – Magtop)

Magneto-thermo-electrical transport properties of topological semimetal TaAs2

Topological semimetals are a new class of quantum materials exhibit exotic properties due to the gapless surface and bulk states promising for modern device applications. One of the hallmarks of TaAs2 is extremely large non saturating magneto resistance makes it promising for magneto electric device application. Here we measured the magneto-thermo- electrical transport properties with applied magnetic field along [-2 0 1] crystallographic directions. The temperature dependence of resistivity measurement at zero and 14.5 T magnetic field shows field induced metal to insulator transition at low temperature limit. Thermoelectric power measurement in the temperature range of 2 K to 300 K indicated almost perfect compensation below 100 K and a negative Seebeck coefficient observed above 100 K, which suggests significant contribution from electron.

The magnetic field dependences of resistivity, Hall, Seebeck and the Nernst signal show pronounced quantum oscillations at high field up to relatively high (~35 K) temperature. The oscillations have more than one periodicity ascribed to the multiband characteristics of the system. From the Fast Fourier transform (FFT) spectrum we observed two fundamental frequency $\alpha \sim 105$ T and $\beta \sim 221$ T, and a second harmonic $2\beta \sim 442$ T of the latter. We noticed at the temperature around 25 K vanishing of the fundamental frequency (β) while 2β reached as its maximum values. This indicated that we observed temperature driven spin zero effect. This is likely related to substantial temperature dependence of the Landé g-factor, which in turn can result from non-parabolic energy dispersion or temperature evolution of the spin orbit coupling.

6.3. Minh Nguyen (IF PAN)

Symmetries and topological invariants in chalcogenide materials

SnTe materials are one of the most flexible material platforms for exploring the interplay of topology and different types of symmetry breaking. We study symmetry-protected topological states in SnTe nanowires in the presence of various combinations of Zeeman field, s−wave superconductivity, and inversion-symmetry-breaking field. We uncover the origin of robust corner states and hinge states in the normal state. In the presence of superconductivity, we find inversion-symmetryprotected gapless bulk Majorana modes, which give rise to quantized thermal conductance in ballistic wires. By introducing an inversion-symmetry-breaking field, the bulk Majorana modes become gapped and topologically protected localized Majorana zero modes appear at the ends of the wire.

6.4. Arathi Das Moosarikandy (IF PAN)

Study of spin-charge current interconversion efficiency in Topological material /Ferromagnetic material bilayer via spin pumping

Topological materials (TM) with high spin -orbit coupling and spin-momentum locked surface states are prime candidates for the generation of pure spin current. The parameters spin diffusion length (λSD), spin mixing conductance ($g\uparrow\downarrow$), and spin Hall angle (Θ(SH)) determine how useful a particular TM is for spin current generation and spintronics applications. I performed Spin Pumping-Inverse Spin Hall Effect (ISHE) voltage measurements on Pb 1-x Sn x Se/Ni 0.81 Fe 0.19 bilayers and studied the ferromagnetic resonance response and ISHE voltage generated in this system and investigated the spin current generation related parameters in trivial and non-trivial phases of Pb 1-x Sn x Se/ Ni 0.81 Fe 0.19 bilayers as a function of thickness, interface quality, and temperature.

7. MAGNETIC PROPERTIES RESEARCH

7.1. Ghulam Hussain (MagTop)

Structural Stability and Electronic Properties of SnTe and PbTe Nanowires

We use the semi-classical and DFT quantum approaches to study SnTe and PbTe nanowires. The Madelung constant and particle density suggest that if the bond is partially ionic and partially covalent, pentagonal phase is expected to be the most stable one. From the DFT quantum approach, the binding energies are calculated revealing cubic nanowires (CNs) are more stable than pentagonal nanowires (PNs) and the stability increases as the thickness of nanowires increases. Moreover, the CNs and PNs are observed to be dynamically stable as indicated by their stable phonon modes. The CNs grown in [001] direction reveal trivial insulating behavior, the band gap decreases with the thickness of nanowires and becomes topological at thickness of ~13.4 nm. The bands connecting valence and conduction electrons in thin PNs mainly originate from the central atomic chain as observed from partial charge density making the disclination responsible for band crossing and thus metallicity.

7.2. Ashutosh Sandeep Wadge (MagTop)

Manipulation of Fermi Arcs at Pb/NbP bad Nb/NbP interface

Weyl semimetals could be superconductivity-capable through a proximity effect. This concept could support zero bias modes equivalent to Majorana fermions. It allows us to realize fault-tolerant quantum computation. An experimental ARPES was used to study NbP with P and Nb terminated surfaces. Surface Fermi arcs (spoon-like shape), trivial surface states (bow-tie shaped) and bulk Weyl points (WPs) are the fingerprints of P- terminated NbP. Here, we have deposited Nb and Pb on freshly cleaved NbP along [0 0 1]. Deposition of such metals modified the surface states in a constant energy contour due to topological Lifshitz transition. We observed the shrinking of bowtie and spoon like features. Despite of evolution of Fermi surfaces, WPs are robust. This indicates that WSM properties of NbP survive the interface formation and superconductivity penetration into NbP can be expected.

7.3. Tania Paul (MagTop)

Interplay of quantum spin Hall effect and spontaneous time-reversal symmetry breaking in electron-hole bilayers

Excitonic correlations in type-II electron-hole bilayers break time-reversal symmetry spontaneously, which results in an insulating phase separating the trivial and quantum spin Hall phase as a function of electron and hole densities. We propose a transport study on a Corbino-disc geometry to prove the existence of this insulating phase, which causes an unconventional topological transition without a bulk gap closing. We also study utilizing this insulating phase that arises out of broken time-reversal symmetry, in close proximity of an s-wave superconductor to realize Majorana Zero Modes. Majorana zero modes can be detected in a Josephson junction via measurement of 4pi periodic Josephson current.

7.4. Rajibul Islam (MagTop)

Robust Weyl and nodal line semimetal phases in 3D superlattice of Hg-based chalcogenides: ab initio studies

The research on topological materials emerges as one of the most active fields in the condensed matter physics. We have investigated how the topological phases evolve in zincblende 3D superlattices using relativistic density functional theory (DFT) calculations. We study one superlattice (SL) composed by two topological materials (i.e. HgTe/HgSe) and one topological/trivial SL (i.e. HgTe/CdTe). The crystal structure does not have inversion symmetry, but it presents a Kramers-type degeneracy along Γ-Z, while it presents Rashba-like spin-orbit splitting along the other k-space directions. The C2 symmetry protected ideal Weyl semimetal phase has been found in HgTe/HgSe 3D SL as shown in Fig.1. The electronic properties of the CdTe/HgTe SL show a nodal line semimetal phase. Finally, we have investigated the effect of strain demonstrating a rich phase diagram of the topological properties.

7.5. Yadhu Krishnan Edathumkandy (MagTop)

Comparative study of magnetic properties of Mn3+ magnetic clusters in GaN using classical and quantum mechanical approach

Investigated the comparative studies of magnetic properties Manganese clusters in GaN using classical and quantum simulations. We compare the results of numerical calculations of magnetic clusters in (Ga,Mn)N where the Mn spins are treated classically with those they are treated quantum-mechanically. A detailed comparative study of magnetization M(H,T) as a function of magnetic field H, temperature T, number of ions in given cluster and the strength of super-exchange interaction J, obtained from both approaches are studied.

8. EXOTIC MATERIALS RESEARCH

8.1. Piotr Baranowski (IF PAN)

Type II excitons in Cd(Se,Te)/ZnTe self-assembled quantum dots

Semiconductor heterostructures can be classified as type I or type II due to relative alignment of conduction and valence band edges. In this presentation, I will report on optical properties of self-assembled Cd(Se,Te)/ZnTe quantum dots (QDs) grown by molecular beam epitaxy. Addition of Se induces type I to type II band alignment transition. Type II band alignment is demonstrated by the variation of the emission energy, increase of decay times and power dependence of the emission from individual quantum dots.

8.2. Magdalena Duda (IF PAN)

CuInS2/ZnS core/shell quantum dots as a spectroscopic nanothermometers

Semiconductor colloidal CuInS2/ZnS core/shell quantum dots (QDs) are widely investigated because of their low toxicity, size-tuneable broadband absorption and emission spectra, and stable optical signal. Based on these properties, CuInS2/ZnS QDs offer dual functionality in cellular research - as fluorescence bio-markers and in temperature detection. In this work, we study the performance of CuInS2/ZnS QDs as nanothermometers. The temperature measurement relies on both the change in QD photoluminescence (PL) intensity and wavelength. We investigate the influence of the ZnS shell thickness on the nanothermometer temporal stability and sensitivity. We find that thinner shell QDs offer higher sensitivity due stronger contribution of non-radiative recombination to the PL process.

8.3. Miriam Karpińska (IF PAN)

Electronic coupling in hybrid monolayer transition metal dichalcogenide/2D perovskite heterostructures

Layered van der Waals stacks are currently the focus of interest due to their unprecedented flexibility, originating essentially from the almost total relaxation of lattice matching requirements. Additionally, as opposed to the single layers, the heterostructures exhibit novel and exotic properties, such as energy or charge transfer. We present the results of experimental and theoretical studies of novel hybrid transition metal dichalcogenide/2D perovskite stacks, which provide us with an insight into understanding of the mechanism of the electronic coupling between these two different families of materials.

8.4. Adil Rehman (UNIPRESS)

Noise Spectroscopy of Low-Dimensional Systems

Noise spectroscopy has huge potential to explore the hidden characteristics of material. Here, we did noise measurements of various low-dimensional systems to understand the nature of the low-frequency noise in these materials for their potential application in various aspects of technology.

8.5. Maria Szoła (UNIPRESS)

THz magnetospectroscopy of MCT bulk films under hydrostatic pressure

The conducted research is focused on the band-gap evolution of Hg1-xCdxTe epitaxial alloys with cadmium content (x) and the hydrostatic pressure (p) probed by THz magnetospectroscopy. Three Mercury Cadmium Telluride (MCT) samples with different cadmium content x = 0.15, 0.16 and 0.17, grown on semi-insulating GaAs substrate, were studied. The obtained transmission spectra feature well defined resonant absorption lines corresponding to the optical transitions between Landau levels in the vicinity of the gapless state. The analysis of these experimental data within the semi-relativistic description allowed to determine the rest mass m and Fermi velocity c of the Kane fermions. The obtained band-gap values are in a good agreement with the previously measured dependence on Cd content.

9. GaN TECHNOLOGY

9.1. Karolina Grabińska (UNIPRESS)

Recent Progress in Basic Amoonothermal GaN Crystal Growth

There is no doubt that GaN-on-GaN technology is required for a faster progress in nitride-based electronic and optoelectronic devices as vertical high power transistors, high electron mobility transistors, or laser diodes. High structural quality GaN crystals, highly conductive and semi-insulating, are needed for preparing substrates for the mentioned devices. Today, there are three main technologies used for growing GaN: halide vapor phase epitaxy (HVPE), sodium flux, and ammonothermal. The last one can be divided to basic and acidic, depending on the type of mineralizers used. The idea of ammonothermal growth is the following: GaN, used as feedstock, is dissolved in supercritical ammonia. The dissolved feedstock is transported to the second zone, where the solution is supersaturated and crystallization of GaN on native seeds takes place. Ammonothermal crystals are used

as seeds. In the basic approach a negative temperature coefficient of solubility is observed. As a consequence, the chemical transport of GaN is directed from the low-temperature solubility zone (with feedstock) to the high-temperature crystallization zone (with seeds).

In this paper we would like to report the recent progress in basic ammonothermal GaN crystal growth. Crystallization on ammonothermal GaN seeds is presented. Structural properties of the seeds are shown and discussed. A new shape of seed crystals is proposed (see Fig. 1). It allows to eliminate the appearance of cracks in the growing GaN. The unwanted lateral growth is restricted and controlled. A higher growth rate, both in lateral and vertical directions, is obtained. Generally, the high structural quality of native seeds is maintained. In case of crystallization in lateral directions the structural quality of the seeds can even be improved. The influence of the crystallization run parameters, growth direction and configuration on the structural quality of the obtained GaN will be discussed.

9.2. Maksym Dub (UNIPRESS)

AlGaN/GaN FinFETs with bow-tie antennas for sub-THz detection

We investigate the methods of fabrication effective antenna structures for broadband detection by antenna-coupled fin-shaped field-effect transistors (FinFETs) in the terahertz radiation range, using AlGaN/GaN technological process. We demonstrate the efficiency of a split bow-tie antenna solution for a single metal layer and method of improving the response in these designs.

9.3. Natalia Fiuczek (UNIPRESS)

Electrochemical etching of p-type GaN using tunnel junction as a carrier injection layer

In this work we demonstrate electrochemical etching (ECE) of p-type GaN under constant bias without external light source. Firstly, ECE of n-type and p-type GaN is explained using the band structure at the semiconductor / solution interface. Then we show that the inherent difficulties of ECE of p-type GaN were overcome by using a tunnel junction (TJ) and structuring of the samples into double-step stripes. The etch rate and threshold etching voltage were determined. Basing on a very good agreement between experimental results and theoretical calculations we provide a way of controllable ECE of p-type GaN using TJ for efficient hole injection.

This work was supported partially by National Science Center Poland within grant no. 2019/35/D/ST5/02950, under POIR.04.04.00-00-4463/17-00 and POIR.04.04.00-00-210C/16-00 projects of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. The research

leading to these results has also received funding from the Norway Grants 2014-2021 via the National Centre for Research and Development within grant no. NOR/SGS/BANANO/0164/2020.

9.4. Piotr Jaroszyński (UNIPRESS)

Ultra-high pressure annealing of Eu-implanted Am-GaN

Europium doping is one of several approaches in which red light emission (~620 nm) is attainable using GaN. Unlike conventional radiative defects, Eu and other rare earth metals tend to emit light due to transitions between atomic orbitals. Consequently, the characteristics of emission peaks include high intensity and low FWHM. This presentation will feature the innovative doping process of GaN composed of ion implantation followed by ultra-high pressure annealing (up to 1 GPa). Furthermore, the analysis of structural and optical properties of Eu-doped GaN grown using ammonothermal method will be presented and discussed.

9.5. Kacper Sierakowski (UNIPRESS)

Beryllium diffuison in HVPE-GaN grown in non-polar directions

The investigation of beryllium diffusion in ion-implanted (I/I) GaN grown in [10-10] and [11-20] crystallographic directions was performed. Ultra-high-pressure annealing (UHPA) was performed to remove post-implantation damage and induce the diffusion. Secondary ion mass spectrometry was employed to determine the depth profiles of beryllium. Different diffusion depths were observed in samples with different crystallographic orientation.

10. LED TECHNOLOGY

10.1. Julia Sławińska (UNIPRESS)

InGaN microLEDs defined by ion implantation.

In recent years nitride LEDs have been broadly employed in general illumination and backlight units due to their higher luminous efficacy and longer lifetime compared to conventional light sources. Depending on the chip size LEDs find various application like smartwatches or smartphones displays with high brightness. Many of them benefit from LEDs in micro scale - µLEDs. Although the operating principle for conventional broad-area LEDs and µLEDs remains unchanged, the processing of a µLEDs involves additional step. It generates new challenges. In this work we show nitride based

microLEDs where emission surface was defined by size of the tunnel junction (TJ) embedded inside diode. The TJs in the GaN-based optoelectronic structures open new possibilities for novel devices such as vertically integrated multicolor light emitting diodes or laser diodes. The epitaxial structures presented here were grown entirely by plasma assisted molecular beam epitaxy (PAMBE) on (0001) bulk GaN crystals. The PAMBE grown LED structure emitting light at 450 nm was capped with TJ (40 nm) and 100 nm n-type GaN. The emission size of microLEDs arrays was defined by He+ implantation of n-type GaN and TJ region. The ion implantation deteriorates p-type conductivity and significantly increases the TJ resistance in the areas outside microLEDs. The regrowth of 200 nm of high conductive n-type GaN enhances the current spreading at the top of the arrays of µLEDs and allow to apply the side contacts to device. We demonstrate that the array of microLEDs emit light only in TJs regions which were masked during ion implantation The arrays of microLEDs with sizes from 40 µm down to 3 µm were investigated. The parameters and applications of microLEDs grown by PAMBE will be discussed.

10.2. Mikołaj Chlipała (UNIPRESS)

Influence of the built-in polarization on the performance of nitride LEDs at cryogenic temperatures

Gallium nitride-based devices are affected by large built-in polarization. This feature is limiting the injection efficiency of typically investigated light emitters, which are obtained on (0001) GaN substrates. In this study we propose a new construction were built-in fields are inverted to enhance LED performance at cryogenic temperatures.

10.3. Mikołaj Żak (UNIPRESS)

Bidirectional LEDs - a new AC driven light devices

The standard light emitting diode (LED) consists of an active region with sets of quantum wells in between n-type and p-type doped regions. Thus, electroluminescence can be obtained with only one direction of constant current (DC). Placing the active region between two tunnel junctions (TJs) allows the light to be emitted for both directions of supply current. In the "reverse bias" term the bottom TJ is reversely polarized and acts as a Zener diode. The holes are effectively injected to the QW from this bottom TJ. On the other hand the top TJ is polarized in forward direction, electrons flow though upper p-type region to the QW in the active region. In the "forward bias" term the bottom TJ is polarized in forward direction, electrons flow though bottom p-type region to the QW in active region. The holes are effectively injected to the QW from the top TJ which acts

as a Zener diode. It is the breakthrough design of the device that pave the way for studying of semiconductor light sources powered directly by alternating current (AC).

10.4. Kiran Saba (UNIPRESS)

Horizontal-to-vertical surface emitting laser diodes and low-loss GaN-based Photonic Integrated Circuits (PICs)

With the growing maturity of gallium nitride based optoelectronic technology, it is possible now to consider the construction of more integrated photonic system operating at visible frequencies provided by InGaN laser diodes. To achieve this, we need not only laser diodes with etched facets easy to integrated on wafer but also a light guiding system being able to distribute the light across GaN chip. To uncouple the light, we propose to use a 45° deflecting mirrors, which direct the light in the direction perpendicular to the wafer plane. These mirrors can transform the planar system into vertically emitting device of arrays, resembling Vertical Cavity Surface Emitting lasers (VCSELs) arrays. This aforementioned work mainly focused on fabricating waveguides suited to work with GaN substrate characterized by high refractive index and monolithically integrated deflecting mirrors, creating new application possibilities. Speaking of Photonic Integrated Circuits (PICs), Silicon nitride (Si3N4), as a complementary metal–oxide–semiconductor (CMOS) material, finds wide use in modern integrated circuit (IC) technology. However, owing to the complex edge coupling, several basic building blocks for the development of a complete integrated platform, including blue laser diodes and passive components (waveguides) are experimentally investigated. In the meantime, owing to the coupling complexity, we propose low-loss GaN-based PICs. It has been reported that miscut influences indium incorporation and luminescence dynamics. As indium incorporation into InGaN (quantum wells) depends on the off-cut, by varying the off-cut spatially we could produce monolithically integrated multicolor emitters. Considering visible light communication system-based photonic integration, we propose large scale on-chip fabrication of photonic integrated circuits consisting, laser coupled low-loss passive (waveguides) areas, fabricated on locally induced miscut angles. Laser diodes on exact-oriented patterned substrates is not only a cost-effective approach but it offers easy coupling between active and passive parts, along with more a robust technology.

This work was supported by the Foundation of Polish Science (Grant No. TEAM TECH/2017-4/24) Patent application number: PL 437357 A1 (2021.03.19) "Sposób wytwarzania dwuwymiarowej matrycy diod laserowych półprzewodnikowych oraz matryca diod laserowych półprzewodnikowych".

10.5. Mateusz Hajdel (UNIPRESS)

Distributed feedback InGaN laser diodes with tunnel junction grown by molecular beam epitaxy

In this talk an electrically driven III-nitride distributed feedback laser diode (DFB LD) grown by plasma-assisted molecular beam epitaxy will be demonstrated. The utilization of tunnel junction allows to implement novel design of DFB patterning and achieve high coupling of emitted light. The laser diode operates at 450.15nm with >35dB side mode suppression ratio in quasi-CW mode.

11. FREMIONS RESEARCH

11.1. Damian Włodzyński (IF PAN)

Structural transition in a mass-imbalanced few-fermion mixture

In a mass-imbalanced mixture of a few ultracold fermionic atoms with strong repulsive interactions, a spatial arrangement of the components depends on the shape of the external confinement. When the mixture is initially prepared in a one-dimensional box trap and then the harmonic potential is slowly turned on, the system undergoes a structural transition. We have analyzed this transition using the exact diagonalization method.

11.2. Tanausú Hernández Yanes (IF PAN)

Spin squeezing for several spin-orbit coupled fermions in an optical lattice

We investigate the dynamical formation of spin squeezing in the system composed of several ultra-cold fermions in a one-dimensional optical lattice from the initial spin coherent state. As the basic Fermi Hubbard model is unable to generate spin squeezing, we include the spin-orbit coupling to induce the production of spin-squeezed states. The corresponding Fermi-Hubbard Hamiltonian is analyzed in the transformed frame to obtain a relevant spin model which explains squeezing generation. An exact numerical analysis of the model for a small number of lattice sites was performed in different scenarios to probe the influence of spin-orbit coupling. Since we are working with a small number of particles, a special focus on boundary conditions was necessary to obtain accurate results. Finally, we show how the squeezing generation can be understood with the help of the OAT model under a certain regime of parameters.

Timetable

Starting time	Monday, Dec 13th 2021			
9:00	Opening			
9:10	1.1.	Sushma Mishra	SEMICONDUCTOR TECHNOLOGY	Mahwish Sarwar
	1.2.	Monika Ożga		
	1.3.	Abinash Adhikari		
	1.4.	Abdul Khaliq		
9:50	Q&A 1			
10:00	Coffee break			
10:30	2.1.	Rafael Freitas Dos Santos	QUANTUM COMPUTING AND ASTRONOMY	Tomasz Rybotycki
	2.2.	Shubhayan Sakar		
	2.3.	Lorenzo Mattioli		
	2.4.	Filip Maciejewski		
	2.5.	Suhani Gupta		
	2.6.	Susane Calegari		
11:30	Q&A 2			
11:45	Break			
12:00	3.1.	Michał Białobrzewski	PROTEIN PHYSICS	Muhammed Aktas
	3.2.	Quyen Vu Van		
12:20	Q&A 3			
12:30	Lunch break			
14:00	Special guest Invited talk TBA			
15:00	Special guest Q&A			SC
15:15	Coffee break			
15:30	4.1.	Zeinab Khosravizadeh	X-RAY AND ELECTRON MICROSCOPY RESEARCH	Kwasi Nyandey
	4.2.	Houri Sadat Rahimi Mosafer		
	4.3.	Dorota Janaszko		
16:00	Q&A 4			

XIII SYMPOSIUM OF PHD STUDENTS
December 13th - 15th, 2021

Starting time	Tuesday, Dec 14th 2021			
9:00	5.1.	Soheil Arbabi	QUANTUM PHYSICS	Filip Maciejewski
	5.2.	Filip Gampel		
	5.3.	Maciej Bartłomiej Kruk		
	5.4.	Jan Głowacki		
9:40	Q&A 5			
9:50	Coffee break			
10:20	6.1.	Pradosh Kumar Sahoo	TOPOLOGICAL MATERIALS RESEARCH	Rajibul Islam
	6.2.	Alam Md Shahin		
	6.3.	Minh Nguyen		
	6.4.	Arathi Das Moosarikandy		
11:00	Q&A 6			
11:10	Coffee break			
11:40	7.1.	Ghulam Hussain	MAGNETIC PROPERTIES RESEARCH	Amar Fakhredine
	7.2.	Ashutosh Sandeep Wadge		
	7.3.	Tania Paul		
	7.4.	Rajibul Islam		
	7.5.	Yadhu Krishnan Edathumkandy		
12:30	Q&A 7			
12:45	Lunch break			
15:15	IF PAN Colloquium (remotely) Prof. Dr. hab. Kazimierz Trębacz from **Maria Curie-Skłodowska University, Lublin**, *Ion channels as receptors for temperature and touch*			

Starting time	Wednesday, Dec 15th 2021			
9:00	8.1.	Piotr Baranowski	EXOTIC MATERIALS RESEARCH	Ashtuosh Sandeep Wadge
	8.2.	Magdalena Duda		
	8.3.	Miriam Karpińska		
	8.4.	Adil Rehman		
	8.5.	Maria Szoła		
9:50	Q&A 8			
10:05	Coffee break			
10:40	9.1.	Karolina Grabińska	GaN TECHNOLOGY	Kiran Saba
	9.2.	Maksym Dub		
	9.3.	Natalia Fiuczek		
	9.4.	Piotr Jaroszyński		
	9.5.	Kacper Sierakowski		
11:30	Q&A 9			
11:45	Coffee break			
12:00	10.1.	Julia Sławińska	LED TECHNOLOGY	Muhammed Aktas
	10.2.	Mikołaj Chlipała		
	10.3.	Mikołaj Żak		
	10.4.	Kiran Saba		
	10.5.	Mateusz Hajdel		
12:50	Q&A 10			
13:05	Lunch break			
14:30	11.1.	Damian Włodzyński	FERMIONS RESEARCH	Joanna Olas
	11.2.	Tanausú Hernández Yanes		
14:50	Q&A 11			
15:00	Closing			