XIV Symposium of PhD Students

IF PAN ◦ IWC PAN ◦ CFT PAN

Abstract Book

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1. EXOTIC MATERIALS RESEARCH

1.1. Md Shahin Alam, IF PAN

Anomalous transport properties of the ferromagnetic Weyl semimetal CeAlSi

Topological Weyl semimetals (WSMs) host emergent massless Weyl fermions as low-energy excitations, in which linear dispersion of valence and conduction bands touch each other in the three-dimensional momentum space through Weyl nodes. CeAlSi crystallizes in a noncentrosymmetric I41md space group and exhibits ferromagnetic order below 8.5 K. This can lead to generation of Weyl nodes due to the broken time reversal or inversion symmetries. We investigated the electrical and thermo-electrical transport properties of CeAlSi. The anomalous Hall conductivity measured for the magnetic field (B) along the magnetically-hard axis is positive (σ_xy^A>0), whereas it turns out to be negative for B along the magnetically easy axis (σ_yz^A<0). In the paramagnetic phase, the magnitude of σ_xy^A is large in comparison to σ_yz^A. Such an anisotropic anomalous Hall response possibly stems from the anisotropic electronic structure of CeAlSi. The anomalous contribution has been also observed in the Nernst conductivity (α_xy^A) measured for B parallel to the hard axis. In the nonmagnetic phase, the temperature dependences of σ_xy^A as well as the α_xy^A can be well approximated using a single band toy model assuming the presence of a Weyl point in the vicinity of the Fermi level. The occurrence of the finite anomalous Hall and Nernst effects appear to be related to a non-zero Berry curvature associated with the Weyl node.

1.2. Jaydeb Dey, IF PAN

Observation of helical magnetic structure in Mn2GaC MAX phase by 55Mn NMR study

The magnetic Mn+1AXn (MAX) phases, where M,A and X denotes early transition elements, IIIA and IVA group elements and carbon or nitrogen respectively, n (1, 2 or 3) being number of atomic layers, shows promising application potential towards spintronics industries and its derivatives as 2D material, the so called MXene, also has tremendous usage in energy storage devices and etc. The atomically nanolaminated magnetic MAX phase Mn2GaC has been under rigorous research activities to understand it's basic structural and magnetic properties which can be extended for understanding the entire family of MAX phase magnetic materials. Previous results from unpolarized neutron reflectometry measurement are in agreement with collinear antiferromagnetic structure (AFM[0001]4A) whereas the remanent magnetization from macroscopic magnetic measurement contradicts with it. The theoretical studies indicate competing ferromagnetic

and antiferromagnetic interactions between Mn layers across Ga layer, governing a complex magnetic structure. In our work, we have used Nuclear Magnetic Resonance (NMR) study carried out at 4.2K in both zero external magnetic field and in field applied in film plane, to get a microscopic insight into the magnetic structure of MgO(111)/Mn2GaC thin film. The use of an external magnetic field makes NMR an effective technique to probe the local orientation of magnetic moments in the system. The observed large local field at Ga, despite Ga being an non-magnetic atom, is due to the uncompensated magnetic moments from its two Mn adjacent layers which exclude the presence of collinear antiferromagnetic ordering. The NMR in external field reveals the orientation of Mn-spins with respect to the orientation of external magnetic field changes with a continuous manner from parallel to anti-parallel direction which suggests the presence of spiral spin structure in the system along the hexagonal c-axis, incommensurate with the crystal lattice period. The asymmetric distribution of signal intensity observed in the 55 Mn spectra recorded in presence of the in-plane external field shows that the spiral structure of spins can be easily altered by the magnetic field, revealing a spatial modulation of the spin turning angle along the spiral axis, the spin turning angle being defined by the magnitude of ferromagnetic and antiferromagnetic exchange interactions within the nearest and next-nearest layers respectively. These observations confirm the extreme sensitivity of Mn2GaC magnetic structure to the competing ferro-antiferro exchange interactions within this material which in addition can be manipulated by the external factors such as magnetic field, temperature etc.

1.3. Arathi Moosarikandy, IF PAN

Study of Spin Pumping in YIG/ Pt bilayers via Ferromagnetic Resonance- ISHE measurements.

The efficient conversion between spin currents and charge currents is fundamental to the development of novel spintronic devices. Spin pumping is one of the prominent methods used to inject pure spin current from a ferromagnetic material to a normal metal, where it can be detected as a charge current via the Inverse Spin Hall Effect. One of the widely known materials for the spin current generation is the heavy metal platinum (Pt). Yttrium iron garnet Y 3 Fe 5 O 12 (YIG) thin films are widely studied ferromagnetic material because of their low magnetization damping. We investigated the spin-pumping effect in a series of yttrium-iron-garnet (YIG)–platinum (Pt) bilayers of Pt thicknesses ranging from 2 nm - 75 nm and compared the spin pumping parameters via both broadband ferromagnetic resonance (FMR) and electrically detected Inverse Spin Hall Effect measurements. We deposited the Pt thin films via UHV Magnetron Sputtering. We conducted broad band FMR measurements on pure YIG and on YIG/Pt bilayers in a frequency range of 2-20 GHz as a function of temperature and determined the effective spin mixing conductance and enhanced Gilbert damping

parameter. We also studied the Inverse Spin Hall Effect voltage generated in YIG/Pt bilayers as a function of temperature (4-300 K) and input RF power.

1.4. Piotr Baranowski, IF PAN

Carrier separation in type II quantum dots inserted in (Zn,Mg)Te/ZnSe nanowire

A recent observation of excitonic Aharonov-Bohm effect in core/shell nanowires has opened an exciting opportunity to study coherently rotating states in these structures, which could be, subsequently, applied in the field of quantum information storage. An important task for the observation of these states is the separation of electron-hole wavefunctions within a nanowire. In ref, it has been achieved on GaAs crystal phase quantum dots, which are characterized by a type II band alignment. In this work, an alternative approach for fabrication of quantum dots with type II band alignment inside a nanowire built of II-VI semiconductors is presented. The nanowire heterostructures are grown by molecular beam epitaxy by applying the vapor-liquid-solid growth mechanism assisted with gold catalysts. In the first step, ZnTe short axial insertion inside (Zn,Mg)Te nanowire is fabricated by turning off Mg-flux for a few seconds during the (Zn,Mg)Te nanowire growth. Since ZnTe has a smaller bandgap than (Zn,Mg)Te, a sufficiently short insertion can be considered as a quantum dot inside a nanowire. Subsequently, a few monolayers thick ZnSe shell is deposited around the entire nanowire. ZnTe/ZnSe heterostructure is well-known for the type II character, where electrons tend to localize in ZnSe and holes in ZnTe region. In the last step, the nanowires are coated in a (Zn,Mg)Te passivation shell with the thickness of about 20 nm in order to reduce the impact of surface states on the optical emission. Optimization procedure of the above mentioned structure has been performed. In particular, the several parameters, such as: the length of ZnTe axial insertion, the thickness of the ZnSe shell and Mg concentration inside (Zn,Mg)Te are adjusted. Our goal has been to observe an optical emission from ZnTe/ZnSe nanowire quantum dot. In the case of a ZnTe/ZnMgTe reference structure without ZnSe shell, one observes clearly two distinct optical emission lines coming either from the nanowire (Zn,Mg)Te cores or from the ZnTe quantum dot. The addition of only one monolayer thick ZnSe shell significantly changes the optical emission spectrum. The emission energy of the quantum dot emission shifts significantly from 2.38 eV to 2.00 eV. Simultaneously, its intensity drops by about two orders of magnitude and the decays times increase by the factor of about 10. These observations are consistent with the type I to type II band alignment transition resulting from the presence of ZnSe shell. In μ-photoluminescence the broad emission at 2.00 eV splits into several relatively lines coming from individual nanowire quantum dots. This association is confirmed by the appearance of multiexcitonic emission lines when increasing the excitation power.

2. ELECTRON MICROSCOPY AND SPECTROSCOPY

2.1. Abinash Adhikari, IF PAN

Pressure dependent bandgap study of {CdO/MgO} SLs using diamond anvil cel

The development of quasi-ternary alloys (here superlattice structure (SLs)), using MBE technique is challenging but meaningful work for technological advancement in semiconductor industries. Here, in this work, short-period SLs composed of alternate CdO and MgO layers were grown on an r-plane sapphire substrate using the plasma-assisted MBE technique. The thickness of the structure was estimated on the basis of growth conditions. Optical investigation was carried out using UV-Vis spectroscopy at room temperature. Using Tauc relation, the direct bandgap was estimated to be around 2.76 eV. The pressure-dependent optical absorption studies were performed using a double gasketed diamond anvil cell (DAC). It has been observed that the optical absorption, associated with the direct bandgap of SLs has been shifted toward higher energy with applied hydrostatic pressure in DAC. The bandgap of SLs was increased from 2.79 eV to 2.87 eV with applied pressure varied from 1.43 to 5.86 GPa. Obtained pressure co-efficient is well correlated with theoretical results obtained using DFT calculation. Hydrostatic pressure exerts an isotropic contractive force on the SLs and changes the lattice parameters of CdO and MgO. The strain alters the interatomic distances and the bandgap of SLs remains affected. We believe that our research may provide valuable insight for a better understanding of {CdO/MgO} SLs for its future application in optoelectronics.

2.2. Anastiasiia Lysak, IF PAN

Effect of rapid thermal annealing on short period {CdO/ZnO}m SLs grown on m-Al2O3

Zinc oxide (ZnO) due to its direct wide bandgap and high exciton binding energy has significant potential in many applications. To expand the functionality of ZnO-based devices, solid alloys can be used. Therefore, the study of the physical properties of up to now poorly tested Zn1-xCdxO solid solutions is justified. In this work we present the results of investigation of quasi ternary alloys in the form of {ZnO/CdO}m short-period superlattices (SLs) with varying layers thicknesses. The structures were grown on (10-10) m-plane sapphire substrate (Al2O3) by molecular beam epitaxy method (MBE). To study the thermal stability of the structures the SLs were annealed for 5 minutes in an O2 environment at a temperature of 900°C. The chemical composition and interface morphology of as-grown and annealed SLs were examined by Secondary-Ion Mass

Spectrometry (SIMS), Scanning Electron Microscopy with energy-dispersive X-ray spectroscopy (SEM/EDX). The high quality of the as grown SLs is evidenced by the XRD study. Upon annealing in oxygen, the properties of {CdO/ZnO}m SLs were studied again. SIMS measurements showed that structural deformation of the SLs takes place. For a more detailed analysis of the Cd distribution with depth, the low temperature (~5 K) cathodoluminescence spectra (CL) were collected from different sample depths (~20, 70, 200 and 400 nm). The CL reveals a redshif with depth and strongly depends on the structure, namely on Cd contents. The CL spectra reflect the Cd profiles measured with SIMS.

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2.3. Wiktoria Zajkowska, IF PAN

Modified carbothermal technique of ZnO nanowires crystalization

ZnO nanowires will be cores for core-shell objects: ZnO // FeGa. Nano-objects prepared in this way will be the subject of in-operadno TEM research: the piezoelectric effect in the core will induce the effect of magnetostriction through mechanical stresses. A new method of crystallizing ZnO nanowires using a modified carbothermal technique will be presented. The "classic" carbothermal technique involves the reduction of a metal oxide (zinc) with carbon, followed by an externally supplied oxygen oxidation of the metal. In our case, it is not necessary to use an external oxygen source because the carbon oxides produced in the process oxidize zinc vapors (they are carrier gases).

2.4. Dorota Janaszko, IF PAN

Strain field and dislocation density analysis in highly mismatched core-shell CdTe/ZnTe nanowires by quantitative TEM investigations

Among II-IV semiconductors CdTe is very promising one, because its great potential in many solid – state device applications, e.g. in photovoltaics, or X-/γ-ray radiation detection. Here are presented the results of investigation of the NWs where lattice mismatch between core/shell compounds exceeds 6,2%. The CdTe nanowires were grown by Molecular Beam Epitaxy (MBE) with the gold droplets as an eutectic catalyzer using Vapor- Liquid- Solid (VLS) growth mechanism. Depending on the diameter, nanowires (NWs) were obtained with sphalerite or wurtzite crystal structure of the core. In the same MBE process, (Cd, Zn)Te shells were grown at low temperatures, when gold eutectic catalyzer was solidified. The NWs were transferred onto holey carbon film and investigated using HRTEM and HRSTEM in

planar wiev. Specimens were also fabricated by perpendicular cross-section with FIB and core/shell morphology was confirmed during EDS profiles and maps analysis. Obtained TEM and STEM images were analyzed using GPA (Geometric Phase Analysis) and DDT (Dislocation Density Tensor). An attempt for MD (Molecular Dynamics) simulation of investigated system was made using LAMMSPS (Large-scale Atomic/Molecular Massively Parallel Simulator). The applied potential BOP (Bond – Order Potential) enables MD simulations of defect formation to approach a quantum – mechanical accuracy level. Among investigated objects two groups were distinguished. Strained NWs with ~40 nm CdTe core, and ~20 nm thick symmetric ZnTe shell, with detected only one single partial dislocation at the end of SF, and also structures with ~80 nm core diameter and asymmetric ~40 – 10 nm thick shell. In the second case the misfit dislocation network on GPA phase as well as GPA amplitude images were visible. For comparable thickness, core and shell accommodated misfit by elastic deformation of both. In the case of more rigid core, plastic relaxation occurred by creation of misfit dislocation at core /shell interface. In the case of dislocation density on the CdTe/ZnTe interface in analyzed nanostructures, it depended on shell thickness, its symmetry, and core diameter.

3. SEMICONDUCTOR RESEARCH

3.1. Abdul Khaliq, IF PAN

Low temperature weak anti-localization effect in GeTe-SnTe epitaxial layers

IV-VI semiconductors hold intriguing multifunctional features e.g topological surface states, room temperature spontaneous ferroelectricity and giant Rashba spin-splitting which offer opportunities for next generation spintronic applications. In present work, we present epitaxially grown layers of α-GeTe and SnTe and their high field magnetotransport results. The crystal structure of α-GeTe shows a rhombohedral symmetry (R3m) below T ≈ 720 K whereas SnTe holds a cubic symmetry (Fm-3m) above T ≈ 80 K. The variable temperature results in the range 4.3 ≤ T [K] ≤ 300 exhibit a weakly dependent charge concentration p(T) = 0.1 – 0.7 × 1021 cm-3 for SnTe and α-GeTe layers, respectively. Likewise, the hole mobility μh(T) persists nearly constant values between 4.3 ≤ T [K] ≤ 15 which changes to a metallic–like behavior at T ≥ 15 K. The high field magnetoresistance ρxx(B) graphs of SnTe layers measured at –13 ≤ B [T] ≤ 13 demonstrate a prominent weak anti-localization (WAL) effect below T = 3 K and B ≤ ± 0.3 T. However; the WL effect disappears at T = 4.2 K for both α-GeTe and SnTe epitaxial layers. Similarly, ρxx(B) graphs of α-GeTe show a small effect only at lowest measured temperature of T = 1.6 K. The calculated prefactor value, α = –14

obtained by fitting the Δσxx(B) graphs with Hikami−Larkin−Nagaoka model indicates bulk conductivity channels in SnTe.

3.2. Mahwish Sarwar, IF PAN

Crystal Lattice Damage and Recovery of Rare-Earth implanted Wide Bandgap Oxides

Rare earth (RE) elements are important for the optical tuning of wide bandgap oxides (WBO) such as Ga2O3 or ZnO, because Ga2O3:RE or ZnO:RE show narrow emission lines in the visible, ultra-violet and infra-red region. Ion implantation is an attractive method to introduce dopant into the crystal lattice with extraordinary control of composition and location but it creates the lattice damage, which may cause the dopant to be optically inactive. In this research work, we investigate the post-implantation crystal lattice damage of two matrices of wide-bandgap oxides, β-Ga2O3 and ZnO, implanted with rare-earth (RE) to a fluence of 5 x 1014, 1 x 1015 and 3 x 1015 atoms/cm2 and post annealed in Ar and O2 atmosphere, respectively. The effect of implantation and annealing on both crystal lattices was investigated by channeling Rutherford backscattering spectrometry (RBS/c) technique. The level of crystal lattice damage caused by implantation with the same RE fluences in the case of β-Ga2O3 seems to be higher than in the case of ZnO. Low temperature photoluminescence was used to investigate the optical activation of RE in both matrices after performed annealing.

3.3. Vasyl Stasiv, IF PAN

(Y,Gd)AlO_3 perovskite single crystals doped with Mn^{2+} ions

Mn2+-doped YAlO3 (YAP) crystals have proven to be a good candidate for thermally stimulated luminescence (TSL) or optically stimulated luminescent (OSL) dosimetry of ionizing radiation (see [1] and references therein). This material having high effective atomic number (Zeff ~ 31.4) is of particular interest for the purposes of estimation of energy range of unknown photon radiation fields [2]. This work aims to study and improve the TSL/OSL characteristics of (Lu, Y, Gd)AlO3:Mn2+,Si(Hf) crystals for their further practical application as luminescence detectors. Compare the characteristics of crystals grown by the Czochralski method and floating zone method. In order to find out an optimal method in which the relative concentration of Mn2+/Mn4+ is greatest. However there are still many unanswered questions about maintaining manganese ions on 2+ oxidation state. Because as a law, when the concentration of Mn2+ ions, which responsible for the main dosimetric peak, increases, the concentration of Mn4+ ions increases as well, which are unwanted. Also important is the task of eliminating shallow traps that have unnecessary afterglow for OSL/ TSL dosimetry, by partial replacement of Y by Lu or Gd in YAP crystals.

3.4. Ajeesh Kumar Somakumar, IF PAN

Fe^{3+} doped LiGaO2 phosphor for Near-infrared applications.

Transition metal-doped, near-infrared (NIR) luminescent lithium gallate (LiGaO2) material has potential applications in the biological field, GaN crystal growth, and energy storage devices. The Iron (Fe3+) doped LiGaO2 sample was synthesized by a simple high-temperature solid-state reaction method. The oxide phosphor was characterized utilizing XRD, SEM, ambient and high-pressure photoluminescence, and decay measurements using diamond anvil cells (DAC), etc. The powder X-ray analysis shows that at room temperature the phosphor has an orthorhombic crystal structure and has a space group of Pna21, with an average crystallite size of around 32nm. The SEM results also show the formation and well-dispersed nature of the micro rod-like structures throughout the sample. The photoluminescence studies in the NIR range were done at ambient, low temperature & high-pressure conditions. The synthesized phosphor has a far-red luminescence band around 746nm related to the 4T1 → 6A1 transition under ambient pressure and it shifted towards higher wavelengths with the increase of pressure. The decay time analysis confirms that the phosphor has a milliseconds lifetime and has a quantum efficiency of 28% at ambient conditions. The overall results point towards the potential application of LiGaO2:Fe^{3+} as a rare-earth-free NIR luminescent phosphor.

3.5. Sania Dad, IF PAN

Hybrid Nanowires Comprising III-V Semiconductor Cores and Narrow Bandgap IV-VI Semiconductor Shells

The binary and ternary IV-VI narrow bandgap chalcogenide alloys have gained significant interest due to their novel quantum properties such as the topological phase of SnTe protected by crystalline symmetry. The nanowire heterostructures can be a good candidate for bandgap engineering in a one-dimension to obtain the hinges states along the edges of nanowires. In the planar semiconductor heteroepitaxial systems, typically large lattice mismatch results in low-quality interfaces and high dislocation densities, which further degrade the electrical properties of the material. These effects can be avoided in the nanostructures, due to the nanoscale dimensions. We study full and half-shells of IV-VI narrow gap semiconductors on III-V nanowires (NWs), which, in a distinct orientation of crystal lattices of both materials bear a lattice mismatch of less than 1%. The topological crystalline insulator Pb1-xSnxTe alloy is chosen as a shell material that possesses the band inversion property for some critical concentration of Sn. We have grown the IV-VI shells on GaAs nanowires with different compositions ranging from binary PbTe, through Pb1-xSnxTe solid solution with increasing Sn content ($0 \leq x \leq 1$) up to binary SnTe. The as-grown samples were then analyzed by

scanning transmission electron microscope (STEM), which revealed the presence of (110) or (100) oriented binary PbSnTe on the {-110} sidewalls of GaAs NWs.

3.6. Syed Shabhi Haider, IF PAN

Designing of Experimental Setup for Impact Induced Mechanoluminescence Measurements

An alternative and integrative approach has been adopted to construct novel low-cost laboratory equipment for measuring the mechanical impact-induced mechanoluminescence (I-ML) properties of materials. The several parts of the constructed setup are perfectly interfaced and capable of measuring the I-ML properties with high accuracy and sensitivity. In this setup, the correlation between incident kinetic energy and mechanoluminescence is comprehensively investigated by the changing incident angle of the shooting up to 40̊, while the range of incident kinetic energy is controlled by the masses of the projectiles. For a 0.28 g ball, the range is 200 mJ to 269 mJ. The designed apparatus is also beneficial for analyzing the cause of ML which may be due to trap states or deep trap states of a certain material, by multishot measurements at high frequencies. The extracted results during multiple measurements of the luminescence materials Sr0.95Ca0.05(SO4):Mn and SrAl2O4:Eu,Dy, justified the extraordinary performance of the setup in different categories of mechanoluminescence studies. The designing and handling of the proposed setup are simple and highly beneficial for broad-range experimental analysis of the I-ML characteristics. The outcomes validate the successful performance and reliability of purpose self-design I-ML apparatus for research laboratories and commercial applications.

4. GaN TECHNOLOGIES

4.1. Adil Rehman, IWC PAN

Temperature Dependent Sub-THz Detection in Graphene and GaN-based Transistors

The presence of naturally occurring 2D nature and high mobile charge carriers in graphene make them an appealing candidate to surpass the other THz detector technologies. In this work, we measured temperature-dependent photo response in the sub-THz regime (0.14 THz) of graphene-based field-effect transistor (FET) and compared the results with fin-shaped¬ AlGaN/GaN-based FET. Instead of measuring the photo voltage via lock-in amplifier, the current induced by the incoming sub-THz radiations was measured directly with a semiconductor parameters analyzer. Such kind of approach allows fast and multiple THz signal detection as a function of temperature. The measured photo current was in good agreement with the phenomenological expression assuming its proportionality to the first derivative of conductance over the gate voltage. We have found a significant enhancement in the current responsivity of both devices as temperature decreases. Though the responsivity saturates at low temperature, the noise equivalent power (NEP), which defines the sensitivity of detectors continued to decrease with temperature. Our results showed that improvement in current responsivity and sensitivity of graphene device with temperature decrease was much steeper than fin-shaped AlGaN/GaN-based FET and clearly show an advantage of graphene-based THz detectors over GaN, while operating at low temperatures.

4.2. Karolina Grabiańska, IWC PAN

An innovative approach to control the morphology of growing GaN crystals.

Surface morphology is one of the most crucial properties of a newly-grown crystal. Researchers argue that a crystal should always be studied in the following order: morphology, structural quality, growth rate, and never the other way round. Moreover, the morphology analysis alone can tell us a lot about the structural quality of the crystal as well as the rate with which it was grown. Regardless of the crystallization method, the morphology of the growing crystal mainly depends on the preparation of the seed's shape and surface (and, therefore, its initial morphology), and supersaturation at the crystallization front. Controlling the surface morphology of the growing bulk crystal does not appear to be as difficult when a single crystal is synthesized. Whether crystallizing from melt, solution, or gas phase, it is optimal to obtain a single hillock on the growing surface. This morphology is the most stable one. It is, however, difficult to control the morphology of many (up to 100) crystals in one growth zone

and have one hillock on each growing crystal. Based on the alkaline-ammonothermal crystallization process, a novel approach to controlling the morphology of many growing crystals in one run is proposed.

4.3. Kacper Sierakowski, IWC PAN

Zn diffusion in GaN crystals

Ion implantation (I/I) seems to be nowadays one of the most important techniques for manufacturing gallium nitride (GaN) based semiconductor devices. High-energy ions might be implanted into crystals in order to create doped regions. To achieve the required conduction in the implanted layer, p-type or n-type, one must anneal the structure to activate the dopant. Temperature treatment is also required to remove the I/I-induced structural damage. In the case of GaN high-temperature annealing is difficult due to thermodynamics of GaN (thermal decomposition above 800°C in atmospheric pressure). Ultra-high-pressure annealing (UHPA), which involves high pressure of nitrogen, allows to avoid the decomposition of GaN samples. The most popular p-type dopant in GaN is magnesium (Mg). However, other elements are also investigated. One of other possible candidates for p-type doping is zinc (Zn) [1]. In the presented work GaN doping by Zn implantation was investigated. HVPE-GaN layers were grown on ammonothermal seeds of three polarities: (0001), (10-10), and (11-20). Zn I/I was performed with the energy of 230 keV and fluence of 1016 cm-2. The samples were then treated with UHPA in the temperature range 1250°C÷1450°C for 30 and 240 minutes. A constant nitrogen pressure of 1 GPa was applied for all the annealing runs. X-ray diffraction measurements were employed to assess the success of structural damage removal by annealing. The depth profiles of Zn and atmospheric impurities were determined by secondary ion mass spectrometry (SIMS). This allowed to study the diffusion of the implanted element in GaN. An anisotropy of diffusion was observed for the different crystallographic directions.

4.4. Piotr Jaroszyński, IWC PAN

The role of calcium in ion implanted gallium nitride

Calcium is a rarely studied dopant of gallium nitride. In the scientific literature, Ca-implanted gallium nitride (GaN) has been shown to exhibit p-type conductivity following rapid thermal annealing (RTA) at high temperatures of >1100 °C. Its ionization level is estimated at 169 meV with a 100% ionization rate. The ionization level is similar to that of Mg (212 meV), which remains the most common p-type dopant of GaN to date. The recently published optical studies of Ca-implanted GaN (Reshchikov et al) feature new results which challenge the view of Ca constituting a shallow level p-type dopant of GaN. In this presentation, the role

of calcium in GaN will be discussed. Moreover, new results will be presented based on the author's study of Ca-implanted GaN grown by halide vapor phase epitaxy (HVPE) method.

5. THIN FILM TECHNOLOGIES

5.1. Pradosh Kumar Sahoo, IF PAN

Magneto-transport study on SnTe thin film

In the recent years, topological materials have opened many possibilities in fundamental science and future technologies because of their exceptional topology protected properties. We present the magneto-transport study of a topological crystalline insulator, SnTe thin film of thickness 100 nm. It was grown using molecular beam epitaxy (MBE) technique on GaAs substrate with CdTe buffer layers. We carved a Hall bar of width 750 nm on the SnTe thin film using electron beam lithography and etching process and performed the transport studies. We measured the resistivity from 300 K to 2 K at different magnetic fields (0, 1, 3, 5, 7 and 9 Tesla) perpendicular to the film plane. We also measured the magnetoresistance by sweeping the magnetic field from +9T to -9T at different temperatures from 300 K to 2 K. The longitudinal magnetoresistance (MR) varies in a quadratic manner for temperatures above 5 K. At 2 K around zero magnetic fields, we observed a valley which can be attributed to weak anti-localization in the transport by the surface states.

5.2. Zeinab Khosravizadeh, IF PAN

Determination of diffusion coefficeinet of atmospheric elements in CdZnO thinfilms

Thermodynamic properties of atmospheric elements namely H, C and N in CdZnO/Si thin films grown using Molecular Beam Epitaxy (MBE) were studied. Depth profiles in as-grown and annealed samples range 500-900C were determined using Secondary Ion Mass Spectrometry (SIMS). They revealed the outdiffusion and segregation at CdZnO/Si interface of the studied species. Depth profiles fitted using the Forward Time Center Space (FTCS) iteration method was used to determine the diffusion coefficients of elements at particular temperatures, as well. Moreover, the stability of Cd content at elevated temperatures was studied using X-ray Photoemission Spectroscopy (XPS) and compared with SIMS method.

5.3. Amar Fakhredine, IF PAN

Huge Dzyaloshinskii-Moriya interactions in Re/Co[n]/Pt thin films

Spin-orbit coupling can lead to intriguing phenomena such as the magnetic anisotropy, the spin Hall effect, the Rashba effect, and Dzyaloshinskii–Moriya (DMI) interaction. DMI is an antisymmetric indirect exchange interaction occurring between two spins. In magnetic materials with broken chiral symmetry, the structural configuration induces these chiral couplings which stabilize two- and three-dimensional localized nanometre in size spin whirls defined as skyrmions [1]. Remarkably, skyrmions can be formed in ultrathin magnetic transition metal thin films, such as cobalt if these are in contact with materials that exhibit high spin-orbit coupling. The discovery of skyrmions is promising for the industry of spintronic applications that offer ultra-small, ultrafast, and low-power devices. The control of the DMI strength in multilayered structures allows us to manipulate the different sizes and stability of these magnetic objects [2]. In this work, we present a theoretical technique using DFT calculations to model the DMI interactions in Re/Co[n]/Pt and report its interfacial and additive character [3]. The total DMI strength (dtot[meV]) in the Re/Co[n]/Pt chiral multilayered system was calculated from the difference in energy between clockwise and anticlockwise configurations of the Co magnetic spin spirals which were further used to determine the micromagnetic DMI [4]. The investigated systems were composed of 5 atomic layers (AL) of Pt and 5 ALs of Re sandwiching the Co layer with a tuneable thickness ranging from 1 to 6 ALs. The micromagnetic DMI (named D) was found as high as 5.78 mJ/m2 for 3 layers of Co. This value of D is considerably large in comparison to other systems. The layer resolved DMI strength shows the highest contributions from the two interfacial Co layers, namely Re/Co and Co/Pt, which add up to produce a huge additive outcome indicating that the DMI is an interfacial effect [5]. This also explains the dependence of the micromagnetic DMI on the number of Co layers since it appears due to the electron hybridization between magnetic moments in the 3d Co atoms and the strong spin-orbit coupling in 5d states of Pt or Re atoms.

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5.4. Sameh Altanany, IF PAN

Berezinskii-Kosterlitz-Thouless transition in ultrathin nobium films

We use resistivity and current-voltage characteristics measurements to evaluate the impact of disorder on the nature of Berezinskii-Kosterlitz-Thouless (BKT) transition in ultrathin niobium (Nb) films. The films, with thickness in the range 3.6 -8.5 nm, show structural transition from polycrystalline to amorphous structure upon decrease of the film thickness.

We show that this transformation results in smearing of the BKT transition, until eventually the BKT scenario breaks down due to film inhomogeneity.

6. DROPLETS

6.1. Maciej Bartłomiej Kruk, IF PAN

Stationary, dynamic and thermal properties of flattened and elongated quantum droplets

We present our ndings with regards to quantum droplets that dier from the usual extended form in 3d by being attened, elongated, or at nonzero temper- ature, but not yet in a hard low dimensional regime that would modify the LHY term. We compare the droplet stability at zero and nite temperatures. We demonstrate an eective low dimensional theory for description of the quantum droplets in the attened and elongated regimes. As a benchmark of the eective theory, we studied droplet dynamics in the case of collisions, showcasing similari- ties and dierences compared to regular 3D droplet collisions.

6.2. Jakub Kopyciński, CFT

Ultrawide dark solitons and droplet-soliton coexistence in a dipolar Bose gas with strong contact interactions

We look into dark solitons in a quasi-1D dipolar Bose gas and in a quantum droplet. We derive the analytical solitonic solution of a Gross-Pitaevskii-like equation accounting for beyond mean-field effects. The results show there is a certain critical value of the dipolar interactions, for which the width of a motionless soliton diverges. Moreover, there is a peculiar solution of the motionless soliton with a non-zero density minimum. We also present the energy spectrum of these solitons with an additional excitation subbranch appearing. Finally, we perform a series of numerical experiments revealing the coexistence of a dark soliton inside a quantum droplet.

7. PROTEIN PHYSICS

7.1. Hung Nguyen Van, IF PAN

Effect of the corona virus on protein synthesis in human ribosomes

Experiments have consistently shown that non-structural protein 1 of SARS-CoV-2 (SARS2 Nsp1) is a factor to restricts cellular gene expression and prevents the translation process at the mRNA entry channel of the 40S ribosomal subunit by blocking host mRNA. However, this is still an unclear mechanism. We used molecular dynamics simulations to estimate the binding affinity of mRNA to 40S ribosome and 40S ribosome [Nsp1]. Our theoretical works showed that mRNA binding to 40S ribosome [Nsp1] is much stronger than that to 40S ribosome. These computational results are also in strong agreement with the experimental results of Schubert et al. and Thoms et al. groups. Our studies demonstrate that the mRNA-40S ribosome translation can be derived from electrostatic interaction energy between mRNA and 40S ribosome. And after entering host cells, SARS2 Nsp1 binds to the 40S ribosome and prevents the translation process of the mRNA-40S ribosome. Especially, the residue Glu159 of SARS2 Nsp1 has a key role to trigger a translation shutdown of the host immune system.

7.2. Michał Białobrzewski, IF PAN

How fluctuations at the nanomolar scale in aqueous solutions give an unique information about hydrodynamics properties and molecular interactions of proteins involved in regulation of gene expression?

Intrinsically disordered proteins (IDPs) play a pivotal role in various fundamental and diverse processes that occur in living organisms. This specific group of proteins participates in recruiting a multiprotein complex responsible for the negative feedback mechanism that can regulate protein levels in the cell. The intermolecular interactions of this complex are yet not fully understood because there are not so many adequate biophysical methods that could be useful to study the dynamics and properties of large molecules with loose structure. In my talk, I will discuss applications of the Fluorescence Correlation Spectroscopy (FCS) to study hydrodynamic properties of the large set of the disordered proteins and highlight our recent findings that could provide answer to the question, how local structural features may play a role in mediating intermolecular interactions in the multiprotein complex.

8. QUANTUM COMPUTING

8.1. Oskar Słowik, CFT PAN

The efficiency of universal sets of quantum gates

Currently available quantum computers, so called Noisy Intermediate-Scale Quantum (NISQ) devices, are characterized by relatively low number of qubits and moderate gate fidelities. In such scenario, the implementation of quantum error correction is impossible and the performance of those devices is quite modest. In particular, the depth of circuits implementable with reasonably high fidelity is limited, and the minimization of circuit depth is required. Such depths depend on the efficiency of the universal set of gates S used in computation, and can be bounded using the Solovay-Kitaev theorem. However, it is known that much better, asymptotically tight bounds of the form O(log(ε^-1)), can be obtained for specific S. Those bounds are controlled by, so called, spectral gap at a certain scale r(ε), denoted gap_r(S). We derive lower bounds on gap_r(S) and, as a consequence, on the efficiency of universal sets of d-dimensional quantum gates S satisfying an additional condition. The condition is naturally met for generic quantum gates, such as e.g. Haar random gates. Our bounds are explicit in the sense that all parameters can be determined by numerical calculations on existing computers, at least for small d.

8.2. Tae-Hun Lee, CFT PAN

What is information?

These days the information is a familiar concept in our daily life, industry and academy. However, a closer look into the details will find that it is quite puzzling to answer what information is in physics. I believe that physical identification of information lies at the heart of the most fundamental problems in quantum mechanics. In this presentation, starting with questions where information is stored and in what physical process information is extracted, I discuss one of the fundamental problems in quantum mechanics, how the classical world can be naturally realized within the standard quantum mechanical. Finally we address what specific research problems need to be solved.

8.3. Tomasz Rybotycki, CFT

Effective algorithms for classical simulation of quantum many-body systems

In this talk, I'll present the advances we've made in quantum computing. I'll first introduce the notion of BosonSampling (BS) and then present our findings. In particular, I'll show a faster version of the generalized Clifford & Clifford sampling algorithm and the average-case scenario accuracy of the approximate lossy BS. I'll conclude the talk with future research directions.

8.4. Owidiusz Makuta, CFT PAN

Generation of graph states in quantum networks

In scientific research concerning quantum networks, it is often assumed that the parties in the network can classically communicate with each other. This is a non problematic and natural assumption when the entire network is contained, e.g., in one laboratory; however, when we start to consider quantum networks spanning hundreds of kilometers, then classical communication could introduce substantial delays to the network. As the latency of a network is one of its most important characteristics, it is interesting to consider quantum networks in which parties cannot communicate with each other and ask what limitations this assumption imposes. In this work we show that quantum states from a well-known class of graph states cannot be generated in a quantum network in which parties are connected via bipartite sources of quantum states, but they cannot communicate with each other classically.

9. ZOOM PANEL

9.1. Natalia Fiuczek, IWC PAN

Influence of band offset in nitrides on electrochemical etching parameters

Electrochemical etching (ECE) parameters, such as threshold etching bias, the pore wall size and the pore morphology, should depend on the conduction band offset in the semiconductor and the Fermi level of the electrons in the electrolyte. This work shows preliminary results on that topic. We explain the basic physics of ECE of nitrides and the expected trends for nitrides with changing band offset. Next, we report on ECE of (In,Ga)N:Si and (Al,Ga)N:Si, with %In=8% and 20%, %Al=8%, respectively. All the layers were doped with Si of the same

concentration level nSi=3*1019cm-3. The etch rate, threshold etching bias and the pore morphology are discussed.

9.2. Maria Szoła, IWC PAN

Narrow-gap HgCdTe magneto-optical spectroscopy

The hydrostatic deformation potentials for the conduction (ac) and valence bands (av) are essential parameters of semiconductors. Their difference ac – av can be determined by measuring the hydrostatic pressure dependence of the band gap, generally by photoluminescence or transport techniques. The precise knowledge of these parameters at low temperatures is particularly important to fully describe bulk crystals and quantum wells. However, these measurements become very difficult for narrow gap semiconductors, and even more in the vicinity of topological phase transitions where the band gap closes. Under these conditions, magneto-optical spectroscopy in the Terahertz (THz) frequency range is a particularly well-suited technique since it makes it possible to measure Eg more precisely than the transport technique. Indeed, the THz magneto spectroscopy method does not require the introduction of third-party parameters. In this research, through combined THz magneto-optical spectroscopy and theoretical work, we study the variation of the band gap of HgCdTe crystals as a function of hydrostatic pressure in the vicinity of the topological phase transition.

9.3. Kwasi Nyandey, IF PAN

Classification of milk fat content categories based on speckle pattern using machine learning

Milk, an important and nutrient-rich liquid food is also a naturally occurring colloidal suspension with diverse constituents. Fat globules in milk are known to be secreted as droplets of variable sizes and in different amounts. Hence for industrial, commercial and consumption purposes, there is always the need to accurately and speedily determine fat globule size distribution and classify content into appropriate amounts in each milk batch produced. We propose a direct approach to classifying speckle images generated by laser scattering of cow milk with different fat contents using convolution neural network. Because the random intensity distribution (speckle) that is observed when coherent light is scattered by a rough surface or transmitted through a scattering medium carries information which can be termed as a fingerprint of the scatterers in question. Hence, we recorded movies of speckles generated by laser scattering from cow milk (with fat content categories; 0.5, 1.5, 2.0 and 3.2%) in a thin cuvette. The extracted frames served as the speckle images, which were used to train our convolution neural network. We trained the network on three and four milk fat content categories with over 51,000 images in each class. Finally, we tested the network's

ability to generalise on independent sets of data for all the fat content categories. Our neural network was able to recognize the milk fat content categories from independent as well as mixed dairy plants, and we obtained the highest validation, test and independent classification accuracies of ~99%.

9.4. Luis Henrique Carnevale, IF PAN

MDPD Simulation of Liquid Thread Break-up and Formation of Droplets

The breakup of liquid threads is a fundamental process in nature and relevant for many industrial applications, such as drug manufacturing, inkjet printing, and nanowire fabrication. The classical theory used to describe the breakup of liquid threads has its origins in the works of Rayleigh and Plateau. By means of linear stability analysis, they have shown that a fluid cylinder is unstable for perturbations characterised by a wavelength larger than its circumference. Moreover, there is a characteristic wavelength that the perturbations are the most unstable. In our study, we have employed large-scale mesoscale simulations of a coarse-grained model to determine the characteristic wavelength of liquid nanothreads within the statistical uncertainty for a range of fluids, characterised by different Ohnesorge numbers and accessible to our model. Also, we have identified the mechanisms of satellite-droplets formation and characterised their properties. We anticipate that our study contributes to the understanding of a fundamental process in nature and paves the way for further developments in this area for relevant applications.

9.5. Kausik Das, IF PAN

Magnetic Dynamical Properties and Ferromagnetic Resonance in (Ga,Mn)N Layers

Dilute ferromagnetic semiconductors (DFS), in particular Ga1−xMnxN, have attained great research attention due to their unique ability to combine properties of semiconductors and magnetic materials [1]. Moreover, GaN being a wide band gap semiconductor has dominated the photonics and high power electronics. So it is important to make an effort to understand the underlying magnetic properties of Ga1−xMnxN. Here we investigate both experimentally and theoretically the magnetic properties of GaN doped with Mn. The MBE grown ferromagnetic Ga1−xMnxN layers, with x ranging between 3% and 7%, are studied by a superconducting quantum interference device (SQUID) and ferromagnetic resonance (FMR). The uniaxial magnetic anisotropy (MA) of investigated material is inferred from magnetization measurements with magnetic field applied in two (perpendicular) directions with respect to the c-axis of GaN. Similarly, the angular dependencies of FMR resonance fields enable probing both the uniaxial (trigonal) and triaxial (Jahn-Teller) anisotropies in

Ga1−xMnxN. The FMR experimental data is first analyzed by a traditional analytical approach using a (macrospin) free energy model [2]. However, such an approach does not give satisfactory results in the case of GaN with few percent randomly distributed Mn ions. Therefore, an atomistic spin model, using stochastic Landau-Lifshitz-Gilbert (sLLG) dynamics [3], is being developed. The model takes into account the Zeeman interaction as well as both trigonal and Jahn-Teller anisotropies (cf. Ref. [4]). A large simulation box, with few thousand Mn ions coupled by ferromagnetic interaction –JS1S2, is used. The magnetic moment M and the microwave power absorbed during a ferromagnetic resonance is calculated after the system has reached a steady state [5]. Preliminary numerical results on small systems suggest the correctness of the applied model. This is the first simulation effort aimed at calculation of both magnetization and FMR in dilute magnetic semiconductor using atomistic approach.

9.6. Yadhu Krishnan Edathumkandy, IF PAN

On the device fabrication for studies of precessional magnetization switching in ferromagnetic (Ga,Mn)N using sub-nanosecond pulses

Controlling the magnetic state using an electric field rather than a conventional magnetic field has many advantages. Besides being more energy-efficient, utilizing an electric field allows more local control of the magnetic state resulting in better scalability of the magnetic device. However, a critical issue in electric field switching is to realize a bistable switching since it does not break time-reversal symmetry and thus does not remove the degeneracy of two magnetic states with opposite magnetization. To this end, our primary work is to demonstrate a bistable magnetization switching in the dilute magnetic insulator (Ga,Mn)N using sub-nanosecond pulses. Our work is based on the demonstration that the piezoelectricity specific to GaN allows to affect magnetization in GaN doped with Mn by magnetoelectric coupling [1]. Here, the application of an electric field along the wurtzite c axis stretches the material's elementary cell. In this way the the sign and the magnitude of the single-ion magnetic anisotropy specific to Mn3+ ions in GaN can be affected. In our approach thin (Ga,Mn)N layer is an active part of a metal-insulator-semiconductor (MIS) structure, forming capacitor-like device [2]. As a preliminary step towards fabrication of the final device to which sub-nanosecond electric pulses (GHz frequency regime) could be applied, we study the combined resistance of GaN:Si conducting layer (one of the conducting plates of the capacitor-like device) and the resistance of metal contacts to ensure a proper impedance match to 50 Ω GHz cables. Hence, we performed wide temperature range conductivity studies of the GaN:Si. This conducting layer was grown on a sapphire substrate using MOVPE. Four probe and two probe measurements are performed to study the sample's conductivity, resistance, and contact resistance variation

with temperature with and without annealing of the electrical contacts. Additionally, results of simulations performed on the MIS capacitors also will be presented.

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9.7. Sushma Mishra, IF PAN

An arbitrary Cross-Sectional Low Temperature-Cathodoluminesence-SEM-Imaging study of ALD-ZnO:N and ZnO films via wide range annealing in O2/N2 atm

ZnO is a versatile material being piezoelectric, dielectric, transparent, semiconducting oxide with a direct band gap of 3.37 eV and a significant excitation binding energy (60 meV). However, p-type conduction is difficult to realize in ZnO due to many subtle reasons. Despite low solubility, nitrogen appears to be the most promising dopant for p-type ZnO. According to present knowledge, the VZn–NO–H, VZn–NO and n·VZn complexes provide shallow acceptor states and are responsible for conductivity conversion. As formation energy of VZn is lower under O-rich conditions, such growth conditions are important to obtain p ZnO. In the present paper we investigate the acceptor- and donor-related cathodoluminescence (CL) for ~2μm thick ALD-ZnO:N and ZnO films grown under O-rich conditions and annealed in two atmosphere O2/N2 at temperature from 400oC to 900oC. As expected [1], the VZn–NO–H complex is supposed to be formed during the ZnO:N-ALD process. However, it is a deep acceptor, so it cannot be the cause of p-type conductivity. Instead, the annealing (RTPN/RTPO) is necessary for the formation of the shallow acceptor VZn–NO complex. In the experiment, SIMS profiles, XRD and low temperature (LT) CL data were taken in order to compare H and N content, crystal structure and donor- and acceptor-related emission after subsequent annealing processes. The concentration of H and N was investigated with successive increment in annealing temperature via SIMS depth profiles. LT CL spectra were recorded on the ZnO or ZnO:N films cross-sections together with LT-SEM color images. They confirmed that donor- or acceptor-related CL in polycrystalline ALD-ZnO films comes directly from crystallites. The impact of annealing on structural disorder like dislocation density, micro-strain, crystallites size and their variation also influences the intensity of acceptor/donor related emission [2]. The activation of an acceptor emission caused by high-temperature annealing is exhibited in CL spectra as an enhancement in FA emission. The annealing process of a nitrogen doped sample, impacts on both acceptor and donor states as well as on micro-structural disorder. It incorporates a complicated interaction of acceptors, donors, and native point defects, resulting in a 3.32eV and 3.36eV increase in the CL line spectra.

9.8. Juby Alphonsa Mathew, IF PAN

The Impact of Mg and O elements on the Structural and Optical properties of PA-MBE grown Europium Doped ZnMgO Thin Films

The influence of Mg and oxygen contents on the structural and luminescence properties of Eu doped ZnMgO layers is studied. ZnMgO:Eu thin layers are deposited on a-Al2O3 substrates by oxygen plasma assisted molecular beam epitaxy. The samples are grown at 550°C under two unlike conditions i) varying Mg fluxes from sample to sample, keeping the oxygen flow constant; ii) keeping all other parameters constant while varying the oxygen flow. Both magnesium and oxygen is found to have crucial impact on the luminescence properties of Europium as seen from the photoluminescence analysis. EDX measurements are carried out to determine specific elemental composition. Compositional depth profiling of Europium is performed using Secondary Ion Mass spectrometry. Structural investigations are carried out using XRD and SEM techniques.

9.9. Jan Głowacki, CFT PAN

A novel formal approach to relational quantum physics

The subject of Quantum Reference Frames (QRFs), aiming at providing a relational framework for quantum theory, potentially more suited for dealing with relativistic concepts than the usual formulation of quantum mechanics, and possibly pointing at new ways of reconciling quantum theory with General Relativity, has recieved growing attention in the last years. Depending on the time given, I will introduce the current status of the field and sketch the framework that I am developing now.

9.10. Soheil Arbabi, IF PAN

Coalescence of surfactant-laden droplets

Droplet coalescence is commonly encountered in nature and is also relevant for various technologies, such as inkjet printing. We present our results on the coalescence of surfactant-laden water droplets, which have been obtained by means of molecular dynamics simulation of a coarse-grained (CG) force-field. In particular, we will discuss the details of the coalescence mechanism and the bridge growth dynamics.

9.11. Russel Kajouri, IF PAN

Durotaxis motion on brush substrates

A range of industries require the self-sustained directed motion of nano-scale droplets on different substrates for various purposes [1, 2], for example, in the context of micro-fabrication [3], coating [4], micro-fluidics and thermal control [3, 4]. One way of causing such motion is durotaxis, where a gradient stiffness of a substrate is used to enable droplets to move along the direction of the gradient. Using molecular dynamics, we show that the motion of a droplet on a brush substrate depends on the range of stiffness variation compared to the chain length and grafting density of the brush, and the interaction between the brush and the droplet. Our analysis indicates that a brush substrate of a moderate grafting density induces the most efficient droplet motion, while motion efficiency depends only weakly on the stiffness gradient. Finally, a larger size of the droplet favours the durotaxis motion on brush substrates.

10. QUANTUM PHYSICS

10.1. Damian Włodzyński, IF PAN

New approach to a small Fermi-polaron system in a harmonic trap

Recent experimental realization of an ultracold mixture with a single impurity immersed in several fermions in a one-dimensional harmonic trap motivated theoretical studies of this problem. Unfortunately, for strong inter-component interactions, typical numerical methods perform poorly in simulating this system. Therefore analyses are usually limited to very small mixtures. I will present an alternative numerically exact approach to this problem. The method is especially effective for heavy impurity.

10.2. Tanausú Hernández Yanes, IF PAN

Accelerating many-body entanglement generation by dipolar interactions in the Bose-Hubbard model

The spin squeezing protocols allow the dynamical generation of massively correlated quantum many-body states, which can be utilized in entanglement-enhanced metrology and technologies. We study a quantum simulator generating twisting dynamics realized in a two-component Bose-Hubbard model with dipolar interactions. We show that the interplay of contact and long-range dipolar interactions between atoms in the superfluid phase

activates the anisotropic two-axis counter-twisting mechanism, accelerating the spin squeezing dynamics and allowing the Heisenberg-limited accuracy in spectroscopic measurements.

10.3. Suhani Gupta, CFT PAN

Non-linear structure formation in modified gravity cosmologies

Large-scale structures (LSS) form via relentless action of gravitational forces on density perturbations over cosmic length and time scales. Thus, the non-linear regime of LSS formation is sensitive to the underlying theory of gravity, and hence provides estimates for observables that can help distinguish modified gravity effects from the expected standard GR results. In this work, I focus on two modified gravity models: namely variants of f(R) and nDGP gravity models. These MG theories offer a very good test bed to explore the freedom of modifying the Einstein-Hilbert action to produce a physical mechanism effectively mimicking the action of the cosmological constant, that would result in cosmic acceleration. These MG models are constructed in such a way that they have negligible consequences at early times and share the same expansion history and cosmological background as ΛCDM. As a result, the effect of these MG models is incorporated in the perturbation equations that govern the gravitational dynamics of LSS, and can potentially impact the formation and evolution of dark matter halos. Thus, the statistical properties of dark matter halos, that form the building blocks of cosmological observables associated with large-scale structures in the universe, offer opportunities for testing modifications to the gravitational forces. In this work, I focus on halo statistics: halo mass function, halo bias and halo density profile, using results generated from MG N-body simulations. We obtain systematic trends in these quantities on comparing MG results with standard GR cases. These trends can be further used to compute semi-analytical modeling for these MG cosmologies and make robust estimates for cosmological observables. This will be advantageous as N-body simulations are prohibitively expensive for the case of most nontrivial MG scenarios.

11. MAGNETIC PROPERTIES RESEARCH

11.1. Aleksander Sanjuan Ciepielewski, IF PAN

Transport signatures of van Hove singularities in mesoscopic twisted bilayer Graphene

Magic-angle twisted bilayer graphene is a fascinating strongly correlated electron system. It has exceptionally flat low-energy bands with van Hove singularities close to the Fermi level, and it is believed that the van Hove singularities play a prominent role in the exotic phenomena of magic-angle twisted bilayer graphene by amplifying the electron correlation effects. Most theoretical and experimental research of twisted bilayer graphene has so far focused on observables in the thermodynamic limit, and transport in large samples in the semiclassical regime where inelastic scattering is important. In this work, we instead concentrate on mesoscopic ballistic samples in the quantum transport regime, which allows us to probe the quantum states and band structure in an energy-resolved fashion. We calculate the four-terminal conductance of twisted bilayer graphene as a function of the twist angle, interlayer hopping amplitude and energy, and we identify signatures of van Hove singularities.

11.2. Sarath Prem, IF PAN

Berry-phase induced entanglement of electron spins coupled to a microwave cavity

Electron spins localized in quantum dots are one of the most viable and scrutinized solid-state qubits. Here we study two moving single-electron quantum dots defined in a two-dimensional spin-orbit coupled semiconductor and interacting with a single-mode microwave cavity. Building on the ideas developed in, we show that the interplay between the non-Abelian Berry phases generated by the motion of the quantum dots in the two-dimensional system and the shared cavity photons allows for fast manipulation, detection, and long-range entanglement of the electron spin qubits in the absence of an external magnetic field. These results suggest that electron spins confined in spin-orbit coupled semiconductors, such as GaAs or InAs, can be processed by purely electrical means and without bringing the quantum dots in proximity with each other by simply harnessing their geometry of states instead of their spectrum.

11.3. Tania Paul, IF PAN

Interplay of quantum spin Hall effect and spontaneous time-reversal symmetry breaking in electron-hole bilayers: Zero-field topological superconductivity

It has been proposed that band-inverted electron-hole bilayers support a phase transition from an insulating phase with spontaneously broken time-reversal symmetry to a quantum spin Hall insulator phase as a function of increasing electron and hole densities. Here, we show that in the presence of proximity-induced superconductivity it is possible to realize Majorana zero modes in the time-reversal symmetry broken phase in the absence of magnetic field. We develop an effective low-energy theory for the system in the presence of time-reversal symmetry breaking order parameter to obtain analytically the Majorana zero modes and we find a good agreement between the numerical and analytical results in the limit of weakly broken time-reversal symmetry. We show that the Majorana zero modes can be detected in superconductor/time-reversal symmetry broken insulator/superconductor Josephson junctions through the measurement of a 4π Josephson current. Finally, we demonstrate that the Majorana fusion-rule detection is feasible by utilizing the gate voltage dependence of the spontaneous time-reversal symmetry breaking order parameter.

11.4. Pardeep Kumar Tanwar, IF PAN

Severe Violation of the Wiedemann-Franz law in Quantum Oscillations of NbP

A characteristic of Weyl semimetals is nontrivial electronic bands that linearly disperse in the energy and momentum space and cross at nodes called Weyl points. Consequently, these materials host topological surface and bulk states with non-zero chirality. These states manifest themselves in many exotic phenomena, like fractional and 3D quantum Hall effect, chiral magnetic effects, etc. One such intriguing phenomenon is the chiral zero sound (CZS) effect, which is supposed to occur in a Weyl semimetal with multiple pairs of Weyl nodes. This allows low-energy chargeless-topological excitations to emerge – they carry only heat, while a complete charge cancellation takes place from Weyl nodes of different chirality. These excitations were studied by measuring the thermal and electrical conductivities (κ and σ, respectively) in the Weyl semimetal NbP. The magnetic field (B) and thermal gradient (and electric current) was applied parallel to [0 0 1] direction. In the low-temperature regime, the electrical conductivity $\sigma(B)$ and thermal conductivity $\kappa(B)$ exhibit quantum oscillations with frequencies: 4.6 (F1), 12 (F2), 30 (F3) and 40 (F4) T for the former, and 15 (F2) 30 (F3) T for the latter. The frequencies of $\kappa(B)$ match and antiphase with two of several frequencies determined from the Shubnikov – de Haas effect. Additionally, the magnitude of $\kappa(B)$ turns out to be two orders larger than the electronic contribution of thermal conductivity, $\kappa_e(B)$. After a thorough analysis, we ascribed such a

huge difference between κ(B) and κe(B) to a recently postulated CZS effect, an additional heat channel to the heat transport.

12. OPTICAL PROPERTIES RESEARCH

12.1. Omer Farooq, IF PAN

Experimental Investigation of Spectral Properties of Quantum Graphs and Networks.

Quantum graphs i.e. network of bonds connected at vertices, provides more efficient model systems for the experimental and theoretical study of closed and open quantum system with chaotic classical dynamics. The models of quantum graphs were widely used to investigate many physical systems, e.g., quantum wires , mesoscopic quantum systems, a topological edge invariant , and the photon number statistics of coherent light. In current study, We show that there is a relationship between the generalized Euler characteristic Ɛo(|VDo|) of the original graph that was split at vertices into two disconnected subgraphs i=1,2 and their generalized Euler characteristics Ɛi(|VDi|). Here, |VDo| and |VDi| denote the numbers of vertices with the Dirichlet boundary conditions in the graphs. The theoretical results are experimentally verified using microwave networks that simulate quantum graphs. We demonstrated that the evaluation of the generalized Euler characteristics Ɛo(|VDo|) and Ɛi(|VDi|) allow us to determine the number of vertices where the two subgraphs were initially connected.

12.2. Joanna Olas, IF PAN

Imaging the $S_0 \rightarrow S_1$ transition moments of single organic dye molecules in a crystalline matrix

Detection of single organic dye molecules has been a very important field of research for over 30 years, as it provides a sensitive nano-environment probe, without the need to average the results over the set of molecules. In this study, an attempt was made to visualize the direction of the $S_0 \rightarrow S_1$ transition in terrylene molecules (Tr) placed in the structure of naphthalene (N) and 2,3-dimethylonaphthalene crystals (23DMN). The direction of the observed transition reflects the direction of the long axis of the Tr molecule, so it is possible to obtain precise information about how the guest molecules integrate into the host crystalline structure. It will be of particular interest for the 23DMN crystals, in which there is an orientation disorder in the direction of the methyl groups of the host molecules. Each guest molecule, Tr, has a

slightly different environment in this crystal type, which should be reflected in the long axis direction of the guest molecules.

For the purposes of this research, the confocal microscope, previously used for research at low temperatures, was rebuilt. Measurements are carried out at the room temperature, so a microscope with an immersion liquid (Nikon 60x / 1.40 Oil) was used. The crystalline sample (places on a slide) was moved in the X and Y axis by a piezo-scanner (PXY36 piezosystemjena). The beam of light used for Tr molecules excitation was linearly polarized with its middle part obscured.

12.3. Ghulam Hussain, IF PAN

Electronic and optical properties of InAs/InAsSb Superlattice

Using first-principles calculations, we calculate the electronic and optical properties of InAs/InAs0.625Sb0.375 superlattices (SL). To accurately approximate the electronic and optical properties, the modified Becke-Johnson exchange-correlation functional is pondered. After analyzing the electronic and optical characteristics of bulk InAs and InSb, we then investigated InAs/InAs0.625Sb0.375 SL. The electronic and optical properties of the InAs/InAs0.625Sb0.375 SL are studied with three lattice constants of the bulk InAs, GaSb and AlSb, respectively. It is observed that the electronic and optical properties strongly depend on the lattice constant. A considerable decrease in the energy gaps and the effective masses of the heavy-holes in the kx-ky plane compared to the bulk phases of the parent compounds can be obseved. We demonstrate that the electrons are s-orbitals delocalized in the entire superlattice, while the holes have mainly 5p-Sb character localized in the In(As,Sb) side of the superlattice. In the superlattice, the low-frequency absorption spectra greatly increase when the electric field is polarized orthogonal to the growth axis allowing the applicability of III-V compounds for the long-wavelength infrared detectors.

13. EMITTER AND SENSOR TECHNOLOGIES

13.1. Ashfaq Ahmad, UNIPRESS

Polarization doping – ab initio verification of the concept: charge conservation and nonlocality.

In this work, we study the emergence of polarization doping in AlxGa1-xN layers with graded composition from a theoretical viewpoint. It is shown that bulk electric charge density emerges in the graded concentration region. The magnitude of the effect, i.e. the relation between the polarization bulk charge density and the concentration gradient is obtained. The appearance of mobile charge was investigated using the combination of ab initio and drift-diffusion models. It was shown that the ab intio results can be recovered precisely by proper parameterization of drift-diffusion representation of the complex nitride system. It was shown that the mobile charge appears due to the increase of the distance between opposite polarization-induced charges. It was demonstrated that for sufficiently large space distance between polarization charges the opposite mobile charges are induced. We demonstrate that the charge conservation law applies for fixed and mobile charge separately, leading to nonlocal compensation phenomena involving (i) the bulk fixed and polarization sheet charge at the heterointerfaces and (ii) the mobile band and the defect charge. Therefore two charge conservation laws are obeyed that induces nonlocality in the system. The magnitude of the effect allows obtaining technically viable mobile charge density for optoelectronic devices without impurity doping (donors or acceptors). Therefore, it provides an additional tool for the device designer, with the potential to attain high conductivities: high carrier concentrations can be obtained even in materials with high dopant ionization energies, and the mobility is not limited by scattering at ionized impurities.

13.2. Julia Sławińska, IWC PAN

Nitride micro-LEDs with tunnel junctions

In past few years nitride micro-LEDs (μLEDs) have drown a lot of attention. Although the operating principle for conventional broad-area LEDs and μLEDs remains unchanged, the processing of μLEDs involves additional step. It generates new challenges. For this reason more growth and fabrication methods are needed. The innovative method of μLEDs fabrication is presented. The light emission area was defined by a size of the tunnel junction (TJ) embedded inside diode. 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 region (86 nm) and 100 nm

n-type GaN. The emission size of μLEDs was defined by ion implantation (IP) of n-type GaN and TJ region. Micro-LEDs with diameter from 40 μm down to 3 μm were investigated.

13.3. Muhammed Aktas, IWC PAN

P-Cladding Layer with Polarization Doping for Nitride Emitter

The wide-bandgap nitride-based AlInGaN semiconductors are crucial materials for the modern optoelectronics, due to their ability to emit light across the whole visible and part of infrared and UV spectrum. Wide-bandgap (1.7-6.5 eV) of these materials, beneficial for their applications, is however a source of many technological hardships. One of the most important is the Mg acceptor high ionization energy, being around 200meV for GaN and around 630meV for AlN. The high ionization energy causes low free hole concentration and limits the p-doping level. Low hole concentration influences the operating voltage of nitride light emitters and consequently their wall plug efficiency. Additionaly, high acceptors ionization energy results in carrier freezing at low temperatures, limiting the use of such a devices in extreme (cryogenic) temperatures. At the same time, Mg acceptors are associated with high optical losses and incorporation of H atoms during MOCVD growth, leading to degradation during the device operation. Polarization doping (PD) can help in overcoming Mg doping issues. Polarization doping is based on polarization charges formed as a result of the presence of spontaneous and piezoelectric polarization gradients in nitride heterostructures. At the heterostructure interface, dielectric polarization allows forming of 2D electron gas or 2D hole gas. The localized polarization charges are created inside of the layer via composition gradients, and free carriers attracted by these fixed charges contribute to the p-type or n-type conductivity In the present work, we study the optoelectrical properties of LED and LD structures with polarization doped p-cladding layers. The PD-LED's electrical properties are similar or better than Mg doped LED, showing that polarization doping works and is efficient. As mentioned above, nitride-based emitters perform poorly at cryogenic temperatures because of low hole concentration (holes freeze-out) When polarization doped LED is investigated at cryogenic temperatures, substantial holes freeze-out region is not observed down to 77K. The optical measurements show that the Mg-doped electron blocking layer helps increasing light emission efficiency. For the LD structure, we used a double graded p-cladding layer. The designed structure should provide the same hole concentration as the Mg doped structure. The LD samples have good electrical properties and lower operating voltage than Mg-doped samples, but unexpectedly they have high optical losses. Because of that, the threshold current is around 500mA at 12°C in CW mode. The Mg-doped sub contact layer is necessary for top metal contact because the undoped layer may cause the Schottky barriers.

13.4. Alexandr Cherniadev, IWC PAN

Vertically coupled resonators-based THz detector as a near-field sensor

Resonator-based sensors became a promising concept for label-free detection of biological substances with high values of sensitivity and low detection limit. Ideally, the sensitivity down to a single molecule is required which was already achieved with an optical microresonator-based sensor. At terahertz (THz) frequencies a big step towards such sensitivity was made this year, when the authors managed to couple free-space THz radiation to a single subwavelength split-ring resonator and estimate the number of electrons from the two dimensional electron gas coupled to the single metallic planar resonator. Systems of coupled resonators may propel the sensitivity values even further due to their asymmetrical resonance profile and steep resonance slope. Recent works of P.H. Bolivar group in the THz frequency range have proved the applicability of frequency selective surfaces for biosensing applications. Here we propose our own solution of a future near- field THz sensor based on vertically coupled planar resonators. Such detectors can be fabricated using the commercial Si CMOS platform with a prospect of enabling to detect low sample volumes.

14. SYMPOSIUM TIMETABLE

Starting time	Monday, September 19th			
9:00	Opening			
9:05	1.1.	Shahin MD Alam	EXOTIC MATERIALS RESEARC	M. Aktas
9:15	1.2.	Jaydeb Dey		
9:25	1.3.	Arathi Das Moosarikandy		
9:35	1.4.	Piotr Baranowski		
9:45	Q & A 1			
9:55	Break			
10:10	2.1.	Abinash Adhikari	ELECTRON MICROSCOPY AND	O. Farooq
10:20	2.2.	Anastasiia Lysak		
10:30	2.3.	Wiktoria Zajkowska		
10:40	2.4.	Dorota Janaszko		
10:50	Q & A 2			
11:00	Coffee break 1			
11:30	3.1.	Abdul Khaliq	SEMICONDUCTOR RESEARCH	A. Ahmed
11:40	3.2.	Mahwish Sarwar		
11:50	3.3.	Vasil Stasiv		
12:00	3.4.	Ajeesh Somakumar		
12:10	3.5.	Sania Dad		
12:20	3.6.	Syed Shabhi Haider		
12:30	Q & A 3			
12:40	Coffee break 2			
13:10	4.1.	Adil Rehman	GaN TECHNOLO-GIES	R. Islam
13:20	4.2.	Karolina Grabiańska		
13:30	4.3.	Kacper Sierakowski		
13:40	4.4.	Piotr Jaroszyński		
13:50	Q & A 4			
14:00	Lunch break			
15:15	5.1.	Pradosh Kumar Sahoo	THIN FILM TECHNOL-OGIES	A. Khaliq
15:25	5.2.	Zeinab Khosravizadeh		
15:35	5.3.	Amar Fakhredine		
15:45	5.4.	Sameh Altanany		
15:55	Q & A 5			
16:05	Break			
16:20	6.1.	Maciej Bartłomiej Kruk	DROPLETS	M. Białobrz
16:30	6.2.	Jakub Kopyciński		
16:40	Q & A 6			
16:45	Break			
16:55	7.1.	Hung Nguyen Van	PROTEIN PHYSICS	J. Olas
17:05	7.2.	Michał Białobrzewski		
17:15	Q & A 7			
17:25	Break			
17:40	8.1.	Oskar Słowik	QUANTUM COMPUTING	M. Ataelahi
17:50	8.2.	Tae-Hun Lee		
18:00	8.3.	Tomasz Rybotycki		
18:10	8.4	Owidiusz Makuta		
18:20	Q & A 8			
End of Day 1 - Supper				

Starting Time	Tuesday, September 20th			
	Breakfast			
9:00	9.1.	Natalia Fiuczek	ZOOM PANEL	Student Council
9:10	9.2.	Maria Szoła		
9:20	9.3.	Kwasi Nyandey		
9:30	9.4.	Luis Carnevale da Cunha		
9:40	9.5.	Kausik Das		
9:50	9.6	Yadhu Krishnan Edathumkandy		
10:00	9.7.	Sushma Mishra		
10:10	9.8.	Juby Alphonsa Matthew		
10:20	9.9.	Jan Głowacki		
10:30	9.10	Soheil Arbabi		
10:40	9.11.	Russel Kajouri		
10:50	Q & A 9			
11:10	Coffee break 1			
11:40	10.1.	Damian Włodzyński	QUANTUM PHYSICS	T. Rybotyc
11:50	10.2.	Tanausu Hernandez Yanes		
12:00	10.3.	Suhani Gupta		
12:10	Q & A 10			
12:20	Coffee break 2			
12:50	11.1.	Aleksander Sanjuan Ciepielewski	MAGNETIC PROPERTIES	A. Fakhreddine
13:00	11.2.	Sarath Prem		
13:10	11.3.	Tania Paul		
13:20	11.4.	Pardeep Kumar Tanwar		
13:30	Q & A 11			
13:40	Break			
13:55	12.1.	Omer Farooq	OPTICAL PROPERTIES	J. Sławińs
14:05	12.2.	Joanna Olas		
14:15	12.3.	Ghulam Hussain		
14:25	Q & A 12			
14:35	Lunch break			
16:00	13.1.	Ashfaq Ahmad	EMITTER AND SENSOR TECHNOL	O. Słowik
16:10	13.2.	Julia Sławińska		
16:20	13.3.	Muhammed Aktas		
16:30	13.4.	Alexandr Cherniadev		
16:40	Q & A 13			
16:50	Break			
17:00	Invited talk – prof. Andrzej Dragan, UW *TBA*			
17:45	Invited talk Q & A			
18:00	Closing			