XIV-th INTERNATIONAL CONFERENCE

on

ION IMPLANTATION
AND OTHER APPLICATIONS OF IONS
AND ELECTRONS

June 24-26, 2025
Kazimierz Dolny, Poland

Edited by
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The Market Square in Kazimierz Dolny drawn by Artur Orłowski

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Tuesday, 24 June, 2025	**Wednesday, 25 June, 2025**	**Thursday, 26 June, 2025**
8:00 Registration	8:00 *Breakfast*	8:00 *Breakfast*
10:00 Opening of the Conference	9:00 Cyprian Mieszczyński – I-10	9:00 Wojciech Nowak – I-11
10:15 Frederico Garrido – I-4	9:30 Paweł Horodek – I-5	9:30 Iraida N. Demchenko – I-3
11:00 Beata Tyburska-Pueschel – I-15	10:00 Leszek Łatka – I-9	10:00 *Coffee break*
11:300 Michał Bockowski – I-2	10:30 *Coffee break*	10:30 Zbigniew Surowiec – O-3
12:00 *Coffee break*	10:50 Krzysztof Gołyga – YSC-1	10:50 Halina Krzyżanowska – O-2
12:20 Jacek Jagielski – I-6	11:10 Patryk Gontarz – YSC-2	11:10 Jerzy Żuk – I-7
12:50 Renata Ratajczak – I-13	11:30 Mariusz Kamiński – YSC-3	11:40 Closing of the Conference
13:20 Michał Krupinski – I-8	11:50 Karol Kawka – YSC-4	12:00 *Lunch*
13:50 *Lunch*	12:10 Ewelina Kucal – YSC-5	13:00 *Departure*
	12:30 Yulin Li – YCS-6	

14:45 Sławomir Prucnal – I-12 15:15 Yonder Berencén – I-1 15:45 Jin Doyeon – O-1	13:00 *Lunch*
16:05 *Break*	14:00 Vairavel Mathayan – YSC-7 14:20 Joanna Matulewicz – YSC-8 14:50 Mahwish Sarwar – YSC-9 15:10 Michał Stróżyk – YSC-10 15:30 Guoxiu Zhang – YSC-11
17:00 Organ concerto The Franciscan Monastery (OFM) in Kazimierz Dolny n/Wisła	
18:15 Poster session	15:50 *Coffee break*
20:00 *Barbecue*	16:40 Limin Wan – O-4 17:00 Wolfgang Skorupa – I-14
	19:00 *Conference dinner*

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INVITED LECTURE

I-1

Room-temperature telecom detection in silicon via ion-implanted deep-level engineering

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Photonic integrated circuits (PICs) are transforming optical communication by offering compact, energy-efficient platforms [1]. However, realizing efficient photodetection in the telecom band (~1550 nm) on silicon remains a key challenge due to its intrinsic transparency at these wavelengths.

We demonstrate a high-speed, high-responsivity photodetector entirely based on silicon, operating at room temperature and compatible with grating and waveguide coupling [2]. By engineering deep-level states through impurity doping near the solubility limit, we achieve strong sub-bandgap absorption without degrading carrier mobility or lifetime. The resulting device exhibits 0.56 A/W responsivity, 2 GHz bandwidth, and low noise at 1550 nm - metrics that meet the demands of telecom applications. This approach offers a CMOS-compatible path toward scalable, monolithic integration of optical receivers in silicon PICs, eliminating the need for heterogeneous materials like germanium.

References

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I-2

Shaping the Future of GaN-on-GaN Technology

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This lecture provides a comprehensive overview of GaN-on-GaN technology, outlining its historical development, key milestones, recent breakthroughs, and future directions. Particular emphasis is placed on bulk GaN crystal growth and epitaxial techniques, including ammonothermal growth, halide vapor phase epitaxy (HVPE), metal-organic vapor phase epitaxy (MOVPE), and molecular beam epitaxy (MBE). The transformation of ammonothermal bulk GaN crystals into functional substrates through high-precision processes such as wafering and surface preparation is also addressed. The advantages and limitations of these epitaxial methods are analyzed, with a focus on crystal purity and structural quality.

As an alternative to epitaxy, ion implantation enables selective doping of GaN with acceptors or donors, facilitating the fabrication of devices such as junction barrier Schottky (JBS) diodes. However, implantation introduces significant lattice damage, requiring high-temperature annealing (≥1300 °C) for defect recovery and dopant activation. In GaN, only ultra-high-pressure annealing (UHPA) has proven effective for this purpose. The lecture will present the latest advancements in UHPA technology in detail.

The presentation concludes with an assessment of the current progress, realistic development timelines, and key application areas of GaN-on-GaN technology in both optoelectronic and high-power electronic devices.

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I-3

Si and N Ion Implantation in (100) β-Ga_2O_3: Multimethod Characterization

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Ga_2O_3 is a promising alternative to GaN for high-power electronic devices such as MOSFETs. Combined with ion implantation, an established technique in semiconductor fabrication, it may enable efficient all-ion-implanted Ga_2O_3 transistors. Ion implantation reduces contact resistance (via shallow donors: Si, Sn, Ge) or creates voltage-blocking barriers (via acceptors: Mg, N). While most studies have focused on (010), (001), and ($2\bar{0}1$) orientations, the (100) plane remains underexplored despite its low formation energy, high smoothness (important for δ-doping), and ease of cleavage. Homoepitaxial films on off-cut (100) surfaces have shown excellent electrical performance. Due to β-Ga_2O_3 anisotropy, all process steps like doping, defect formation, contact engineering, must be tailored to each orientation. For instance, [010]-aligned structural defects impact growth and leakage differently depending on the surface. Contact resistance also depends on orientation. We investigate Si and N implantation into (100)-oriented Czochralski-grown β-Ga_2O_3 substrates at room and elevated temperatures. Resulting defect structures are complex and require complementary methods for characterization. Our study uses RBS, PIXE, HRXRD, Raman, TEM, and synchrotron-based XANES, supported by DFT and FMS [1], to reveal implantation effects and defect behavior relevant for device operation.

Acknowledgments: This work was supported by the National Science Centre, Poland (UMO-2020/39/B/ST5/03580).

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Alpha-decay damage in natural apatite: buildup and recovery mechanisms for thermochronological applications

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Thermochronology is an earth science discipline involved in the reconstruction and timing of past geological processes. One of the techniques useful in the thermal history modelling of rocks is apatite (U-Th)/He thermochronology. Under this technique, an apparent thermal age termed as "He age" is measured for each apatite crystal via analytical measurement of its present-day U, Th, Sm, and He contents. The measured amount of He inside is calculated as the difference between production and diffusional losses: (1) He production from the alpha decay events (Sm, Th, U) less the (2) amount of He that diffused out of the crystal at high temperatures.

The diffusion coefficient of He in apatite is based on the Arrhenius Law. Recent studies strongly indicate that the amount of radiation damage in a crystal modifies the He diffusion coefficient. The aim of this research is to investigate in a fundamental level using *in situ* and *ex situ* ion implantation, Rutherford Backscattering Spectrometry in channelling mode (RBS/C) and Monte Carlo simulations using the McChasy code, and Transmission Electron Microscopy (TEM), the kinetics and mechanism of the following physical processes linked with alpha decay: (i) radiation damage buildup separately-induced in apatite by the recoil nuclei and alpha particles, and (ii) the athermal, ionization-induced recovery of pre-existing defects attributed to the electronic energy loss of alpha particles.

The presentation will focus on the use of ion beams as unvaluable tools to get new insights on thermal history modelling codes to perform the next step of geological calibration and applications.

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I-5

Positron annihilation and complementary studies of WC-2.2wt.%Co cemented carbide materials exposed to helium implantation

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Cemented WC is a promising material for neutron reflectors in nuclear reactors and in the aerospace industry. However, the formation of structural defects in the radiation environment promotes the retention of hydrogen or helium, leading to the effective degradation of the material. The investigations in this context are essential for improving the radiation resistance and extending the operational lifetime of this kind of components.

We report experimental studies performed for WC-2.2wt.%Co samples exposed to 220 keV He^+ implantation with 10^{14}, 10^{15}, 10^{16} and 10^{17} He/cm^2. The aim is to find the impact of structural defects on the implanted He behavior. Positron beam studies show the presence of two kinds of defects prior and after He implantation. The first one was recognized as divacancies of WC, while the second one as huge vacancy clusters localized on the junctions of grains. No effect is found for divacancies. However, progressive filling of clusters with He atoms is observed. Grazing Angle X-Ray Diffraction and Raman Spectroscopy results support these investigations.

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I-6

Opportunities and Challenges in Materials Research for Emerging Nuclear Technologies

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The Polish Nuclear Energy Program, initiated several years ago, along with the recent commencement of the country's first nuclear power plant construction, has created significant opportunities for interdisciplinary scientific engagement ranging from geology to advanced materials science. With growing global recognition that nuclear energy represents a rational and sustainable solution to climate and energy challenges, numerous nations are launching or expanding nuclear programs. This international momentum has fostered collaborative research initiatives, such as the Connect NM Partnership, which is currently soliciting proposals under its inaugural call.

The scope of ongoing and proposed research is extensive, encompassing both the optimization of existing technologies such as Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR) and the development of next-generation systems, including Generation IV reactors like High-Temperature Gas-Cooled Reactors (HTGR), Lead-Cooled Fast Reactors (LFR), and Sodium-Cooled Fast Reactors (SFR). A central challenge shared by all these technologies is the need for materials capable of withstanding prolonged radiation exposure and ensuring safe reactor operation for up to 100 years.

This presentation will outline the key material challenges facing current and future nuclear technologies, with a particular focus on radiation-induced degradation. It will also provide an overview of the state of materials research in Poland and internationally, highlighting opportunities for new research groups to participate in existing frameworks and collaborative consortia.

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I-7

Ion Implantation Technology for Silicon Photonics

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Silicon is the fundamental material of modern microelectronics, but it is not efficient in optoelectronics due to indirect band gap structure. In addition, due to the rather large band gap (1.12 eV), it is transparent to infrared light. This determines the loss of about 30% of the energy of solar radiation which is not used in solar cells. Besides, silicon photodetectors are not effective for the three main fiber optic communication frequency bands: S (1460-1530 nm), C (1530-1565 nm) and L (1565-1625 nm). Replacing electronic inter/intra-chip switching with optical ones promises a huge gain in speed in silicon microelectronics.

Silicon as an indirect-gap semiconductor has a low quantum efficiency of interband radiative recombination. In recent years, specialists in the field of micro- and optoelectronics have been intensively working on the development of highly efficient light emitters and photodetectors on Si in the NIR (from ~0.8 to ~2 μm), MIR (from ~2 to ~25 μm) and visible (from ~0.3 to ~0.8 μm) ranges, which would allow combining electronic and optical devices in a single integrated circuit.

Here, we show that ion implantation with subsequent annealing is an effective method to create quantum dot (QD) arrays of direct narrow-gap A^3B^5 semiconductors in Si matrix and A^2B^6 QDs in SiO_2/Si, which are efficient light-emitting systems in a broad spectral range.

Also, the laboratory technology and experimental samples of the UV, VIS and IR photodetectors based on silicon layers hyperdoped with selenium or tellurium as well as innovation solar cells are presented and discussed in this report.

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I-8

Magnetism of RE-TM systems modified by ion implantation

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Alterations of magnetic properties associated with introduction of defects or implanted ions are of great importance for majority of magnetic nanosystems. In particular, amorphous rare earth-transition metal (RE-TM) thin films and nanoparticles can demonstrate modified magnetic characteristics and magnetization switching behavior in comparison with bulk counterparts caused by developed surface or by defects introduced e.g. by ion bombardment [1-3].

Understanding and experimental identification what fundamental processes are responsible for changes in the magnetism is, however, a challenge due to the variety of possible overlapping contributions and effects [4]. In the talk, I will demonstrate how to study magnetism in modified amorphous ferrimagnetic RE-TM thin films and how to determine the impact of defects. I will show that the ion implantation can be used to engineer magnetic properties such as magnetization, magnetic anisotropy, and compensation temperature in RE-TM systems and to control the spin-flop reorientation transition in GdFe alloys. In particular, fine-tuning of the compensation point is possible without losing perpendicular magnetic anisotropy by appropriate selection of ion energy and irradiation dose. The experimental results are supported by atomistic simulations revealing that the observed changes can be attributed to selective oxidation of rare earth atoms. Therefore, part of the presentation will be devoted to building realistic atomistic spin models that can be validated by experimental results. The analysis demonstrated that defects introduced by ion bombardment using different ion species create easy diffusion paths for oxygen to penetrate the system [2]. Therefore, the choice of ion species and fluence enables the effective composition of the films to be tailored by reducing the amount of magnetically-active RE elements.

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I-9

Plasma spraying: from workshop to scientific laboratories and back again

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Since more than 100 years thermal spraying existing on the field of surface engineering in many industry branches as well as a part of general science. There are few methods and many new modifications are still developed, e.g. arc spraying, high velocity oxy fuel spraying, plasma spraying etc. From scientific point of view plasma spraying is an area where different scientific disciplines are joined and permeated, e.g. physic, chemistry, mechanical engineering, materials science and electronic.

At the beginning of invention this method was treated only as manufacturing tool, without scientific fundamentals. After 1960s, the increasing interest of the scientific community was observed. Currently, the plasma spraying process is one of the most well-known method in whole thermal spraying family. Physical and chemical fundamentals allowed to develop new plasma torches, modifications of elementary method as well as the complex diagnostic process.

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I-10

Integration of Molecular Dynamics and Monte Carlo for RBS/C Simulations

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Rutherford Backscattering Spectrometry in channeling mode (RBS/C) is a widely employed technique for characterizing the structural properties of ion-implanted single crystals. Consequently, the development and implementation of a robust analytical instrument capable of conducting detailed, quantitative analysis, thereby facilitating the identification of various defect types present in the investigated crystals, is of great importance. As a result, the McChasy program was developed in the mid-nineties and has undergone continuous improvement since then. The latest version of the program has been updated to align with the latest trends and advancements in programming capabilities. It facilitates the calculation of backscattering probabilities and the simulation of RBS/C experimental spectra based on arbitrary atomic positions within large virtual structures.

The simulation results obtained using the two latest generations of the McChasy code [1,2] are analyzed for a diverse set of structures, including Ga_2O_3, GaN, Ni, NiFe, and NiFeCoCr single crystals. Structural characterization is conducted using RBS/C, complemented by scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

Acknowledgments
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I-11

On the use of GD-OES for analysis of plasma-facing materials

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Nowadays, intensive experimental and theoretical research are required to produce neutron-tolerant material for DEMO and future reactors. The 14 MeV fusion neutrons induce irradiation defects and produce He and H in plasma-facing materials (PFM). The accumulation of these elements in defects accelerates irradiation embrittlement and causes fast degradation and failure. A popular method used to determine the retention of these gases is Thermal Desorption Spectroscopy. Although it successfully provides information about the presence of these gases, it is not without limitations. Here, sensitivity to surface conditions or the inability to determine the depth of gas localization can be mentioned.

In this work for the gas products detection in PFM glow discharge optical emission spectrometry (GD-OES) method is proposed. GD-OES method is known from its flexibility of elements measurements [1]. Especially elements which are hardly measurable by e.g. SEM/EDS/WDS, like e.g. boron or carbon are very good measurable by GD-OES [2, 3, 4]. This equipment is available to measure simultaneously 40 elements by detectors in polychromator and one additional element placed in monochromator. However, using of monochromator requires calibration. In the present work a measurement of elements from gas transformation or defecs depth by GD-OES is shown and the future potential of method is drawn.

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I-12

Transition metal oxides: Challenges and emerging perspectives

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Air pollution and the energy crisis are the two main driving forces behind the development of alternative, environmentally friendly methods of energy production. Photoactive materials can be used both to clean the environment and to produce green energy. Transition metal oxides (TMOs) are one of the most considered materials for high-performance photocatalysis and hydrogen production. Moreover, TMOs Today, metal oxides are present in the majority of electronic devices and are used as either passive or active layers in different filters to neutralise contaminants. In this work, the focus will be on the production and functionalisation of titanium dioxide (TiO_2) and zinc oxide (ZnO) for environmental protection, with a particular focus on photocatalysis and plasmonics effects. The TiO_2 and ZnO thin films are made by room temperature magnetron sputtering on different substrates including glass, silicon and metal fibres, and functionalize by ms-range flash lamp annealing. While ZnO nanowires are grown by hydrothermal method mainly on Ti and Cu felt (see Fig. 1). We will present the influence of fabrication parameters on the microstructural, optical and electrical properties of TMOs with a view to their end-use applications. Both ZnO and TiO_2 show exceptional performance in degrading methyl blue (MB) and methyl orange (MO) [1,2]. In addition, ZnO and TiO_2 are the basis of low-emissivity glass. The functionalization of the low-e coating is made by post-grown ms-range flash lamp annealing (FLA) that is five times cheaper than the conventional annealing (0.12 €/m^2 vs 0.60 €/m^2). The use of FLA instead of conventional annealing, increases production efficiency, reduces electricity consumption by 30 % and CO_2 emission. In addition, FLA low-e coatings have better performance than traditionally activated coatings.

Figure 1: Process flow for the fabrication and functionalization of a ZnO-based photocatalyst for wastewater treatment.

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I-13

Insights into Defect Formation and Structural Evolution in β-Ga_2O_3:RE Systems

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β-Ga_2O_3:RE systems are attractive in applications such as phosphors, displays, high-power LEDs, and high-end photodetectors, that can operate even in harsh environments. A crucial challenge in this field is the development of precise and controllable RE doping techniques. One of the attractive ways to produce β-Ga_2O_3:RE systems is the ion implantation technique.

At this conference, we present our studies of defect kinetics and other structural changes following ion implantation and subsequent thermal treatments. Our findings show that defect accumulation is highly complex, leading to defect structure transformations, and phase transitions into amorphous and γ-Ga_2O_3 crystalline phases. Notably, these phases segregate into distinct damage zones. Although both radiation-induced phases disappear after annealing, complete structural recovery is not achieved. Furthermore, we demonstrate that annealing conditions significantly affect the resulting microstructure and the optical activation of RE ions.

These results provide valuable insights into defect engineering and the thermal stability of dopants in β-Ga_2O_3:RE systems, supporting their potential in robust optoelectronic device applications.

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I-14

Truth and Fake in Research: Facts, Fiction and Fancy

Skorupa Wolfgang[*]

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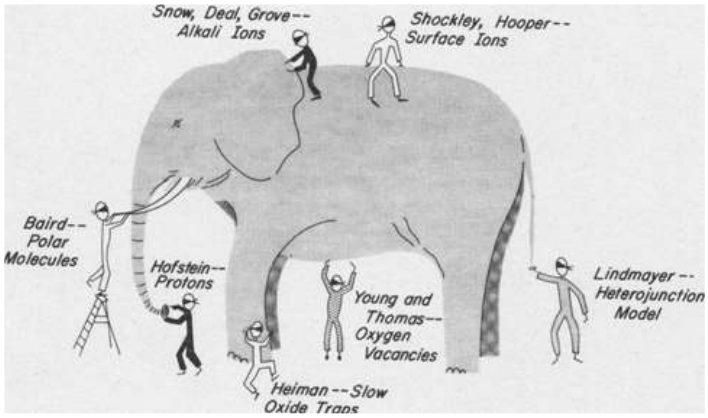
Having worked nearly half a century (1975-2022) in a research institution as well as collecting and distributing knowledge about that on an international scale one is confronted with a lot of pros and cons about this matter.

Such are related to the daily reality as well as philosophical, psychological and historical aspects of the life as a researcher. I try to work out this matter with examples from those 47(+) years mentioned before. Active research was for me - educated in electrical engineering and physics of electronic devices - a mixture of applied science and creative engineering.

I reached my present age under two systems of rule which makes the things a bit more special: A first experience regards the life between 1975 and 1989 under the auspice of a pseudo-communist experiment (→GDR). Between autumn ’89 and Jan.1, 1992 I was freely lancing in an employment vacuum. After that we entered the “welcomed” western world. In both worlds truth and fake were in dialectic coexistence.

The focus is partly on early results achieved mainly under my supervision in the late 70‘s to 90’s related to ion beam processing of insulating films and semiconductor materials, gettering of metallic impurities, generation of blue instead of red luminescence from silicon-based material, short time thermal processing etc.



‘The blind men and the elephant’ B.E. Deal, J.Electrochem.Soc. 121 (1974) 198C

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I-15

Response of structural materials to irradiation and salt corrosion for MSR

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The deployment of Molten Salt Reactors (MSRs) presents significant materials challenges, as structural components must withstand prolonged radiation exposure and aggressive high-temperature corrosion. Although extensive studies exist on irradiation in light-water reactor (LWR) conditions and corrosion in fluoride salts, the combined effects of irradiation and corrosion in molten salt environments—particularly under MSR-relevant conditions (500–750 °C, high dpa)—remain largely unexplored. Existing experimental data are sparse, fragmented across various salt–material systems, and often limited to low-dose, short-duration exposures, restricting their relevance for long-term reactor applications.

In this contribution, we review the current state of knowledge on salt corrosion and irradiation effects, emphasizing the critical gaps that impede the qualification of materials for MSRs. We also present how the newly established infrastructure at DIFFER is uniquely positioned to address these gaps. With integrated capabilities for high-temperature corrosion testing, controlled proton irradiation (DICE), and advanced characterization (SEM, TEM, IBA, ICP-MS), alongside the AI-driven materials discovery platform SDL-NUCMAT, our lab is equipped to systematically investigate and disentangle irradiation-corrosion interactions under realistic reactor conditions. These facilities enable both mechanistic studies and accelerated discovery of next-generation structural materials tailored for chloride-based MSRs.

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ORAL PRESENTATION

O-1

Thermal stability of pristine and P-implanted TMDCs van der Waals crystals

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The integration of monolayer thick transition metal dichalcogenides (TMDCs) into the complementary metal-oxide semiconductor technology requires controllable doping technique that offers effective tuning of optoelectronic properties of two-dimensional materials (2D). For conventional bulk semiconductors like Si, ion implantation is the most common method offering stable and tunable doping. Unfortunately, during ion implantation, defects are introduced in addition to the intended dopant, which must be removed by post-implantation annealing. The dopant activation efficiency and defect removal depend on the annealing time, temperature and atmosphere. In this work, we present the effect of implanted ion dose and annealing parameters on the stability of 2D layers. Both not-implanted and P-implanted monolayer thick WS_2 flakes were annealed in argon, nitrogen or in air for 4 minutes. The thermal stability of WS_2 and WSe_2 under different annealing conditions was *in-situ* investigated by micro-Raman and micro photoluminescence spectroscopies. The thermal stability of the 2D materials was determined by the degradation of the photoluminescence intensity and the change in phonon energy in the micro-Raman spectra. The maximum annealing temperature was determined by the thermal stability of the sample. The as-grown WS_2 monolayer annealed in argon are stable up to 375°C while the first degradation in WSe_2 appears above 425°C. Annealing in air results in significant degradation of the pristine flake and triangular defects are observed as a consequence of interaction of oxygen with chalcogenide vacancies like V_S and V_{Se} (see Figure 1). After ion implantation, the threshold decomposition temperature of WS_2 decreases with increasing ion fluence. Samples implanted with a P fluence of 5×10^{12} cm^{-2} degrade at around 300°C, while increasing the ion fluence to 1×10^{13} cm^{-2} reduces the threshold temperature to around 250°C. The threshold decomposition temperature for ion-implanted WS_2 monolayers can be increased by using a non-equilibrium treatment such as flash annealing for 3.2 ms or an oxygen-free capping layer such as h-BN. [1].

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Figure 1. Optical image (a) and SEM images (b and c) of WS_2 monolayer made by CVD after annealing in air at 400 °C for 4 min. Triangular holes are formed by oxygen etching of WS_2.

Reference:

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O-2

Erbium-implanted materials as candidates for quantum communication applications

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Rare-earth-doped materials have garnered significant attention as material platforms in emerging quantum information and integrated photonic technologies. However, demonstrating the full range of properties required to realize a practical quantum network with Er^{3+} remains an outstanding challenge. Application of ion implantation and post-implantation processes can bring us closer to achieve this goal. Typically, the doses of Er ions varied between 10^{12}-10^{14} cm^{-2} with energies up to 350 keV, which corresponds to an implantation depth of ≈ 100 nm [1].

In this talk, recent studies of host materials such as MgO, TiO_2, $PbWO_4$, ZnO, and LN implanted with Er for quantum communication application [1-3] will be presented. Optical spectroscopy methods, i.g. LT photoluminescence excitation, microPL, and time-resolved PL were applied for characterizing the implanted specimens.

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O-3

Characterisation of surface-modified magnetite nanoparticles for biomedical applications

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The growing interest in magnetite nanoparticles, has its justification in their wide application. Mostly, iron oxides are used in the biomedical field, especially as contrast agent in magnetic resonance imaging, in drug delivery, protein and enzyme immobilization or in magnetic hyperthermia treatment [1,2]. Due to their numerous advantages (low toxicity, biocompatibility, unique physical properties), magnetite nanoparticles are the most desirable candidates for use in a human body. Moreover, Fe_3O_4 NPs exhibit superparamagnetism at room temperature, which means that they can be manipulated by influence of an alternating external magnetic field. The XRD analyses carried out on powder samples demonstrated the presence of magnetite nanoparticles with crystallite sizes of d = 8.9(5) nm. The morphological analysis of the nanoparticles performed by means of SEM microscopy confirmed the compatibility of the grain size distribution with the logarithmic-normal distribution, and the nanoparticles observed exhibited a spherical shape.

Mössbauer investigation performed at room temperature indicate that the nanoparticles have superparamagnetic properties. Lowering the temperature of the system leads to extension of the relaxation time of the superparamagnetic nanoparticles in accordance with the Néel-Brown formula.

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O-4

Defect and Crack Evolution Induced by H^+ and He^+ Implantation during the Crystal Ion Slicing of $LiTaO_3$ Single-Crystal Thin Films

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This study explores defect formation and its thermal evolution in $LiTaO_3$ crystals induced by ion implantation. Helium or hydrogen ions at varying doses were implanted to create distinct damage profiles, followed by annealing to investigate defect evolution. Characterization techniques, including Rutherford backscattering spectroscopy (RBS), X-ray diffraction (XRD), and transmission electron microscopy (TEM), were employed to analyze lattice damage, strain, and defect morphology. Results reveal that helium implantation induces high lattice damage and strain, leading to non-horizontal crack growth along (100) and (012) planes, which hinders crack coalescence and bubble merging. In contrast, hydrogen implantation produces lower lattice damage and strain, facilitating (001) oriented crack growth and seamless merging. These findings underscore the importance of minimizing end-of-range damage and strain under dose-threshold conditions to achieve effective $LiTaO_3$ thin-film transfer in Crystal Ion Slicing (CIS) technology. The study also provides insights and methodologies that are valuable for optimizing CIS applications in other materials.

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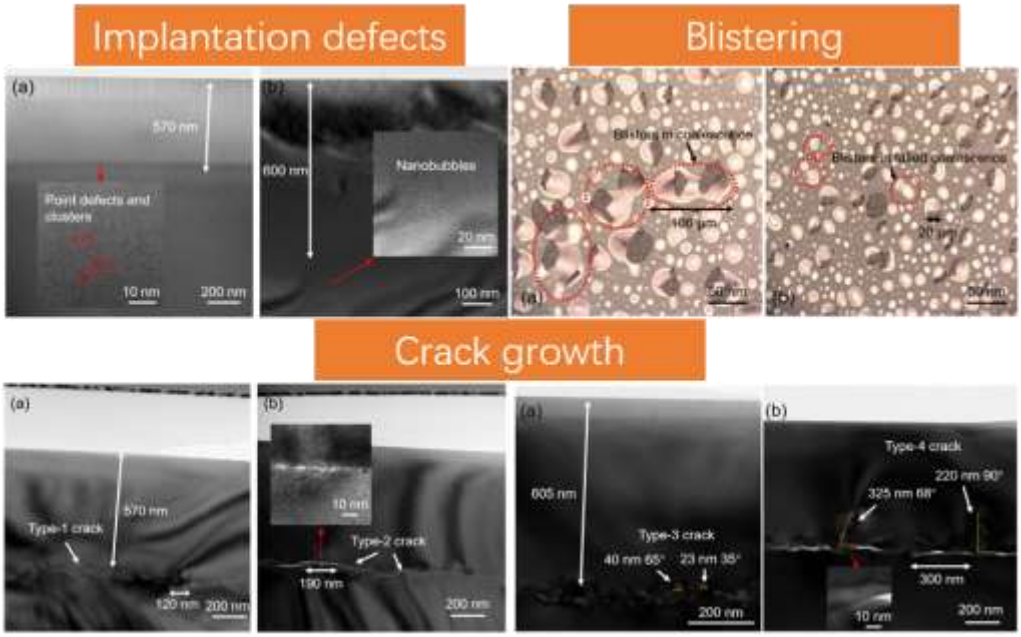
Implantation defects
Blistering
Crack growth
(a)
570 nm
Point defects and clusters
10 nm
300 nm
(b)
600 nm
Nanobubbles
20 nm
100 nm
Blisters in coalescence
100 μm
(a)
Blisters in fully coalescence
20 μm
(b)
(a)
Type-1 crack
570 nm
120 nm
200 nm
(b)
10 nm
Type-2 crack
190 nm
200 nm
(a)
605 nm
Type-3 crack
40 nm 65°
23 nm 35°
200 nm
(b)
Type-4 crack
220 nm 90°
325 nm 68°
300 nm
10 nm
200 nm

YOUNG SCIENTISTS CONTEST

YSC-1

Ion Implantation and UHPA-Assisted GaN Bonding: A Novel Path Toward Dual-Sided Ammonothermal Growth

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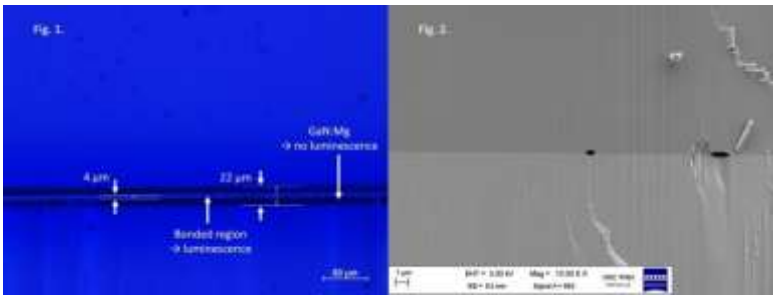
Gallium nitride (GaN) is regarded as a key semiconductor material used in optoelectronic devices (e.g., laser diodes) and is considered a promising candidate for electronic applications such as vertical transistors and Schottky diodes [1]. Currently, the highest structural quality GaN substrates are fabricated from crystals obtained through the basic ammonothermal (Am) growth process. [2]

This Am-GaN growth is conducted in autoclaves, where it is simultaneously carried out on dozens of seed crystals. The seeds are secured in metallic holders intended to enforce growth in the <000-1> direction. This approach is used to suppress lateral overgrowth and extension in the <0001> direction, both of which may induce internal stresses and increase dislocation density in the crystal.

The seed mounting procedure is complex, time-consuming and limits the number of seeds that can be installed in a single process. One way to overcome these limitations involves introduction of seeds formed by directly bonding two Ga-polar (0001) surfaces of Am-GaN crystals. This approach could enable GaN growth on both sides of the bonded structure, thereby increasing the available growth area.

In this study, results of bonding two Am-GaN crystals are presented. The bonding was achieved using Mg ion implantation followed by ultra-high pressure annealing (UHPA) under thermodynamically stable conditions for GaN. Direct bonding of the crystals was confirmed by UV (fig. 1.) and SEM (fig. 2.) imaging. Theoretical calculations indicate that the resulting lattice is energetically stable. The bonding is attributed to surface modifications induced by ion implantation.



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The process of negative ion formation from selected oxides and organic samples

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The process of anion formation begins with the formation of a Temporary Negative Ion (TNI). This means that on the surface of a heated cathode, a neutral gas molecule attaches an electron to itself to form the TNI. The temporary negative ion can stabilise under high vacuum conditions by one of the following two processes: dissociative electron attachment (DEA) or electron self-dissociation. In the DEA process, the TNI dissociates into an anion and a neutral part.[1] The efficiency of negative ion formation is described by the Saha-Langmuir equation:

$$\alpha = \frac{g_-}{g_0} exp\left[\frac{(EA-\varphi)}{k_B T}\right] \quad (1)$$

where: α - degree of ionization of molecules, g_-/g_0 - ratio of statistical weights of anions to neutral molecules, k_B - Boltzmann's constant, T - temperature of the gas, φ - work of exit of an electron from the metal surface, EA - electron affinity of molecules.

During the presentation, results on the processes of forming O- anions from simple gases: CO_2, CO, O_2, NO_2, NO will be presented and discussed. The formation processes of negative ions formed from two gases CH_3NH_2 (methylamine) and $C_2H_5NH_2$ (ethylamine) will also be discussed. For methylamine, negative ions of masses 16 (NH_2), 26 (CN) and 27 (HCN) were observed. For ethylamine, four negative ions with masses of 16 (NH_2), 22, 26 (CN) and 27 (HCN) were observed. By analyzing the processes leading to the formation of anions, it is possible to understand the channels of dissociation processes and determine the dissociation energy.

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YSC-3

Machine Learning-Based Analysis of Mechanical and Structural Changes Induced by 160 MeV Xe-Ion Irradiation in Nimonic 90 Superalloy

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Changes in the crystal structure and tribological and mechanical properties of Nimonic 90 superalloy after irradiation with 160 MeV Xe^{24+} ions at fluences of 1.0×10^{14}, 2.5×10^{14} and 5.0×10^{14} ions/cm² were studied using X-ray diffraction, friction testing and microhardness measurements. To quantitatively relate irradiation fluence to the observed structural and performance changes, complementary machine-learning models were trained on extracted features from friction curves, wear profiles and irradiation parameters. Irradiation altered the alloy's crystal structure and impaired its wear resistance and microhardness at fluences of 1.0×10^{14} and 2.5×10^{14} ions/cm². At the highest dose (5.0×10^{14} ions/cm²), surface microhardness increased slightly while wear degradation was less pronounced. The absence of significant change in friction coefficient beyond the ion penetration range indicates a long-range irradiation effect.

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Limited Diffusion of Silicon in GaN: A DFT Study Supported by Experimental Evidence

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Silicon (Si) is the primary donor dopant in gallium nitride (GaN), typically introduced via epitaxy or implantation. Its diffusion behavior critically impacts device performance. In this work, the diffusion mechanisms of Si in bulk GaN are explored through first-principles density functional theory (DFT) calculations, with additional insight provided by ultra-high-pressure annealing (UHPA) experiments.

The theoretical analysis was carried out using the SIESTA code, focusing on vacancy-assisted diffusion pathways. Minimum energy paths (MEPs) and activation barriers along key crystallographic directions were evaluated using the nudged elastic band (NEB) method. The calculated diffusion barriers show strong anisotropy: the lowest barrier, 3.2 eV, is found along the [11-20] direction, while the highest, ~9.9 eV, occurs along the [1-100] direction. In contrast to vacancy-mediated diffusion, alternative mechanisms such as direct exchange or ring-like migration exhibit significantly higher energy barriers exceeding 12 eV, making them energetically unfavorable. Phonon calculations further demonstrate that thermal effects only marginally reduce the effective diffusion barriers.

Experimental validation was performed on Si-implanted GaN samples subjected to UHPA at temperatures up to 1450°C and nitrogen pressures of 1 GPa. Secondary ion mass spectrometry (SIMS) measurements reveal no measurable change in Si profiles after annealing, confirming the theoretical prediction of minimal Si mobility under these conditions.

These results offer a consistent view of Si diffusion in GaN and support the design of stable doping strategies for electronic and optoelectronic devices.

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YSC-5

Investigation of the lattice location of chromium in uranium dioxide single crystal with using PIXE/C analysis

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The doping of UO_2 with chromium is the subject of scientific investigation, as it enhances grain size in nuclear fuel pellets and leads to the development of Accident Tolerant Fuel. Although Cr-doped UO_2 has been extensively studied, lattice location of Cr in the UO_2 is still an open question [1]. In this work, UO_2 single crystals irradiated by 170 keV Cr^+ ions were analyzed by coupled PIXE/C and RBS/C experiments in order to record angular scans across major crystallographic axes and along main planes. The Cr signals were detected by the PIXE/C method, while RBS/C was used for collecting the matrix signal. As PIXE/C spectra contain strong background components located close to the relevant Cr signal, background reduction was crucial for the analysis. For this purpose, the custom, newly developed PIXEK program was developed as a standalone application written in Python code for PIXE spectra treatment using the Wavelet Transform for background removal. Wavelet transforms are a very useful tool for processing signals with different frequency components or non-periodic signals [2]. During the presentation, the experiments with Cr-doped UO_2 will be discussed, along with the development of the PIXEK code itself.

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Stability of intermetallic phases in cobalt-free high entropy alloys

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Cobalt-free high-entropy alloys (HEAs) are promising structural materials for nuclear reactor systems due to their excellent properties under high doses of radiation. To obtain the solid solution phase in HEAs, it is critical to determine the phase stability of the hard and brittle intermetallic (IM) phases. The formation rules of IM phases in Co-free HEAs were proposed based on calculations of widely used semi-empirical parameters, including electronegativity difference (ΔX), valence electron concentration (VEC), enthalpy of mixing (ΔH_{mix}) and atomic size difference (δ). The ΔH_{mix} - δ map was found to be a critical criterion for predicting the IM phase stability in both RHEAs and regular HEAs. The proposed IM phase formation rules were verified by the novel $V_{10}Cr_{25}Fe_{25}Mn_5Ni_{35}$ alloy. The findings offer a practical approach to efficiently design new Co-free HEA compositions using semi-empirical parameters to predict IM phase stability.

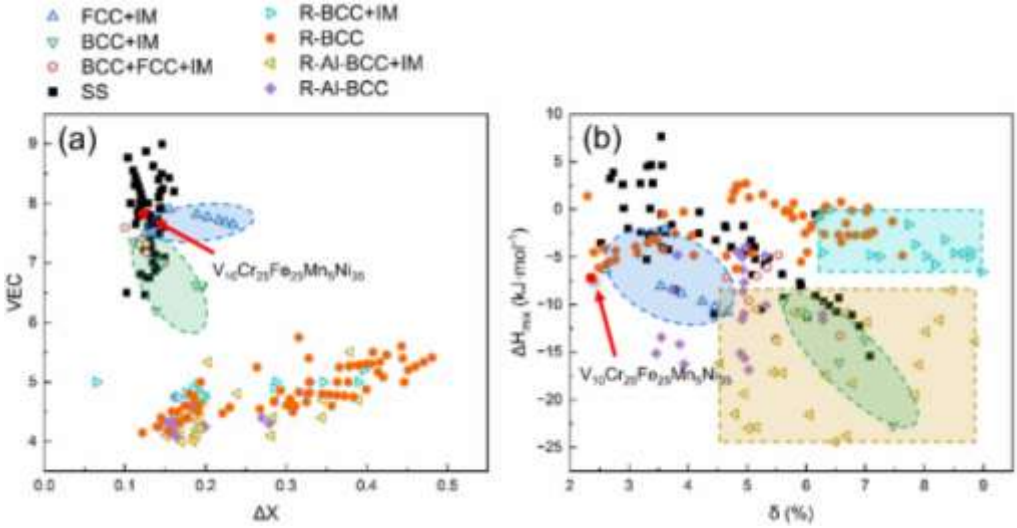

Figure 1: Binary factor map of (a) VEC and ΔX, and (b) ΔH_{mix} and ΔX on phase stability in Co-free HEAs, including the newly designed $V_{10}Cr_{25}Fe_{25}Mn_5Ni_{35}$ alloy.

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YSC-7

Operando IBA for real-time analysis of electrochemical material transformations

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Recently many operando IBA techniques are used to understand the electrochemical devices such as solid-state batteries. However, operando IBA technique are rarely employed in electrochemical devices working with solid-liquid interfaces. The complexity of operando IBA lies in the design of working devices at high vacuum experimental stations [1,2]. In this context we demonstrate a working electrochemical flow reactor in a high vacuum ion beam experimental chamber. As study cases we measured the operando Rutherford backscattering spectrometry (RBS) along with cyclic voltammetry measurement of Ru and Ni oxygen evolution reactions (OER). In Ru, Ru dissolution is quantified by RBS. Rate of Ru dissolution is found to be around 16 ng cm^{-2} s^{-1} at lower CV cycles and rate of dissolution is reduced to 8 ng cm^{-2} s^{-1} at higher CV cycles. In Ni, Pt accumulation near the Ni surface is observed during OER. This study provide a pathway for operando IBA as one of the techniques to monitor the electrode-liquid electrolyte interfaces.

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The effect of ion implantation on differently oriented β-Ga_2O_3 crystals implanted with ytterbium

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β-Ga_2O_3 is an ultrawide bandgap semiconductor with potential use in future power and optoelectronic devices operating in harsh conditions. Implantation of β-Ga_2O_3 with rare earth elements, such as ytterbium, modifies the optical response, and broadens the scope of applications. However, ion implantation causes structural damage and phase transitions that can affect the properties of the material. In the case of β-Ga_2O_3 the effects of ion implantation are still under investigation.

Due to a complicated crystal structure, β-Ga_2O_3 is characterized by strong anisotropy. For this reason, we used differently oriented crystals in our research: (001)-, (010)-, and (-201)-oriented β-Ga_2O_3 crystals implanted with Yb ions. Differences in response to ion implantation were studied using several experimental techniques: high-resolution X-ray diffraction (HRXRD), Rutherford backscattering spectrometry in channeling mode (RBS/c), Raman and photoluminescence (PL) spectroscopies, with the RBS/c studies supported by Monte Carlo simulations. These methods allow us to better understand the behavior of differently oriented β-Ga_2O_3 implanted with rare earth ions. In particular, we observed distinct behavior of (010)-oriented crystals.

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YSC-9

Optical properties of β-Ga_2O_3:RE systems

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β-Ga_2O_3 is a wide bandgap semiconductor (~4.8 eV) that paves its way for applicability in extremely radiative and harsh environments. Doping with rare earth (RE) ions by ion implantation broadens this material's potential optoelectronic applications due to the ability to tune the light emission from UV to other spectral regions. However, directly after implantation, the RE ions are optically inactive. Annealing enables efficient optical activation while simultaneously recovering the crystal damaged by implantation.

At this conference, we will present results obtained for β-Ga_2O_3 systems implanted with various RE ions, i.e., Sm, Eu, Yb, Er, and Dy ions, with fluences ranging from 1×10^{13} to 3×10^{15} at/cm^2, followed by rapid thermal annealing (RTA). The damage level of β-Ga_2O_3:RE systems was analyzed by channeling Rutherford backscattering spectrometry (RBS/c), which shows its increase with the ion fluence and can be reduced after the RTA only for lower-used fluences (below 1×10^{15} at/cm²). The photoluminescence (PL) measurements performed at room temperature on annealed samples revealed that, in most cases, the optimal fluence ensuring the most efficient RE luminescence is around 1×10^{15} at/cm², and is quenched for higher fluences. Moreover, it was found that even though the level of defects caused by different RE ions with the same fluence seemed to be similar, their optical behavior is diverse. We observed a very strong luminescence response coming from RE in the visible spectral region in contrast to the IR region, which suggests different mechanisms of their excitation. Our studies clearly show that despite the structural changes of β-Ga_2O_3 caused by ion implantation and annealing, it has proven to be an especially suitable host for RE ions due to its ability to support efficient optical activation.

Acknowledgments
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YSC-10

Preliminary study of chromium coatings for nuclear applications

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Following the Fukushima Daiichi disaster, global research efforts intensified around the development of Accident Tolerant Fuel (ATF) systems [1]. These new types of nuclear fuel cladding materials are designed to prevent the oxidation of zirconium during severe incidents like a Loss of Coolant Accident (LOCA), reduce cladding degradation and lower the amount of heat released during emergency core cooling (ECC) procedures. Zirconium alloy cladding with a protective chromium (Cr) coating is considered one of the promising candidates, largely due to its relatively short timeline for deployment in nuclear power plants [2].

In this work, a preliminary study of mechanical, structural and thermal properties of Cr-coated zirconium alloy is presented. Oxidation behaviour of both coated and uncoated specimens was evaluated using high temperature X-ray diffraction (HTXRD) over a temperature range from RT to 1100ºC. The temperatures corresponding to the formation and transformation of oxide phases are reported. The condition of the Cr-coating and the Cr-zirconium alloy interface was examined using scanning and transmission electron microscopy (SEM and TEM), in both as-deposited and post-HTXRD states.

Acknowledgement
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YSC-11

Novel low-emissivity coating for smart windows made of ALD-grown Al-delta-doped ZnO superlattices

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In this study, Al delta-doped ZnO (δ-AZO) superlattices are systematically investigated and optimized for low-emissivity glass coatings [1]. The δ-AZO thin films were fabricated via atomic layer deposition (ALD) and subsequently treated using millisecond (ms)-range flash-lamp annealing (FLA). Hall-effect measurements revealed a maximum carrier concentration of 2.7×10^{21} cm^{-3} and a minimum resistivity of 8.8×10^{-4} Ω·cm, achieved for a Al:Zn layer ratio of 1:20. Glass substrates coated with the optimized δ-AZO superlattice exhibited near/mid-infrared reflectance exceeding 65%, while maintaining a visible-light transmittance above 80%. X-ray diffraction, photoluminescence spectroscopy and cross-section TEM investigation undisputedly confirm a significant improvement in the crystal structure of the coating and a reduction of point defects. The heat reflectance test proves that our innovative δ-AZO coating is a promising and cost-effective alternative to conventional indium tin oxide (ITO) or silver-based coatings for low-emissivity glazing applications.

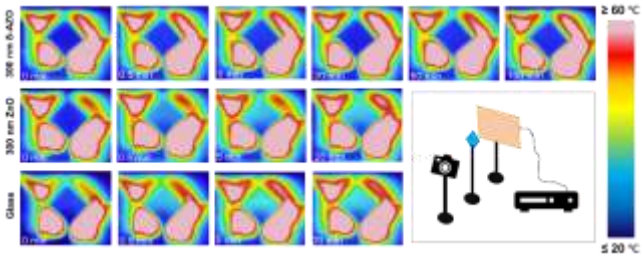

Figure 1: Proof-of-concenpt for a low-emissivity coating made of δ-AZO superlattices. The infrared images of the hot-plate are made through uncoated glass (the lowest panel) and glasses coated with δ-AZO superlattices (the upper panel) and with simple 300 nm thick ZnO film (the middle panel). The hot-plate used in the experiment and showing pink-like colour was heated to about 180ºC. The investigated glass samples are bluish squares in the middle of each image.

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POSTER PRESENTATIONS

P-1

Title Study of radiation-induced processes in the near-surface layers of nitride coatings on HEA (AlTiZrYNb)

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High-entropy alloys (HEA) are a new class of materials with increased entropy when mixed. High entropy of mixtures prevents the formation of intermetallics and interstitial solid solutions during crystallization. Five or more components taken in equal or close proportions can form a single-phase crystalline alloy. HEA-based nitride coatings are a very perspective area of research. They are characterized by good physical and mechanical properties (high values of Young's hardness, wear resistance, low friction coefficient, high thermal stability, etc.).

In this paper, the method of nuclear-resonance spectroscopy in the electron backscattering mode (EBS) was used to study HEA nitride coatings (AlTiZrYNb), produced by cathodic vacuum arc sputtering in a nitrogen atmosphere. Then the samples were implanted with ^{57}Fe ions with an energy of 200 keV to a fluence of $5 \cdot 10^{16}$ cm^{-2} at the UKP-2-1 complex charge-exchange accelerator (INP, Almaty).

Irradiation was carried out with an ion beam current of ~100 nA. The target temperature for the selected irradiation modes did not exceed 60°C. The projective range of ^{57}Fe ions in the coating was ~100 nm, therefore, iron ions were implanted into the near-surface region commensurate in depth with the layer thickness available for analysis by the CEMS method. Ferritic-martensitic steel (Fe-12% Cr) was taken as a substrate.

Successive two-hour isochronous annealings of the samples were carried out in a vacuum furnace at temperatures of 870, 1070, 1170, 1220 and 1270K. After each annealing stage, the coating structure was studied. The elemental composition of the synthesized samples was determined using a HITACHI 4000 scanning electron microscope equipped with an Oxford Instruments energy dispersive analyzer.

Changes in the crystal structure of the studied materials before and after implantation were recorded on a Bruker D8 ADVANCE diffractometer with a Cu-Kα emitter in the Bragg-Brentano geometry. The phases were identified using an ASTM and TCPDS card index. The electron environment of Fe^{57} atoms after the completion of the implantation process was estimated using the KEMS method. Mössbauer studies were carried out on an MS-1104Em spectrometer at room temperature; Co^{57} in a chromium matrix served as the source of γ-quanta. The Mössbauer spectra were processed by the model decoding method in the SpectrRelax program.

It is shown that iron ions implantations and the HEA nitride-based coating before annealing is represented by a significantly broadened paramagnetic line. This indicates

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a strong distortion of the electronic structure in the region of the Fe impurity atom, leading to an amorphization state of the HEA structure. Isochronous annealing leads to a monotonic decrease in the widths of the resonance lines. At the last stage of the annealing process (T=1270 K), the sample demonstrates a disordered substitution solid solution.

It was established that the group of Al, Ti, and Nb elements with a cubic structure of fcc and bcc syngony are responsible for the singlet; Zr and Y, having a hexagonal close packing (hcp) lattice, generated a doublet in the near-surface layers of the coating. The XRD data are in agreement with the CEMS studies. The substrate of the HEA coating was ferritic-martensitic steel Fe-12% Cr. On the diffraction pattern it is represented by three reflections (110), (200), (211), and the coating is two sublattices of the fcc and hcp structure.

Acknowledgement

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P-2

Effect of xenon ion irradiation with 160 MeV energy on mechanical and tribological properties of Inconel X750 superalloy

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Changes in the crystal structure as well as tribological properties and friction mechanism of Inconel X750 superalloy after irradiation with xenon ions of 160 MeV with a fluence of 1.0, 2.5 and 5.0×10^{14} Xe^{24+}/cm^2 were studied. This material, which is widely used in the nuclear power industry, shows high resistance to corrosion, oxidation and high strength at elevated temperatures. The aim of this study was to investigate radiation damage caused by fission products of uranium nuclei under laboratory conditions. GXRD measurements showed that irradiation causes smaller changes in the crystal structure of Inconel X750 superalloy than that of Inconel 718 superalloy. The calculated range of xenon ions is 8.0 μm while changes in the crystal structure occurred in a layer less than 0.5 μm. After irradiation, improvements in tribological and mechanical properties were observed. For all irradiated samples, a reduction in the friction coefficient and a significant reduction in wear reaching up to 70% in comparison with unirradiated samples were observed in pin/ball-on-disk tests. These changes are related to a change in the friction mechanism of the tested samples after irradiation, as confirmed by EDX measurements. The largest increase in microhardness of the irradiated samples compared to the unirradiated ones was 67%.

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P-3

Multilayered Thin Film Coatings: Mechanisms and Material Responses to Ion Irradiation

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Ion-beam-induced mixing of layered structures using ions with energies of several hundred keV is a highly effective method for obtaining stable, metastable, or even non-equilibrium phases in a thin layer near the surface, without the compositional limitations of direct implantation. In immiscible systems the displacement processes involved become competitive. While ballistic effects lead to the introduction of both species into each other, thermodynamic effects drive phase separation.

In this context, we have chosen the Cu-W system for the study. This system is strongly immiscible. Its mixing enthalpy in the solid state, calculated using Miedema's model, is $\Delta H = 36$ kJ/at.g. Here, we present results confirming the feasibility of material mixing in the Cu/W system, which has been previously investigated in detail in [1]. The Cu/W multilayers obtained using our newly developed magnetron sputtering system will serve as the starting material for the investigation of the mechanical properties of the resulting layers. The experimental characterization will be carried out using instruments available in our laboratory. The ultrananoindenter equipped with a nanoscratch-testing module enables precise determination of mechanical properties, layer thicknesses, identification of interfacial boundaries, and assessment of the structural integrity of both single and multilayer architectures. This approach is effectively complemented by atomic force microscopy (AFM), which provides high-resolution imaging of surface topography, generates three-dimensional surface maps, and facilitates the detection of local deformations induced by nanoindentation. Additional characterization will be performed using an X-ray diffractometer in θ–2θ geometry with Cu K_α radiation ($\lambda = 1.54$ Å).

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P-4

Anisotropy of radiation-induced damage in ion-bombarded Ga_2O_3 and GaN

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Gallium oxide (Ga_2O_3) and gallium nitride (GaN) have garnered significant interest for their advanced electronic and optoelectronic applications. Nevertheless, the response of these materials to ion bombardment poses significant challenges. Ion implantation, a technique extensively utilized for doping and material modification, introduces structural defects that can compromise performance and necessitate post-irradiation annealing. It is imperative to comprehend the mechanisms of defect formation and transformation in these materials to optimize their properties.

Rutherford backscattering spectrometry in ion channeling mode (RBS/C) provides valuable insights into the evolution of disorder in ion-bombarded materials. However, conventional analytical analysis frequently encounters difficulties in distinguishing various defect types via backscattering and dechanneling interactions that contribute to RBS/C spectra. This has led to the adoption of Monte Carlo McChasy simulations [1], which enable precise characterization of displaced atoms, edge dislocations, and dislocation loops, aiding in the research of damage evolution under specific ion fluences. The present study investigates the anisotropic nature of radiation-induced damage in Yb-implanted Ga_2O_3 and Ar-bombarded GaN.

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Acknowledgments

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P-5

Structure and broad infrared absorption of silicon hyperdoped with ion implanted selenium

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Silicon layers hyperdoped with selenium have been formed by Se implantation (140 keV, 3.1×10^{15} cm^{-2} and 6.1×10^{15} cm^{-2}) followed with pulsed laser annealing (PLA) ($\lambda = 694$ nm, $W = 2.0$ J/cm^2, $\tau = 70$ ns) or isothermal annealing (550-850°C). For PLA, the formation of intermediate sub-band inside the Si band gap was proven by scanning tunneling spectroscopy. To estimate the degree of crystallinity of the doped silicon layer and to determine the fraction of Se atoms in Si lattice sites, the values of backscattering yield χ^{Si} and χ^{Se} retrieved from the RBS spectra, obtained in the channeling regime, were used. Characteristics of the experimentally registered and theoretically estimated sub-band properties are compared and discussed. Light absorption increase in the wide spectral region (0.2-23.0 μm) was observed. The intensity of absorption band increases with Se concentration in the doped layer and reaches 24% and 35% for the samples with a concentration of 0.75% and 1.5%, respectively. The MIR absorption band is very broad and extends down to at least 0.05 eV.

At isothermal annealing ~50% of Se atoms get into the Si lattice sites. A noticeable increase in optical absorption in the IR range (1.1-2.5 μm) was not registered for isothermal annealing and it did not exceed 1-2%. The results of the studies indicate that most of the Se atoms in the sites of the silicon matrix lattice are in electrically inactive states after isothermal heat treatments. This effect can be explained by the formation of a large number of neutral complexes of selenium atoms, when they are embedded in neighboring sites of the silicon lattice and form covalent bonds with each other.

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P-6

Simulation of excess carrier generation in silicon and silicon dioxide during proton and swift heavy ion irradiation

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Time and space evolution of excited carrier density for the initial stages of ion track formation in silicon and silicon dioxide irradiated with protons and swift heavy ions have been simulated using TREKIS-3 software [1]. Calculations were performed for H^+ ions with energies from 0.06 MeV to 88 MeV, Fe^+ ions with energies 16 and 435 MeV, 257 MeV Kr^+ and 547 MeV Xe^+ ions. Iteration number for Monte-Carlo calculations was 100, 300 and 1000; layer thickness – 10 nm.

The calculated maximum concentrations of excited electrons in the central region of 547 MeV Xe ion track in silicon is $1.6 \cdot 10^{23}$ cm^{-3} and remains as high as $5.4 \cdot 10^{21}$ cm^{-3} by the time of 100 fs. The outer electron shells of Si atoms are fully ionized in the region with radius up to 5 Å for 547 MeV Xe irradiation and 4 Å for 257 MeV Kr irradiation. At the same time, the significant part of deposited energy is localized in the valence holes subsystem (~73% for all simulated heavy ions). Analytical approximations of calculated carrier concentration radial and time dependencies and generation rates for excess electrons and holes are obtained.

A sequential analysis of the simulation results and evaluation of analytical approximations using different goodness-of-fit critetia was carried out.

The results of this work could be useful for calculating track structure in semiconductors and SiO_2-based structures, single-event effects modeling in silicon-based electronic devices, and refining of the carrier generating rate in the calculations of proton-irradiation induced working characteristics changes, such as threshold voltage shift in power MOSFETs and IGBTs.

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P-7

Defects formation in TiO_{2-x} coatings manufacturing by suspension plasma spraying

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Reduction of bandgap value in semiconductor coatings could be achieved by high concentrations of defects inside its structure. Reduction of TiO_2 material during deposition by suspension plasma spraying (SPS) is realized by adding hydrogen as secondary plasma gas. In the literature it is a research gap about influence of SPS parameters on the defects formation. Current studies show the relationship between the process conditions and defects formation in TiO_{2-x} coatings. The variable parameters were: spray distance and solid content in suspension. The flow rate of hydrogen was kept on constant value. Obtained coatings were examined in terms of microstructure, phase composition and presence of defects. The results confirmed that on the surface the main phase was anatase, whereas inside coatings in was a mix anatase with rutile. Investigations carried out by electron paramagnetic resonance (EPR) confirmed presence of Ti_{3+} subsurface species in all samples. On the other hand, presence of electron trapped in oxygen vacancies was observed only for low concentration suspension (10 and 15 wt.%) and the longest spray distance (70 mm). Additionally, photoluminescence (PL) examinations confirmed these results.

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P-8

Influence of radiation effects on superconducting parameters of the second-generation high-temperature superconductor tape based on Gd – present and future

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HTS tapes are used in devices operating in extreme radiation conditions with the prospect of their use in the space industry. Ionizing radiation, including heavy ion (e.g. $^{40}Ar^{8+}$, $^{84}Kr^{17+}$, $^{132}Xe^{27+}$) bombardment (Figure 1), can introduce defects (e.g. Schottky, Frenkel) into the tape microstructure, which leads to a deterioration of superconducting parameters such as critical temperature (T_c), superconducting transition width (ΔT), critical current density (J_c) [1].

To determine the effect of radiation on superconducting parameters, the superconducting layer of the second-generation high-temperature superconductor (2G HTS) tape based on Gd was irradiated with Ne^+ ions with energies of 250 keV and fluences from 10^{12} Ne^+/cm^2 to 10^{14} Ne^+/cm^2 (Figure 1) [2] and with He^+ ions with energies of 85 keV and 180 keV and fluences from 10^{13} He^+/cm^2 to 10^{16} He^+/cm^2.

Comprehensive studies of microstructural, structural, magnetic and electrical properties of the irradiated tapes prove that the deterioration of the tapes has a microscopic basis. It results mainly from oxygen deficiency and microstructural and structural defects.

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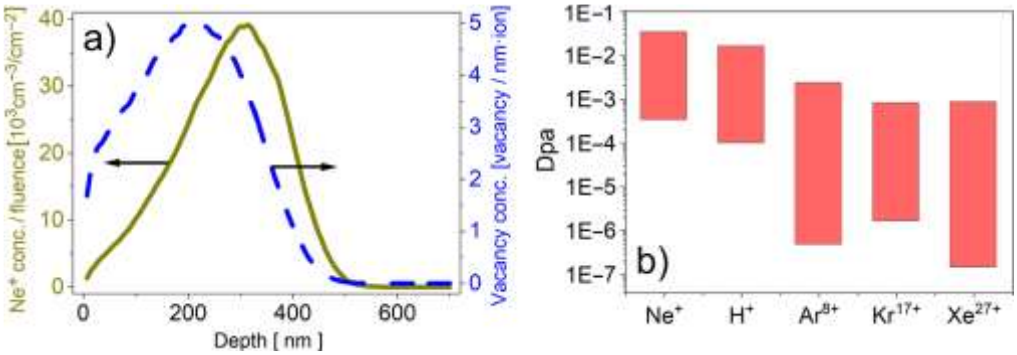

Figure 1: (**a**) Depth distribution of Ne^+ introduced into the 2G HTS layer (solid line) and depth distribution of vacancies (dashed line) produced during the bombardment; (**b**) Dpa - displacements per atom (logarithmic scale) for Ne^+ and comparison at the same fluences for H^+, and $^{40}Ar^{8+}$, $^{84}Kr^{17+}$, $^{132}Xe^{27+}$, at the same fluences [2]

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P-9

Simulation of ion implantation of Al in 4H-SiC and post-implantation annealing

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Silicon carbide's wide band-gap, high breakdown field and superior thermal conductivity make it the material of choice for next-generation high-power electronics. Achieving reliable p-type doping, however, still hinges on efficiently activating aluminium (Al) implants while minimising implantation-induced damage. This work employs large-scale molecular dynamics simulations to optimise both the implantation of Al ions into 4H-SiC and the subsequent high-temperature annealing cycle. Using SRIM to calculate electron stopping data, randomly seeded Al ions (10^{14}-10^{15} cm^{-2}, tens of keV) are driven into a 7200-atom crystal and relaxed after each impact in LAMMPS. Post-implantation recovery is then modelled by ramping the lattice to 3300K, holding for 2 ns and cooling at a matched rate. OVITO's common-neighbour analysis and polyhedral template matching track point defects, amorphous pockets and dopant location in real time. The study quantifies depth profiles, residual vacancy/interstitial concentrations, and the fraction of Al occupying substitutional sites as a function of anneal temperature–time budget. These atomistic insights translate into concrete guidelines for industrial SiC processing, specifically optimal implant energies, incidence angles, and thermal budgets, which can enhance device yield and on-state performance.

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P-10

Effect of nitrogen ion implantation on cavitation erosion resitance of cobalt-based hardfacings

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The work investigates the effect of nitrogen ion implantation (NII) of CoCrWC and hardfacings on the improvement of resistance to cavitation erosion (CE). Two types of cobalt-based hardfacing were deposited via the tungsten inert gas method on a structural steel substrate. The CE resistance of stellites ion-implanted by 120 keV N^+ ions, two fluences: 5×10^{16} cm^{-2} and 1×10^{17} cm^{-2}, were comparatively analysed with the unimplanted stellite and AISI 304 stainless steel. CE tests were conducted according to ASTM G32 with stationary specimen method. Erosion rate curves and mean depth of erosion confirm that the nitrogen-implanted hardfacings, two times, exceed the resistance to CE than unimplanted stellite, and have almost ten times higher CE reference than stainless steel. The profilometric surface analysis confirms the erosion stages identified by SEM. The X-ray diffraction (XRD) confirms that NII of cobalt-based hardfacing favours transformation of the ε(hcp) to γ(fcc) structure. Unimplanted stellite ε-rich matrix is less prone to plastic deformation than γ, and consequently, an increase of γ phase effectively holds carbide eutectics. This phenomenon elongates the CE incubation stage three times, slows the erosion rate and mitigates the material loss. Metastable γ structure formed by ion implantation consumes the cavitation load for work-hardening and $\gamma \rightarrow \varepsilon$ martensitic transformation. In further CE stages, phases transform as for unimplanted alloy, namely, the cavitation-inducted recovery process, removal of strain, dislocations resulting in an increase of γ phase.

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P-11

Analysis of the effect of Countersample coatings on friction and surface topography of DC01 steel sheets in bending-under-tension friction tests

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The study analyzed the influence of the type of anti-wear coatings on the tribological behavior of deep-drawing DC01 steel sheet during the forming process, with particular emphasis on friction on rounded tool edges. The study was conducted using a specially designed tribometer that reflects the actual conditions of tool-sheet contact. The influence of various surface modifications of counter-samples, such as ion implantation or electron beam remelting, on the friction coefficient, sheet surface topography and temperature in the contact friction zone, in dry and lubricated friction conditions, was assessed. It was found that the type of coating and lubricating oil viscosity have a significant influence on the friction process. Additionally, significant changes in the roughness and texture parameters of the sheet surface were observed as a result of the friction process.

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P-12

Ion Beam Emittance Calculations for a Disc-shaped Hot Cavity

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Surface ionization ion sources with hot cavity were developed in 1970s [1] and since that time were successfully used in a variety of isotope separation facilities. Recently, a flat-disc cavity was proposed [2], which should be defined as a special case of cylindrical ionizer characterized by shorter length with respect to its radius. Such shape can enlarge the number of particle-wall collisions as they move toward extraction hole. It was shown that the flat disk shape could be very effective in the case of stable and long-lived isotopes, especially those which are hard-to-ionize.

In the paper the results of emittance calculations for values of the inner cavity radius for stable isotopes are shown and discussed. The discussion is enriched by presentation of average number of particle-wall hits and mean time a particle stays inside the cavity. Evolution of ion beam emittance with ionization probability, half-life period for different cavity shape configurations are also under investigation. Influence of the extraction channel geometry i.e. the extraction opening radius and its length on ion beam quality described by its emittance and previously used [3] concept of scaled efficiency is also studied.

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P-13

Optical, electronic and microstructural properties of PET and PEN modified by 150 keV Mg^+ ion irradiation

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The role that polymers play in everyday life has becomes more and more important. Since decades polymers have attracted attention of scientists and engineers due to their excellent properties such as low cost, low density, strength and durability, plasticity etc. [1]. PEN, Poly(ethylene 2,6-naphthalate), could be regarded as competitive with PET, poly(ethylene terephtalate), in some performance-driven areas due to on its superior properties like strength, heat stability and gas barrier properties [2]. PEN is newer and in some aspects better than PET, it is however, more expensive and its properties are often not fully exploited.

The aim of this paper is examine and compare the influence of irradiation on the polymer molecular structure and some physical properties of both PEN and PET polymer in the case of relatively light projectile (Mg^+) other than alkaline metals, which were recently extensively studied. Modification of the implanted polymer microstructure in the subsurface layer is investigated using both ATR-FTIR and Raman spectroscopies giving information about of bond destruction and formation of new structures. Radiation resistance of both polymers could be compared in the considered case. Optical properties i.e. absorption in the UV-ViS is also studied with a special attention given to modification of the optical bandgap. The average number of carbon atom in graphitelike structures in the subsurface layer is compared for both polymers. Last but not least, changes of surface resistance due to ion bombardment of PET and PEN are investigated and discussed.

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Thermal desorption spectroscopy studies of Xe implanted into germanium

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Thermal desorption spectroscopy (TDS) is widely used technique for studies of adsorbates (like gases) release from the surface depending on its temperature providing important information about the species present and their reactions on a surface [1]. This could easily extended to the release of the implanted species from the subsurface layers of solids (semiconductors, metals etc.). Such experiments may give some insight on the lattice defects like vacancies and their clusters as well as their kinetics. It could be also helpful in determination of diffusion coefficients [2]. TDS is often combined with ion implantation, as this could be a direct way to gain knowledge on disorder introduced to lattice by ion impact .

The paper is devoted to investigations of thermal desorption of very heavy noble gas – xenon. Its most abundant isotope (^{132}Xe) was implanted into the germanium target with the energies 100 keV and 150 keV and fluence $2 \cdot 10^{16}$ cm^{-2}. The TDS spectra were registered for the linear heating profiles with ramp rates in the range 0.3 K/s up to 1.5 K/s. The spectra were analysed in order to derive the values of desorption activation energy E_a. An abrupt emission of Xe was registered in the temperature range 800K-840K. A single peak (width of several K up to ~25 K) is most probably a result of gas release from pressurized cavities formed by vacancy coalescence. The estimated values of E_a are: 3.15 eV and 2.1 eV for the implantation energies 100 keV and 150 keV, respectively.

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Effect of adding molybdenum on microstructure, hardness and corrosion resistance of $AlCoCrFeNiMo_{0.25}$ high entropy alloy

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The components designed to operate in flow environments exposed to effects of the corrosive environment require the use of new metal alloys with favorable material characteristics compared to the conventional corrosion-resistant steels. In this regard, a new group of materials of high entropy alloys (HEA) appears to be fairly promising. Therefore, the $AlCoCrFeNiMo_{0.25}$ high entropy alloy was studied in this paper and compared to AISI 304L steel and AlCoCrFeNiMo reference alloy. HEAs were manufactured by vacuum arc melting. The effects of molybdenum addition on structure, hardness and corrosion were evaluated. The potentiodynamic polarization tests were carried out in 3.5% NaCl solution in a three-electrode electrochemical system. The corrosion behaviour of HEA has been determined in electrochemical impedance spectroscopy (EIS) measurements by means of Atlas 0531 set dedicated for corrosion testing. The surfaces after corrosion test were subjected to SEM and EDS analysis. The addition of molybdenum to the $AlCoCrFeNiMo_x$ alloy results in the occurrence of a σ phase and an intermetallic phase, as well as in the changes in the microstructure leading to grain fragmentation and a structure with a mosaic pattern. Furthermore, the addition of Mo was found to result in improved corrosion resistance and higher hardness. Pitting corrosion affects HEA alloys in Al- and Ni-rich areas which is related to Cr chemical segregation. Generally, the addition of Mo elements has a significant influence on the microstructure and the properties of $AlCoCrFeNiMo_{0.25}$ alloy.

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