Report for the 2018-2020 years.

Theme 1126, project "Development Of the Experimental Techniques and Applied Researches with Slow Monochromatic Positron Beams"

1. The development of the experimental base.

Slow positron specialized channel.

The slow positron specialized channel (SPSC) construction was completed (Fig.1). The channel magnetic system is composed of the bending solenoid 1, coils of longitudinal magnetic field 2, the solenoid system for ordering positrons 3, the transverse field coils for correcting the trajectory of positrons (not shown in Fig. 1).

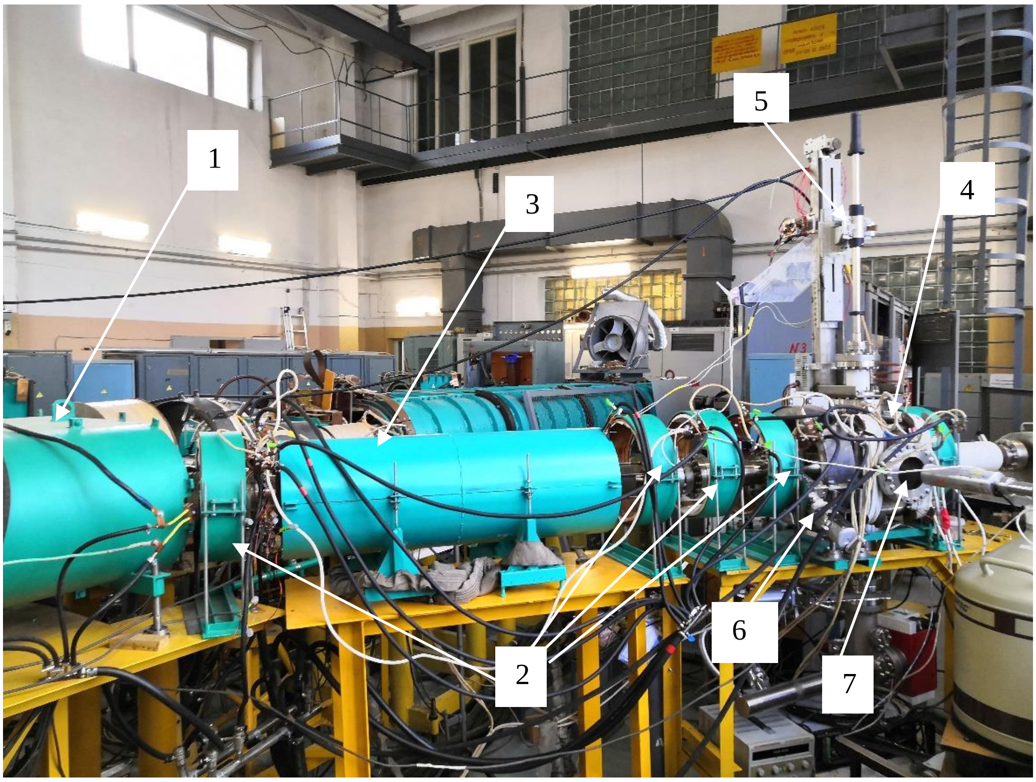

Figure 1. Slow positron specialized channel.

Inside magnetic system the channel vacuum chamber is located. It ends with experimental station 4. The holder with the samples is placed inside the experimental station through the side flange 7 and is fixed to the manipulator 5. At each opening of the vacuum volume one can place up to seven samples. The movement of the manipulator is carried out electrically by remote control. The experimental volume has its own vacuum pumps and is separated from the main vacuum volume of the channel by the gate 6.

System for ordering the positron flow.

The positron flow ordering system is part of the created spectrometer for measuring the lifetime of a positron in a material (Positron Annihilation Lifetime Spectroscopy – PALS). Positron flow ordering occurs when the particles pass through the acceleration gap, to which the RF voltage of a special form is applied. By attaching to a high-voltage phase, one can know exactly when the positron enters the sample. To generate a special form of voltage, three harmonic signals (100, 200, 300 MHz) with a certain amplitude and phase are used, which are applied to two acceleration gaps. For this purpose, the RF resonator was developed and manufactured (Fig.2).

Figure 2. Resonator of the positron ordering system.

The resonator has two cylindrical cavities. One is working at 1^{st} (100 MHz) and 3^{rd} (200 MHz) harmonics, another at 2^{nd} harmonic. The resonator is assembled, tuned to three harmonics, and prepared for installation inside the vacuum chamber.

A high-stability generator and frequency multiplication devices have been purchased, and work to create an attaching system in the RF voltage phase is in progress.

Reactive ion etching system.

A system of reactive ion etching was developed to make it possible studying thin-film samples. It is based on an ion source produced by PREVAC C^{o}. The system is located under the experimental volume (Fig. 3).

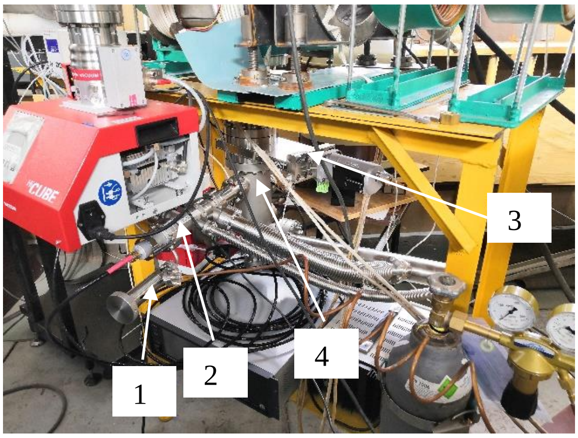

Figure 3. Reactive ion etching system.

For etching, argon ions are used, which are formed in the ionization chamber of the ion source 2 when argon flow enters it through leak valve 1. The etching is produced in Chamber 4 when the holder with samples is lowered after the opening of the gate 3, located under experimental volume. In standby, the vacuum in the etching chamber is kept by an ion pump. When the ion source is operating with the gate 3 open, a turbo molecular station of experimental volume is used for pumping.

1. **Experimental research by the methods of PAS.**

Experimental research was conducted in several areas.

Studies of materials modification after ion implantation.

Ion implantation is usually used for subsurface modifications, especially useful for doping semiconductors in planar technology. In a simple way, you can localize different ions at different depths from the input surface and change, for example, the electronic properties in the implanted layer. However, this generates a lot of damage, ranging from point defects to phase transitions. The performed studies characterize the defects created by low-energy ions in the structure of semiconductors such as Si, GaAs, TiO_2, WO_3, and metal oxides.

Research of radiation damage and related phenomena in nuclear materials and pure metals.

Nuclear materials are used at increased radiation exposure. Our research of nuclear materials started in 2019 and focuses on materials for IV generation reactors, such as SiC and tungsten. The influence of grain boundaries, inclusions, and other defects on radiation resistance, in nanocrystalline Ti and Zr/Nb thin-layer structure, has been studied. The second part of the research focused on the study of the long - range effect (LRE) that occurs during irradiation. It has been studied for several pure metals Ti, Fe, Ag, Au, Nb, Pd, Bi. For some of them, such as Fe and Bi, structural defects were found not only at the depth of ion penetration, but also much deeper. This effect has not yet been convincingly explained.

Research of damages appearing from mechanical impacts.

Defects play not only a negative role in materials. Proper mechanical action can be used to produce materials with high strength and durability. Grain shredding methods are a well-known process that reduces the grain size and improves its mechanical properties. Recent studies include the study of defects caused by hydrostatic extrusion, surface modification during abrasion, and sandblasting. Bronze, steel, dental alloys, and pure copper were studied. The characteristics of defects occurring under the surface, including their type and concentration, as well as the role of various technological parameters in the formation of defects, are studied in detail. For example, the process of sandblasting was carried out over different periods of time; processing was carried out at different directions of the nozzle axis relative to the sample surface; the size, shape and material of abrasive particles were changed; compression deformation was applied.

Study of the destruction of materials because of the cavitation process.

Wear of materials occurs because of operation, for example, because of friction or cavitation erosion in liquid-jet machines. During these processes, defects of various profiles and types are formed, which change in time and eventually cause fatigue and destruction of structural parts. Understanding this process can help you find a way to reduce material wear and reduce the probability of design errors.

The first group of studies includes the evolution of cavitation damage over time for steels and bronzes. It is well known that four periods can be distinguished in this process: incubation, acceleration, the area of maximum erosion rate, and the attenuation stage. During each period, various defects are formed, which can be determined by PAS methods.

The second group of studies includes the study of defects that occur during friction. Dependence on various factors such as load, friction speed and time were investigated. The role of these parameters on subsurface zone defects in pure niobium and zirconium metals was studied.

2. Plans for 2021-2023.

1. Completion of the positron ordering system and commissioning of the PALS spectrometer with a monochromatic positron beam.

2. Improvement of the DUAL spectrometer: creation of the scheme registering the coincidence of two annihilation gamma quanta in the measurement scheme.

3. Research of materials using available PAS methods.

Publications:

1. K.Siemek, J.Dryzek, M.Mitura-Nowak, A.Lomygin, M.Schabikowski, *Positron annihilation studies of long range effect in Ar, N and C-implanted silicon*, Nuclear Instruments and Methods in Physics Research B 465 (2020) 73.

2. P.Horodek, K.Siemek, J.Dryzek, M. Wróbel, *Impact of abradant size on damaged zone of 304 AISI steel characterized by positron spectroscopy*, Metallurgical and Materials Transactions A 50 (2019) 1502.

3. J.Dryzek, K.Siemek, *Positron Annihilation Studies of Subsurface Zone Created during Friction in Pure Silver*, Tribology Transactions 62 (2019) 658.

4. J.Dryzek, K.Siemek, *Defects and their range in pure bismuth irradiated with swift Xe ions studied by positron annihilation techniques*, Applied Physics A 125 (2019) 85.

5. K.Siemek, M. Kulik, M. K. Eseev, A. G. Kobets, M. Wróbel, O. S. Orlov, A. A. Sidorin' *Surface and subsurface defects studies of dental alloys exposed to sandblasting*, Acta Metallurgica Sinica (English Letters) 32 (2019) 1181.

6. P. Horodek, *Application of positron annihilation spectroscopy techniques for the long range effect detection*, Acta Physica Polonica A, 136(2) (2019) 361.

7. P. Horodek, *Positron annihilation studies of irradiation-induced defects with swift heavy ions in gold* Vacuum, 164 (2019) 421.

8. P. Horodek, M. Kulik, *Application of positron beam for the long range effect studies in proton implanted iron* Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 443 (2019) 84.

9. M.Eseev, P.Horodek, V.Khilinov, A.Kobets, V.Kobets, I.Meshkov, O.Orlov, K.Siemek, A.A.Sidorin, *Development of Positron Annihilation Spectroscopy at Joint Institute for Nuclear Research*, Acta Physica Polonica A 136 (2019) 315.

10. P.Horodek, A.Kobets, K.Siemek, V.Skuratov, *Defects and their range in pure bismuth irradiated with swift Xe ions studied by positron annihilation techniques,* Acta Physica Polonica A 136 (2019) 318.

11. P.Horodek, L.H.Khiem, K.Siemek, L.A.Tuyen, A.G.Kobets, *Positron Annihilation Spectroscopy in Material Studies*, Communications in Physics 29 (2019) 501.

12. K.Skowron, K.Siemek, *Positron annihilation spectroscopy studies of sandblasted copper*, Acta Physica Polonica B Proceedings Supplement, 11 (2018) 4.

13. E.Romanowka, E.Dryzek, J.Morgiel, K.Siemek, Ł.Kołek, M. Zagula-Yavorska *„Microstructure and positron lifetimes of zirconium modified aluminide coatings"* Archives of Civil and Mechanical Engineering 18 (2018) 1150.

14. P. Horodek, J. Dryzek, *Positron lifetime studies of defects distribution in Xe^{26+} irradiated pure titanium* Surface and Coatings Technology 355 (2018) 247.

15. E.V.Ahmanova, M.K. Eseev, V.I. Hilinov, P. Horodek, A.G. Kobets, V.V. Kobets, I.N. Meshkov, O.S. Orlov, K. Siemek, A.A. Sidorin, *Measurement of Monochromatic Positron Lifetime in a Continuous Flux* Physics of Particles and Nuclei Letters 15 (2018) 975.

16. J. Dryzek, P. Horodek, M. Dryzek, *Damage range in swift Xe^{26+} ion-irradiated polycrystalline iron and silver studied by positron annihilation technique, long-range effect* Applied Physics A: Materials Science and Processing, 124 (2018) art. no. 45.

17. A.Szpakiewicz-Szatan, D. Dabrowski, P. Horodek, M. Peryt, K. Roslon, *Slow control of positron polarisation system's power supply* Acta Physica Polonica B, Proceedings Supplement, 11 (2018) 825.

18. P. Horodek, K. Siemek, J. Dryzek , M. Wróbel, *Positron Annihilation and Complementary Studies of Copper Sandblasted with Alumina Particles at Different Pressures Materials* 10 (2017) 1343

19. J. Dryzek, P. Horodek, *Positron Annihilation Studies of the Near-Surface Regions of Niobium before and after Wear Treatment* Tribology Letters, 65 (2017) art. no. 117.

20. J.Dryzek, P. Horodek, V.A. Skuratov, *Defect range and evolution in swift Xe-Ion irradiated pure silver studied by positron annihilation technique* Acta Physica Polonica A, 132 (2017) 1585.

21. M. Sarnek, E. Dryzek, P. Horodek, W. Pachla, *Estimate of the crystallite size for nanocrystalline AISI 316L stainless steel and armco iron processed by hydrostatic extrusion using variable energy positron beam* Acta Physica Polonica A, 132 (2017) 1598.

22. P. Horodek, J. Dryzek, V.A. Skuratov, *Positron annihilation study of defects in copper irradiated with swift* Xe^{26+} *ions* Vacuum, 138 (2017) 15-21.

23. J. Dryzek, P. Horodek, *Slow positron beam studies of zirconium exposed to dry sliding* Journal of Physics: Conference Series, 791 (2017) art. no. 012020 .

24. E.V. Ahmanova, M.K. Eseev, A.G. Kobets, I.N. Meshkov, O.S. Orlov, A.A. Sidorin, K. Siemek, P. Horodek, *Positron annihilation spectroscopy on a beam of positrons the LEPTA facility* EPJ Web of Conferences, 132 (2017) art. no. 03014.

25. P. Horodek, K. Siemek, J. Dryzek, A.G. Kobets, M. Wróbel, "*Positron annihilation and complementary studies of stainless steel exposed to sandblasting at different angles*" Tribol. Lett. 64 (2017) 30-37

26. S Kurdyumov, K Siemek, P. Horodek, *Positron annihilation spectroscopy studies of bronze exposed to sandblasting at different pressure* J. Phys.: Conf. Ser. 929 (2017) 012029

27. K. Siemek, E.V. Ahmanova, M.K. Eseev, V.I. Hilinov, P. Horodek, A.G. Kobets, I.N. Meshkov, O.S. Orlov, A.A. Sidorin, *Realization of positron annihilation spectroscopy at LEPTA facility* 25^{th} Russian Particle Accelerator Conference, RuPAC (2016) 496.

28. J. Dryzek, K. Siemek, *Formation of subsurface zone induced by sliding wear in zircionium studied by positron lifetime spectroscopy* Tribol. Lett. 64 (2016) 15-25

29. C.S. Osokin, M.K. Eseev, A.A. Goshev, P. Horodek, S.N. Kapustin, A.G. Kobets, A.S. Volkov, *Investigation of the dielectric properties and defectoscopy of nanocomposites based on silica and polymers reinforced with carbon nanotubes* Journal of Physics: Conference Series, 769 (2016) art. no. 012033 .

30. P. Horodek, V.A Skuratov, *Variable energy positron beam studies of defects in heavy ion implanted palladium* Surface and Coatings Technology, 296 (2016) 65.

31. P. Horodek, J. Dryzek, V.A Skuratov, *Studies of iron exposed to heavy ion implantation using positron annihilation spectroscopy* Radiation Physics and Chemistry, 122 (2016) 60.

32. P. Horodek, J. Dryzek, *Application of encapsulated* ^{22}Na *isotope to Doppler spectroscopy based on positrons emitted directly from the source* Acta Physica Polonica B, Proceedings Supplement, 9 (2016) 231.

33. I.N. Meshkov, E.V. Ahmanova, V.I. Hilinov, O.S. Orlov, A.A. Sidorin, M.K. Eseev, P. Horodek, K. Siemek, A.G. Kobets, *Development of positron annihilation spectroscopy at the LEPTA facility* 25^{th} Russian Particle Accelerator Conference, RuPAC (2016) 499.