Questionnaire

Project: Development of experimental techniques and applied research with slow monochromatic positron beams (PAS)

Project leaders: A.G.Kobets, K.Siemek

Scientific leader: I.N.Meshkov

Theme: 1126

Year of last approval: 2020

PART A: Achievements

1. Research activities:

Group members are responsible for the research and development of positron annihilation spectroscopy methods at JINR and collaborate with the following institutions:

- Institute of Nuclear Physics PAS, Kraków, Poland (P. Horodek, E. Dryzek, K. Skowron)
- Tomsk Polytechnic University, Tomsk, Russia (R. S. Laptev, A. M. Lider)
- Center for Nuclear Techniques, Ho Chi Minh City, Vietnam (Luu Anh Tuyen)
- Northern (Arctic) Federal University named after M.V. Lomonosov, Arkhangelsk, Russia (M. K. Eseev, I. V. Kuziv)
- Institute of Electrophysics & Radiation Technologies NAS of Ukraine, Kharkiv, Ukraine (V. Klepikov, V. Lytvynenko)

Current measurement possibilities:

- conventional positron lifetime measurements
- Doppler broadening of annihilation line measurements can be performed both on the variable energy positron beam and conventional positron source

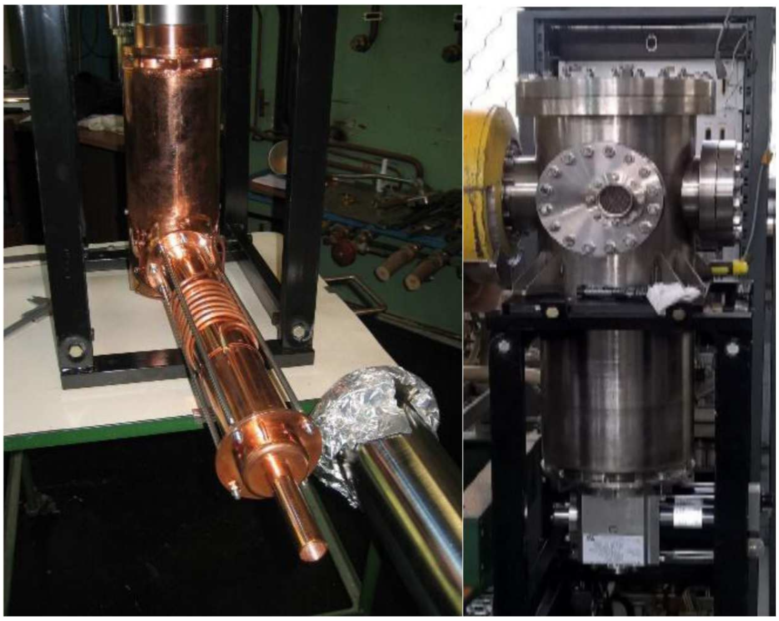
2. Project history

The project started in 2016 with the name: "LEPTA Project: Experiment Technology Development and Applied Research with Slow Monochromatic Positron Beams". This project included works on both Positron Annihilation Spectroscopy (PAS) and previously opened Low Energy Particle Toroidal Accumulator (LEPTA) project. During the prolongation of the project in 2018, the Scientific and Technical Council of the Laboratory of Nuclear Problems did not support the LEPTA part of the project, and it was, therefore, implemented only as a PAS project. Its name was changed to: "Experiment Technology Development and Applied Research with Slow Monochromatic Positron Beams". Currently, no one is implementing the LEPTA project, and all team-members are involved only in the PAS project. The current report does not include any LEPTA activities.

3. Experiment Technology Development in the previous years:

a) Cryogenic Source of Slow Monochromatic Positrons (CSSMP-2)

The positron beam works using a frozen solid Ne moderator and requires cooling with He. The implemented cryogenic Source of Slow Monochromatic Positrons (CSSMP-2) solved the problem with the transporting of He needed for the cooling of the moderator. A Sumitomo company cryocooler was bought and designed to operate in a closed cooling helium cycle. In September 2015, CSSMP-2 was constructed (Fig. 1) and installed at the injector of slow positrons.



a) b)

Fig. 1. CSSMP-2 source: a) interior, b) installed CSSMP-2.

b) Specialized slow monochromatic positron channel

A specialized channel of slow positrons (SCSP) was commissioned in 2018-19 (Fig. 2). The experimental station has its own pumping system and is separated from the main vacuum volume of the channel by the gate. This enables a quick exchange of samples.

Fig. 2. Specialized channel of the slow-positron beam.

c) Positron flow ordering system

The positron flow ordering system is the essential part for positron lifetime spectroscopy performed using a variable energy positron beam. The first attempts to use the Surko trap for this purpose failed. Between 2017 and 2018, a new way of ordering positrons was proposed, and its implementation began. In this conception, the monochromatic ordered positron beam is formed in the section of a special high-frequency voltage signal. For this purpose, an RF cavity (Fig.3), vacuum, and magnetic systems were developed and manufactured. The cavity system was assembled, tuned to three harmonics, and installed inside the vacuum chamber. The first experiments on the ordering of slow positrons began. Delays in the implementation of the positron flow ordering system are caused by the pandemic.

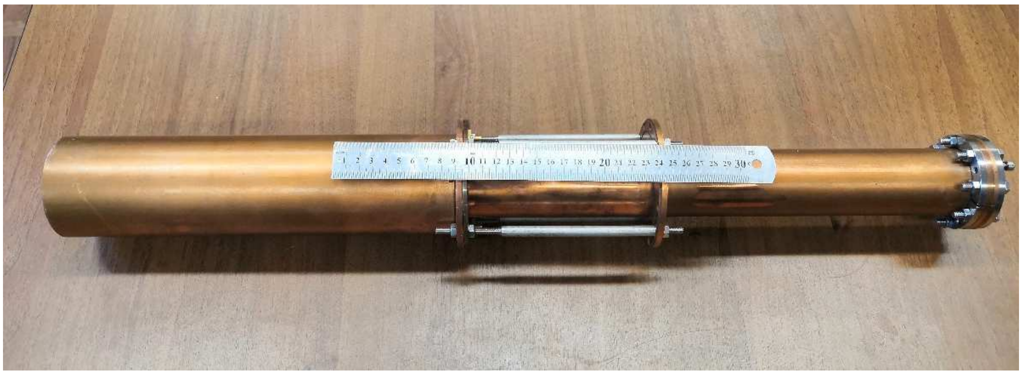


Fig. 3. Cavity system for ordering the monochromatic positron flow.

d) Ion etching system

A device for reactive ion etching has been developed to make it possible to study thin-film samples. It is based on a commercial ion source from PREVAC Co. The system is located under the experimental chamber (Fig. 4). The system works, but it cannot be used when the RF cavity is tested.

Fig. 4. Reactive ion etching system.

e) PALS spectroscopy

The positron annihilation lifetime spectroscopy system was implemented in 2017 by the standard scheme using the conventional ^{22}Na source (Fig. 5). It consists of BaF_2 scintillators, two Hamamatsu multipliers, and an APV8702 spectrometer. A similar setup with an additional modification of the input signal in the lifetime spectrometer is planned for the ordered positron beam. In a conventional system, one of the signals is taken from the decay of ^{22}Na. However, in the beam, this signal comes from the cavity system.

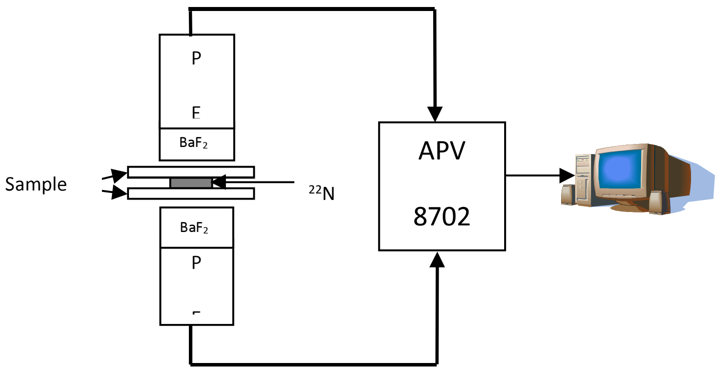


Fig.5. Scheme of a conventional PALS system.

f**) Improving the DBAL spectroscopy**

We are improving the DBAL spectroscopy by introducing the registration of the annihilation gamma photons in coincidence into the measurement system. For this purpose, a new experimental chamber was developed at the end of 2020. The manufacturing of vacuum chamber elements has begun in 2021. After mounting the chamber, the coincidence detector system will be ready. Actually, only one preamplifier is needed to finish the detector part of the system.

3. Publications since 2020:

a) using monochromatic positron beam:

- K.Siemek, M.K.Eseev, P.Horodek, A.G.Kobets, I.V.Kuziv *Defects studies of nickel aluminum bronze subjected to cavitation*, Applied Surface Science 546 (2021) 149107. Measurements and analysis of the results obtained by the positron annihilation method were performed at JINR by the corresponding author K.Siemek. The paper contains the results of the Doppler broadening of annihilation line measurements based on the variable energy positron beam, conventional Doppler broadening of annihilation line measurements and conventional positron lifetime measurements.
- K.Siemek, P.Horodek, V.A.Skuratov, J.Waliszewski, A.Sohatsky, *Positron annihilation studies of irradiation induced defects in nanostructured titanium,* Vacuum 190 (2021) 110282. Measurements and analysis of the results obtained by the positron annihilation method were performed at JINR by the corresponding author K.Siemek. The paper contains the results of the Doppler broadening of annihilation line measurements based on the variable energy positron beam, conventional Doppler broadening of annihilation line measurements and conventional positron lifetime measurements.
- 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 456 (2020) 73. Measurements and analysis of the results obtained by the positron annihilation method were performed at JINR by the corresponding author K.Siemek. The paper contains the results of the Doppler broadening of annihilation line measurements based on the variable energy positron beam.

- R.Laptev, A. Lomygin, D. Krotkevich, M. Syrtanov, E. Kashkarov, Y. Bordulev, K. Siemek, A. Kobets, *Effect of Proton Irradiation on the Defect Evolution of Zr/Nb Nanoscale Multilayers*, Metals 10 (2020) 535. The paper contains the results of the Doppler broadening of annihilation line measurements based on the variable energy positron beam.
- R.Laptev, L. Svyatkin, D. Krotkevich, E. Stepanova, N. Pushilina, A. Lomygin, S. Ognev, K. Siemek, V. Uglov, *First-Principles Calculations and Experimental Study of H+-Irradiated Zr/Nb Nanoscale Multilayer System*, Metals 11 (2021) 627. The paper contains the results of the Doppler broadening of annihilation line measurements based on the variable energy positron beam.

b) using only conventional ^{22}Na positron source:

- K.Siemek, A.P.Yelisseyev, P.Horodek, S.I. Lobanov, A.A.Goloshumova, A.V.Belushkin, L.I.Isaenko, *Optical and positron annihilation studies of structural defects in $LiInSe_2$ single crystals*, Optical Materials 109 (2020) 110262. Measurements and analysis of the results obtained by the positron annihilation method were performed at JINR by the corresponding author K.Siemek. The paper contains the results of conventional positron lifetime measurements and ab-initio calculations of positron lifetimes.
- W. Nowak, K. Siemek, K. Ochał, B.Kościelniak, B. Wierzba *Consequences of different mechanical surface preparation of Ni-base alloys during high temperature exposure*, Materials 13 (2020) 3529. Measurements and analysis of the results obtained by the positron annihilation method were performed at JINR. The paper contains the results of the conventional Doppler broadening of annihilation line measurements and conventional positron lifetime measurements.
- E. Demir, M.N. Mirzayev, E.P. Popov, P. Horodek, I.G. Genov, K. Siemek, D.M. Mirzayeva, V.A. Turchenko, M. Bulavin, A.I. Beskrovnyi, A.H. Valizade, H.V. Akhundzada, S.I. Karaaslan*, Effects of high-energetic $^3He^+$ ion irradiation on tungsten-based composites*, Vacuum 184 (2021) 109934. The paper contains the results of the conventional positon lifetime measurements.
- M.N.Mirzayev, A.Abdurakhimov, E.Demir, A.A.Donkov, E.Popov, M.Yu.Tashmetov, I.G.Genov, T.T.Thabethe, K.Siemek, K.Krezhov, F.Mamedov, D.M.Mirzayeva, M.V.Bulavin, V.A.Turchenko, T.X.Thang, T.Z.Abdurakhmonov, P.Horodek, *Investigation of the formation of defects under fast neutrons and gamma irradiation*

in 3C-SiC nano powder, Physica B Condens. Matter. 611 (2021) 412842. The paper contains the results of the conventional positon lifetime measurements.

4. Theses:

PhD 24.09.2020 Kobets A. G. “Development and creation of a source of low-energy positrons and electrons for diagnostics of point defects in condensed matter”.

DSc 30.09.2019 Horodek P. “Studies of structural defects profiles with positron annihilation method”.

5. Talks since 2020:

- K. Siemek *Positron annihilation spectroscopy in studies of defects in solid materials*, lecture, Seminar of Solid State Physics Department, IFJ PAN, Kraków, Poland, 07.07 2020
- K. Siemek *Fundamental studies of irradiation effects in nanostructured titanium,* lecture, LNF JINR, Dubna, Russia, 02.10 2020

Last year, due to the pandemic, most of the conferences were canceled.

PART B: Plans and requests

6. Plans

In the coming years, the planned positron annihilation experiments will be focused on defect engineering and defect-related investigations, i.e., modification of materials (by ion implantation, mechanical processing) and studies of the destruction process (irradiation damages, cavitation, friction). Together with the performed material studies, the formation of the ordered positron beam is also continued. In the near future, the purchase of the detector system necessary for the positron lifetime measurement on the ordered positron beam is planned. The project plan aims at creating a modern stand for positron annihilation spectroscopy and performing experimental studies with the positron lifetime spectroscopy and the coincidence Doppler broadening of the annihilation line spectroscopy.

7. Request

The funding received in the previous and the current year is not sufficient to complete the project. The minimum quote to purchase a modified positron lifetime spectrometer, a detector for beam measurements and materials is 40 000 USD / per year. Lowering the project funding below this amount makes its implementation impossible.

8. Group size, composition and budget

№	Name	Position	Tasks	FTE
1	Meshkov I.N.	chief researcher	Development of PAS set up concept and design, collaborations	0,25
2	Kobets A.G.	research scientist	R&D, Development of PAS setup concept and technical implementation, collaborations	0,25
4	Sidorin A. A.	engineer	Preparation and carrying out a positron beam experiment, technical support, development of PAS set up	0,85
5	Siemek K.	head of sector	Setting up, preparing, carrying out PAS experiments with a positron beam and conventional positron source, ab-initio calculations, result analysis, collaborations	1,0
6	Yakovenko S. L.	DLNP chief engineer	Development of PAS set up	0,1
7	Orlov O. Yu.	engineer	Preparation and carrying out a positron beam experiment, technical support, development of PAS set up	0,85
8	Hilinov V. I.	engineer	Design, manufacturing, mounting of the PAS equipment	0,85
9	Soboleva L. V.	senior engineer	Documentation, preparation and formation of reports	0,85

Schedule and necessary resources for the project:

<table>
<tr><td colspan="3" rowspan="2">Appellation of costs, resources, and funding sources</td><td rowspan="2">Cost
(thousands of dollars).
Resource requirements</td><td colspan="3">Proposal of the laboratory for the distribution of funding and resources</td></tr>
<tr><td>1 year</td><td>2 year</td><td>3 year</td></tr>
<tr><td colspan="2">Costs</td><td>1. Measuring equipment
2. RF components
3. Vacuum equipment
4. Materials</td><td>70
17
18
15</td><td>20
7
8
5</td><td>25
5
5
5</td><td>25
5
5
5</td></tr>
<tr><td>Funding source</td><td>Budgetary funds</td><td>Budget costs, including foreign exchange funds</td><td>120</td><td>40</td><td>40</td><td>40</td></tr>
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Cost estimates for the project:

NN	Name of cost items	Full cost	1 year	2 year	3 year and so on
	Direct Project Costs				
1.	Materials	15 thousands of dollars	5	5	5
2.	Equipment	105 thousands of dollars.	35	35	35
3.	Travel expenses, including	20 thousands of dollars			
	а) to non-ruble zone countries		8	8	8
	б) to cities of the ruble zone countries		2	2	2
	Total direct expenses:	150	50	50	50

Scientific leader:

I.N.Meshkov

Project leaders:

A.G.Kobets, K.Siemek