Review of the project “Development of experimental techniques and applied research with slow monochromatic positron beams (PAS)”

Positron annihilation spectroscopy (PAS) is a well-established, selective and extremely sensitive method of studying the density and momentum distribution of electrons in condensed matter; its most important application being to obtain information on open volumes (vacancies, voids and similar defects) in solids. The predecessor of PROJECT-PAS was tabled at the 2017 summer meeting of the PAC for Condensed Matter Physics. Its condensed-matter-related part aimed at developing a slow-positron beamline (SCSMP, Specialized Channel of Slow Monochromatic Positrons, a.k.a. SCSP, Specialized Channel of Slow Positrons) for PAS at the LEPTA facility. In its first phase, an important objective of the project was completing the beamline with a germanium detector to make it capable of measuring the Doppler broadening of the annihilation line (DBAL) as a function of the positron energy. Indeed, when using a variable-energy positron beam as positron source, material properties can be studied as a function of depth, a precondition of applying the method for thin films, ion-beam modified materials, microelectronic elements, nanoporous materials used in catalysis and other systems of extreme technological importance. While, accordingly, variable-energy positron sources are needed for most cutting-edge PAS studies, the number of such sources available for performing measurements is limited. A crucial element of such beamlines is the moderator used for thermalizing high-energy positrons emitted by a radioactive source (as a rule, ^{22}Na). Cryogenic moderators have a better performance than the widely used room-temperature W mesh moderators. A key objective of the first phase of the project was completing and commissioning a solid Ne moderator operating at 7 K. Furthermore, the installation of a Surko trap was envisaged to collect sufficient number of positrons needed for developing a pulsed positron beam in the second phase of the project.

Another widely used technique of PAS is based on measuring the lifetime of the positron in condensed matter (positron annihilation lifetime spectroscopy, PALS). In contrast to DBAL, PALS gives more details on the microscopic environment of the annihilating positron. In the first phase of the project, a conventional PALS spectrometer independent from SCSP was planned to be installed. Besides the fact that the implantation depth of positrons cannot be controlled in a conventional PALS spectrometer, it is further handicapped by being a coincidence method considerably reducing its efficiency.

The proposal of 2017 was complemented with an ambitious research project mainly based on collaboration with groups from JINR Member States and from other JINR laboratories (in the first line with FLNR).

The PAC noted with satisfaction the progress in the development of the PAS method at the LEPTA facility at DLNP including the construction of SCSP at its 2017 summer meeting and recommended the extension of the project until the end of 2020.

The present project report and extension proposal PROJECT-PAS starts with describing the current state of PAS at DLNP. Clearly, all condensed-matter-related objectives of the 2017 proposal have been fulfilled. In fact, SCSP including the solid Ne moderator originally developed in 2015–2016 is now driven by a closed-cycle He refrigerator and also the Surko trap is operational. DBAL is routinely used both off-line as well as at SCSP. Both the magnetic and the vacuum systems of SCSP were considerably developed. A cavity system needed for the ordered positron flux (OPF) i.e. the pulsed positron beam was constructed. The sample environment was extended by an in-situ etching chamber allowing for studying multilayer surfaces of layer thicknesses with a few nanometers accuracy. Therefore, I have no doubt that the report on the first phase of the project should be highly acknowledged and accepted by the PAC.

The second phase of the development of the experimental base presented in the proposal PROJECT-PAS focuses on three items. First, the DBAL spectrometer will be extended by a coincidence system capable of detecting two simultaneous annihilation gammas, a method considerably improving the peak-to-background ratio and, thereby, significantly increasing the capabilities of the system. Second, the OPF system allowing for forming monochromatic bunches of slow positrons of less than 100 ps width with a repetition time of about 1 μs will be developed. The suggested method of the ordered positron flux formation also described in a recent paper of the proposers (Ref. [1] of the proposal) is an advanced version of the well-known method of bunching continuous particle flux using harmonic RF voltage. Should the advanced and completely original concept prove to be successful, it will mark a real break-through in the field of slow-positron sources by forming, for the first time, true positron bunches rather than only ordering the positron flux. The main impact of this development will affect the PALS method. Indeed, it will increase its performance by at least one order of magnitude by replacing the conventional coincidence counting with detecting all annihilation gamma quanta and measuring their time distribution relative to the known implantation time of the monochromatic positron bunch. This will make possible performing PALS experiments limited to the top submicron region of a layered sample with a depth resolution down to less than 100 nm and allowing for measuring positron lifetimes below 30 ps, all exceptional parameters for existing ^{22}Na-based slow positron sources. Third, the in-situ ion etching system will be further developed to improve the depth resolution on one hand and to allow for studying deeper regions of thin films by gradually removing upper layers on the other hand.

The research topics suggested in PROJECT-PAS include as a priority area the study of defect formation in materials used in nuclear energetics. Clearly, this is a field of utmost importance both from technological and ecological point of view and, therefore, it should be fully supported by the PAC. Nevertheless, I strongly believe that the scientific research area of the group should also comprise other fields initiated by external partners from JINR, JINR Member States and, potentially, beyond.

The personnel and financial efforts outlined in the proposal are fully justified and also necessary for completing the project. However, as also mentioned in the SWOT analysis of the proposal, it would be important to see the joining of a solid-state theoretician to the project.

There exists a strong international community doing positron studies in condensed matter and this community needs cutting-edge slow-positron sources. Admittedly, ^{22}Na-based slow-positron sources will never have the intensity of those working at nuclear reactors or linacs, however the latter ones are mostly used for more sophisticated positron experiments and, therefore, it is almost impossible to get beamtime at these facilities for routine condensed-matter applications. This fact justifies the existence of numerous ^{22}Na-based slow-positron sources worldwide only a few of which having an OPF system and, to my best knowledge, none in JINR Member States. With the envisaged development, the DLNP slow-positron facility will be definitely one of the most efficient and of highest performance in its category globally. In view of this, I strongly recommend to announce an international user programme at this facility as soon as the OPF system, i.e. the pulsed monochromatic positron beam will become available.

In conclusion, I very much recommend the proposal PROJECT-PAS to be supported by the PAC for the next funding period starting with 2021.

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