

MIT Open Access Articles

SPOT IL - Slow positron facility in Israel

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Or, P. et al. "SPOT IL - Slow positron facility in Israel." 18TH INTERNATIONAL CONFERENCE ON POSITRON ANNIHILATION (ICPA-18): Positron Annihilation Spectroscopy-Fundamentals, Techniques ad Applications, AIP Conference Proceedings, 2182, AIP Publishing, 2019, 040009. © 2019 Author(s)

As Published: <http://dx.doi.org/10.1063/1.5135841>

Publisher: AIP Publishing

Persistent URL: <https://hdl.handle.net/1721.1/129627>

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

Terms of use: Creative Commons Attribution-Noncommercial-Share Alike



SPOT IL - Slow POSitron faciliTy in Israel

P. Or^{1, a)}, D. Dribin¹, D. Cohen¹, G. Erlichman¹, E. Cohen³, O. Hen², E. Piasetzky³,
I. Sabo-Napadensky^{4, 1}, H. Steinberg¹, S. May-Tal Beck^{5, 2}, G. Ron¹

¹*Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, Israel 91904*

²*Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

³*School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, Israel 69978*

⁴*Soreq NRC, Yavne, Israel 81800*

⁵*NRCN, P.O.Box 9001, Beer-Sheva, Israel 84190*

^{a)}Corresponding author: paz.or@mail.huji.ac.il

Abstract. A slow positron facility is being built in Israel, at the Hebrew University, for basic and applied research. It consists of a slow positron beam and a compact Positrons Annihilation Lifetime (PAL) spectrometer. The slow positron beam follows a traditional design, using a ²²Na source, of about ~1.5 GBq (40 mCi), a Tungsten moderator and a unique grounded target cell, with positrons energy that can vary between 0.03 keV and 30 keV. The detection system will be comprised of High Purity Germanium and BaF₂ detectors, facing each other, for low background Doppler Broadening (DB) measurements. The target cell is designed to allow a combined measurement of sample conductivity and DB, with the flexibility to add more detection options in the future. The compact PAL spectrometer includes two fast scintillation detectors read by a fast digitizer (DRS4), with a sampling rate of 5.12 GS/s. A dedicated software package was developed to emulate analogue data acquisition. Lifetime measurements were performed using a ~25μCi ²²Na source. The time resolution was defined using a ⁶⁰Co source, to be 180-200 ps. First positron lifetime validation measurements of Ti resulted in positrons lifetime of 157±4 ps, consistent with previously published values.

SLOW POSITRON BEAM CONSTRUCTION

The slow positron beam follows a traditional design, as shown in Fig. 1. A ²²Na positron source, with current activity of ~1.5 GBq (40 mCi) [1], is used to inject the positrons into the beam-line. It is held inside an ultra-high vacuum system that consists of the source chamber, a vacuum tube of ~2 m, with a 90° bend, an accelerator unit and a target chamber. The entire system is held at ~10⁻⁸ mbar, allowing the positrons a long Mean Free Path (MFP >> 2 m) and preventing annihilation events before reaching the target chamber.

The positron source obtained from the manufacturer [2], is encapsulated with 5μm thick Ti window, which only marginally change the energy distribution of the positrons [3]. The positrons pass through the Ti and then through a 7 μm thick tungsten moderator which is clamped to the source capsule. Positrons slowdown in the moderator, those reaching thermal energy are eventually emitted with E ~ 3 eV due to the tungsten negative positron work function. The positrons are directed into the beam-line using a pre-accelerator with an extra voltage of +27 V, applied by three commercially available 9 V batteries. These positrons are then “selected” by the beam bending and accelerated into the target chamber as a mono-energetic positron beam [3]. Positrons with higher energies do not bend as much and annihilate on the beam tube walls. High Voltage (HV) platform is kept between the source chamber and the accelerator unit, with HV ranging between 0.03 kV and 30 kV, where the 0.03 kV is set by the 9 V batteries and the tungsten work function. This beam region is protected by a Perspex cage for safety reasons.

For radiation shielding purposes the source is surrounded by a 55 mm thick tungsten inside the vacuum, and by lead shielding walls, 50 - 150 mm thick, surrounding the source chamber region and the bend region.

The vacuum tubes are surrounded by solenoids and Helmholtz coils, which help directing the positrons towards the target and keep them centered on the beam axis. A steering magnet is located at the bending point of the beam and in front and behind the target chamber, to allow control over the beam spot size and position at the target chamber.

The slow positrons passing the 90° bend are then go through an accelerator unit, made of nine steel rings separated by ceramic rings and held in fixed degrading voltages. The accelerator lower gradually the electric field from the HV, applied at the source chamber, to the grounded sample inside the target chamber. The positrons kinetic energy gained due to energy conservation vary from 0.03 keV to 30 keV as a function of the HV supplied to the source chamber.

The unique grounded target cell in Fig. 1(a) is a 30.48 cm diameter sphere, which is designed to allow a combined measurement of sample conductivity and DB, with the flexibility to add more detection options in the future, such as low temperature for integrated in-situ electronic measurements. It also consists of a load lock system allowing insertion and removal of samples to and from the target chamber without breaking vacuum to the system.

At the center of the target chamber, a Micro Channel Plate (MCP) detector containing a phosphorous screen at its end is installed. The MCP detector allows visualization of the beam spot. By applying a small magnetic field perpendicular to the positron flux, beam spot position on the screen is easily controlled, see Fig. 1(b). In addition, it can be aimed at the measured target. Two gamma ray detectors are installed outside the target chamber, facing each other at a distance of ~36 cm and ~18 cm from the center of the target cell. The two are a High Purity Germanium (HPGe) and a BaF₂ scintillator, for low background Doppler Broadening (DB) measurements. For now, this simple configuration allows DB measurements at room temperature only, but simple modifications of the system can be done to adjust it for measurements under in-situ cooling or heating.

The beam has been tested with a tungsten filament as a thermionic electron source, and we were able to visualize electrons emitted from the filament and the MCP, focus them, and control their position on the MCP. The final step will be to attach the tungsten 7 μm foil moderator to the source, position it and test the beam with positrons.

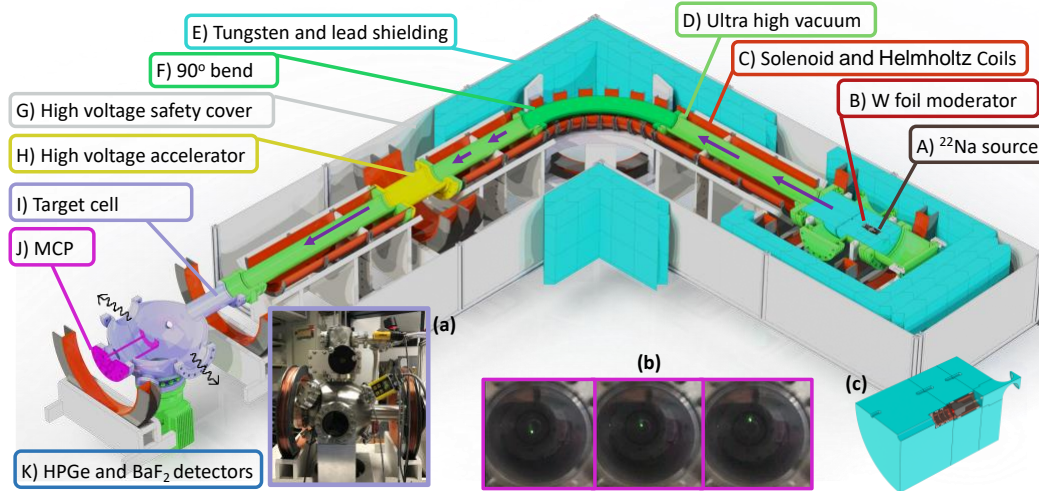


FIGURE 1. A model of the positron beam. (a) The unique target cell designed to allow a combined measurement of sample conductivity and DB. (b) A focused electron beam hitting the centre of the MCP. (c) A section view of the source housing and pre-accelerator.

THE PAL SPECTROMETER

A compact Positron Annihilation Lifetime (PAL) spectrometer (PAL) has been assembled. Positron lifetimes are measured as the time difference between two gamma particles, one signs the positron creation in the beta decaying source isotope and the other is emitted from the positron annihilation process in the material.

The positron source in the PAL spectrometer is a ²²Na source [4], with current activity of about ~925 kBq (~25 μCi). The time resolution of the PAL system is measured as the time difference distribution between two photons emitted simultaneously from a ⁶⁰Co source [5]. However, the energy selection criteria are chosen to match for the positron lifetime measurement, namely, the 1274 keV and 511 keV regions. We select these energies because of the time resolution depends upon the energy delivered to the detectors during lifetime measurements. The Full Width Half Maximum (FWHM) of the resulted Gaussian is defined as the time resolution of the system. A resolution of 180 - 200 ps was achieved.

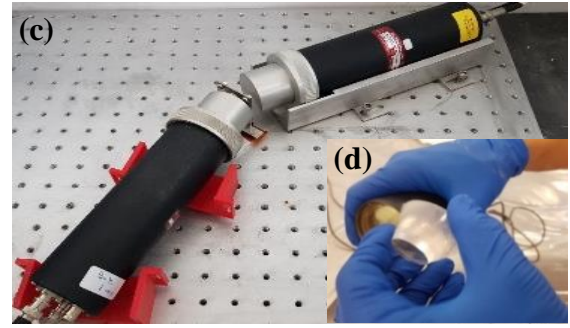
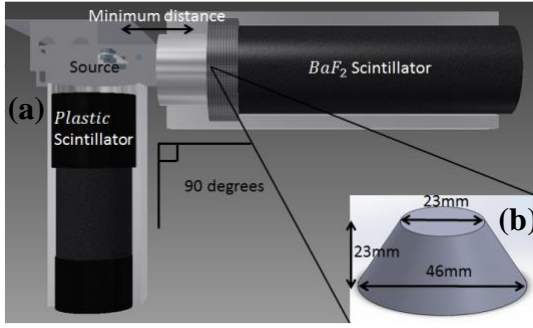


FIGURE 2. (a) Scheme of one of the configurations of the experimental setup. The source, on the left top corner, is held in its housing. The plastic and BaF₂ detectors are placed at a 90°, in close proximity to the source. The plastic detector is placed in front of the source, due to its smaller scintillator size and thus smaller efficiency. (b) Plastic scintillator cross-section dimensions. (c) Different experimental configuration: the detectors are placed at a 120°. Both detectors are Siconix BaF₂. (d) Saint-Gobain BC422Q (1%) plastic scintillator is coupled to the Hamamatsu R9779 PMT.

Each of the gamma detectors is a fast scintillator coupled to a fast Photo Multiplier Tube (PMT). One is a Siconix BaF₂ detector consists of a ~2" cylindrical BaF₂ crystal, with rise-time (rt) of 0.8 ns, coupled to a 2" Hamamatsu R3377 PMT (rt: 0.7 ns) with a quartz window, covered by an external mu-metal shield. The other is a Saint-Gobain BC422Q (1%) plastic scintillator (rt: 0.7 ns), coupled to Hamamatsu R9779 PMT (rt: 1.8 ns). The latter has a truncated conic shape for better timing performance (Fig. 2(b), (d)). The plastic detector was re-assembled recently, the scintillator's circumference was wrapped with 3 layers of Teflon tape, over which a layer of aluminum foil and electric tape were wrapped. The scintillator was placed in a specially-made housing contraption that coupled the scintillator with the PMT, holding them both in place. The whole assembly was covered in electric black tape to prevent light leaks into the detector. On top of that a layer of Al foil was placed as shielding from electric fields.

In order to optimize the system, we re-examine its performance, namely – its time resolution. It is done in four configurations in which the angle between the detectors is 90° or 120°, and different combinations of the detectors are used. Two configurations are comprised of a plastic and BaF₂ detectors and the other two from two BaF₂ detectors. (see Fig. 2(a),(c)). The time resolution listed above was measured for the configuration shown in Fig. 2(a).

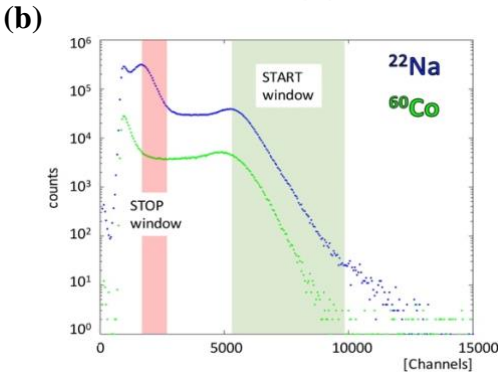
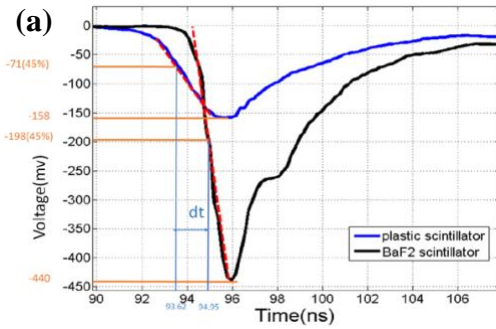
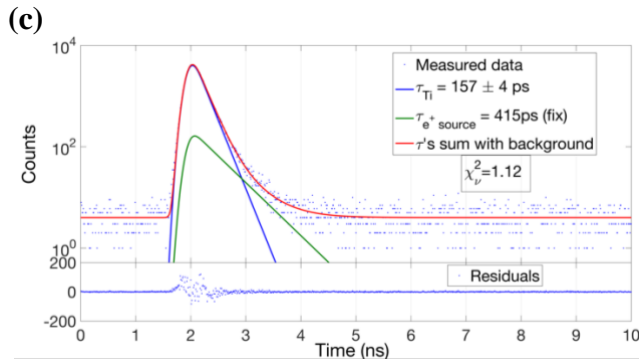


FIGURE 3. (a) An example of the output of coincidence events and lifetime extraction algorithm. A linear fit is applied to the initial slope, a threshold of 45% of the peak maximum is applied, and a zero time for each pulse is found. The time difference is defined as the difference between zero times of both pulses. (b) Energy spectra of ⁶⁰Co and ²²Na. The green shaded region is the energy window of the start signal (1274 keV), and the red shaded region is the energy window of the stop signal (511 keV). A "good event" will be defined as a combination of a start signal from one detector and a stop signal from the other detector. (c) Lifetime spectrum of positrons in Ti sample, taken in the setup shown in Fig. 2(a). Lifetime fits and fit residuals are also displayed.



A fast digitizer, the PSI DRS4 [6], is used for data acquisition, with a sampling rate of 5.12 GS/s. A trigger for acquiring an annihilation event is given when two “scope-like” pulses from the detectors arrive within 20 ns. A trigger is given, and they are recorded in time bins of ~200 ps and voltage resolution of 10 bits, for 200 ns around the trigger - the DRS4 memory depth. The 20 ns time difference requirement choose short positron lifetimes, which can originate either from positron annihilation events in materials or Positronium (Ps) decays to two photons. Both are used to probe defects in materials. The activity of the ^{22}Na source translates to one decay in ~500 ns, thus only one event is expected in the 200 ns time window.

Integration over the pulses, which represent the energy transferred to the detectors, is calculated and saved if above pre-defined threshold. A linear fit is found for the rising slope of each pulse. The time at a designated fraction value, found empirically as 45%, for the resulted best time resolution, was defined as the signal time stamp for both channels. The difference between these time stamps was calculated and saved together with the energy information for each coincident event, see Fig. 3(b). Using this method, we achieved high resolution results without using any other electronic units usually used in other PAL systems. In a second path energy windows are applied (Fig. 3(b)), around 511 keV in one of the detectors and around 1274 keV in the other one, in two possible combinations, and the skimmed data are saved for lifetime analysis. Lifetime spectra are analyzed using the PALSFIT program [7].

First validation measurements, of positron lifetimes in Ti, was performed using the setup shown in Fig. 2(a). The best fit results included two decaying exponentials, contributed by the source component (415 ps) and by the Ti samples and source housing: 157 ± 4 ps, as can be seen in Fig. 3(c), consistent with previously published values [8].

SUMMARY

SPOT IL will be a user facility for basic and applied research. It will contribute to studies in research fields such as materials science, nuclear physics and condensed matter. SPOT IL is designed to produce a monoenergetic positron beam across a wide range of energies that will go up to 30 KeV. Currently, the beam line was tested successfully using an electron source. Our next step is to attach the Tungsten $7\ \mu\text{m}$ foil moderator to the source, position it and test the beam with positrons. The lifetime measurement system is at the stage of performance optimizations. First validation measurements of positron lifetime in Ti resulted in a value of 157 ± 4 ps, consistent with published values [8].

Having the slow positron beam and the PAL spectrometer system in one lab will allow better understanding of the materials under study. As the SPOT IL is the first such facility in Israel, it will allow material scientists of the Israeli community to add the positron related methods to the tool-box of materials research.

ACKNOWLEDGMENTS

This project is supported by the Ministry of Economy under the KAMIN program and by the Pazy grant of the IAEC. We wish to thank the SPONSOR group at HZDR, Germany, for sharing their knowledge and for guiding and supporting us in all aspects of the source and beam design. Special thanks to Wolfgang Anwand from HZDR, who was always available and willingly devoted his time to teach and help us.

REFERENCES

1. iThemba Laboratory for Accelerator Based Sciences, http://tlabs.ac.za/?page_id=282.
2. <http://positron.physik.uni-halle.de/source.html>
3. W. Anwand et al. Design and construction of a slow positron beam for solid and surface investigations. Defects and diffusion forum 331, 25 (2012).
4. Eckert & Ziegler Reference & Calibration Sources catalogue / Sources for Research Applications /Positron Sources – POSN-22, https://www.stuarthunt.com/uploads/PDFS/EZIP_Ref___Cal_Catalog.pdf
5. S. May-Tal Beck et al., "Reliability Test of a PAL Spectrometer - Selected Results on Fe", Materials Science Forum, Vols. 445-446, pp 495-497 (2004).
6. S. Ritt, "Design and performance of the 6 GHz waveform digitizing chip DRS4," 2008 IEEE Nuclear Science Symposium Conference Record, Dresden, Germany, pp. 1512-1515 (2008). doi: 10.1109/NSSMIC.2008.4774700
7. M. E. Jens V. Olsen, Peter Kirkegaard, Palsfit3. URL <http://palsfit.dk/>
8. D. Dribin, “Positron Lifetime Measurement in a Voltage-biased System”, M.Sc. thesis, Hebrew University (2017). http://harmanlib.huji.ac.il/index_e.html. And reference therein.