A METHOD FOR MEASURING THE POSITRON LIFETIME IN SOLID MATTER WITH A CONTINUOUS POSITRON BEAM

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Abstract

The report proposes the scheme and design of the setup for formation a continuous monochromatic positron flux with controlled time of arrival at the target, independent of the injection time in a limited time interval. The setup is designed to perform experiments to measure the positron lifetime with the positron annihilation spectroscopy method (Positron Annihilation Lifetime Spectroscopy – PALS). PALS method allows to distinguish defect types in the materials. It is possible to vary the positron energy in the present version of the setup that allows us to analyze the distribution of defects along the depth of the sample. The scheme of periodic RF voltage generation of a given form and measurement of the positron lifetime, is discussed.

PALS METHOD

In positron annihilation spectroscopy the most informative and hence the most attractive for applications is a method based on the measurement of the positron lifetime in the sample (Positron Annihilation Lifetime Spectroscopy — PALS) [1]. In the simplest case of PALS positron-active isotope ^{22}Na most commonly used, decays emitting the positron, and, with a delay of about 3 ps, a gamma quantum. The last one is used as a start signal; a stop sign is a pair of gamma-quanta, which appear at annihilation of a positron with an electron of the atom of the target (test sample). Significantly, the lifetime of positrons in vacancies increases several times.

Flow of monochromatic positrons is efficient to use in the PALS method. The flux is generated by the sources with ^{22}Na isotope and moderator — monochromatizator. The yield of slow positrons, about 1% of the total decays, is achieved by using as the moderator solid neon, which is freeze from the gaseous phase on the foil of the closed radioactive source that is cooled to a temperature of 7-8 K. So the Cryogenic Source of Slow Monochromatic Positrons (CSSMP) is developed and being used at the Joint Institute for Nuclear Research. [2]. The method of formation of an ordered positron flux (OPF) and measurement of positron lifetime in the sample with a precision of about 30 ps is proposed. The proposed method is a development of the well-known scheme of bunching the flux of slow positrons.

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ORDERED POSITRON FLUX FORMATION

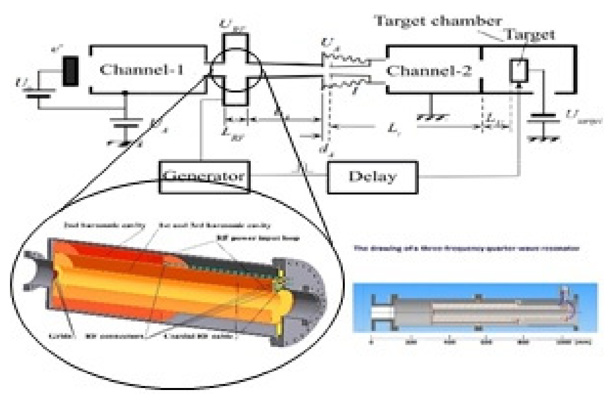

Figure 1: The scheme of installation for generation of an ordered flux of positrons: e$^+$ - cryogenic source of slow positrons based on the ^{22}Na isotope, Channel-1, 2 — the positron transfer channels, $U_0 > 0$ is the potential between the source and the Channel-1, $U_A > 0$ — potential difference between Channels 1 and 2, L_{RF} — RF voltage system with U_{RF} of special form, L_A — 1-st drift section of the PAS channel, d_A — accelerating gap with the static electric field U_A, I — vacuum insulator, L_t — 2nd drift section of the PAS channel, L_U — the gap between the entrance to the test chamber and the target with the sample to be studied, U_{target} — negative potential of the target.

Generation of an OPF (see Fig. 1) is performed by using a RF-voltage $U_{RF}(t)$ of the special form (see Fig. 2 and 3). Positrons from CSSMP come to the entrance of the RF gap from channel 1 at some random time tinj (injection). When crossing the gap with RF ordering voltage the positron accelerates depending of time arrival to the entrance of the RF gap. Then positrons reach the target strictly periodically, independently of time when they came to the RF gap. The positron transfer channel is equipped with an

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additional gap ("acceleration gap") with a static accelerating voltage of the order of 5 kV that is placed after the ordering gap. This allows minimizing influence of the positron energy spread existing at injection from the CSSMP. And positron bombards the target [3].

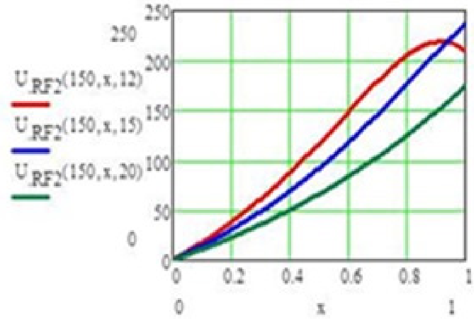

Figure 2: Function $U_{RF}(t)$, T_0 = 10 ns (100 MHz), the positron energy E_0 = 150 eV and L_A = 20, 15, 12 cm (curves from the top to the bottom); $x = t/T_0$

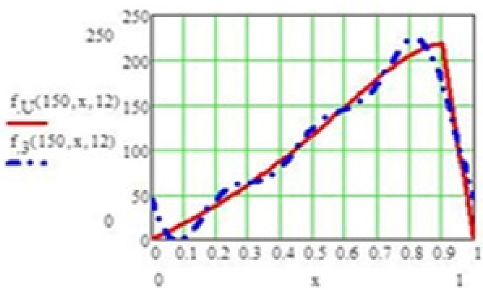

Figure 3: The voltage pulse (V) in the accelerating gap of the RF system for the original form (solid curve) and composed with to the first three harmonics (dashed curve).

The resonator was designed and assembled. Now it is being configured (see Fig. 4).

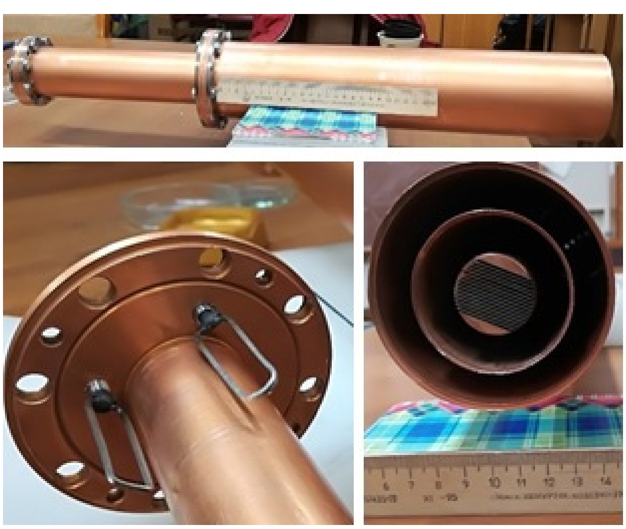

Figure 4: Resonator.

RF SYSTEM

The most convenient and simple way is forming the function of the periodic voltage pulses $F_U(x)$ by harmonic functions, which are Fourier components of this function. The formation of the RF voltage using three RF cavities of the 1st, 2nd and 3rd harmonics of $F_U(x)$ gives satisfactory results when the optimal values of the energy E_0 and other parameters of the channel are chosen. Typical installation parameters are the following: $50 \leq E_0 \leq 250$ eV, $10 \leq L_A \leq 30$ cm, U_A = 5 kV, L_t = 250 cm.

The RF voltage pulse period is equal to T_0 = 10 ns (repetition rate 100 MHz). For the calculation below, a dimensionless parameter is chosen as ratio T_0: $x = t_{inj} / T_0$.

The ordering gap is placed at the end face of two coaxial cylindrical cavities, which generate three first harmonics of RF voltage: λ_1 and λ_3 harmonics are exited in common cavity of the length of $\lambda_1/4$, the λ_2 harmonics is excited in other cavity of the length of $\lambda_1/8$ (see Fig. 4). Three grids of high transparency cover the end face of the cavities. This RF system is designed and fabricated presently.

Each pulse of the periodic ordering voltage is described with the following function [4]:

$$F_U(x) = \begin{cases} U_{RF}^{(1)}(x), 0 \leq x \leq 1, \\ U_{RF}^{(2)} \cdot \frac{1.1-x}{0.1}, 1 < x \leq 1.1 \end{cases}, \quad (1)$$

where, $U_{RF}^{(1)}(t_{inj}) = \left[\left(1 - \sqrt{\frac{2E_0}{m}} \cdot \frac{t_{inj}+\delta t_2}{L_A}\right)^{-2} - 1\right] \cdot \frac{E_0}{e}$

$$\delta t_2 = L_t \left(\frac{1}{v_A(t_{inj})} - \frac{1}{v_A(0)}\right).$$

The second line in Formula for $F_U(x)$ describes the rear front of the pulse.

"START" AND "STOP" SIGNALS

The system of start-stop signals differs significantly from the one used in the classical scheme: the signal from decay gamma-quant of ^{22}Na does not correlate actually with a positron travelling in the PALS channel. Therefore, we suggest using a "timer" signal connected to a certain phase of RF voltage U_{RF} (t), for instance zero phase (see Fig. 5). Then signal of a photon from positron annihilation gives us start signal and the next synchro-signal, nearest to the start one, the stop signal. Now, to find the lifetime of the positron, we have to know the value its t_{flight} – the time duration of positron travelling from the entrance of the ordering gap to the target. The value of t_{flight} is the same for all positron. Therefore, one can find t_{flight} using a reference sample, which lifetime is measured, for instance, on the conventional PALS set up. Then $t_{flight} = (t_{start} - \tau_{life})_{reference}$ and (τ_{life})sample $= t_{stop} - t_{start} - t_{flight}$

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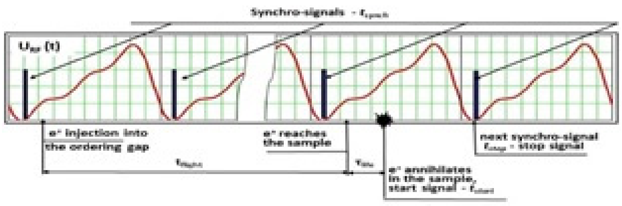

Figure 5: Periodic U_{RF} voltage and start/stop signals.

NEAREST FEATURE PLANS

1. Generation of the ordered positron flux;
2. Start of PAS experiments with samples using ordered positron flux by PALS-OPF method;
3. Continuing experiments on PAS.

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