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A high performance electrostatic positron beam

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Abstract

A new electrostatic positron beam for Doppler broadening measurements in the near surface layers has been constructed and tested in the Trento laboratory. The beam energy is tuneable from 50 eV to 50 keV. The diameter of the beam spot at the sample is two mm FWHM, when a commercial ^{22}Na source of 3 mm in diameter is used. The beam could be easily upgraded to become a microbeam. The apparatus is described and the preliminary tests are presented.

1. Introduction

Since the beginning of eighties, a slow positron beam of the solenoid type was available in the Trento laboratory for Doppler measurements [1]. The advantage and disadvantage of a beam formed and transported by a magnetic field are well known. The advantage is that a high transport efficiency of the particles can be obtained, the disadvantage is that the geometrical characteristic of the beam can not be fully controlled. In this beam the sample was immersed in the solenoid field and the last accelerating voltage applied directly to the sample itself. This configuration maximizes the number of positrons at the sample, but it becomes very difficult or, in same case, impossible to handle or characterize the samples in situ. On the other hand the Doppler broadening technique, associated with a variable positron beam, has demonstrated to be a powerful technique in material analysis [2] and also in studying fundamental properties of positron solid state physics, like diffusion [3]. The fields of applicability of the Doppler broadening technique is enlarging due to the always increasing theoretical capacity in ab initio calculation and improvement in experimental technique [4].

On this basis we have decided to upgrade the magnetically guided positron beam with a fully electrostatic positron beam. The beam was positioned in a vertical axis, so that in a future also liquids could be studied.

The apparatus was designed taking into account possible upgrading. With a very small effort a brightness enhancement stage could be added to transform the beam in a micro-beam. The sample chamber has been designed to accept surface analysis facilities. Beam scanning over the sample area is already available.

In the following paragraphs a brief description of the apparatus, of the electron optic design and some preliminary results about the tests will be given.

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2. Description of the apparatus

A schematic layout of the apparatus (acronym SURF) is shown in Fig. 1. The apparatus is composed by three vacuum chambers separated by valves: the first one (preparation chamber; not shown because in a plane normal to the drawing) is used to heat the moderator film by electron bombardment. The second one (beam chamber) contains the positron source and the electron optics. The third one (sample chamber) is used to change and/or treat the samples. The apparatus is routinely working in a vacuum close to 10^{-9} mbar, and all the chambers are separately bakeable at 200–250°C. The sample, at the ground potential, can be cooled down to 77 K, and heated up to 700 K during the measurements. In future, will be possible to reach a 10 K temperature with a closed circuit cryostat.

The earth magnetic field is compensated by a system of six square Helmoltz coils 3.0 m side. Furthermore the apparatus is shielded by a μ-metal cover 1 mm thick.

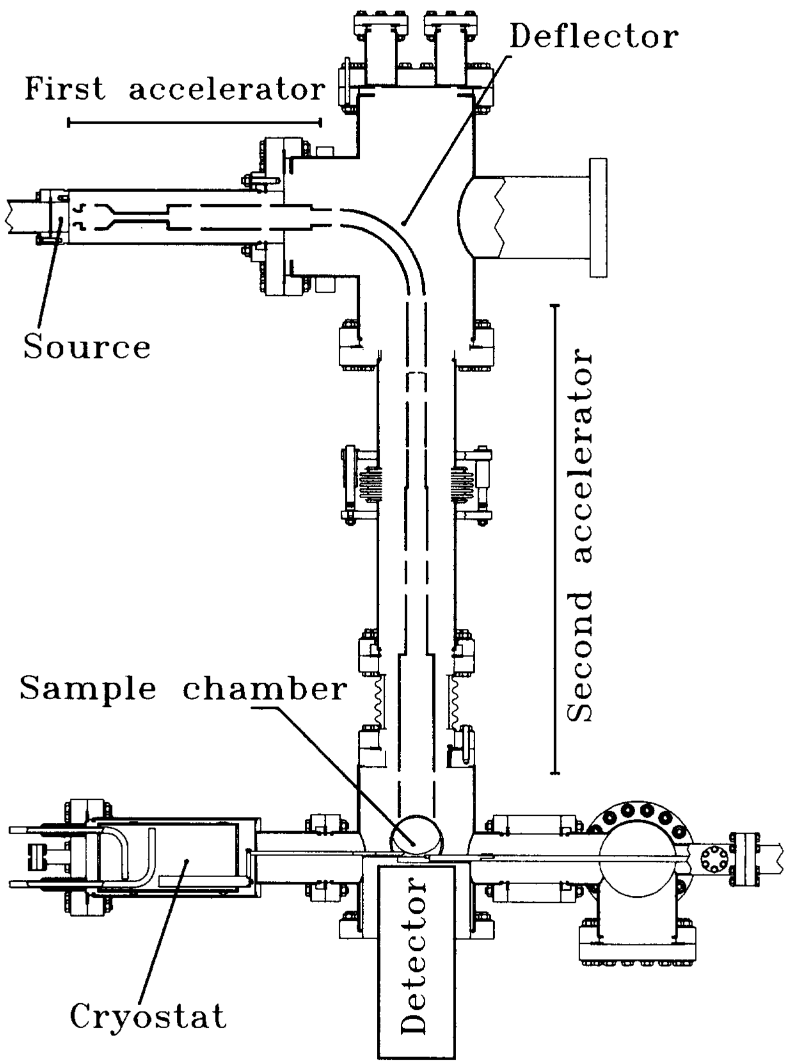

Fig. 1. A schematic layout of the electrostatic positron beam constructed in the Trento laboratory.

The preparation chamber is equipped with a telefocus type 80 W electron gun [5] for in situ heating of the moderator. The radioactive source used for testing the apparatus was a 3 mCi, ^{22}Na source from Amersham, with a nominal diameter of 3 mm. The 2 μm W(100) single crystal film is positioned at about 0.3 mm from the titanium source protection foil.

Ge detector (28% efficiency) is positioned below the sample at a distance of about 0.8 cm. Particular attention has been paid to minimize the gamma background produced by the annihilation of positrons backscattered from the sample; in fact the fraction of incident positrons on the sample that are backscattered range from about 10% in Si to 30–35% in W [8]. To solve this problem we have surrounded the sample, inside the vacuum chamber, by a 5 mm tungsten plate which shadows the detector from the 511 keV annihilation gamma rays due to the annihilating backscattered positrons.

3. Electron optics design

A first accelerator extracts slow positrons from the film and injects them in a 90° electrostatic spherical deflector. The 90° deflector has been used to avoid that fast positrons reach the sample, and make easier the ^{22}Na source shielding. The extraction of positrons is controlled by the shape of the equipotentials in the very short first electrode [6]. With our source-moderator assembly, we have assumed for the electron optics design a slow positron spot size at the moderator of 4 mm with a zero beam angle (θ_b) and a 15° pencil angle (θ_p). The electron optics was simulated by the SIMION program [7].

The second decelerating lens of the first accelerator makes an image of 3 mm at the entrance of the deflector. A real aperture of 3.5 mm is inserted at the position of this image. The beam is injected into the deflector with a $\theta_b = 0.35°$, a $\theta_p = 2°$ and a 200 eV beam energy. Two set of deflection plates are used in this first accelerator to correct small mechanical misalignments in the source-moderator assemblies and/or in the optical elements.

The deflector was designed to have a high transmission of positrons. The mean radius of the spherical deflector is 100 mm, and the distance between the two spheres is 20 mm. The filling factor inside the deflector reaches a 55% at maximum. The beam, after deflection, is presented at the real exit aperture of 3.5 mm dia. There the spot size is 3 mm, $\theta_b = 0.45°$, $\theta_p = 2.1°$: about the same characteristic of the beam at the entrance of the deflector. Now the beam is transported, formed, and focused at the sample position by a second accelerator. The second accelerator is a system of five lenses and a set of deflection plates positioned immediately after the exit aperture of the deflector. The accelerator forms an intermediate image before focusing, with the last lens, the positrons at the sample position. To focus the positron beam at a selected energy it is necessary to change only the voltage of two electrodes. This is a big advantage in the automatic control of the measurements by computer.

4. Preliminary results

The SURF apparatus has been tested with a standard sealed ^{22}Na source with a nominal activity of 3 mCi, at a beam energy from 50 eV to 30 keV. We have checked the beam intensity with a channeltron (Glasspol, Poland), with a cone of 8 mm in diameter, as a detector.

With our source-moderator assembly, 23% of the high energy positrons from the source enter the moderator within a 4 mm spot. With a 2 μm W film we have measured 2000 e^+/s at the channeltron. These numbers, taking into account the channeltron detection efficiency, give us a total efficiency (film efficiency time, transmission efficiency) of $2.5 \cdot 10^{-4}$. Evaluating the film efficiency is difficult because, being not well known the angular distribution of reemitted slow positrons, we are not able to estimate correctly how many positrons are rejected by the angular acceptance of our optical system. Our film efficiency is probably $3 \cdot 10^{-4}$.

The counts at the channeltron as a function of the positron energy were about constant taking into account the scaling of the channeltron efficiency with energy.

The beam diameter at the sample position has been measured with a Ge detector, placing a moveable gamma-ray shield with holes of different diameter at the sample position. With these preliminary tests we have found 100% of the beam in a spot less than 4 mm dia at all the energies from 50 eV to 30 keV, and 40% of the beam in less than 2 mm for energies above 200 eV.

References

[1] R.S. Brusa, A. Dupasquier, R. Grisenti, S. Liu, S. Oss and A. Zecca, J. Phys.: Condens. Matter 1 (1989) 5411.
[2] P. Asoka-Kumar, K.G. Lynn and D.O. Welch, J. Appl. Phys. 76 (1994) 4935.
[3] R.S. Brusa, A. Dupasquier, E. Galvanetto and A. Zecca, Appl. Phys. A 54 (1992) 233.
[4] M. Alatalo, H. Kauppinen, K. Saarinen, M.J. Puska, J. Mäkinen, P. Hautojärvi and R.M. Nieminen, Phys. Rev. B 51 (1995) 4176.
[5] O. Klemperer and M.E. Barnett, Electron Optics, 3rd ed. (Cambridge University Press, 1971).
[6] A. Zecca and R.S. Brusa, Nucl. Instr. Meth. A 313 (1992) 337.
[7] SIMION program from D.A. Dahl, MS2208, Idaho National Engineering Laboratory, EG&G Idaho Inc., Idaho Falls, ID 83415, USA.
[8] G.R. Massoumi, W.N. Lennard, P.J. Shultz, A.B. Walker and K.O. Jensen, Phys. Rev. B 47 (1993) 11007.