Positron Re-emission Studies from W (100)

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Abstract. A tunable low energy positron beam has been established at The University of Western Australia. The positron beam can deliver approximately 700 positrons per second in the energy range of 0-1 keV. Initial studies of thermal positron re-emission from a W(100) target showed that the positron work function was 2.75 ± 0.01 eV. It was also found that the positron reemission yield was sensitive to the sample temperature and surface cleanliness.

1. Introduction
As the positron implantation depth increases with increasing incident energy, surface physics studies require tunable positron sources in the low energy range. A detailed account of slow positron beams and the interaction of positrons with surfaces and thin films can be found in the review by Schultz and Lynn [1]. A tunable, low energy positron beam for surface studies has been established at The University of Western Australia (UWA). The salient design features of the positron beam, various experimental capabilities built around the facility, and our initial measurements of low energy positron re-emission from W(100) are described in the paper.

2. The variable energy positron beam at UWA
2.1. The positron beam set up and features
The positron beam apparatus at UWA consists of three stages: thermal positron production, positron transport and an experimental chamber containing a sample. The positrons are produced by a 20 mCi 22Na source (procured from iThemba labs, South Africa) and are moderated by a polycrystalline tungsten film of thickness 1μm, in transmission geometry. The moderated positrons are electrostatically transported to the experimental chamber. The principal design of the beam transport is based on that used at the University of Texas at Arlington, USA [2]. The moderated positrons are extracted and electrostatically transported through a 90 degree bender. The potentials on various elements of the lens assembly and beam optics have been optimized using SIMION. The fast positrons from the source which were not moderated are not passed through the bent section of the beam transport. The potential between the moderator and the sample determines the beam energy.
A schematic of the experimental chamber is shown in Fig.1. The chamber is equipped with a position sensitive micro channel plate (MCP) detector at 45° with respect to the incident beam. The position sensitive MCP in combination with two grids is used as retarding field analyzer (RFA) to measure the energy and intensity of positrons or electrons. Two grids are placed in front of the MCP to provide the retarding field. A W(100) sample is in the center of the chamber on a manipulator. The single crystal can be moved in 3D and the angle with respect to incident beam can be changed as required. The experimental chamber is equipped with a UHV compatible evaporator to deposit thin films of Fe, Ag and LiF on the W single crystal substrate, and a microbalance to calibrate the deposition rates. The sample can be annealed in situ. A facility to magnetize the thin ferromagnetic films and change the direction of magnetization by reversing the direction of current in a copper coil placed next to the sample was added to study magnetic films. The entire beam line is under a vacuum of 2-4×10^{-10} mbar.

![Schematic of the experimental chamber](image1.png)

**Figure 1.** The schematic of the experimental chamber showing various capabilities of the positron beam at UWA.

![Transmission intensity of positrons](image2.png)

**Figure 2.** The transmitted intensity of the positrons at different energies. The insets show the maximum dimension of the positron beam.

2.2. Characterization of the variable energy positron source

The positron beam has been optimized and characterized in terms of the transmission intensity, focusing, and the energy distribution. To measure the beam intensity and size at different positron energies, the position sensitive MCP is moved into the direct path of the beam behind the sample. The dimensions of the MCP are such that the beam intensity and its diameter can be measured at about 10 cm downstream from the sample position. The potential of the beam exit or delivery point into the chamber is grounded and positrons are in a field free region in the chamber. The beam intensity and spot size in the energy range of 0-900 eV is shown in Fig.2. The size of the inset box containing the beam profile is 4 x 4cm. These dimensions represent the upper limit of the beam spot size at the sample position, as they are measured downstream from the sample. A measurement of the positron retarding curve of elastically scattered positrons gives a full-width-at-half-maximum (FWHM) of 0.7 eV for the elastic peak. This can be taken as a measure of the energy spread in the incident beam.

3. Positron re-emission from W(100)

Positrons implanted in a solid quickly thermalize. At low energies, the implantation depths are small compared to the positron mean diffusion length and hence most positrons will encounter the surface during their random walk diffusion. The surface dipole layer, which is responsible for the positive electron work function, can in some cases eject the energetic positrons. For a positron, the ground state in many metals lies higher in energy than the vacuum level thereby resulting in the spontaneous
reemission of positrons from those metals. Positrons also undergo refraction at the surface during re-emission which results in the re-emission being confined to a narrow angular range about the surface normal [3].

Tungsten meshes, films and crystals are the most commonly used moderators in variable energy positron beams. Our first measurements with the newly constructed positron beam at UWA concern positron re-emission from a tungsten single crystal. Although workable procedures for the use of tungsten as a moderator have evolved over the years and are being practiced [4], the understanding of the physics of moderation and the factors influencing the moderation efficiency are far from complete.

3.1. Positron work function of W(100)
Positrons with an energy given by the work function of the material are re-emitted from the surface. The positron work function is difficult to determine due to the difficulties associated with contact potential differences in determining the exact energy of reemitted positrons, and the influence of surface characteristics of the sample on the re-emission process. This is reflected in the range of work functions of W(100) reported in literature. For example, Jin et al measured the work function of W(100) foil to be $-1.9 \pm 0.3$ eV at a pressure of $10^{-6}$ Torr [5], measurements at $10^{-10}$ Torr by Amarendra et al [6] for W(100) foil gave $-2.48 \pm 0.05$ eV, and a value of $-3.0 \pm 0.3$ was reported by Chen et al [7] and Hugenschmidt et al [8].

The energy spectra of re-emitted positrons can be measured by applying either a positive retarding bias to the detector or a negative retarding bias to the sample. The positron retarding curve measured using a positive retarding potential on the MCP and the negative of its derivate are shown in Fig.3 as circles. The sample was cleaned by annealing in the presence of oxygen (at 1400 °C) and then with electron flashes in vacuum (2400 °C). The cleaning procedure adopted was based on reported procedures for obtaining clean W(100) surfaces [6]. The low energy part of the re-emitted positron energy spectrum is reported to range down to 0 eV [6-8]. However, in the present experiment no low energy tailing was observed, probably due to the cleanliness of the sample and it was difficult to estimate the contact potential difference or retarding bias where the positron counts in energy spectra approach zero. When the retarding potential is applied to the sample, and in the absence of contact potential difference between the sample and the detector, the peak position in the derivative of the retarding curve (energy spectra) is expected at a negative voltage which is equal in magnitude to the earlier case where positrons were retarded by the grid in front of the detector. The peak position of the energy spectra could be different from work function value due to contact potential difference with analyser. The retarding curve and energy spectra of re-emitted positrons measured with a negative potential on sample is also shown in Fig.3 as triangles. The overall equations governing the measurement with the incorporation of contact potential differences can be summarized as:

$$-\varphi_{e^+} = e V_{ret}^G + (\varphi_G - \varphi_S) = -e V_{ret}^{SG} - (\varphi_G - \varphi_S)$$

where $\varphi_{e^+}$ is the positron work function of the sample, $V_{ret}^G$ and $V_{ret}^{SG}$ are the retarding potentials on the grid and sample respectively, corresponding to maxima in the re-emitted energy spectra; and $(\varphi_G - \varphi_S)$ is the contact potential difference between the grid and the sample. The peak position of the energy spectra measured by both methods differs by twice the contact potential difference. The positron work function is estimated from the above measurements as:

$$-2\varphi_{e^+} = e V_{ret}^{SG} - e V_{ret}^G$$

and was found to be $-2.75 \pm 0.01$ eV. The energy spread of the re-emitted positrons was about 180 meV which is in reasonable agreement with energy spread of 250 meV reported by Amarendra et al [6].

3.2 Effect of temperature
To get further insights into the thermalized positron re-emission efficiency of W(100), the positrons reemitted in the direction normal to the surface were measured under different conditions. The W single crystal surface was cleaned with electron flashes (heated to 2400°C) and the re-emission yield from W was measured at regular time intervals after the electron flashing, as shown in Fig.4. The
positron yield was found to increase rapidly as the sample cooled and approached a maximum after 1.5 hours. The possible lower yield at high temperature might be caused by either a broader angular distribution of remitted positrons due to phonon scattering or a reduction in the work function of the material [9], or increased trapping of positrons in defects reducing their diffusion length [10]. The reduction in the intensity of positrons was nominal for more than 20 hours. With progression in time, the temperature of the sample was reduced and the contamination of the surface increased [11]. The results show that the positron yield is lower from hot tungsten although the exact temperature of the crystal, when the maximum in yield was achieved, could not be ascertained in this study. The reasons for the marginal rise in the intensity beyond 25 hours are not clear.

4. Conclusion
A slow positron beam which can deliver ~700 positrons/sec in the energy of 0-1keV was established and characterized at The University of Western Australia. The beam was utilized to study positron re-emission and scattering from metallic surface. The re-emitted positron measurements from W(100) have shown that the positron work function is 2.75 ± 0.01 eV. The positron re-emission process was shown to be sensitive to the temperature and cleanliness of the sample.

5. References
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