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Spin polarized low-energy positron source

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Abstract. This paper presents an investigation of spin polarization of positrons from a source based on the decay of ^{22}Na isotopes. Positrons are moderated by transmission through a tungsten film and electrostatically focussed and transported through a 90 deg deflector to produce a slow positron beam with polarization vector normal to the linear momentum. The polarization of the beam was determined to be about 10% by comparison with polarized electron scattering asymmetries from a thin Fe film on W(110) at 10^{-10} Torr. Low energy electron emission from Fe layer on W(100) surfaces under positron impact is explored. It is shown that the intensity asymmetry of the electron emission as a function of the incident positron energy can be used to estimate the polarization of the positron beam. Also several materials with long mean free paths for spin relaxation are considered as possible moderators with increased polarization of the emergent positrons.

1. Introduction

Comprehensive studies of the characteristics of surfaces and thin films frequently depend on effective sources [1] and detectors [2] of polarized electrons. Electron exchange and various spin-obit coupling phenomena are usually identified through angular momenta measurements and their symmetries. Correlations between quantum particles must concern both charge and spin degrees of freedom. Our research is directed towards improved understanding of quantum correlations and hence the development and use of sources and detectors of polarized electrons and positrons.

One major aspect of our research direction concerns the applicability of a positron beam as a tool for the detailed investigation of magnetic properties of material surfaces. This report concerns the design of a low-energy spin-polarized positron source and preliminary measurements. Positrons emitted from radioactive sources have preferred spin direction because of parity violation in the process of beta decay [3] and generally retain their spin orientation, even after the moderation process when passing through a thin (~ 1 micron) tungsten film. These features are the basis for a slow spin-polarized positron beam.

2. Experimental

The experiments were carried out at the University of Western Australia using a positron beam system fabricated at the University of Texas [4] and subsequently modified for working at UHV about 10^{-10} Torr. The positron beam system consist of two parts namely variable energy positron beam system (figure 1) and experimental scattering chamber (figure 2), fitted with surface science instrumentation. The positron beam-forming apparatus in figure 1 consists of a radioactive source of positrons, a positron moderator and positron optics. The positron source is based on the radioactive decay of ~20 mCi ^{22}Na. Polycrystalline tungsten foil of thickness of 1μm is used to moderate positrons which are electrostatically focused and transported into the experimental chamber. The potential between the moderator and the sample determines the beam energy. The use of an electrostatic (non-magnetic) transport system maintains the direction of spin polarization of the positron beam. Potentials on the various elements of the optical system were optimized using SIMION (www.simion.com) program. The experimental chamber contained position-sensitive microchannel plate detectors grids fitted with several planar grids to enable, for example, retarding potential energy analysis of either secondary electrons or positrons. A vacuum of low 10^{-10} mbar was maintained. Details of the system can be found in ref [5].

The direction of the spin polarization of the positron beam leaving the 90 degree deflector is horizontal in the plane of the paper of figure 1. Electrons ejected from the foil were detected by one of two MCP detectors fixed at 90 degrees one to another and at 45 degrees to the beam.

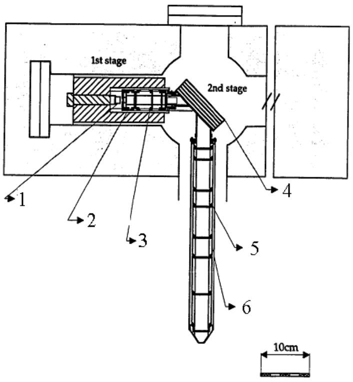

Figure 1. Schematic of positron beam system delivering positrons into the scattering chamber (figure 2). 1. A radioactive source of positrons 2. Moderator. 3. Input of positron optics, 4. The system of rotation of positrons 5. Focusing system 6. Output of the positron optics.

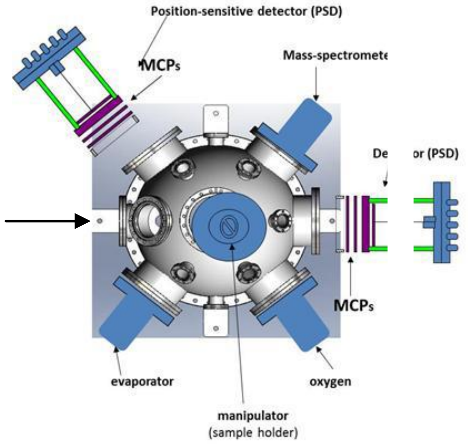

Figure 2. The experimental surface scattering chamber showing the location of detectors and attached surface characterization instruments. The positrons beam enters horizontally from the left.

3. Results and discussion

Samples of W (100), with or without Fe over layers, were studied by various methods of electron spectroscopy to determine their electronic and magnetic characteristics.

Figure 3 shows the dependence of the intensity of positrons and electrons as a function of the energy of the positrons incident (moderator voltage) on the tungsten surface. It is seen that at the energy of about 15 eV for positrons and electrons the peak is clearly observed that corresponds to the first diffraction maximum. Note that when using a position-sensitive microchannel detector for positrons, we observed a typical diffraction pattern as a set of corresponding reflections.

Figure 4 shows the energy spectrum of positrons emanating from the W(100) surface when the incident positron energy is set by the moderator potential at 15 V. The energy of the specularly scattered positrons is 17.5 eV It can be seen that the spectrum looks like a typical spectrum for secondary electrons in the case of surface excitation with an electron beam. The shift of the elastic peak by 2.5 eV with reference to moderator voltage is due to the negative work function of the moderator for positrons.

Figure 5 shows the spectrum of secondary electrons when 17.5 eV positrons from the positron beam are incident on the tungsten surface. It can be seen that there are no elastic peaks in the spectrum, and there is a significant part of low-energy electrons. Note also that the intensity of the electrons at the energy of 17.5 eV and above does not equal zero. This is due to the mechanism of formation of secondary electrons. Annihilation of positrons in the surface region leads to the formation of holes that are filled with electrons. The liberated energy was used for the appearance of secondary electrons, even with energy higher than the energy of the primary positrons.

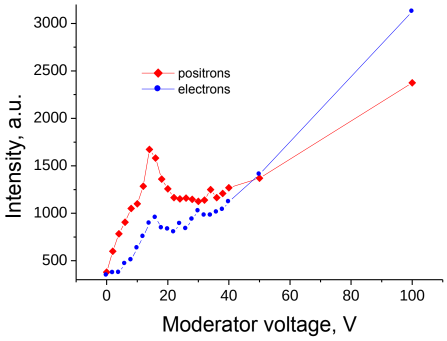

Figure 3. Intensity of positrons and electrons as a function of the energy of positrons incident on the tungsten surface observed at an angle of 22.5 degrees.

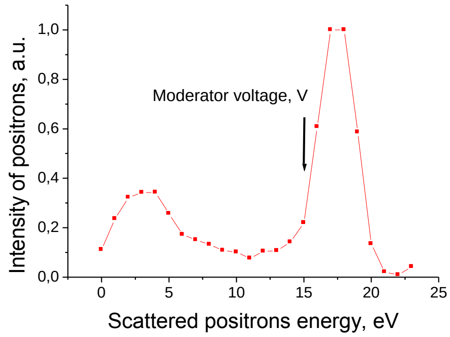

Figure 4. Spectrum of scattered positrons from W(100). Voltage of the moderator is 15 V.

In the next phase of work the magnetic properties of iron films deposited on the tungsten surface were investigated (figure 6). It was found that for both samples, there is a peak that appeared due to the surface resonance [6]. It allowed us to use the W (100)-Fe film system to measure spin polarization of the positron beam. Note that figure 3 shows all emitted electrons as a function of the moderator potential, whereas figure 6 shows only electrons with the energy close to the incident energy of positrons. In the latter case an appropriate potential was applied to the grid in front of the detector.

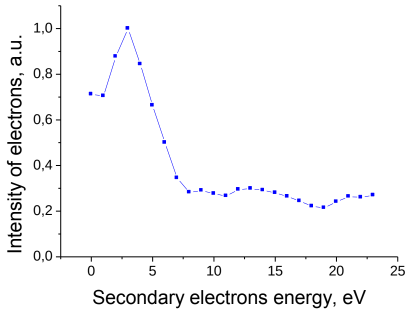

Figure 5. Spectrum of secondary electrons with the incident positron energy of 17.5 eV.

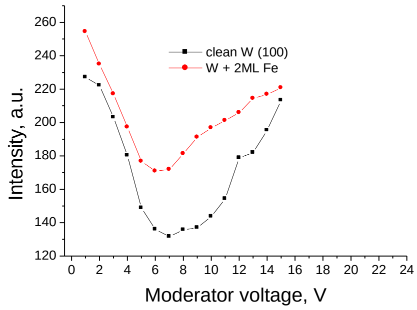

Figure 6. The intensity of the electrons (of energy approximately equal to the incident positron) as a function of incident positron energy from clean W(100) and W(100) deposited with over layers of Fe.

Subsequently, the iron film was sequentially magnetized in opposite directions and the electron emission intensity (as in figure 6) was measured as a function of primary positron energy. The asymmetry in the intensity of the electron emission is calculated by the formula $A=(I^+ - I^-)/(I^+ + I^-)$, where I^+ and I^- are the electron intensities for different directions of magnetization

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of the iron film, relative to the direction of polarization of the positron beam (figure 7). Below is a simple model that explains our result.

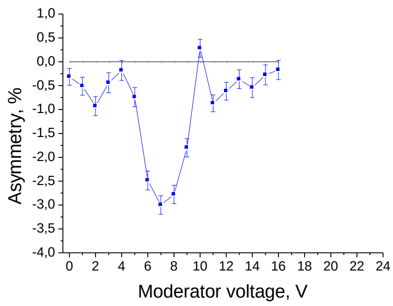

Figure 7. The asymmetry in the intensity of the emitted electrons as a function of energy of the incident positrons. The sample is the Fe film deposited on the W (100).

It can be assumed that the polarized positrons with a certain energy and polarization excite more electrons with a certain spin direction and less with another spin direction and excite them into resonance states. The electrons escaping from the resonance state can be detected at a certain energy and exit angle. In parallel, these resonant electrons interact with iron, which acts as a spin filter. As a result of this process there is an asymmetry of the intensity of the electrons leaving the surface due to the changing of the magnetization vector of the iron film.

One can also consider a model where the positrons are polarized while passing through the magnetic film. However, in the first model, the electrons due to resonance spend significantly longer time in the interface region than the positrons and the probability of processes involving spin is larger. Therefore, we believe that the first model is preferable.

It is seen that in the field of electron resonance the asymmetry reaches a significant value, so you can use this method to calculate the polarization of a positron beam. According to our calculations, it is about 10% in our beam. For this calculation, we used data on the scattering of polarized electrons on tungsten [7].

According to the research conducted in the laboratory of surface magnetism at St. Petersburg Polytechnic University the best material for the moderator that decelerates positrons is palladium, a material that has a very large mean free path of electrons with respect to the spin relaxation (Spin relaxation length Λ_S). Spin relaxation length Λ_S of palladium is hundreds of times greater than a similar property of tungsten.

4. Conclusion

We demonstrate the evidence that the low-energy positron beam generated by our positron gun is spin-polarized. To continue work on the improvement and creation of a truly high efficiency low-energy spin-polarized positron source it is desirable to use an alternative moderator and another scheme of spin detection. For the positron spin detection a classical Mott detector can be used.

Acknowledgement

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