Direct Positron Surface State Trapping at a Gold Surface

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We present secondary electron spectra arising from very low energy (2.5 to 4 eV) positron impact on a polycrystalline gold surface. Significant secondary electron emission has been observed at and below an incident positron energy of 4 ± 0.4 eV, providing the first experimental confirmation of direct positron surface state trapping.

1. Introduction

Positron annihilation spectroscopy is a most effective means of studying open volume defects in metals and semiconductors [1]. Frequently however, any surface information is lost in a convolution with the bulk data. Recently a number of reactor-based positron sources have come online. With intense, low energy, pulsed positron systems it will be possible to access the surface independently of the bulk.

While great progress has been made in describing the behaviour of positrons in the bulk of solids, much less is known about the energetics of positrons at the surface. For both the positron and its antiparticle, surface states exist that have no equivalent in the bulk [2,3]. A positron can access the surface state via two routes. Once implanted, positrons can diffuse back to the surface and become trapped in a surface potential well; or incident positrons can fall directly into a surface state without entering the bulk [4]. In this direct process some or all of the positron's kinetic energy and the surface state binding energy can be transferred to an electron at or near the Fermi level, and then the electron may be ejected from the surface if it has sufficient energy. Here we provide direct experimental confirmation of this process through measurements of the energy distribution of secondary electrons generated by very low energy (2.5 to 4 eV) positron impact on a polycrystalline gold surface.

The spectra contain contributions from two processes: 1) annihilation-induced Auger electrons that have lost energy before leaving the surface and 2) secondary electrons resulting from direct energy exchange with the incident positron [5,6]. We will show that this second channel is still active at and below the threshold where energy conservation precludes the generation of secondaries via a bulk collision, providing strong evidence of direct surface state trapping.

2. Experimental Details

The experiments were performed on the University of Texas at Arlington positron annihilation Auger spectrometer which is described in detail elsewhere [7]. Positrons are obtained from a 4 mCi ^{22}Na source and moderated by a 3 μm tungsten foil in transmission geometry. In short the system consists of a magnetically confined variable energy positron beam which impacts a surface, and a novel time-of-flight system is employed to analyse the energy of the Auger/secondary electrons which result from the interaction of the positrons with the surface. Low energy positrons from the moderator are guided to the sample surface 3.5 m away through a series of E×B plates. A positron hits the sample and annihilates within a time scale of about 100 ps producing two antiparallel 511 keV gamma rays. The annihilation gammas are detected by BaF_2 and NaI scintillation detectors which trigger the start of a time-to-amplitude converter (TAC). The secondary electrons generated during the lifetime of the positron are directed away from the sample towards a micro-channel plate (MCP), the MCP output provides the TAC stop signal. The TAC output is proportional to the flight time of the electron from which the kinetic energy can be deduced.

The beam energy is determined by the potential between the sample and the moderator and is given by $E_B = \Phi^+_m + V_m - V_s$, where Φ^+_m is the positron work function of the moderator and V_m and V_s are the moderator and sample potentials, respectively. The resolution of the incident beam was measured to be 400 meV. Secondary spectra were measured for incident positron energies in the range of 2.5 to 4 eV. The spectra are normalised to the beam intensity obtained by integrating the 511 keV peak in the gamma energy spectrum.

A polycrystalline gold sample is employed as a target for these experiments. The sample is cleaned using Ar ion bombardment under standard conditions. The interaction chamber is maintained at ultra high vacuum (UHV) conditions, ~10^{-9} Torr, and positron Auger results have shown that the sample is free from surface contamination.

3. Results

At low energies the secondary electron spectra contain contributions from two sources: secondaries arising from a direct energy exchange with the incident positron and Auger-induced secondary electrons. In the latter an implanted positron annihilates with a core electron creating a core hole leading to Auger electron emission. Secondaries result from collisions with the Auger electron as it traverses the surface. Fig. 1 shows the integral of the Auger peak in the spectra for different beam energies. It is apparent that the Auger yield is approximately constant with beam energy. This suggests that the secondary background due to Auger emission is a constant background independent of the beam energy.

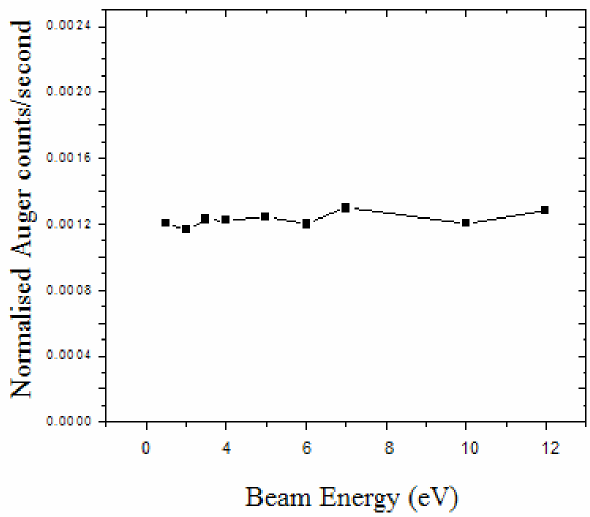

Fig 1. Integral of the Auger peak in the normalised energy spectra.

Fig. 2 displays an idealised potential and energy level diagram for a positron incident on a metallic surface [4,8]. It illustrates the channels by which secondary electron emission is possible due to a direct energy exchange. For secondaries arising from a collision with a positron in the bulk the maximum energy available to the electron is given by the difference between the beam energy and the positron bulk state energy. Thus, the maximum kinetic energy of an ejected electron is given by $E_{k1} = E_B + \Phi^+ - \Phi^-$, where E_B is the beam energy (defined above) and Φ^+ and Φ^- are the positron and electron work functions respectively. For gold $\Phi^+ = 1$ eV and $\Phi^- = 5.1$ eV, and so in order to generate secondaries by this process (E_{k1} >0) the beam energy must exceed 4.1 eV.

Alternatively the positron can fall directly into a surface state without entering the bulk of the solid. This is referred to as direct surface state trapping. In this case the maximum energy available to a secondary electron is given by the difference between the beam energy and the surface state binding energy E_{ss}. The maximum kinetic energy of an outgoing electron is then given by $E_{k2} = E_B + E_{ss} - \Phi^-$.

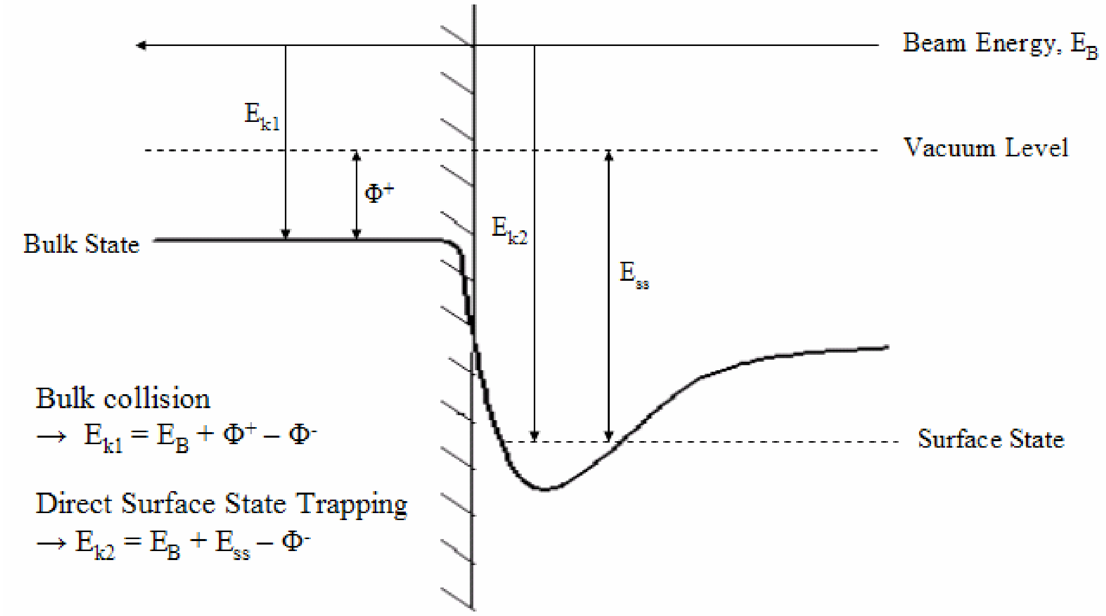

Fig. 2 Idealised positron potential and energy level diagram.

Fig 3. shows the measured energy spectra of secondary electrons leaving a gold surface after positron impact for incident energies in the range of 2.5 to 4 eV. The spectra have been normalised to the number of incident positrons to allow direct comparison. The spectra have shapes identical to typical secondary electron spectra, displaying a sharp rise to a peak value followed by a decay.

It can be seen that narrow secondary electron peaks are present at and below 4 eV beam energy and that the shape and intensity of these peaks varies as the beam energy is reduced. Energy conservation dictates that these electrons are not the result of a bulk collision with the primary positron. Furthermore, the variation in intensity implies that these electrons are not purely an Auger-induced background. Gamma-induced secondaries are also possible, however, as with the Auger process, any gamma background is independent of the beam energy. Therefore, the presence of secondary electron peaks below 4.1 eV and the fact that variation is observed in the intensity of the spectra below this threshold confirms that significant secondary emission occurs due to direct positron surface state trapping.

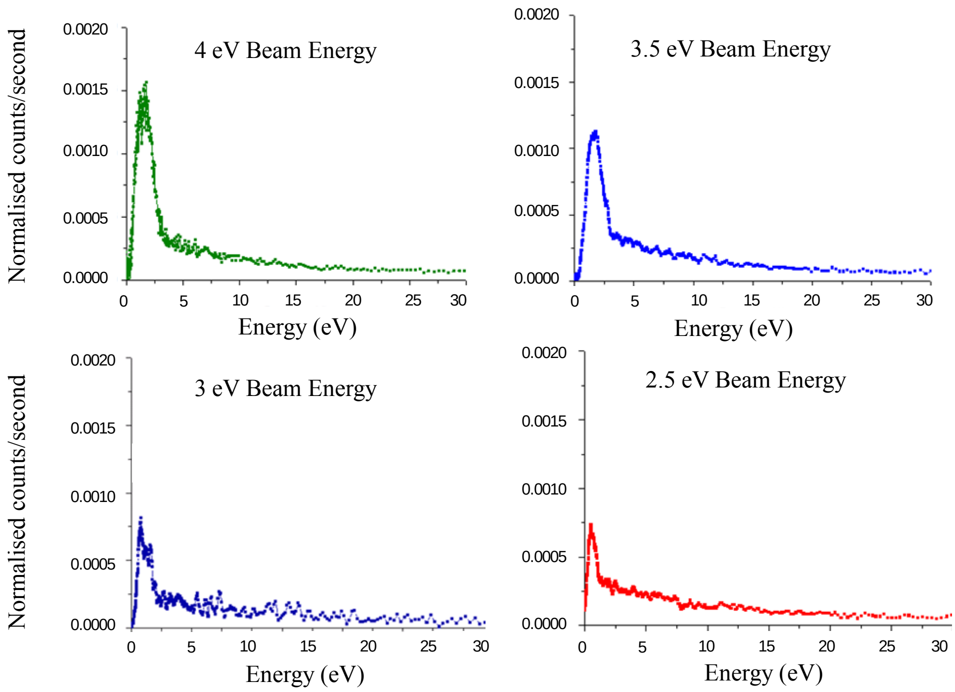

Fig 3. Positron-induced secondary electron spectra for 2.5-4 eV incident energies. The spectra have been normalised to the number of incident positrons.

4. Conclusion

Positron-induced secondary electron spectra have been measured with beam energies ranging from 2.5 to 4 eV from a clean polycrystalline gold surface under UHV conditions. The generation of narrow secondary peaks with incident energies at and below 4 eV provides clear evidence that these electrons are due to the transfer of energy from positrons that fall directly into a surface state without entering the bulk. This provides the first experimental confirmation of direct positron surface state trapping.

References

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