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OBSERVATIONS OF DISCRETE ENERGY LOSS EFFECTS IN SPECTRA OF POSITRONS REFLECTED FROM SOLID SURFACES

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ABSTRACT

Surfaces of tungsten and silicon have been bombarded with monoenergetic beams of positrons and electrons. Spectra of reflected particles show energy loss tails with discrete peaks at kinetic energies about 15 ev lower than that of the elastic peaks. In the higher energy loss range for tungsten, positron spectra show fine structure that is not apparent in the electron specta. This suggests that the positrons are losing energy through mechanisms different from that of the electrons.

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Significant progress has been made in the past several years by various groups in producing monoenergetic slow positron beams of usable intensities.[1-4] In addition to their application to studies of scattering from gas molecules, new spectroscopies of solids and solid surfaces are also rapidly being developed. Rosenberg, Weiss and Canter have reported the first measurements of low energy positron diffraction (LEPD) spectra from single crystal surfaces.[5] It is expected that positron spectroscopy measurements will complement those made by electron methods. Results should be similar, but yet significantly different because of exchange and correlation effects. In LEPD, for example, Bragg peaks occur for positrons,[5] which is not unexpected, but their intensities are different. In this letter we compare the spectra of positrons and electrons scattered from the same surfaces under identical geometries and show that the lower energy loss events appear to be similar whereas the higher energy loss events are significantly different, possibly because different energy loss mechanisms are involved.

A 50 mCi ^{22}Na source was used in the positron gun. The positrons were made monoenergetic by means of a moderator constructed from surfaces of single crystal tungsten (110). Surface cleaning and annealing were done in a similar manner to that reported for polycrystalline tungsten moderators.[1] The source and moderator cavity were biased to the desired acceleration potential and coupled to an einzel lens. Angular spread of the positron beam at the target was about 6° FWHM. The scattering geometry was approximately specular, with a total scattering angle of 16°. The spectrometer for analyzing the scattered beam was a 20 cm spherical sector electrostatic type of the Siegbahn design.[6]

Entrance and exit slits were 0.5 mm wide, 10 mm high. A channel electron multiplier which will detect positrons as well as electrons[7] was placed at the exit slit. Resolution of the spectrometer was 0.1%.

The tungsten scattering surface was prepared by heating a polycrystalline ribbon to approximately 1600°C at 10^{-6} torr. Air exposure occurred, after the specimen cooled, during loading. The silicon (100) scattering surface was prepared by lapping a single crystal to about 1/2 mm thickness. Final cleaning was by chemical polish and distilled water rinse. X-ray photoelectron spectroscopy (XPS) showed that the tungsten was covered with less than 3 monolayers of oxide. We estimate that the silicon was covered with less than ten.

Secondary electrons, as well as positrons, were ejected from the moderator by radiation from the ^{22}Na source. Depending on the bias potentials of the source, moderator, and lenses, either positrons on electrons could be focused into a monoenergetic beam for use in the scattering experiments. The FWHM of the electron and positron beams were 3.2 ev and 2.1 ev, respectively. Alternate spectral measurements of the scattering of positrons and electrons by the tungsten and silicon surfaces were made, in situ, by simply reversing potentials on the gun and spectrometer, without need for changing target positions.

Figures 1(a) and 1(b) compare the spectra of scattered positrons and electrons for the W and Si surfaces for an acceleration energy of 785 ev. Figure 1(c) shows spectra for the case of 546 ev positrons and electrons scattered from a tungsten surface. All spectra are normalized such that the heights of the eleastic peaks are the same. Because of the positron negative work function[8] the actual acceleration energies of the positrons were about 2 ev greater than those for electrons. The positron spectra in the figures have been shifted to the left by 1.8 ev so that the elastic peaks are coincident.

Note that in all the spectra of Figure 1, for both positrons and electrons, the main energy loss peaks occur at kinetic energies about 15 ev lower than those of the elastic peaks. For the 785 ev tungsten spectrum, Fig. 1(a), the positron fine structure can be clearly seen in the remainder of the energy loss tail. Because of poor counting statistics this structure is obscured in the 546 ev tungsten spectrum, Fig. 1(c), but it appears to be similar. The intensity relationship between the positron and electron energy loss spectra for silicon, Fig. 1(b), is quite different than that for tungsten.

The discrete energy loss peaks at 15 ev are reminiscent of the plasmon excitation effects[9] that have been documented for free electron metals such as Al and Mg. Tungsten and silicon are not free electron metals, however, so we cannot quantitatively interpret their spectra in terms of plasmon excitation. Also, experimental conditions are complicated by the oxide contaminations. Discrete energy loss peaks of this type always follow elastic peaks in XPS and Auger spectra, however, even for non-conductive specimens. It is a general consensus that they are due to collective excitations of electrons in valence bands. Siegbahn[6] has explained that this phenomenon is a fortunate aspect of low energy electron spectrometry; if scattered electrons lost energy in 0.1 or 0.01 ev quantities the elastic peaks of XPS and Auger spectra would be smeared, obliterating chemical shift information. It appears that good fortune prevails for positron scattering also; the elastic peak is well resolved from the loss spectra.

The "plasmon" tails for the electron spectra of W and Si fall off after the peak at 15 ev, whereas the positron loss spectra remain intense. We think these structures are not due to multiple plasmon excitations, but rather to additional loss processes. A possible explanation for some of the structure of the energy loss tail for tungsten is depicted in Fig. 1(a). The arrows mark the positions of energy loss that would be expected if the positron energy were decreased through ionization of tungsten 4f and 5p electrons. The energy difference between arrow 1 and the elastic peak corresponds to the binding energy of the tungsten $5p_{1/2}$ electron; arrow 2 the $5p_{3/2}$ and $4f_{5/2}$ electrons; and arrow 3 the $4f_{7/2}$ electron. Silicon has no core levels with binding energies in this energy range. The reason for the seemingly constant intensity of the positron energy loss tail for silicon is not apparent.

The contaminated surface conditions of these experiments make interpretations subject to question. Preparations for clean surface experiments are underway. We felt that these preliminary results are interesting and encouraging, however. It appears that positrons scatter from surfaces in a significantly different manner than electrons. Perhaps positron scattering data will complement that of electrons.

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FIGURE CAPTIONS

FIG. 1 Positron and electron energy-loss spectra. (a) 785 eV e^+ and e^- scattered from W (numbered arrows are explained in text) (b) 785 eV e^+ and e^- scattered from Si (c) 546 eV e^+ e^- scattered from W

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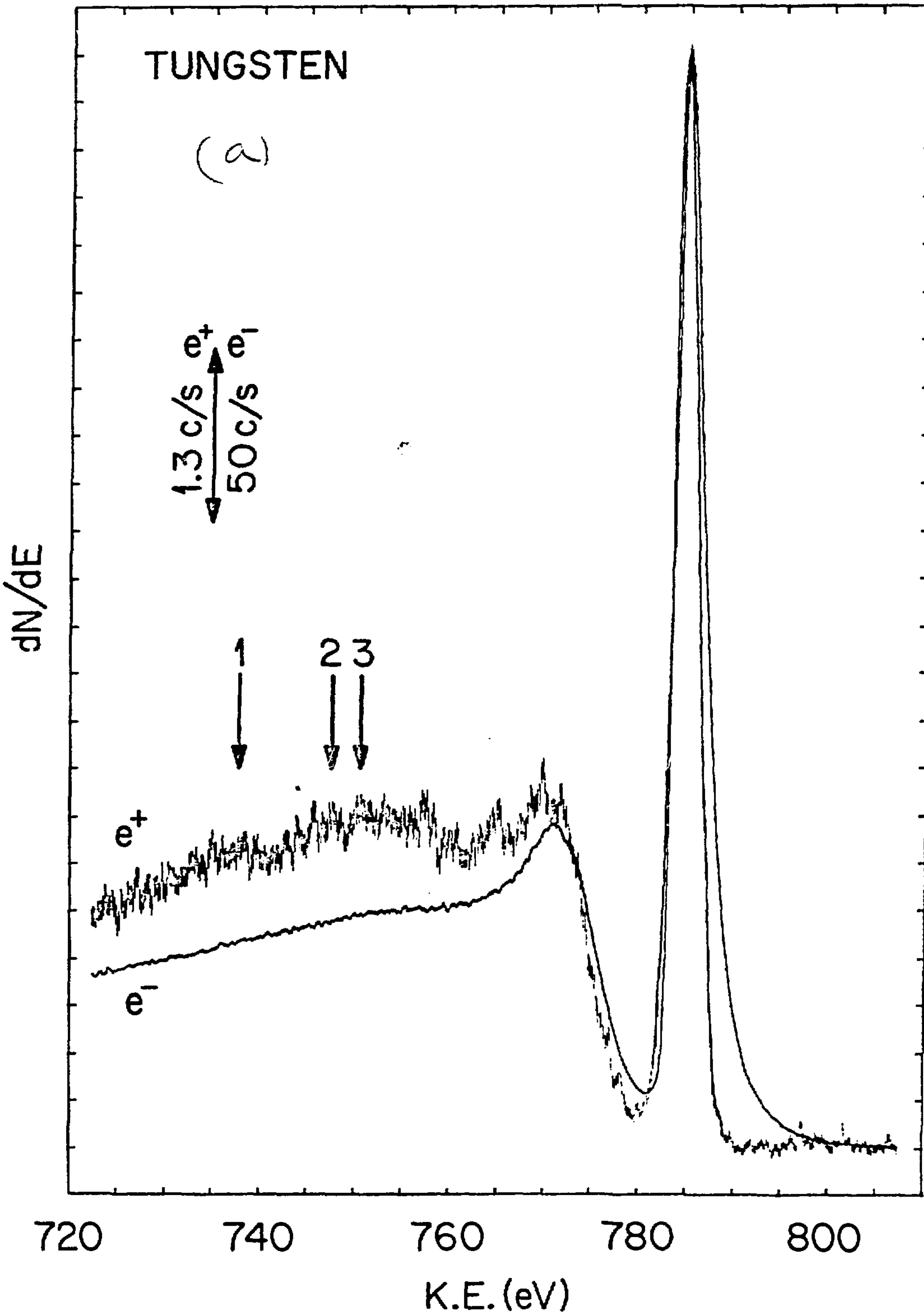

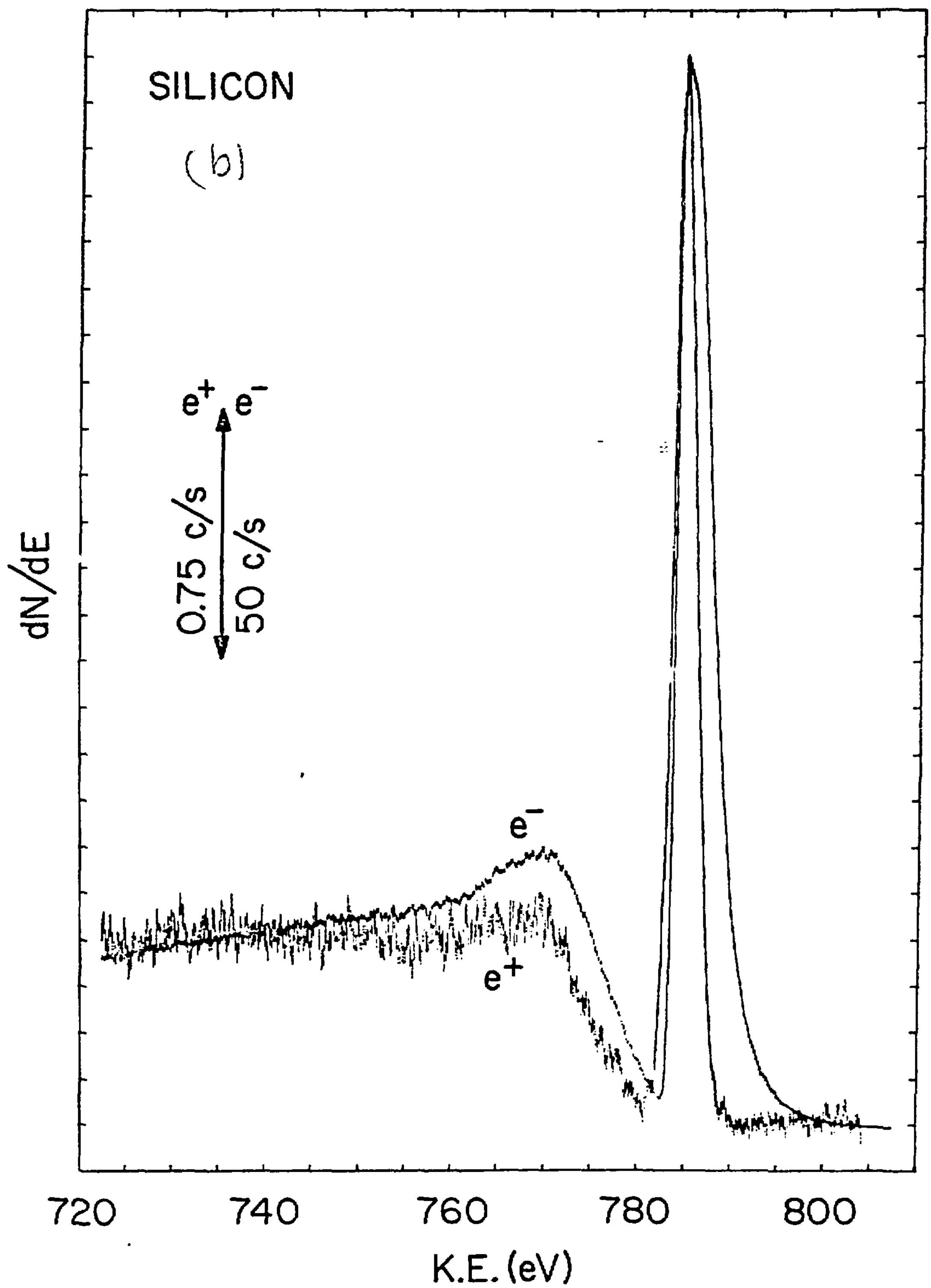
SILICON
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50 c/s
dN/dE
e−
e+
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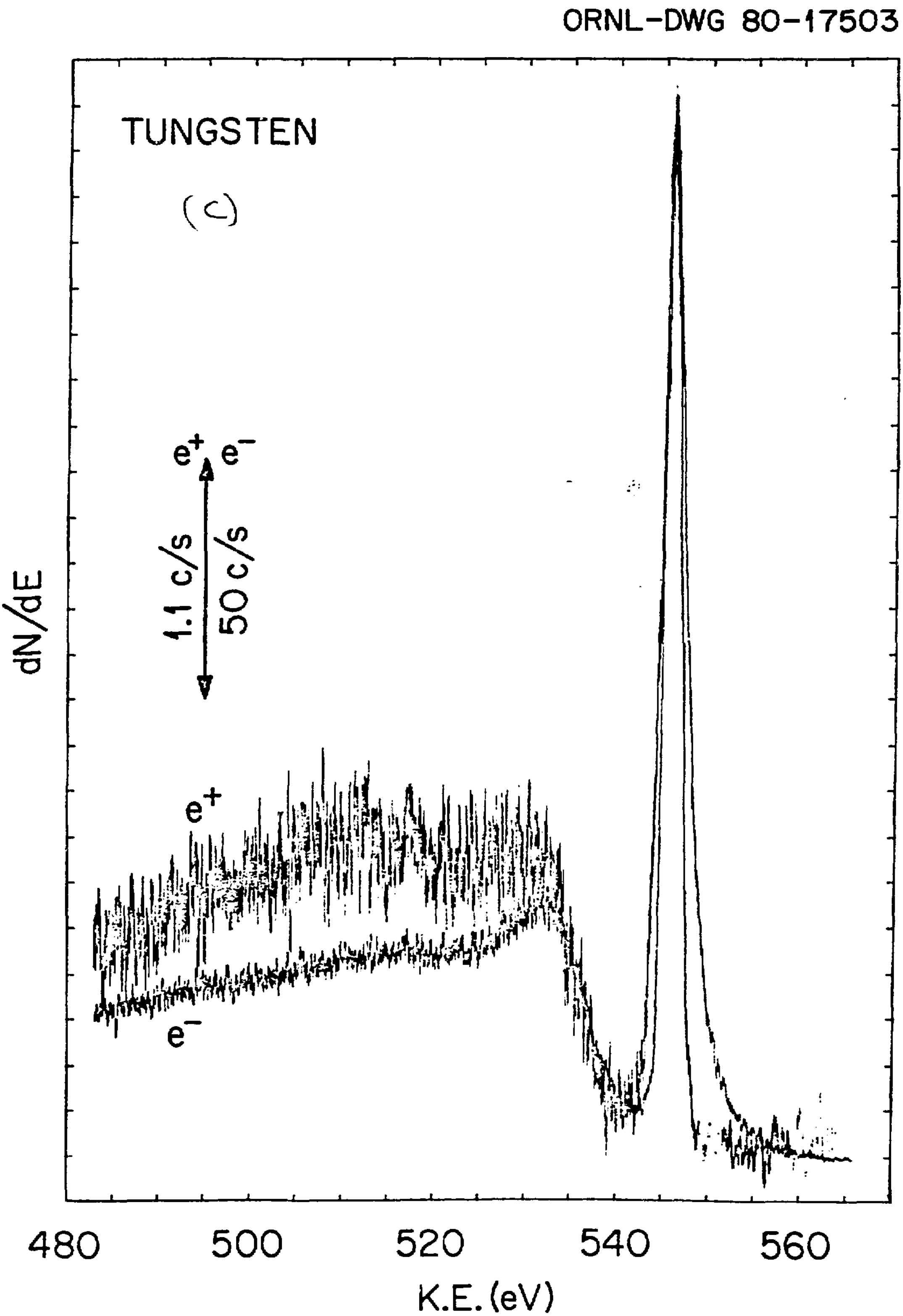
740
760
780
800
K.E. (eV)


ORNL-DWG 80-17503
TUNGSTEN
(c)
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1.1 c/s
50 c/s
dN/dE
e+
e−
480
500
520
540
560
K.E. (eV)