Specular reflection of conduction electrons from the crystal surface in tungsten or copper

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By using transverse electron focusing (EF) [V. S. Tsoĭ, JETP Lett. **19**, 65 (1974)], we measured the coefficient q of specular reflection from the crystal surface in tungsten or copper. Just as in the case of bismuth [V. S. Tsoĭ and N. P. Tsoĭ, Abstract of papers at Nineteenth All-Union Conference on Low-Temperature Physics, Minsk, 1976], the value of q for tungsten depends strongly on the orientation of the reflecting plane, with $q_{110} \approx 0.65$ for the (110) plane and $q_{100} \approx 0.1$ for the (100) plane. A value $q \approx 0.35$ was obtained for copper.

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Using transverse electron focusing (EF)[1] we investigated the reflection of carriers from the crystal surface in tungsten or copper under normal incidence. In contrast to antimony,[2] the electrons and holes are reflected in tungsten in like fashion, but the character of the reflection, just as in bismuth,[3] depends strongly on the crystallographic orientation of the reflecting plane: the carriers are reflected from the (110) plane specularly (the specular reflection coefficient is $q_{110} \approx 0.65$), and from the (100) plane diffusely ($q_{100} \approx 0.1$). In the case of copper, the reflection of electrons from the (110) plane was investigated, and a value ≈ 0.35 was obtained for q.

Reflection of conduction electrons from the surface of the crystal in a normal metal at large incidence angles on the boundary is usually assumed to be

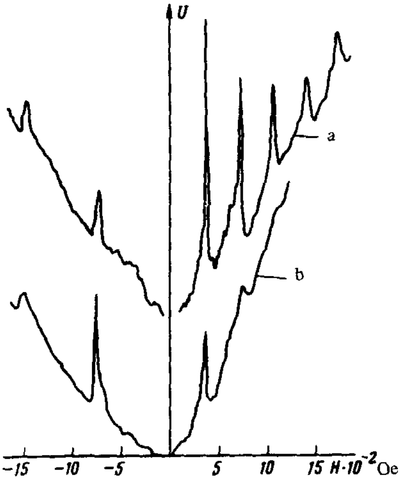

FIG. 1. Plot of $U(H)$, $T=1.6$K $\mathbf{H}\parallel[001]$, *a* $-\mathbf{n}\perp(110)$, b—$n\perp(100)$.

diffuse. It is assumed that the conduction electron, reaching the surface of the crystal, should experience strong random scattering with loss of any drift momentum. The main argument favoring the diffuse scattering is the short wavelength of the electrons in comparison with the dimensions of the metal-surface roughness (the electron wavelength in a normal metal is of the order of the interatomic distance). Up to now, however, no direct experimental measurements have been made of the coefficient of specular reflection of conduction electrons normally incident on the sample surface in a metal.

In the present study we determined the value of q from electron-focusing measurements.[1] We used the same experimental setup as in[1]. Two microjunctions—an emitter and a collector, were placed on the surface of the crystal. Current was made to flow through the emitter and the collector voltage U was measured as a function of the magnetic field **H** in the plane of the sample and directed perpendicular to the emitter— collector line. The samples were plane-parallel single-crystal plates produced by the procedure described in[2]. The resistivity ratios for tungsten and copper were respectively $\rho_{300\mathrm{K}}/\rho_{4.2\mathrm{K}} \approx 40\,000$ and $\rho_{300\mathrm{K}}/\rho_{4.2\mathrm{K}} \approx 35\,000$. The crystallographic orientations of the samples and were the following: the tungsten crystals had two orientations, 1) $W^{\mathrm{I}}-\mathbf{n}\perp(110)$, 2) $W^{\mathrm{II}}-n\perp(100)$; the copper crystals had $\mathbf{n}\perp(110)$ ($\mathbf{n}$ is the normal to the plane of the sample).

Figure 1 shows experimental plots of $U(H)$ for tungsten samples with two orientations, curve a for sample W^{I} and curve b for W^{II}. In both cases the

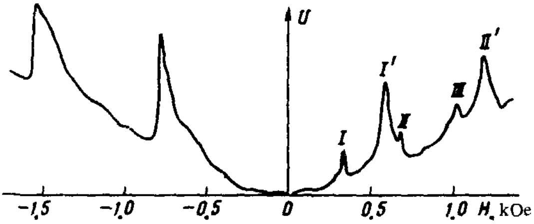

FIG. 2. Plot of $U(H)$, $T=1.6$K, $\mathbf{n}\perp(110)$, $\mathbf{H}\parallel[112]$.

magnetic field H was directed along the [001] axis. At this direction of H, the electron-focusing lines on curves a and b were due to the focusing of the carriers of the central sections of the "electron spheroid" ($H>0$) and the "hole octahedra" ($H<0$) of the Fermi surface of the tungsten, designated by the letters S and H, respectively in Fig. 3(a). For sample W^{I}, with the magnetic field H directed along [112] (the emitter—collector line was perpendicular to H) we observed at $H>0$ two systems of electron-focusing lines (Fig. 2), one I, II, III) corresponding to the focusing of the carriers of the "electron spheroids" S, and the other (I′, II′) corresponding to the focusing of the carriers of the central section of the "electron jack" Γ ([Fig. 3(a)]). At $H<0$, the electron-focusing lines in Fig. 2, just as in Fig. 1, correspond to focusing of the "hole octahedra" of the Fermi surface of tungsten.

The system of "peaks" on the $U(H)$ curves of Figs. 1 and 2, which repeat with increasing H, is the result of focusing of the electrons ($H>0$) and of the holes ($H<0$) after $0,1,2,\cdots$ etc., reflections from the surface.[1] The weak damping of the amplitude of the electron-focusing line with increasing number of collisions with the surface points to an almost specular character of the reflection of the carriers from the (110) plane of the tungsten sample. The ratio of the amplitudes of the tungsten sample. The ratio of the amplitudes of the neighboring lines is determined by the value of q at normal incidence,[1,4,5] and for the (110) plane of the W^{I} sample we have $q_{110}\approx 0.65$. The coefficient of specular reflection q in tungsten is the same for both electrons belonging to different sections of the Fermi surface (Fig. 2) and holes.

It is interesting that electrochemical etching of the tungsten crystal for which $n\perp(110)$ in a KOH solution did not lead to diffuse reflection of the carriers, but merely decreased to approximately one-half, despite the fact that the appearance of the sample was dull in this case. Thus, the surface of the sample after etching reflected the electrons specularly with a noticable probability. A similar phenomenon occurs for an electromagnetic wave in the visible band, when an etched spherical metallic single crystal reflects visible light in the same manner as a sample with a flat mirror surface. This circumstance seems to indicate that the employed etching procedure does not upset substantially the atomic structure of the boundary plane (110) of the tungsten crystal, and by the same token the specular character of the reflection of the carriers.

The reflection, however, became practically diffuse (the amplitude of the second line decreased sharply in comparison with the amplitude of the first line of Fig. 1b when the boundary of the tungsten crystal was the (100) plane. In this case the specular reflection coefficient was $q_{100}\approx 0.1$ and was the same for electrons and holes. The substantial difference in the character of the re-

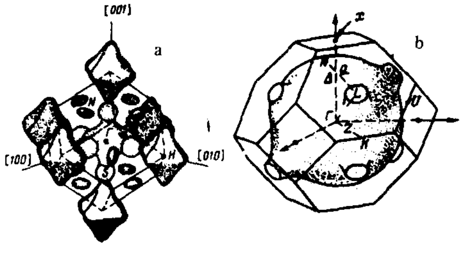

FIG. 3. Fermi surface of tungsten (a) and of copper (b).

flection from the boundary planes (110) and (100) was observed earlier in[6,7] for tungsten surfaces whose surfaces were treated in a special manner in an ultrahigh vacuum. The physical reason for the difference in the character of the reflection from the (110) and (100) planes of tungsten is not clear to this day, and calls for further research. It is not impossible that the reason is the difference between the roughnesses of the surfaces of the faces (110) and (100).

In the experiments with copper, **H** was directed along [001], in which case the electrons taking part in the focusing came from the central cross section of the spherical section of the Fermi surface of copper (Fig. 3b). The value obtained for q_{110} was ≈ 0.35.

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