coupled with the large scattering efficiency induced by the field, makes the soft mode a prime candidate for an electric-field–tunable Raman laser. In addition, the natural infrared activity of the mode would provide radiation in the 10- to 100-cm^{-1} region of the spectrum. The knowledge of the soft-mode frequency and its variation with temperature and electric field should prove useful in other experiments. One example has already been given here by relating the variation in the phonon frequency to the dielectric properties of $SrTiO_3$. Many other physical parameters, such as thermal conductivity, depend upon the phonons for their microscopic origin. A movable phonon mode is a very useful probe for testing theories of optical, thermal, and mechanical properties of solids.

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ANOMALOUS TOTAL-ENERGY DISTRIBUTION FOR A MOLYBDENUM FIELD EMITTER

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The possibility of using field-electron microscopy to elucidate special features of bulk electronic band structure for metals has been proposed in previous theoretical[1,2] and experimental findings.[3,4] In a previous publication[3] an anomalous total-energy distribution (TED) from the ⟨100⟩ direction of tungsten, consisting of an enhanced emission (see Fig. 1) approximately 0.35 eV below the Fermi level E_F, was reported. Upon examination of theoretically and experimentally suggested band structures and Fermi surface shapes along the ⟨100⟩ of tungsten one could correlate the TED results with special bulk electronic features. Although molybdenum is nearly identical to tungsten both geometrically and electronically speaking, some notable differences along the ⟨100⟩ direction band structure, which might be manifested in TED measurements, motivated our undertaking of a similar investigation of Mo.

The expected electronic band structure for tungsten along the ⟨100⟩ direction (the ΓH direction in $\vec{k}$ space) is reproduced in Fig. 2 from a previous publication by Mattheiss.[5] Introduction of spin-orbit interactions (proportional to ξ_{5d}) results in a splitting of the Δ_5 degeneracy and removal of the Δ_7 crossing. Mattheiss points out that a value of $\xi_{5d} = 0.03$ Ry (0.4 eV) can account for the disappearance of the electron lenses along the ⟨100⟩ axes in tungsten, a result obtained by Sparlin and Marcus[6] from de Haas–van Alphen measurements. Thus, if the upper Δ_7 band does not dip below the Fermi level E_F [see Figs. 2(e) or 2(d)] one expects TED measurements of field-emitted electrons near E_F to be normal (i.e., obey the Sommerfeld model for field emission); however, at approximately 0.35 eV below E_F, emission

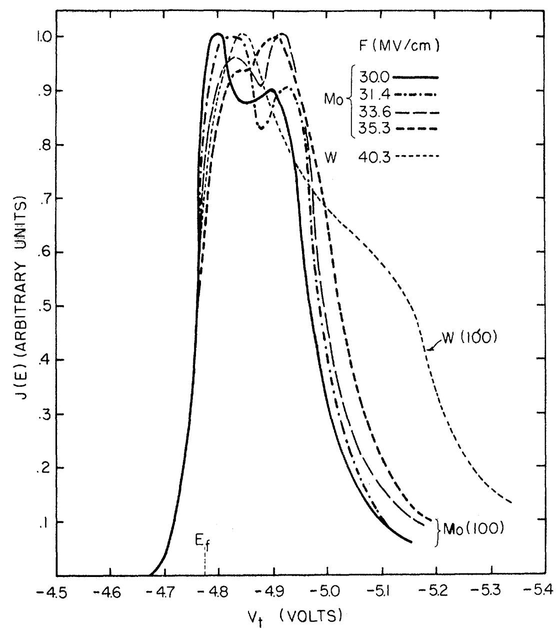

FIG. 1. Experimental total energy distribution plots along the ⟨100⟩ direction of clean Mo and W at 77°K.

from the protuberance of the lower Δ_7 band can enhance the emission and cause deviation from the expected exponential decay of the TED. This is in close agreement with the experimental facts reported[3] earlier for the ⟨100⟩ direction of tungsten.

In contrast to the tungsten results, Sparlin and Marcus[6] reported the existence of electron lenses along ΓH for molybdenum, thus implying a smaller spin-orbit interaction. In view of this and the implicit assumption that bulk band structure is not significantly altered at the surface, one may expect TED measurements along the ⟨100⟩ direction of molybdenum to show a smaller energy gap between the upper and lower Δ_7 bands [e.g., Fig. 2(b)]. That this is the case can be observed from the results, shown in Fig. 1, of the TED measurements along the ⟨100⟩ direction of molybdenum. Here we observe a satellite peak in the TED approximately 0.15 eV below E_{F} which becomes the predominant peak at higher field strengths. Also given in Fig. 1 is the earlier reported[3] result for the ⟨100⟩ direction of tungsten. If the lower peak in both cases is attributed to enhanced emission from the protuberance in the lower Δ_7 band, one concludes that the splitting due to spin-orbit interaction is of the order of 0.35 and 0.15 eV for tungsten and molybdenum, respectively.

According to the Sommerfeld model of field emission, the current per unit energy $J(E)$ at $T=0°\mathrm{K}$ diminishes from its maximum value at E_{F} according to $\exp[E-E_{\mathrm{F}})/d]$, where $d=\hbar eF/2(2m\varphi)^{1/2}t(y)$ (the notation is defined in Ref. 3). Deviations from this law can be expected on-

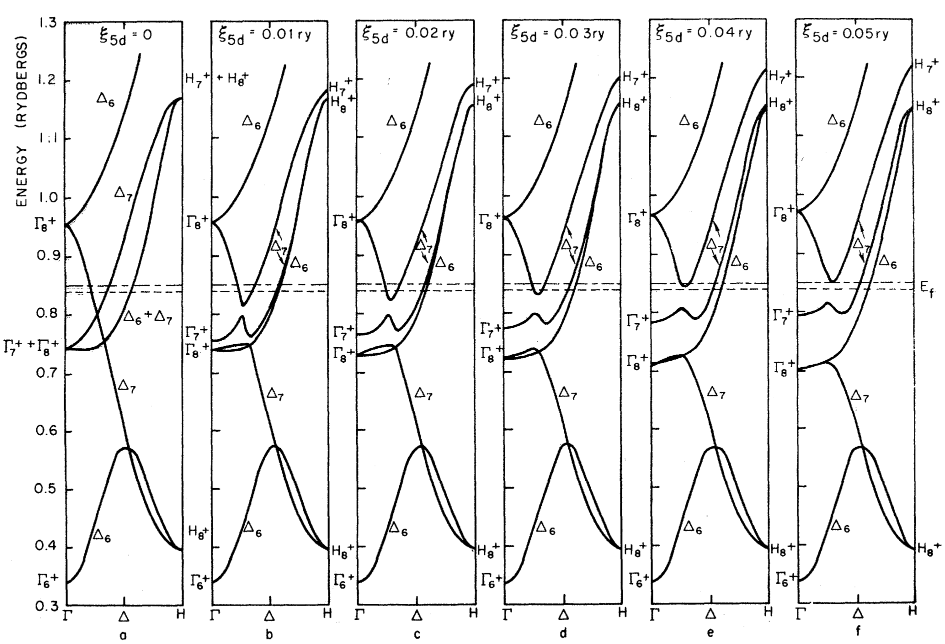

FIG. 2. Theoretical plots, taken from Ref. 5, of the electronic band structure of W along the ⟨100⟩ direction as a function of the spin-orbit interaction parameter ξ_{5d}.

ly if emission arises from an extremely small energy surface or if a band gap occurs near the Fermi surface.[1,2] In the case of molybdenum and tungsten it appears that the energy gap separating the upper and lower Δ_7 bands is the primary factor in producing the deviation in $J(E)$ from the expectations of the Sommerfeld model. The resolution of the band gap in Fig. 1 is not complete presumably because of emission from the Δ_6 and one leg of the Δ_7 band, both of which cross the gap region.

Further substantiation that the lower energy peak in Fig. 2 comes from the lower portion of the Δ_7 band is provided by the increase in relative emission from this band as the field strength is increased (see Fig. 1). This follows from the larger relative increase in transmission with electric field for emission from the lower energy band.

We therefore conclude from these results that field emission TED measurements can be employed to elucidate certain special features of the bulk electronic structure of metals. Also, the close correlation of the TED results with the internal band structure of molybdenum and tungsten suggests that bulk electronic properties are not greatly perturbed by the presence of a nearby physical surface.

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ELECTROMAGNETIC EXCITATION OF TRANSVERSE MICROWAVE PHONONS IN METALS

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We have generated coherent transverse phonons in indium films by direct excitation with microwaves. We have also observed the converse effect, electromagnetic radiation from the surface of indium films when excited by transverse microwave phonons. Just below the superconducting transition temperature T_c the effect rises slightly above the normal-state value, and then on further cooling it decreases rapidly. The experimental results can be explained semiquantitatively if it is assumed that the major coupling mechanism between the lattice and the electromagnetic field is provided by the normal electrons scattering at the boundaries of the film.[1] The condition necessary for the occurrence of the effect in a film or in a semi-infinite metal is that the electronic mean free path be larger than both the microwave penetration depth and the phonon wave number. In that case the two opposing forces exerted on the ions, the electric field and the impact of the colliding electrons, do not cancel each other. In a recent Letter, Houck et al.[2] presented evidence of rf-acoustic coupling near the surface of metals. However, their experiment differs from ours in that it was performed at lower frequencies, 10-40 Mc/sec, and the presence of a dc magnetic field was required. No dc magnetic field was used in this experiment.

The experimental arrangement is illustrated in Fig. 1. The indium films, several thousand angstroms in thickness, were evaporated on an optically polished surface of a high-purity single-crystal germanium rod. The axis of the rod was along the [110] direction and its end faces were polished parallel to 5 sec of arc. The germanium face, with the indium on it, was pressed against the bottom wall of a resonant rectangular microwave cavity. The wall was provided with a 0.5-cm-diam hole so that some of the microwave current flowed through the film. The cavity was excited with 9.3-GHz microwave pulses, 1 μsec in duration, 10-W peak power, and 5×10^{-4}

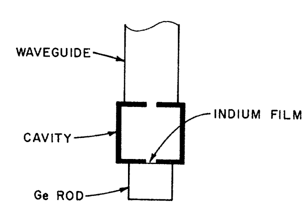

FIG. 1. Schematic of experimental setup.