beyond that caused by normal volume changes because of the increased overlap. This overlap results in a change of the electronic polarizability and an enhancement of the dielectric response. Our results, therefore, show that local fields are not necessary to explain this enhancement. Furthermore, since microscopic-field effects are apparently small, the broad features in the spectra of the optical properties can provide direct information about chemical bonding not only in Se but in the wider range of materials closely related to it.

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Spin Polarization of Field-Emitted Electrons and Magnetism at the (100) Surface of Ni

M. Landolt* and M. Campagna
Bell Laboratories, Murray Hill, New Jersey 07974

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The electron spin polarization of field-emitted electrons from atomically clean, field-evaporated in ultrahigh vacuum, single-crystal Ni tips has been measured with the probe hole selecting emission from the high-work-function (100) plane. We find $P = (-3.0 \pm 1)\%$ (magnetic moment antiparallel to the magnetization of the crystal). From an analysis of these and recent photoemission data we conclude that the magnetic (and electronic) properties of the surface and bulk Ni must be very similar.

Electron spin polarization (ESP) measurements in photoemission[1] from Ni single crystals have revealed negative ESP at threshold. At photothreshold, many-body effects of the type proposed by Anderson[2] and others[3] are not operative, and furthermore, because of the large escape depth of the low-kinetic-energy electrons, photoemission tests primarily bulk properties. Con-

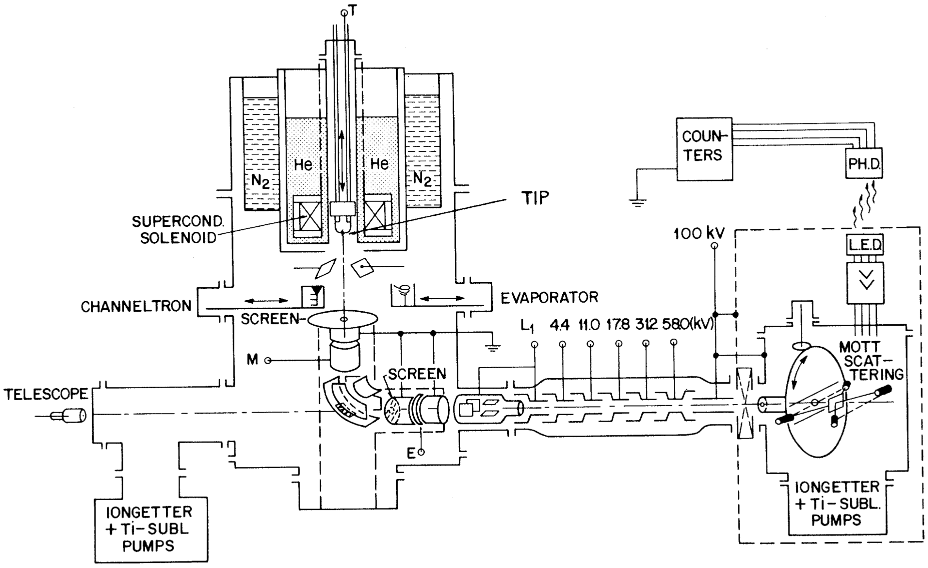

FIG. 1. Schematic diagram of the apparatus. The base pressure without liquid N_2 and He is 2×10^{-10} Torr.

sequently the negative ESP at threshold is attributed[1] to the spin-dependent *bulk* (initial) density of states at the Fermi level. The present ESP measurement in field emission (FE) from a high-symmetry plane of Ni now gives information on the spin-dependent *surface* density of states at the Fermi level, strongly weighted in the surface-normal direction.[4] A comparison between ESP in photoemission at threshold and FE provides direct information on the change in magnetic and electronic behavior in going from the bulk to the surface, and information of great relevance for the future understanding of the electronic properties of clean transition-metal surfaces.

Preliminary ESP measurements in FE from clean Ni along high-index directions[5] showed that the polarization is strongly direction dependent. Therefore, it is very important to select precisely electrons emitted in a well-defined [*hkl*] crystallographic direction for meaningful ESP measurements.[6] This is achieved by using the principle of the field-emission microscope invented by Erwin Müller and a screen with a probe-hole arrangement. FE tips are electrolytically etched from zone-refined single-crystal Ni wire (5*N*) provided by FEI Co., Oregon. They are cleaned, after previous annealing at 600°C, by low-temperature dc field evaporation in ultrahigh vacuum (UHV).[5] The evaporation rate is monitored by a Channeltron which can be moved in front of the tip. Fifty to a hundred monolayers are desorbed to obtain the first evaporated endform. During the ESP measurement the total FE current, which is a sensitive vacuum gauge, does not change within the first 15 min; and after a 5% decrease in the total FE current, occuring within about 50 min, the tip is cleaned again by field evaporation. No change of the FE pattern can be detected during ESP measurements, which were carried out at a tip temperature of about 80°K.

Figure 1 shows a scheme of the apparatus.[7] The field-emission pattern appearing on the first fluorescent screen (10 cm diam.) can be observed at an angle of 40° through a mirror. Figure 2 shows the field-evaporated endform of a (100)-oriented single-crystal Ni tip without magnetic field. During ESP measurements, the tip is centered in the superconducting solenoid. The magnetic field $\vec{H}$ defines the direction of magnetization of the sample in space. $\vec{H}$ compresses and distorts the emission pattern on the screen, but on the other hand, it can be used as an image-steering and -focusing device. This is achieved by moving the solenoid in the plane perpendicular to the tip axis, and by choosing suitable field strengths.

Figure 3 shows the emission pattern of the same tip during a polarization measurement in a magnetic field of 1.5 kOe. The probe hole (dashed line) is centered onto the (100) dark plane. With a total FE current of 5×10^{-8} A, counting rates of 10–15 Hz were obtained in the Mott-scattering detectors. The acceptance of the probe hole is 5°± 2° full angle, as determined from the

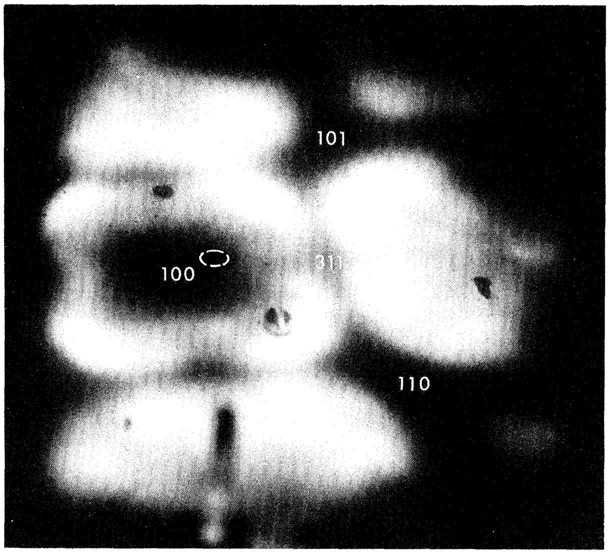

FIG. 2. Field-emission pattern of a UHV dc-field-evaporated endform of a single-crystal Ni(100) tip, indexed crystallographically. The left part of the fourfold FE image, which is observed at an angle of 40°, is shaded out by the Channeltron.

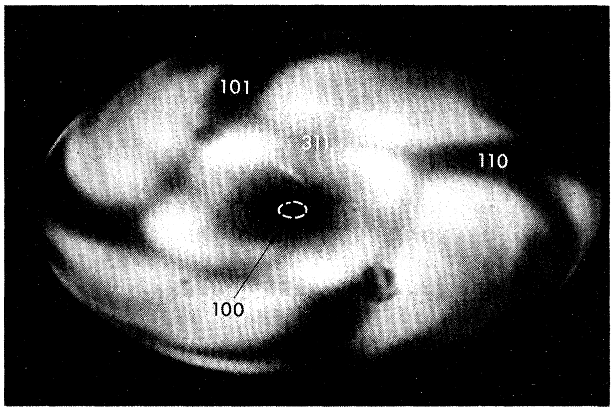

FIG. 3. Same as Fig. 2, but with an external magnetic field of 1.5 kOe. The probe hole (dashed line) selects emission from the (100) plane.

pattern. Because of angular momentum conservation, all the electrons with positive k_z, emitted only from an essentially flat (100) plane which contains a small number of steps,[8] are selected for ESP measurements. It can be seen from Fig. 2 that the distortion of the image is weak near the center and strong near the edge. This indicates that ESP measurements along directions with large angles from the axis of the tip and of the magnetic field can lead to erroneous results because of both rotations of the spin in crossed magnetic and electric fields[9] and improper selection of $[hkl]$.

For Ni(100) and with different tips we found $P = (-3.0 \pm 1)\%$, the error being due to statistics. ESP measurements at $T \sim 600°\mathrm{C}$, above the Curie point of Ni, and by focusing the total emission through the probe hole, gave $P = (0 \pm 0.2)\%$. (The tip was contaminated because of surface diffusion and surface segregation of bulk impurities.) Negative ESP means that the current of minority-spin electrons exceeds that of the majority-spin electrons. This result is in agreement in sign and magnitude with the photoemission result at threshold.[1] The FE value is smaller by one order of magnitude because s-band tunneling is predominant in FE,[10] while mainly d electrons are emitted in photoemission near threshold. Furthermore, the s-electron current in FE from the (100) plane of Ni is unpolarized[11] since s-d hybridization is very small at E_F for $\vec{k}$ parallel Γ-X in the Brillouin zone. From this agreement we conclude that the spin-dependent density of states near the Fermi energy is similar in the bulk and on the (100) surface of Ni. This means that the existence of magnetic "dead layers" on the clean surface of Ni[12] can be excluded. The results provide a test for the calculations of surface electronic properties of itinerant magnets similar to Ni.[13]

We note that the observed ESP in both FE and photoemission near threshold can be understood in the framework of band theory. Politzer and Cutler[14] first calculated ESP in field emission from Ni(100), assuming a rigid splitting between d bands and no s polarization, and found -4%, in good agreement with the present experimental results. Using the band model and assuming direct optical transitions and constant matrix elements, Smith and Traum[15] predicted negative ESP at photothreshold and a sharp increase to positive polarization values at photon energies only a few tenth of an eV above threshold. The experimental ESP data in photoemission[1] are in good agreement with this calculation near threshold. Only at higher photon energies is the agreement poor, suggesting that the considerations given in Refs. 2 and 3 are important. This fact and the present data support the view that band theory may be capable of explaining ground-state properties of itinerant magnets while important corrections are needed for interpreting excitation spectra at photon energies far above photothreshold.

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*Fellow of Schweizerischer Nationalfonds. Postdoctoral Research Fellow at Bell Laboratories.

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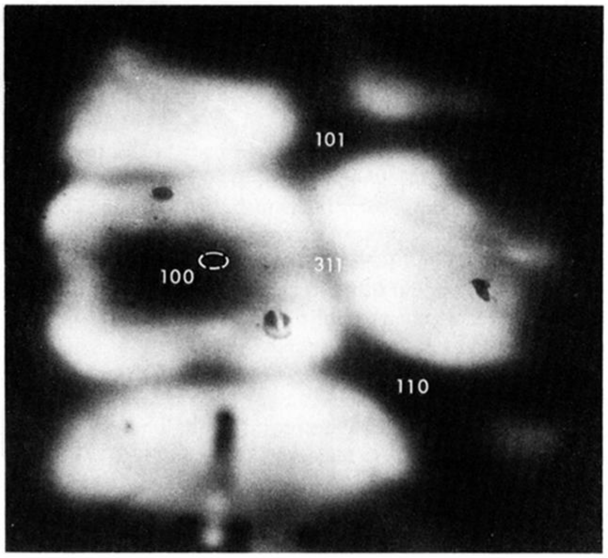
ERRATUM

OBSERVATION OF PROMPT SINGLE MUONS AND DIMUONS IN HADRON-NUCLEUS COLLISIONS AT 200 GeV/*c*. J. G. Branson, G. H. Sanders, A. J. S. Smith, J. J. Thaler, K. J. Anderson, G. G. Henry, K. T. McDonald, J. E. Pilcher, and E. I. Rosenberg [Phys. Rev. Lett. 38, 457 (1977)].

On page 458, column 1, line 19, the citation of Ref. 5 should be Ref. 4. On page 460, in Fig. 2 and its caption, Ref. 5 should read Ref. 4.



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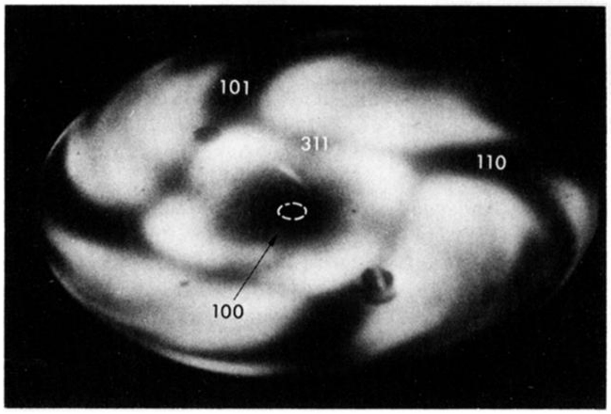

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