

High Resolution Photoemission Study of the Spin-Dependent Band Structure of Permalloy and Ni

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High resolution, angular-resolved photoemission is used in a comparison of the energy bands of permalloy ($\text{Ni}_{0.8}\text{Fe}_{0.2}$) and single crystal Ni. The nickel was cleaned with a combination of Ar-ion bombardment and annealing. The permalloy was grown epitaxially on the clean single crystal Ni surface to minimize lattice mismatch. The magnetically split bands at the Fermi level that are responsible for spin-dependent transport are resolved in both systems. In addition, spectra are shown demonstrating both “*s,p*” and *d* bands in Ni. © 2000 American Vacuum Society. [S1055-5269(99)00104-8]

Keywords: permalloy; nickel; photoemission; single crystal

PACS: 79.60.Bm, 71.20.Be, 75.50.Bb

SPECIMEN DESCRIPTION (Accession #00509) —————

Host Material: Epitaxial permalloy ($\text{Ni}_{0.8}\text{Fe}_{0.2}$ film on Ni(100))

Host Material Characteristics: homogeneous; solid; unknown crystallinity; conductor; metal; thin film

Chemical Name: not specified

Source: thermally grown $\text{Ni}_{0.8}\text{Fe}_{0.2}$ on $T=200$ K Ni(100) substrate ($\text{Ni}_{0.8}\text{Fe}_{0.2}$ wire heated by electron bombardment), annealed to RT

Host Composition: $\text{Ni}_{0.8}\text{Fe}_{0.2}$

Form: epitaxial permalloy film on Ni(100), single crystal

Structure: [100] fcc

History & Significance: Permalloy is one of the most used materials in magnetic storage and sensor applications. Its properties include high permeability, low coercivity, no magnetostriction and a large difference in conductivity between majority and minority spins (Ref. 1).

As Received Condition: as grown

Analyzed Region: same as host material

Ex Situ Preparation/Mounting: The Ni(100) substrate was polished to $0.3 \mu\text{m}$ and chemically etched for 60–90 s in a 5:3:1:1 solution of glacial acetic acid: HNO_3 : H_2SO_4 : H_3PO_4 .

In Situ Preparation: Argon ion sputtering and annealing of Ni substrate for 5 min at 600°C , then 10 ML $\text{Ni}_{0.8}\text{Fe}_{0.2}$ thermally grown on the cooled (200 K) Ni and post-annealed to 350°C for 20 s.

Charge Control: none necessary

Temp. During Analysis: 100 K

Pressure During Analysis: $<2.6 \times 10^{-8}$ Pa

SPECIMEN DESCRIPTION (Accession #00510) —————

Host Material: Ni(100)

CAS Registry #: 7440-02-0

Host Material Characteristics: homogeneous; solid; single crystal; conductor; metal

Chemical Name: not specified

Accession #s 00509, 00510, 00511

Technique: UPS

Host Material: #00509: Epitaxial permalloy ($\text{Ni}_{0.8}\text{Fe}_{0.2}$ film on Ni(100)); #00510: Ni(100); #00511: Ni(110)

Instrument: Scienta SC200

Major Elements in Spectrum: Ni, Fe

Minor Elements in Spectrum: none

Printed Spectra: 6

Spectra in Electronic Record: 6

Spectral Category: comparison

Original Submission: 8/16/99

Accepted for Publication: 9/28/99

Host Composition: Ni

Form: single crystal [100]

Structure: [100] fcc

As Received Condition: not specified

Analyzed Region: same as host material

Ex Situ Preparation/Mounting: mechanically polished to $0.3 \mu\text{m}$ and chemically etched for 60–90 s in a 5:3:1:1 solution of glacial acetic acid: HNO_3 : H_2SO_4 : H_3PO_4

In Situ Preparation: Argon ion sputter cleaning (500 V) and annealing for 5 min at 600°C

Charge Control: none necessary

Temp. During Analysis: 100 K

Pressure During Analysis: $<2.6 \times 10^{-8}$ Pa

SPECIMEN DESCRIPTION (Accession #00511) —————

Host Material: Ni(110)

CAS Registry #: 7440-02-0

Host Material Characteristics: homogeneous; solid; single crystal; conductor; metal

Chemical Name: not specified

Host Composition: Ni

Form: single crystal [110]

Structure: [110] fcc

As Received Condition: not specified

Analyzed Region: same as host material

Ex Situ Preparation/Mounting: mechanically polished to $0.3 \mu\text{m}$ and chemically etched for 60–90 s in a 5:3:1:1 solution of glacial acetic acid: HNO_3 : H_2SO_4 : H_3PO_4

In Situ Preparation: Argon ion sputter cleaning (500 V) and annealing for 5 min at 600°C

Charge Control: not specified

Temp. During Analysis: 100 K

Pressure During Analysis: $<2.6 \times 10^{-8}$ Pa

INSTRUMENT DESCRIPTION

Manufacturer and Model: Scienta SC200

Analyzer Type: spherical sector

Detector: The detector is a channelplate and phosphor screen in conjunction with a CCD camera. The Scienta allows simultaneous 2D multidetection of both energy and angular information with a fixed sample position. The optics are designed to focus all electrons at a given emission angle to a single column on the multichannel plate and all electrons with a single energy are mapped to a single row. For a fixed energy, 60 angular channels over a range of emission angles of 12.5° are simultaneously measured. At the same time, 50 energy channels over a 1 eV range are simultaneously measured for each emission angle.

Number of Detector Elements: 60 angular channels at each energy, 50 energy channels at each emission angle

INSTRUMENT PARAMETERS COMMON TO ALL SPECTRA

■ Spectrometer

Analyzer Mode: constant pass energy

Throughput ($T=E^N$): $N=-1$

Excitation Source Window: not specified

Excitation Source: Synchrotron radiation

Source Strength: not specified

Analyzer Width: $2500 \mu\text{m} \times 1000 \mu\text{m}$

Signal Mode: multichannel indirect

Effective Detector Width: 0.5 eV

■ Geometry

Incident Angle: varies by spectrum

Source to Analyzer Angle: varies by spectrum

Emission Angle: varies by spectrum

Specimen Azimuthal Angle: 0°

Acceptance Angle from Analyzer Axis: 0°

Analyzer Angular Acceptance Width: $14^\circ \times 14^\circ$

Comments: In plane electric field vector selects even states such as *s, p* band.

DATA ANALYSIS METHOD

Energy Scale Correction: The Fermi level was found through fitting of Fermi function at $h\nu - 4.13$ eV. This value is used to convert to a binding energy scale.

Intensity Scale Correction: Because spectra were taken with angle-resolved multichannel detection, possible channel asymmetries had to be removed. This was done by repeating a spectrum at a higher photon energy (5 V higher) and dividing, channel by channel, the original spectrum by this new scan of the secondaries.

ACKNOWLEDGMENTS

This work was supported by the NSF under Award Nos. DMR-9624753, DMR-9632527, DMR-9704196, and DMR-9400399. It was conducted at the Synchrotron Radiation Center, which is also supported by the NSF under Award No. DMR-9531009.

REFERENCES

1. D. Y. Petrovykh, K. N. Altmann, H. Höchst, M. Lanbscher, S. Maat, G. J. Mankey, and F. J. Himpsel, *Appl. Phys. Lett.* **73**, 1459 (1998).
2. K. N. Altmann, D. Y. Petrovykh, G. J. Mankey, N. Shannon, N. Gilman, M. Hochstrasser, R. F. Willis, and F. J. Himpsel (to be published).

Footnote to Spectrum 00509-01: The number of data points for this spectrum is the product of the sum of 5 angular channels and 261 energy channels = 261. The figure shows the Σ_1 band crossing in permalloy at $h\nu=44$ eV, $k^{\parallel} = 0.67 \text{ \AA}^{-1}$.

Footnote to Spectrum 00510-01: The number of data points in this spectrum is the product of 1 angular channel and 261 energy channels = 261. The figure shows the Σ_1 band crossing in Ni(100) at $h\nu=44$ eV, $k^{\parallel}=0.93 \text{ \AA}^{-1}$.

Footnote to Spectrum 00511-01: The number of data points for this spectrum is the product of 50 angular channels and 101 energy channels = 5050. The figure shows energy and momentum distribution of photoelectrons near the Fermi level crossing of the Σ_1 band in Ni(110) (high photoelectron intensity is dark). $K^{\parallel}=(2m \times E)/\hbar \times \sin(\Theta)=0.51 \times (E) * \sin(\Theta)$, in \AA^{-1} , where m is the electron mass, E is the kinetic energy (in eV), \hbar is the reduced Planck constant, and Θ is the emission angle relative to the sample normal.

Footnote to Spectrum 00511-02: The number of data points for this spectrum is the product of 50 angular channels and 1 energy channel =50. The figure shows momentum distribution of photoelectrons at E_F (horizontal cut at E_F in Accession #00511-01). $K^{\parallel}=(2m \times E)/\hbar \times \sin(\Theta)=0.51 \times (E) * \sin(\Theta)$, in \AA^{-1} , where m is the electron mass, E is the kinetic energy (in eV), \hbar is the reduced Planck constant, and Θ is the emission angle relative to the sample normal.

Footnote to Spectrum 00511-03: The number of data points for this spectrum is the product of the sum of 7 angular channels and 201 energy channels=201. The figure shows the d bands near the x pt. in Ni(110), $h\nu=15$ eV, normal emission.

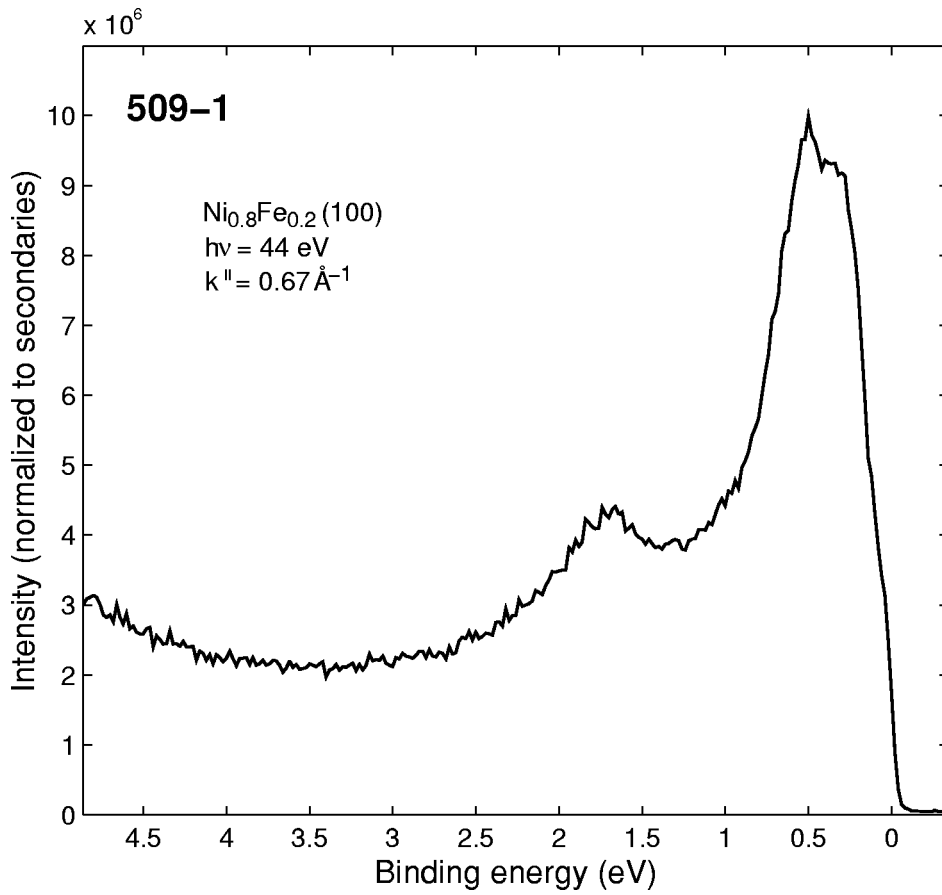
Footnote to Spectrum 00511-04: The number of data points for this spectrum is the product of the sum of 3 angular channels and 101 energy channels = 101. The figure shows the Σ_1 band crossing in Ni(110) at $h\nu=27$ eV, $k^{\parallel}=1.60 \text{ \AA}^{-1}$ (vertical cut in Accession #00511-01).

GUIDE TO FIGURES

Spectrum (Accession) #	Spectral Region	Sample Voltage*	Multiplier	Baseline	Comment #
509-1	Valence band	0	1	0	1, 4
510-1	Valence band	0	1	0	1, 5
511-1	k -resolved valence band	0	1	0	2, 6
511-2	k -resolved Fermi level	0	1	0	2, 6
511-3	Valence band	0	1	0	3, 7
511-4	Valence band	0	1	0	2, 8

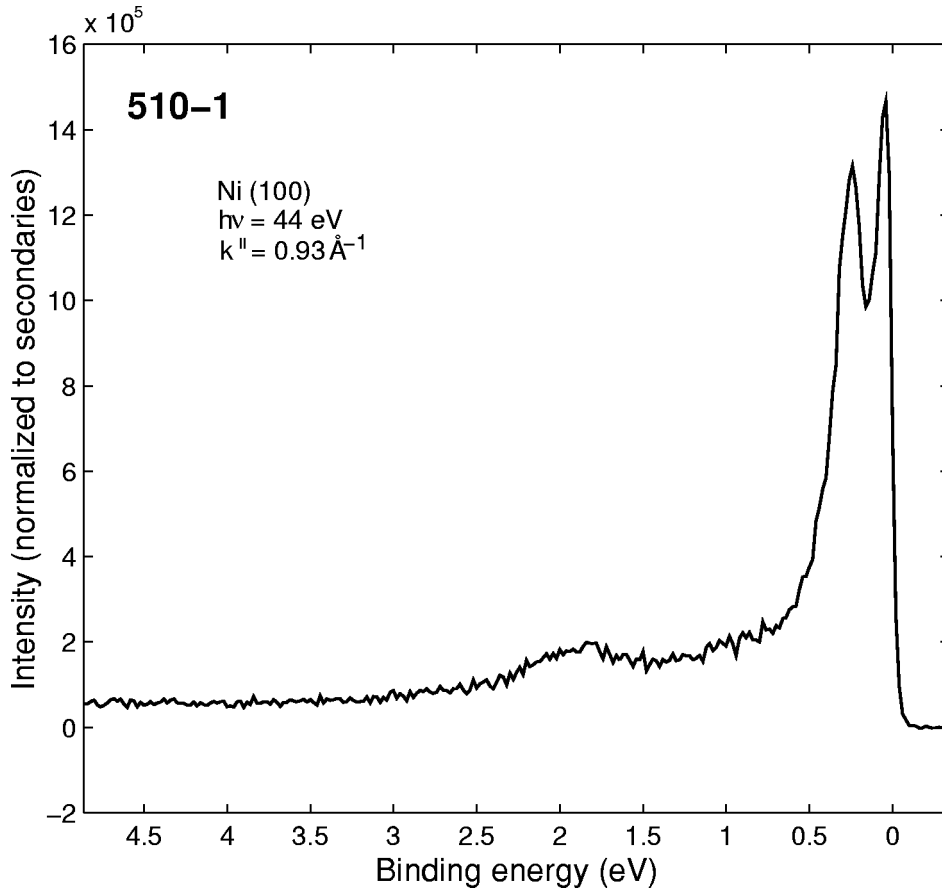
*Inferred sample potential relative to spectrometer ground due to charging, flood gun, or other phenomena.

1. Photon energy 44 eV.
2. Photon energy 27 eV.
3. Photon energy 15 eV.
4. Emission angle 12.0°, incident angle 46°.
5. Emission angle 16.8°, incident angle 46°.
6. Multiple emission angles, incident angle 19°.
7. Emission angle 0°, incident angle 61°.
8. Emission angle 41.4°, incident angle 19°.



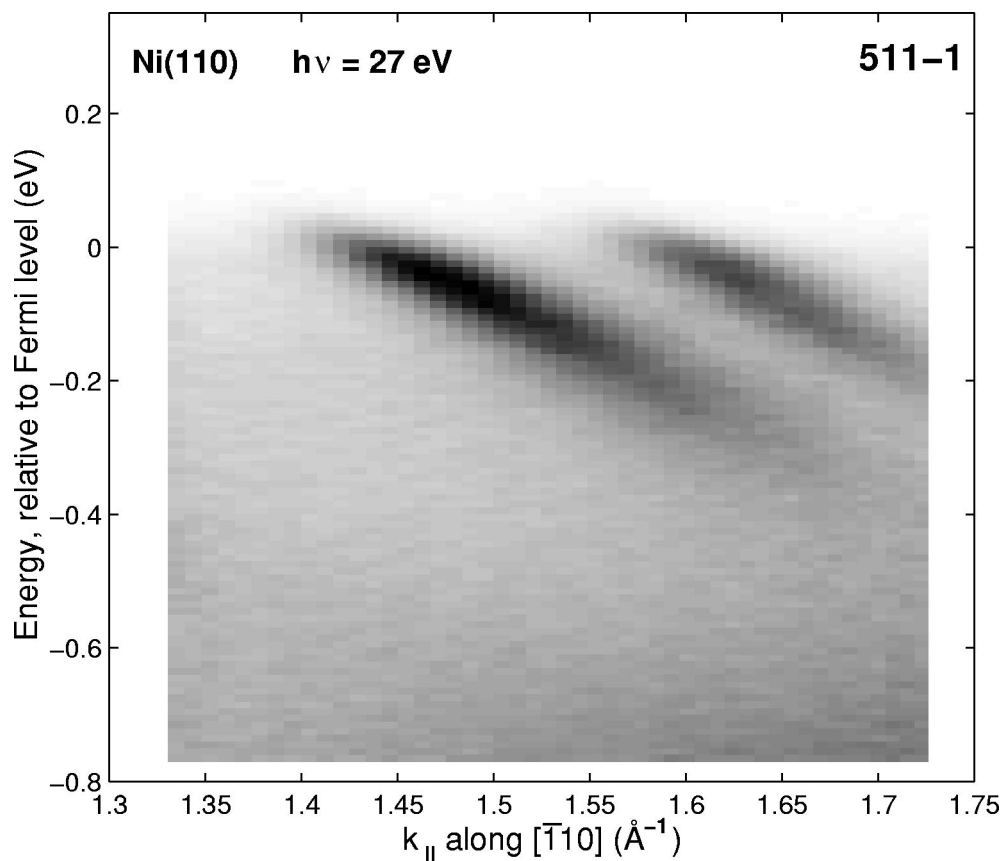
- **Accession #:** 00509-01
- **Host Material:** Epitaxial permalloy ($\text{Ni}_{0.8}\text{Fe}_{0.2}$ film on Ni(100))
- **Technique:** UPS
- **Spectral Region:** valence band

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 44 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: 12.0°
 Incident Angle: 46°
 Total Signal Accumulation Time: 130 s
 Total Elapsed Time: 130 s
 Number of Scans: 5
 Comment: See footnote after References.



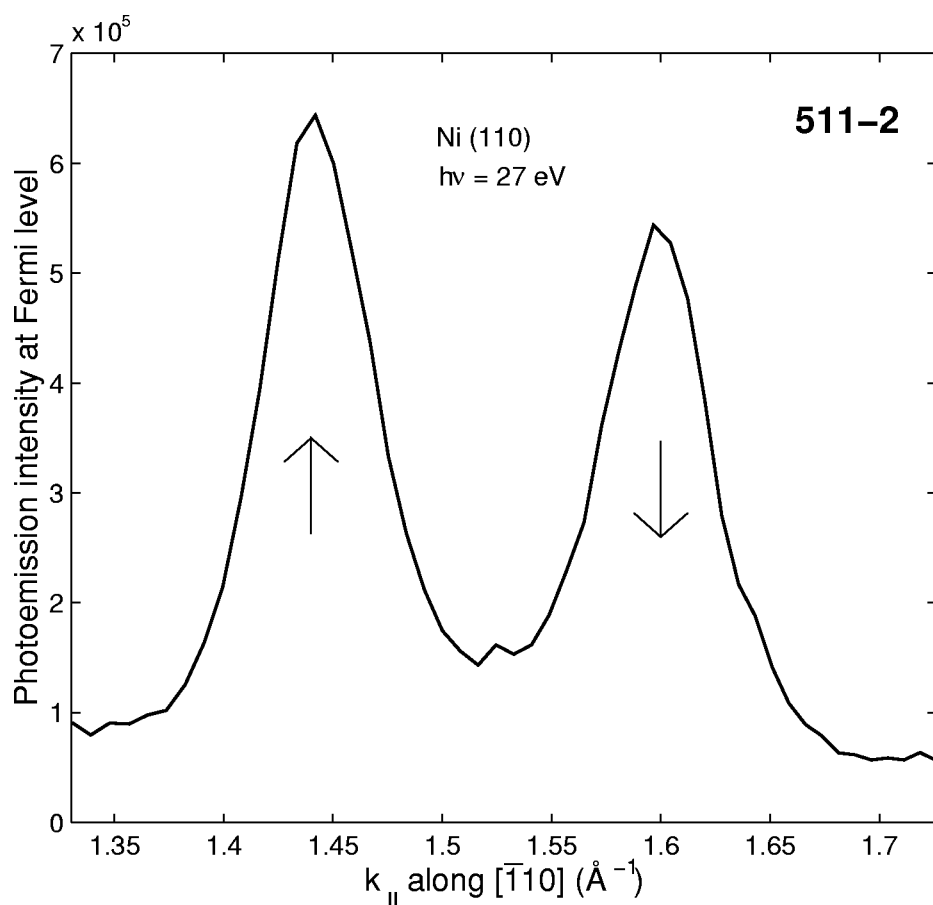
- **Accession #:** 00510-01
- **Host Material:** Ni(100)
- **Technique:** UPS
- **Spectral Region:** valence band

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 44 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: 16.8°
 Incident Angle: 46°
 Total Signal Accumulation Time: 130 s
 Total Elapsed Time: 130 s
 Number of Scans: 5
 Comment: See footnote after References.



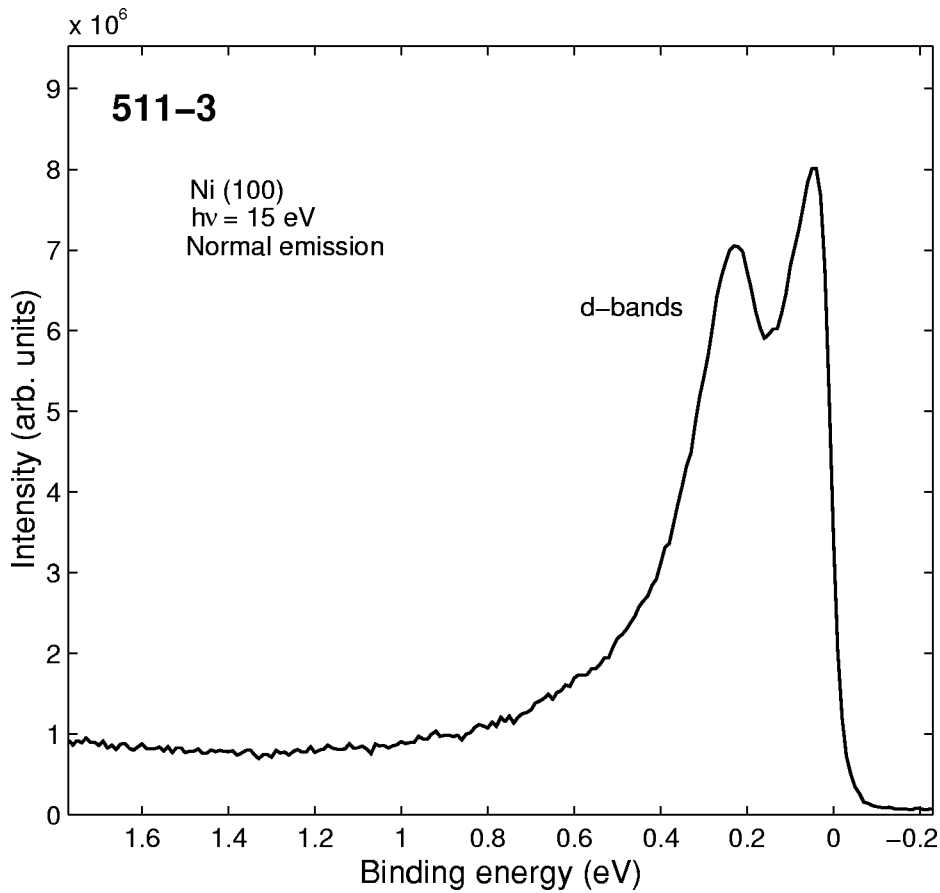
- Accession #: 00511-01
- Host Material: Ni(110)
- Technique: UPS
- Spectral Region: k -resolved valence band

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 27 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: multiple emission angles
 Incident Angle: 19°
 Total Signal Accumulation Time: 101 s
 Total Elapsed Time: 101 s
 Number of Scans: 10
 Comment: See footnote after References, and also Ref. 2.



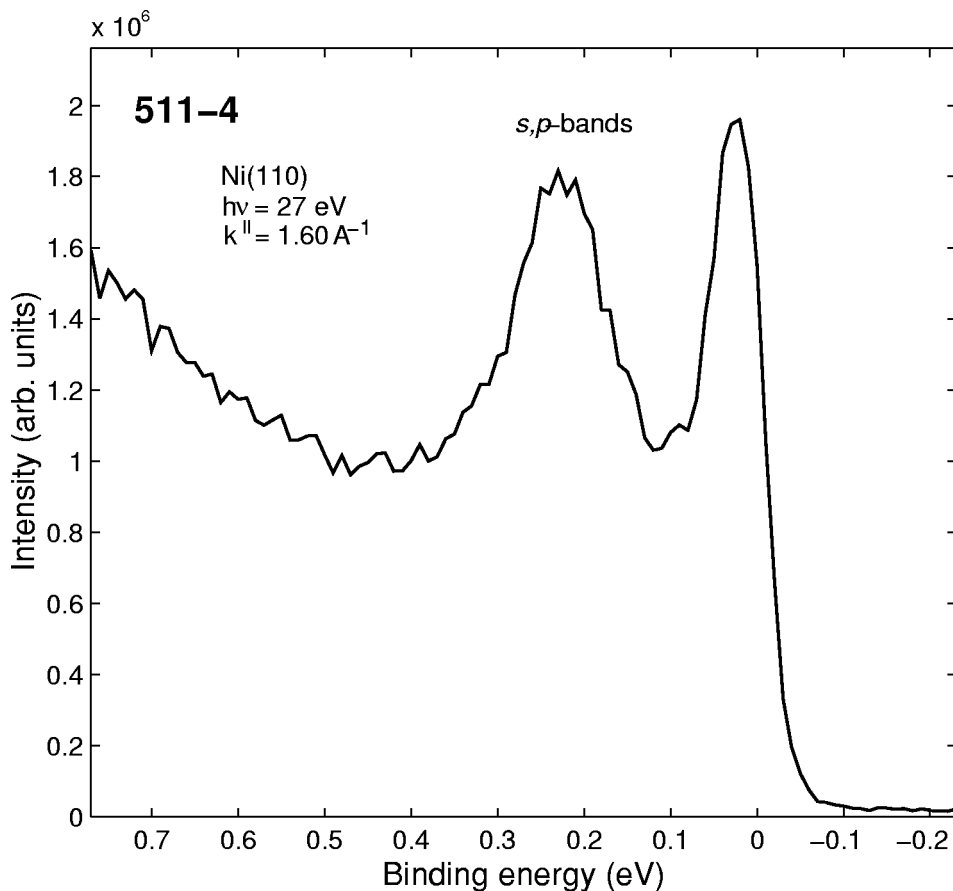
- Accession #: 00511-02
- Host Material: Ni(110)
- Technique: UPS
- Spectral Region: k -resolved Fermi level intensity

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 27 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: multiple emission angles
 Incident Angle: 19°
 Total Signal Accumulation Time: 1 s
 Total Elapsed Time: 1 s
 Number of Scans: 10
 Comment: See footnote after References.



■ **Accession #:** 00511-03
 ■ **Host Material:** Ni(110)
 ■ **Technique:** UPS
 ■ **Spectral Region:** valence band

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 15 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: 0°
 Incident Angle: 61°
 Total Signal Accumulation Time: 20 s
 Total Elapsed Time: 20 s
 Number of Scans: 1
 Comment: See footnote after References.



■ **Accession #:** 00511-04
 ■ **Host Material:** Ni(110)
 ■ **Technique:** UPS
 ■ **Spectral Region:** valence band

Instrument: Scienta SC200
 Excitation Source: Synchrotron radiation
 Source Energy: 27 eV
 Source Strength: not specified
 Source Size: not specified
 Analyzer Type: spherical sector
 Analyzer Pass Energy: 5 eV
 Analyzer Resolution: 0.006 eV
 Emission Angle: 41.4°
 Incident Angle: 19°
 Total Signal Accumulation Time: 101 s
 Total Elapsed Time: 101 s
 Number of Scans: 10
 Comment: See footnote after References.