Enhanced surface and reduced interface moments for Ni/Cu(001)

K. Lenz, A. Ney[a], A. Scherz, P. Poulopoulos[b], H. Wende, and K. Baberschke

Freie Universität Berlin, Institut für Experimentalphysik
Arnimallee 14, 14195 Berlin-Dahlem, Germany
[a]Paul-Drude Institut, Hausvogteiplatz 5-7, 10117 Berlin-Mitte, Germany
[b]University of Patras, Materials Science Department, 26504 Patras, Greece

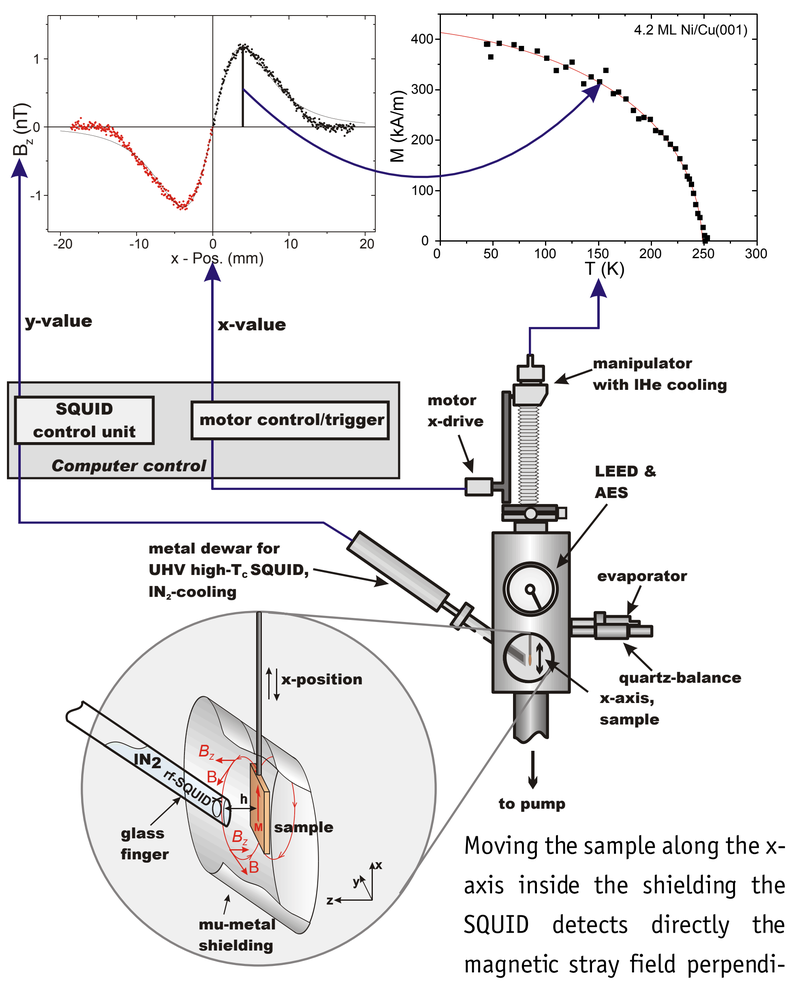
Abstract

The total magnetic moments of ultrathin Ni/Cu(001) films from 2 to 12 monolayers were determined using an ultrahigh vacuum compatible high-T_c SQUID magnetometer [1]. We deduce separately surface and interface magnetic moment contributions by analyzing thickness-dependent moments of Ni/Cu(001) and Cu/Ni/Cu(001). The surface atoms are shown to carry a by 44% enhanced moment, while the interface moment is reduced by 50% [2]. This is attributed to a reduced coordination number of the surface atoms and hybridization effects between Ni and Cu at the interface. The resulting magnetization of thin Ni films is almost bulk-like.

Sample preparation & measurement

- evaporation of Ni at room-temperature
  → pseudomorph, strained and layer-by-layer growth on Cu(001) [9]
- thickness-determination using a quartz-micro-balance
- magnetic saturation with pulse-driven electromagnet after cooling
  → ultrahin films remain in a single-domain state [10]
- SQUID-measurement in remanence
- evaporation of Cu-cap at room-temperature after SQUID-measurement

Setup of the UHV-high-T_c SQUID magnetometer



Moving the sample along the x-axis inside the shielding the SQUID detects directly the magnetic stray field perpendicular to its plane (red arrows).

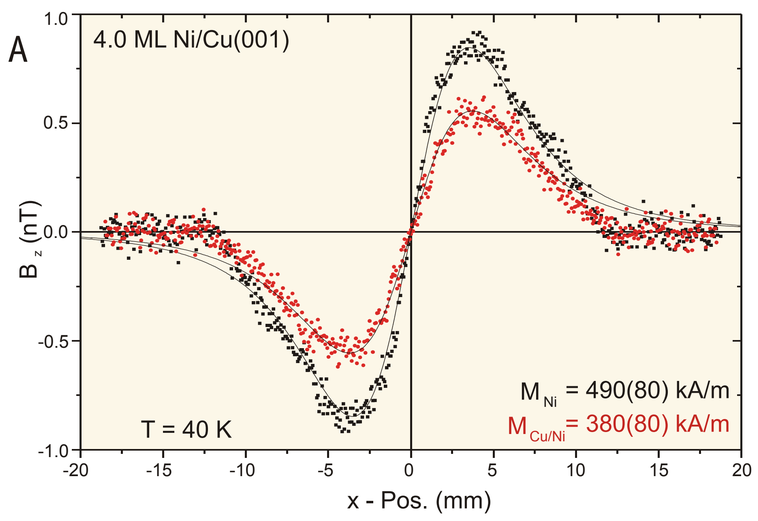
This stray field is recorded as a function of space. The upper-left graph shows such a single measurement of an in-plane magnetized sample.

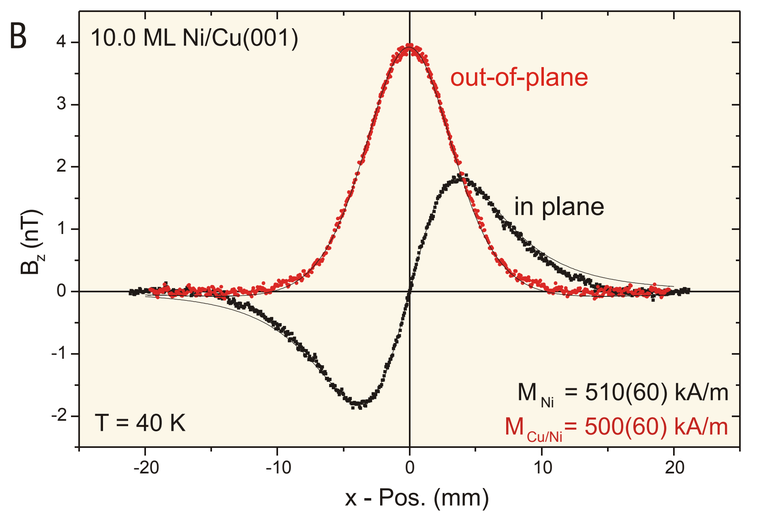
The magnetization is derived by fitting a calculated field distribution to the data. Its temperature dependence for 4.2 ML Ni is shown in the upper-right graph. The accessible temperature range is 40 to 300 K using lHe.

References

[1] A. Ney *et al.*, Phys. Rev. B **62**, 11336 (2000)
[2] A. Ney *et al.*, Phys. Rev. B **65**, 024411 (2001)
[3] P. Srivastava *et al.*, Phys. Rev. B **58**, 5701 (1998)
[4] W. Kuch *et al.*, Phys. Rev. B **62**, 3824 (2000)
[5] S. Hope *et al.*, Phys. Rev. B **55**, 11422 (1997)
[6] A. Ernst *et al.*, J. Phys.: Condens. Mat. **12**, 5599 (2000)
[7] Z. Yang *et al.*, Surf. Sci. **447**, 212 (2000)
[8] S. H. Kim *et al.*, Phys. Rev. B **55**, 7904 (1997)
[9] P. Poulopoulos *et al.*, Surf. Sci. **437**,277 (1999)
[10] R. Allenspach, J. Magn. Magn. Mater. **129**, 160 (1994)
[11] A. Ney *et al.*, Europhys. Lett. **54**, 820 (2001)

Magnetization of Ni/Cu(001)





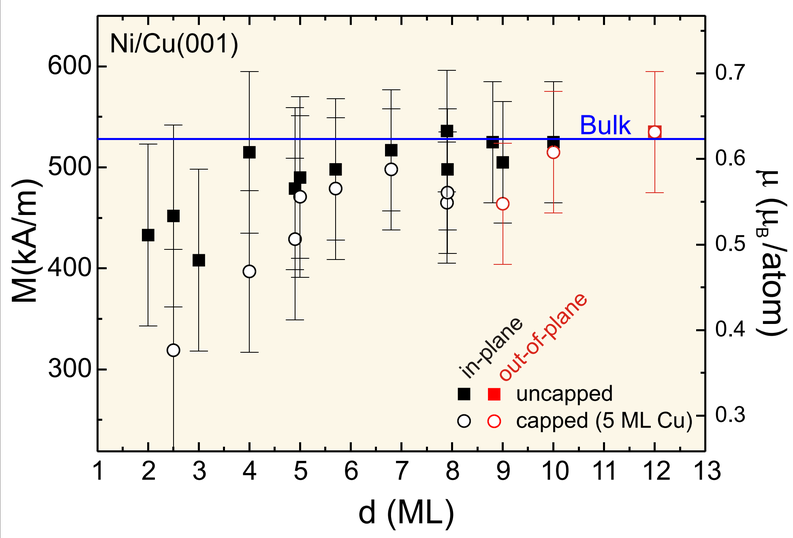
Stray field of capped (●) and uncapped (■) Ni films 4 ML and 10 ML thick.

A. The reduction is caused by two reasons: (i) the surface is turned into an interface, (ii) the Curie temperature is lowered.

B. Upon Cu capping the easy axis of the magnetization changes from in- to out-of-plane. The absolute magnetizations stays the same.

The excellent signal-to-noise ratio for the thin Ni film demonstrates the high sensitivity (submonolayers of Co) of the present setup.

Magnetization of Ni/Cu(001)



The measured remanent magnetizations at 40 K were extrapolated to T=0K. A series of Ni/Cu(001) films between 2 and 12 ML is shown before (■,■) and after (❍,❍) Cu capping.

All films above 4 ML present bulklike magnetizations and no thickness-dependence. The values for the Cu-capped films are about 10% smaller.

One can see the reorientation-transition from in-plane to out-of-plane at 10-11 ML for the uncapped and 8-9 ML for the Cu-capped film, respectively.

Acknowledgment

This work was supported by the DFG, Sfb 290, TP A2.
We are grateful to the FINO AG, Hildesheim for technical assistance, support, and providing the SQUID chip.

Published contesting experimental results for Ni

Ni-thickness	tot. moment (μ_B /atom)	
4 ML	0,3(1)	(ref. [3])
2 to 12 ML	0,61(9)	(this work, ref. [2])
11 to 14 ML	0,65	(ref. [4])
3 nm (17 ML)	0,10(9)	(ref. [5])
8 nm (45 ML)	0,23(5)	
10 nm (56 ML)	0,41(4)	
15 nm (85 ML)	0,63(3)	

The experimental results of the total magnetic moment of Ni-films differ over a wide range. Not long ago it was believed, that Ni shows a strongly reduced magnetic moment, but recent works [2,4] show no reduction and a thickness independent bulk-like value of 0.615 μ_B.

Reduced values due to a reorientation of the easy axis to 45°can be clearly ruled out, as well as floating Cu-layers [8] coming from the substrate, because the SQUID detects the bulk-value without a cap and a clear reduction after capping.

Theory vs. Experiment

tot. Ni-moment (μ_B/atom)	experiment this work	theory ref. [6]	theory ref. [7]	
bulk	0,61(8)	0,57 [a]	0,72 [b]	*(0,65)*
4 ML uncapped	0,61(9)	0,52	0,69	*(0,62)*
4 ML capped	0,47(9)	-	0,61	*(0,55)*
surface	0,88(12)	0,64	0,81	*(0,73)*
bulk	0,61(8)	0,55	0,71	*(0,64)*
interface	0,31(10)	0,37	0,51	*(0,46)*

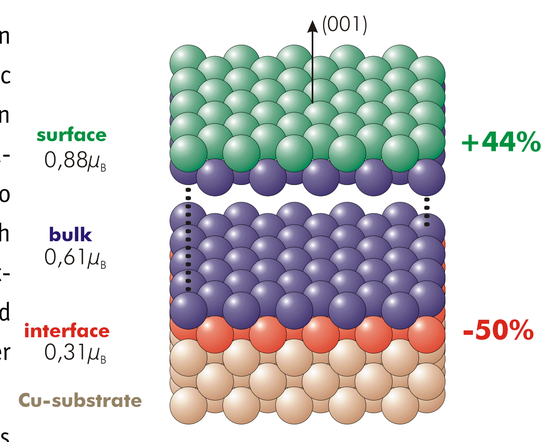
[a] In Ref. 6 the moments were calculated in the Korringa-Kohn-Rostoker (KKR) approach and they are assumed to be the spin plus the orbital contribution.
[b] In Ref. 7 spin and orbital moment are calculated by means of the generalized-gradient approximation (GGA). It is known (Ref. 28) that the GGA overestimates the moment by 8–10 %. Therefore, 10% reduced values are given in parenthesis.

Comparison between the total magnetic moments of 4 ML Ni/Cu(001) from the present experiment and previous theoretical works [6,7].

The moment distribution over surface, bulk, and interface layer is derived from the thickness-dependent in-situ measurements with/without a Cu-cap. The lower section shows that the surface-moment is by 44% enhanced with respect to the bulk-moment, while the interface-moment is reduced by 50%. Enhancement and reduction cancel out each other for the uncapped film, resulting in the bulk-like moment. This shows clear the reduced moment of the Cu-capped film.

Ni moment distribution

Resulting distribution of the total magnetic moment of Ni films on Cu(001) [2]. The surface moment is found to be enhanced with respect to the bulk-value due to Ni d-band narrowing and lower coordination.



The interface moment is reduced. This effect is attributed to hybridization effects between the d-bands of Ni and Cu.

The substrate- and the cap-facing layers are assumed to be equivalent with respect to the magnetic properties.

Contrary to that, the strongly enhanced surface-moment of Co/Cu(001) leads to an increasing total moment while the thickness decreases. [11]