Soft-X-ray magnetic circular dichroism
Tjeng, L.H.; Idzerda, Y.U.; Rudolf, Petra; Sette, F.; Chen, C.T.

Published in:
Journal of Magnetism and Magnetic Materials

DOI:
10.1016/0304-8853(92)91762-I

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1992

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.
Soft-X-ray magnetic circular dichroism: a new technique for probing magnetic properties of magnetic surfaces and ultrathin films

L.H. Tjeng a, Y.U. Idzerda b, P. Rudolf a, F. Sette a and C.T. Chen a

a AT&T Bell Laboratories, Murray Hill, NJ 07974, USA
b Naval Research Laboratory, Washington, DC 20375, USA

Received 12 July 1991; in revised form 10 October 1991

We demonstrate the feasibility of applying the novel soft-X-ray magnetic circular dichroism (SXMCD) technique to investigate the magnetic properties of magnetic surfaces and ultrathin films. Measurements have been carried out on Ni films of various thickness on a Cu(100) substrate at the Ni L₂,₃ absorption edges. The SXMCD data exhibit strong temperature and thickness dependence, giving film thickness dependent Curie temperatures and suggesting that a single monolayer of Ni on a Cu(100) substrate may be non-magnetic.

1. Introduction

Recent advances in synchrotron radiation instrumentation have made possible the production of high quality circularly polarized light in the soft-X-ray region (100–1500 eV) [1,2]. Soft-X-ray magnetic circular dichroism (SXMCD), the difference in the absorption intensity of magnetic systems using left- and right-circularly polarized soft-X-rays, provides a unique means to probe the element and site specific magnetic moments in a broad range of magnetic systems. It offers new information complementary to that from spin-polarized photoemission spectroscopy, and can resolve ambiguities in absorption studies using unpolarized light.

Magnetic circular dichroism (MCD) measurements using soft-X-rays have several advantages over using photons in other energy regions. The soft-X-ray region gives access to the strong dipole-permitted core 2p to valence 3d excitations of transition-metal and core 3d to valence 4f of rare-earth magnetic materials. These 3d and 4f states are responsible for most of the magnetic properties. In the hard-X-ray region [3] these 3d and 4f states can only be reached, respectively, through the weak quadrupole transitions from the 1s core level of transition-metals and 2p core level of rare-earths. The broad natural linewidth of these deep 1s and 2p core levels also trends to smear out the fine structure in absorption and MCD spectra. On the other hand, in the VUV region [4] the MCD can be measured through the strong dipole-permitted core 3p to valence 3d excitations of transition-metal and core 4d to valence 4f excitations of rare-earths, however, the unresolvable spin–orbit splitting of the 3p₁/₂ and 3p₃/₂, and of the 4d½ and 4d₄/₂ levels make the data analysis a difficult task. In comparison to the well-established magneto-optic Kerr effect technique [5], MCD in the visible light region, the SXMCD process involves only local excitations, and therefore gives element and site specifications and a relatively easier data interpretation than that of the MOKE, where detailed knowledge of the delocalized valence (occupied) and conduction (unoccupied) states together with the momentum dependent optical transition matrix.

0304-8853/92/$05.00 © 1992 – Elsevier Science Publishers B.V. All rights reserved
elements are required. The situation for MOKE is even more complicated for systems where electron correlation effects play an important role in the electronic structure, and for thin films or multilayer systems where interference effects of the visible light between various interfaces have to be taken into account.

In this paper, we demonstrate the feasibility of applying SXMCD to the investigation of the magnetic properties of ultrathin films by measuring the temperature dependent SXMCD of Ni films of various thicknesses grown on Cu(100), yielding layer thickness dependent Curie temperatures.

2. Experimental

The experiments were performed at the AT&T Bell Laboratories Dragon high resolution soft-X-ray beamline located at the National Synchrotron Light Source, Brookhaven National Laboratories [1]. The beamline optical arrangement in the circular polarization mode has been described previously [2]. In the MCD experiments presented here, the monochromator resolution was kept at 0.5 eV in the 840–890 eV photon energy range and the degree of circular polarization was calculated to be ≈ 90%. The X-ray absorption spectra from Ni on Cu(100) films were recorded in the partial electron yield mode where electrons with kinetic energies higher than 20 eV are counted using a channeltron. The light was at grazing incidence along the (010) surface plane direction and the illuminated area of the sample was 9 × 2 mm². A remnant magnetic field was established in the Ni film by using an electromagnet pulsed parallel or anti-parallel to the same (010) surface direction. For the temperature dependent MCD experiment, the absorption intensity was measured only at the L₃ white line and at 5 eV below. This allows about 20 cycles of parallel and anti-parallel magnetizations in 5 minutes to achieve a ≈ 0.3% sensitivity in the MCD to absorption ratio. This sensitivity is mainly limited by the instability of the electron orbit of the synchrotron radiation ring.

3. Results and discussion

Thin films of Ni were evaporated onto a clean and well-ordered Cu(100) surface which was kept at room temperature. During evaporation a beam of 2 keV electrons was directed onto the sample, and the electron beam induced crystal current (EBIC) was monitored [6]. Changes in the current can be related to abrupt changes in the Ni/Cu Auger intensity, which in turn can be associated with the completion of a monolayer [7,8]; the thickness of the Ni films are determined by counting the number of oscillations, in a way similar to the reflection high energy electron diffraction (RHEED) method used in metal molecular beam epitaxy (MBE) [9]. Fig. 1 shows such oscillations and suggests good epitaxy growth for up to 6 layers [8,10]. For the 6 layer sample, the Cu 2p X-ray photoemission spectroscopy (XPS) signal is an order of magnitude smaller than that of the Ni 2p as expected. No changes in the XPS spectra were found when annealing the sample up to 500 K, suggesting the absence of island formation or alloying. We note that no EBIC oscillations were observed when the Cu substrate was kept at 400 K during evaporation, and that the corresponding Cu 2p XPS intensity

![Fig. 1. Electron beam induced crystal current (EBIC) as a function of Ni evaporation time. The Cu(100) substrate was kept at room temperature. The inset shows a 20 times enlargement of the spectrum with a smooth background subtracted.](image-url)
was comparable to the Ni 2p, strongly indicating the formation of Ni islands. Evaporation at 77 K substrate temperature gave only 2 oscillations but showed that same XPS as for the room temperature evaporation, indicating that flat epitaxial films cannot be grown beyond 2 layers due to insufficient Ni surface mobility, resulting in statistically rough surfaces. The base pressure of the vacuum chamber was in the low $10^{-10}$ Torr. The carbon and oxygen contamination measured by XPS 4 hours after the evaporation is found to be less than 0.1 monolayer.

Fig. 2 shows the X-ray absorption spectrum (XAS) and MCD spectrum of a bulk like thick Ni film. A recent relativistic Slater–Koster tight-binding analysis [11] has obtained a good fit for most of the spectral features in both the XAS and MCD spectra, and yielded values for the Ni 3d spin–orbit interaction, exchange splitting and local magnetic moment. It is interesting to note that while peaks A, A' only appear in the XAS spectrum and can be reproduced within the tight-binding analysis, peaks B, B' are imperceptible in the XAS spectrum, but manifest as distinct shoulders in the MCD spectrum. The latter peaks can not be explained within the tight-binding analysis, indicating the need to include many body effects [12].

The MCD signal for various Ni film thicknesses as a function of temperature are shown in fig. 3. The data were taken while the sample was warming up. Note the striking dependence of the Curie temperature on film thickness. The solid curves in fig. 3 are fits using the assumption that the magnetization is proportional to $(T_c - T)^\beta$, with $T_c$ being the Curie temperature. Limited by our current MCD detection sensitivity ($\approx 0.3\%$), it is very difficult to measure the small MCD signal near the Curie temperature with high accuracy, and therefore, a reliable $\beta$ parameter cannot be obtained at this time. The Dragon beamline is about to be upgraded to a double-headed version to enhance the current MCD detection sensitivity by two orders of magnitude [13]. Fig. 4 shows the thickness dependence of the Curie temperature, together with the results of Ni films on Cu(111) from ref. [5]. It can be observed that the Curie temperature for a given thickness is substantially lower for Ni on Cu(100) than on Cu(111). Moreover, extrapolating down to lower coverages, two monolayers of Ni on Cu(100) would have a Curie temperature of about 50 K and one monolayer of Ni might be non-magnetic, unlike the Ni on Cu(111) case. This would then contradict the results from theoretical calculations [14,15] and suggestions from experiments using electron capture spectroscopy [16] and spin-polarized angle-resolved photoemission [17]. Ear-
Fig. 3. Magnetic circular dichroism (MCD) signal at the L$_3$ white line from Ni films of various thickness (in units of monolayers) on Cu(100) as a function of temperature. Solid curves are power law fits as described in the text.

Fig. 4. Thickness dependence of the Curie temperature $T_C$ of Ni on Cu(100) (this work) and that of Ni on Cu(111) (ref. [5]).

Fig. 5. Temperature dependence of the MCD signal for Ni films of various thickness on Cu(100). Solid curves are power law fits as described in the text.

To conclude, we have measured the magnetic properties of ultrathin Ni films on a Cu(100) substrate using soft-X-ray magnetic circular dichroism spectroscopy, thereby demonstrating the feasibility of using this technique on a broad range of magnetic surfaces and ultrathin films, particularly, on multicomponent systems. Our data seem to suggest that a monolayer of Ni on Cu(100) is non-magnetic.

Acknowledgements

It is a pleasure to acknowledge the technical assistance of G. Meigs and E.E. Chaban. YUI was supported by the Office of Naval Research and PR by the C.N.R. Rome, Italy. The National Synchrotron Light Source is supported by the US Department of Energy under Contract no. DE-AC02-76CH00016.

References


