Stereo photographs of Atomic Arrangement in Nb(110) surface

Michiaki FUJIKADO[A] (8456), Yukako KATO[A] (13252), Fang Zhun GUO[B](8451), Tomohiro MATSUSHITA[B] (1154), Fumihiko MATSUI[A,C] (5945), Hiroshi DAIMON[A,C](1258)

Nara Institute of Science and Technology (NAIST)[A], JASRI[B], CREST[C]

Stereo photographs of atomic arrangement can be taken by taking advantage of the phenomenon of circular dichroism in photoelectron angular distribution (PEAD)[1]. The azimuthal shifts of forward focusing peaks in PEAD pattern obtained by left and right helicity light are found to be the same as the parallax in stereo-view. This method has been applied to the observation of atomic structure of many substances such as W(110) [1], Fe/Cu(001) [2,3], MoS_2[4], and so on. The magnetism and the atomic structure in the Fe layer on copper surface changes drastically with layer thickness. The relation between bcc structure and magnetism attracted much attention. Here the stereo photograph of bcc crystal was re-examined using Nb single crystal.

The Nb(110) single crystal sample was cleaned in situ by repeated cycles of Ar^+ bombardment and annealing to 1200°C. The surface quality was checked by reflection high energy electron diffraction (RHEED) (Fig.1(a)) and X-ray photoelectron spectroscopy.

The two-dimensional display-type spherical mirror analyzer[5-7] was used to obtain PEAD patterns. The circularly-polarized light from helical undulator was incident on the surface along the direction 45° off from the surface normal as shown in Fig.1(c).

Figures 1(b) is an example of stereo photograph of Nb(110) single crystal, which is a set of Nb $3d_{5/2}$ PEAD patterns taken at kinetic energy of E_k = 500 eV. Here the forward focusing peaks corresponding to first and second layer atoms appear strongly. This photograph shows the bcc structure as shown in Fig. 1(c). Hence the 3D bcc structure was clearly reconstructed in stereo photograph.

1) H. Daimon, *Phys. Rev. Lett.* **86**, 2034 (2001).
2) S. Okamoto, et al., *Trans. Magn. Soc. Japan*, **2**, 228 (2002).
3) A. N. Hattori, et al., *Thin Solid Films* (2004) accepted.
4) F.Z. Guo, et al., *Thin Solid Films* (2004) accepted.
5) H. Daimon, *Rev. Sci. Instrum.*, **59**, 545 (1988).
6) H. Daimon, and S. Ino, *Rev. Sci. Instrum.*, **61**, 57 (1990).
7) M.Kotsugi, et al. *Nucl. Instrum. & Method in Physics Research A*, **467**, 1493 (2001)

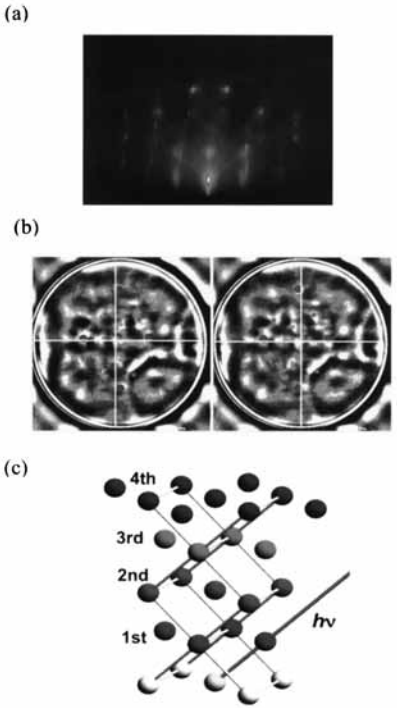

Fig.1 (a) RHEED pattern of Nb surface. (b) Stereo photographs of Nb crystal taken at kinetic energy of around 500 eV. By viewing left and right patterns with each eye, we can image a three-dimensional arrangement of bcc structure as shown in (c).

Surface magnetic property of c(2×2)CuMn/Cu(001) 2-dimensional ordered surface alloy: Probed by soft x-ray magnetic circular dichroism

A. Kimura (4385)*[1], S. Asanao (9780)[1], T. Kambe (8272)[1], T. Xie (7957)[1], S. Qiao (7608)[2], T. Muro (1255)[3], S. Imada (1257)[3], S. Suga (1250)[3], M. Taniguchi (6211)[1,2]

[1]*Graduate School of Science, Hiroshima University*
[2]*Synchrotron Radiation Center, Hiroshima University*, [3]*JASRI*
[4]*Graduate School of Engineering Science, Osaka University*

Crystalline Mn is known as an antiferromagnetic or a paramagnetic material with a quite small magnetic moment. However, once Mn atoms crystallize with non-magnetic elements, like Sb and even an oxygen atom, ferromagnetism appears as is found in MnSb or in $La_{1-x}Sr_xMnO_3$ [1]. Very small amount of Mn in a semiconductor can also derive a ferromagnetism, as discovered in (Ga, Mn)As [2]. One possibly extend his idea to a low dimensional case. An example is a Mn based alloy fabricated on noble metal surfaces.

Wuttig et al. discovered that Mn based two-dimensional (2D) ordered alloy can be formed on Cu(001) clean surface at a coverage of 0.5ML, where Mn and substrate atoms are alternatively placed forming a c(2×2) "checkerboard" structure as shown in Fig.1 [3]. A low energy electron diffrac-

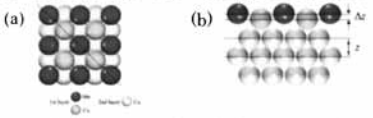

Fig.1: Surface structure of c(2×2) CuMn orderd surface alloy. (a) Top view and (b) side view.

tion (LEED) *I-V* measurement shows that c(2×2) CuMn surface alloy has a pronounced corrugation, in which Mn atoms in the first layer are displaced outwards by δz=0.30±0.02 Å, which is 17% with respect to the atomic distance in the bulk [3]. A theoretical band structure calculation predicts that the most stable magnetic state for c(2×2) CuMn orderd surface alloy is a ferromagnetic structure in the ground state [3]. The theory also explains that the observed large corrugation of the Mn atoms are derived from the magnetism [3]. However, the experimental evidence of the ferromagnetic state of this surface alloy has not been obtained so far. The lack of the experimental evidence possibly comes from the lower ferromagnetic transition temperature (Curie temperature) as usually found in ultra-thin films with a couple of 3d transition metal monolayers. With this reason, we have tried to observe the soft X-ray magnetic circular dichroism (XMCD) spectra in the Mn 2*p* core absorption region at BL-25SU of SPring-8 [4].

The external magnetic field of ~1.4T at the sample position was applied. The XMCD spectra were taken for a fixed direction of the magnetic field by 1Hz helicity switching of the incident circularly polarized undulator radiation. In the present report, the XMCD spectrum is defined as $\mu_+ - \mu_-$, where μ_+ and μ_- represent the absorption coefficients for the direction of the magnetization parallel and anti-parallel to the photon helicity, respectively. Manganese was evaporated from an electron beam evaporation source with a water cooling shroud at a rate of 0.2ML/min. We finally observed very clear c(2×2) LEED pattern for 0.5ML Mn/Cu(001) as shown in Fig.2 (b).

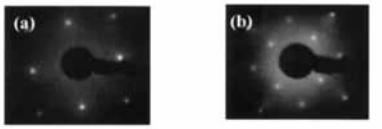

Fig.2: LEED patterns of (a) clean Cu(001) and (b) 0.5ML Mn/Cu(001)

In Fig.3, the temperature dependence of the L_3 XMCD spectra are shown in the temperature range of 43K-136K. As shown in Fig.3 (a), we clearly find that the XMCD integrated intensity decreases with increasing temperature. The inset shows the inverse plot of the XMCD integrated intensity v.s. temperature. It can be recognized from this plot that the $(XMCD)^{-1}$ decreases linearly with decreasing temperature, which indicates that the magnetic susceptibility obeys a Curie-Weiss law above 40K for CuMn surface alloy. Besides, the estimated value of Curie-Weiss temperature Θ=21K suggesting the ferromagnetic phase transition below about 20K.

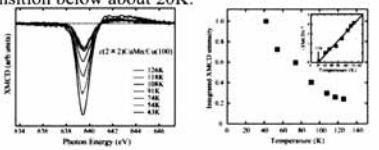

Fig.3: (a) Temperature dependence of the Mn L_3 XMCD spectra (see text). (b) The integrated intensity v.s. temperature.

References
1) M. Imada, A. Fujimori, and Y. Tokura, Rev. Mod. Phys. **70** (1998) 1039.
2) H. Ohno, J. Magn. Magn Mater. **200** (1999) 110.
3) M. Wuttig, C. C. Knight, T. Flores, and Y. Gauthier, Surf. Sci. **292** (1993) 189. M. Wuttig, Y. Gauthier and S. Blügel, Phys. Rev. Lett. **70** (1993) 3619.
4) A. Kimura, T. Kanbe, T. Xie, S. Qiao, M. Taniguchi, T. Muro, S. Imada, and S. Suga, Jpn. J. Appl. Phys. **42** (2003) 4692.