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Polarization dependent soft X-ray emission spectroscopy of cobalt nano-islands on a nitrogen-adsorbed Cu(0 0 1) surface

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ABSTRACT

We have investigated the incident polarization dependence of the Co L_3 soft X-ray emission spectra for the single- and double-atomic height Co islands grown on the nitrogen-adsorbed Cu(0 0 1) surface. For non-resonant incident X-ray in the depolarized configuration, a shoulder structure appeared at the high-energy side of the main peak of the spectra while there is no shoulder in the polarized configuration. The shoulder is attributed to the excitation of correlation satellite originated from the periphery Co atoms of the Co nano-islands. The resonant X-ray emission spectrum in the polarized configuration with the excitation energy of the L_3 absorption peak shows a peak located at the high-energy side of the main peak. This additional peak was not observed in the depolarized configuration.

1. Introduction

Electronic and magnetic properties of ferromagnetic transition metal thin films as well as its nano-sized islands have attracted much interest for many years. Significant change of the electronic states and enhancement of the electron correlation are expected because of their limited size. Among various combinations of the elements, Co on a Cu substrate has been intensively studied as a model system. When the Co thickness becomes small down to a single- or double-atomic height, the Co 3*d* band-width becomes narrow [1], and this changes the magnetic properties of the Co thin films [2,3].

Recently, we have experimentally showed the narrowing of the Co 3*d* valence band-width of the single-layer Co islands grown on a nitrogen-adsorbed Cu(0 0 1) substrate by using Co L_3 soft X-ray emission spectroscopy (XES) [4]. We used N-saturated surface to avoid the intermixing of Co with the substrate Cu atoms deposited at room temperature (RT) [5]. The N atoms behave as a surfactant and the interface between the Co overlayer and Cu substrate becomes very sharp [6]. This enables us to compare its valence electronic state directly with the calculated Co 3*d* partial density of states (PDOS) for a few mono-layer (ML) films and islands on the Cu substrate.

The localized feature of the Co 3*d* states in this system also appears as a correlation satellite in the Co $L_{3,2}$ soft X-ray absorption spectrum only with the in-plane polarized incident light [7]. It is originated from the electron correlation effect at the periphery of the single- and double-layer Co islands where the coordination number is reduced.

To directly address the changes in the 3*d* valence electronic states and the correlation effect, polarization dependent XES is suitable for its element specific measurements. On the molecular adsorbed metal surfaces, the orientation and electronic states of the molecules are studied by the emitted light polarization dependence [8,9]. In the case of transition metal compounds, which have localized or delocalized properties of 3*d* states, detailed information of the inelastic scattering and the symmetry of the electronic states are obtained from the incident light polarization dependence in the resonance condition [10–12]. The polarization dependence

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of the resonant XE spectra on the present Co nano-islands will also give the electronic states symmetry.

In the present paper, we have measured the incident polarization and excitation energy dependence of the Co L_3 XE spectra to further study the Co 3*d* electronic states of the single- and double-layer Co islands grown on N-saturated Cu(0 0 1) surfaces. The observed polarization dependence at non-resonant photon energy is attributed to the excitation of the correlation satellite originated from the Co nano-islands. We have also found another type of the polarization dependence in the resonant XE spectra with the excitation energy of L_3 absorption peak.

2. Methods

The XES by Co 2*p* excitation was measured at the BL27SU in SPring-8 using linearly polarized light [13]. The emitted soft X-ray was detected by a flat-field soft X-ray emission spectrometer in an ultrahigh-vacuum analysis chamber [14,15]. The polarization dependence of the spectra was taken in a depolarized and a polarized configurations [12] in which the polarization vector of the incident light is in-plane (e_x) and out-of-plane (e_z) of the sample plane, respectively. The emitted in-plane (e_y) and out-of-plane (e_z) polarized lights are detected together in both the configurations. The details of the experimental set-up are given in Ref. [4].

A Cu(0 0 1) substrate was cleaned by repeated cycles of Ar^+ ion sputtering and subsequent annealing at 900 K. The nitrogen-saturated surface was prepared by nitrogen ion exposure at 500 eV at RT and subsequent annealing at 600 K. Cobalt was deposited on it at RT in the deposition rate of 0.3 ML/min. The amount of Co on the surface was calibrated by Auger electron spectroscopy and X-ray absorption spectroscopy.

The Co 3*d* PDOS was calculated for each 3*d* atomic orbital based on the first-principles method. It was performed with an extended version of TAPP (Tokyo ab-initio program package) [16]. The details of the calculation are given in Ref. [7].

3. Results

Figure 1 shows the Co coverage dependence of the Co L_3 X-ray emission spectra taken in the depolarized and polarized configurations and non-resonantly excited by 808 eV photons, which is 30.5 eV higher than the Co L_3 absorption peak (777.5 eV). The spectra recorded in the depolarized configuration and resonantly excited by 777.5 eV photons are also shown for comparison. Here, N-adsorbed single- and double-layer Co islands are formed on the Cu substrate in the case of the sub-ML (0.25 ML and 0.5 ML) of Co deposition on the N-saturated Cu(0 0 1) surface, and most of the substrate is covered by the N-adsorbed double-layer islands at 2 ML [7].

For the sub-ML of Co on the N-saturated surface, the spectra in the depolarized configuration have shoulder structures at the high-energy side of the main peak as indicated by the arrows while it is absent in the polarized configuration. On the contrary, no polarization dependence was found in the non-resonant spectra for the 4.0 ML of Co on the clean surface and 2.0 ML of Co on the N-saturated surface.

In the case of 4.0 ML of Co on the clean Cu(0 0 1) surface (Fig. 1(a)), we notice high-energy tail above 777.5 eV in the non-resonant spectrum as indicated by the arrow [4]. The tail was commonly observed in the non-resonant spectra in the case of Co deposited on the N-saturated surface (Fig. 1(b–d)), and can be attributed to the multiple electron excitations as previously reported for Cu [17].

As shown in Fig. 2, the shoulders for the sub-ML regime on the N-saturated surface appear in the spectra resonantly excited by 780.3 eV photons, which is 2.8 eV higher than the Co L_3 absorp-

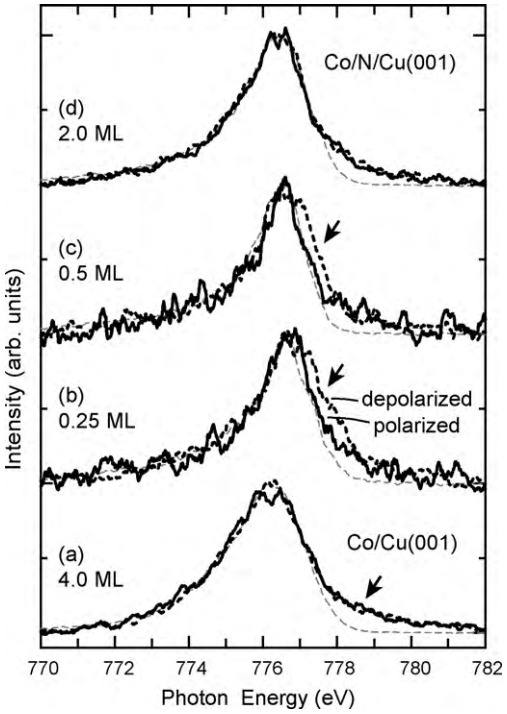

Fig. 1. Co L_3 X-ray emission spectra taken in the depolarized (dashed line) and polarized (solid line) configurations for the incident photon energy at 808 eV. The average Co coverages are (a) 4.0 ML on the clean Cu(0 0 1) surface, (b) 0.25 ML, (c) 0.5 ML and (d) 2.0 ML on the N-saturated surface. The gray dashed lines represent the spectra in the depolarized configuration with the incident photon energy of 777.5 eV. The spectra are normalized to the intensity of the main peak located around 776.5 eV.

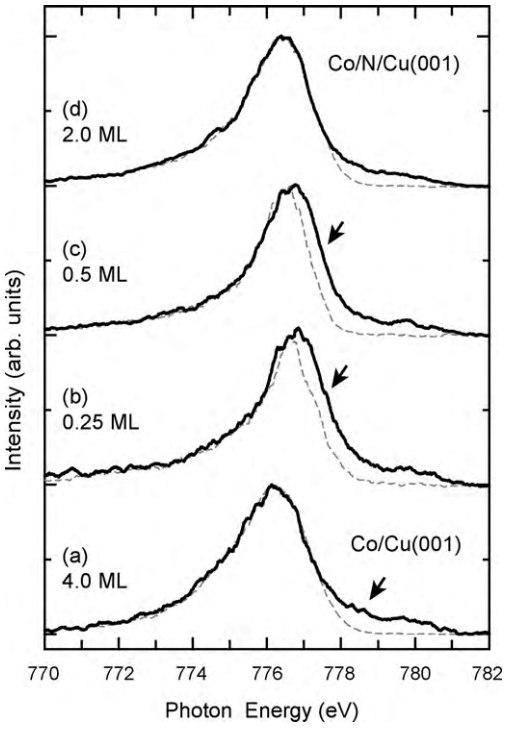

Fig. 2. Co L_3 X-ray emission spectra for (a) 4.0 ML of Co on the clean surface, and for (b) 0.25 ML, (c) 0.5 ML and (d) 2.0 ML of Co on the N-saturated surface in the depolarized configuration with the incident photon energy of 780.3 eV (solid line). The gray dashed lines represent the spectra in the depolarized configuration with the incident photon energy of 777.5 eV. The spectra are normalized to the intensity of the main peak located around 776.5 eV.