

# Magnetic interaction between adsorbed NO and *fcc* Co(001) thin films studied by X-ray magnetic circular dichroism

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Recently, we have performed O *K*-edge XMCD experiments for CO on perpendicularly or in-plane magnetized *fcc* Co(001) films (denoted as Co<sub>⊥</sub> and Co<sub>//</sub>, respectively). We have observed the parallel alignment of the orbital magnetic moment  $M_l$  of the O atom with the magnetization of Co<sub>⊥</sub>, while the antiparallel alignment was detected for Co<sub>//</sub>. In this work, we report N and O *K*-edge XMCD spectra from NO/Co<sub>⊥</sub> and NO/Co<sub>//</sub> in order to clarify the effect of the unpaired electron of NO.

XMCD spectra were taken at BL11A ( $P_c=0.75$ ) with the partial electron yield mode. For preparation of a Co<sub>//</sub> film, 3 ML Co was deposited directly on Cu(001). The Co thickness was monitored by *in-situ* observation of the RHEED oscillations. For Co<sub>⊥</sub>, 2 ML Co was deposited on 30 ML Ni that shows PMA. Both the films were cooled down to 200 K and were exposed to 15 L NO.

Co *L*<sub>III,II</sub>-edge XMCD shows noticeable reduction of the spin and orbital moments upon NO adsorption:  $M_s=1.70$  and  $M_l=0.20$  for clean Co<sub>⊥</sub>, and  $M_s=0.88$  and  $M_l=0.11$  for NO/Co<sub>⊥</sub>. Such suppression is much greater than the CO case:  $M_s=1.66$  and  $M_l=0.23$  for clean Co<sub>⊥</sub>, and  $M_s=1.40$  and  $M_l=0.20$  for CO/Co<sub>⊥</sub>. Similar tendency was observed in the Co<sub>//</sub> case. NO is regarded as a more efficient magnetic killer than CO because of antiferro-magnetic interaction between NO  $2\pi^*$  spin and Co  $3d$  ones.

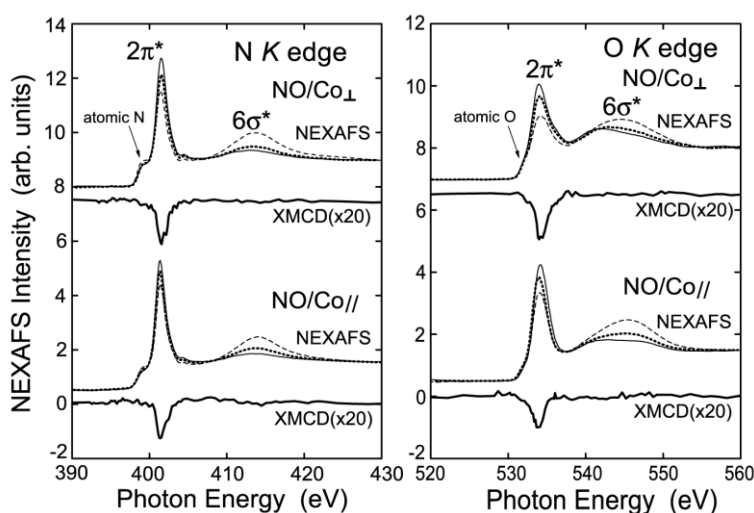
Figure 1 shows the NEXAFS and XMCD spectra of N *K*- and O *K*-edge of NO adsorbed on Co<sub>⊥</sub> and Co<sub>//</sub> films. From the polarization dependence of the  $2\pi^*$  and  $6\sigma^*$  resonances, the tilt angle of the molecular axis was determined to be  $\omega=25\pm 5^\circ$  for NO/Co<sub>//</sub> and  $21\pm 5^\circ$  for NO/Co<sub>⊥</sub>, verifying small but meaningful inclined orientation of NO. In all the XMCD spectra, only one negative peak can be observed at the  $2\pi^*$  resonance. When we apply the *K*-edge sum rule to present observation, the negative signs implies that  $M_l$  is parallel to that of the total magnetization for both Co<sub>⊥</sub> and Co<sub>//</sub> films and for both N and O *K* edges.

It should be noted that the XMCD intensity at the N *K* edge is almost similar to that at the O *K* edge. These results strongly indicate that the observed XMCD signals originate from the delocalized NO  $2\pi^*$  molecular orbital. We can conclude that the molecular orbital picture is more appropriate

to describe the observed N and O *K*-edge XMCD signals and that the NO  $2\pi^*$  orbital preserves the orbital magnetic moment even in the adsorbed phase, though the absolute value of  $M_l$  should be quite small. The  $6\sigma^*$  resonance does not show the XMCD signal because the  $6\sigma^*$  orbital has inherently no orbital angular momentum.

The present observation is substantially different from the previous CO/Co systems, where a negative orbital moment is expected for CO/Co<sub>//</sub>. This may be caused by the presence of a  $2\pi^*$  unpaired electron. Although the  $2\pi^*$  orbital is hybridized with Co  $3d$ , the  $2\pi^*$  electron is considered to be somehow localized at the NO site due to electron correlation. In such a case, the NO  $2\pi^*$  electron is likely to rotate so that the NO  $2\pi^*$  orbital magnetic moment is parallel to the Co magnetization. The orbital magnetic moment of NO may be aligned through the *spin-other-orbit* interaction. This effect should be stronger than the hybridization effect that is dominant in the CO case. This interpretation is based on inclined orientation of the NO molecule. Details will be discussed elsewhere.

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**Fig. 1.** N and O *K*-edge NEXAFS and XMCD for NO/Co<sub>//</sub> and NO/Co<sub>⊥</sub> measured at 200 K. For NEXAFS, polarization dependence is also shown; thin solid, dotted and dashed lines correspond respectively to the X-ray incidence angles  $\chi$  of  $90^\circ$  (normal incidence),  $55^\circ$  (magic angle incidence) and  $30^\circ$  (grazing incidence). The XMCD spectra (thick solid line) were taken at grazing X-ray incidence ( $\theta=30^\circ$ ) for NO/Co<sub>//</sub> and at normal X-ray incidence ( $\theta=0^\circ$ ) for NO/Co<sub>⊥</sub>, respectively. Note that the XMCD signals are multiplied by a factor of 20.