Journal of Physics: Conference Series **712** (2016) 012033 doi:10.1088/1742-6596/712/1/012033

Depth-resolved X-ray magnetic circular dichroism measurement by a multi-anode microchannel plate detector combined with polarization switching

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Abstract. A depth-resolved X-ray magnetic circular dichroism (XMCD) technique has been developed in the soft X-ray region by combining a multi-anode microchannel plate detector with polarization switching between right and left circular polarizations. A simultaneous measurement for 30-channel anodes has been achieved with a continuous data acquisition rate of 1 kHz, which is fast enough for 10 Hz polarization switching. This enables us to realize the layer-resolved XMCD analysis with a high signal-to-noise ratio.

1. Introduction

In the past decade, the depth-resolved X-ray magnetic circular dichroism (XMCD) technique has been developed in the soft X-ray region, which realizes the atomic-layer resolved XMCD analysis for magnetic ultrathin films [1-3]. The technique is based on the fact that the effective escape depth of the Auger electrons, which are emitted after X-ray absorption, depends on the emission angle of the electrons. Therefore, a set of XMCD data at different probing depths is simultaneously obtained at different detection angles. In addition, it has been demonstrated that the signal-to-noise ratio of the XMCD data is significantly improved by using polarization switching between right and left circular polarizations (RCP and LCP) [4-6]. In this paper, we apply the polarization switching to the depth-resolved XMCD technique in order to realize the high-sensitivity depth-resolved XMCD analysis. To simultaneously record the Auger electron signals at different detection angles with much higher data acquisition rate than the polarization switching frequency (10 Hz), we adopt a multi-anode microchannel plate (MCP) detector. The XMCD spectra are obtained for a naturally-oxidized Co thin film, in which the surface of the film is preferentially oxidized, and it is demonstrated that the spectral features depend on the electron detection angles as expected.

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2. Detector and data acquisition system

Up until now depth-resolved XMCD measurements have been performed by using an imaging-type detector, consisting of a MCP, a phosphor screen and a CCD camera as shown in Fig. 1(a) [1-3]. A retarding voltage is applied to the second grid in order to preferentially observe the Auger electrons, while the first grid is grounded. To apply the polarization switching technique to the depth-resolved XMCD measurement, it is necessary to simultaneously record the XMCD data at different detection angles, θ_d, at a much higher data acquisition rate than the polarization switching frequency. Although this can be realized by using a high-speed CCD camera, we adopt a multi-anode MCP system, as illustrated in Fig. 1(b), for higher detection efficiency. Figure 1(c) shows the 30-channel multi-anode MCP detector, which was fabricated by Hamamatsu Photonics K.K. The detector was mounted on a vacuum flange, and the 30-channel anodes were separately connected to electric feedthroughs.

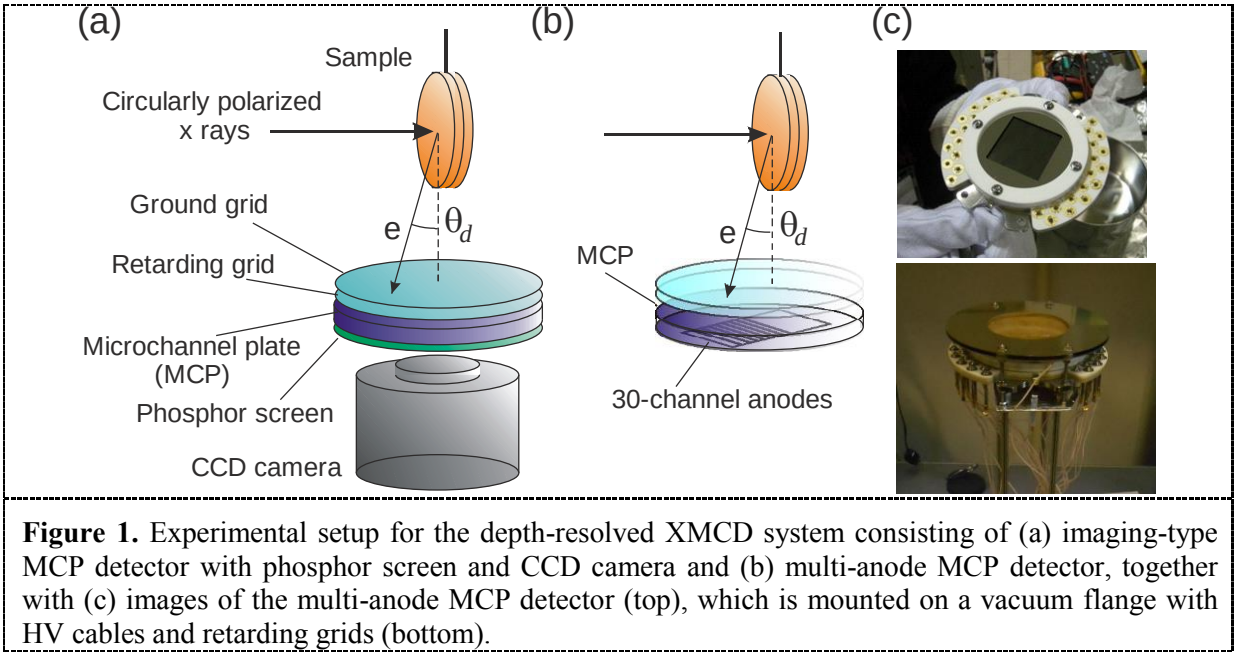

Figure 1. Experimental setup for the depth-resolved XMCD system consisting of (a) imaging-type MCP detector with phosphor screen and CCD camera and (b) multi-anode MCP detector, together with (c) images of the multi-anode MCP detector (top), which is mounted on a vacuum flange with HV cables and retarding grids (bottom).

Figure 2 schematically illustrate the data acquisition system. A high voltage (HV) of 2.1 kV is applied to the anodes via electric feedthroughs, by using a HV divider placed out of vacuum, while a bias voltage of 1.85 kV is applied to the bottom of the MCP. A typical pulse height for the obtained electron signal is 5-10 mV. The signals are separately amplified by a 32-channel application specific integrated circuit (ASIC), and are counted by a field-programmable gate array (FPGA). The X-ray intensity signal (I_0) is also connected to the ASIC, together with the undulator status signal, which represents the polarization of the X rays at each moment. The pulse counts from the anodes in each 1 ms are continuously recorded at a data acquisition rate of 1 kHz. The recorded data are transferred via SiTCP [7].

3. Demonstration of depth-resolved XMCD measurement

The depth-resolved XMCD measurement was performed at the soft X-ray beamline, BL-16A, of the Photon Factory, Japan, by using 10 Hz polarization switching [8,9]. Two APPLE-type undulators, ID1 and ID2, installed in the tandem configuration, are set to opposite circular polarizations (*e.g.* RCP and LCP), and the electron orbit through the undulators is modulated by kicker magnets in order to alternate the undulators which provide light for the beamline [4-6,9]. A naturally-oxidized Co thin film with ~5 nm thickness was used as a test sample, after being magnetized by a pulse magnetic field of ~100 Oe. Figure 3(a) shows time dependence of the electron pulse count, I, for channel (Ch) 18, together with that of the X-ray intensity, I_0. The I_0 signal exhibits two peaks in each 100 ms, which

correspond to RCP and LCP. It is recognized that the pulse count changes in accordance with the change in I_0. Moreover, I/I_0 for LCP is higher than that for RCP, which directly indicates a negative XMCD signal at the Co L_3 edge. The XMCD spectrum at each detection angle, θ_d, is obtained by separately integrating the pulse count for RCP and LCP, and taking the difference of them after the normalization by the X-ray intensity. Here, the I and I_0 signals in each 30 ms are used to obtain the XMCD data for RCP and LCP, μ_+ and μ_-, respectively, as indicated in Fig. 3.

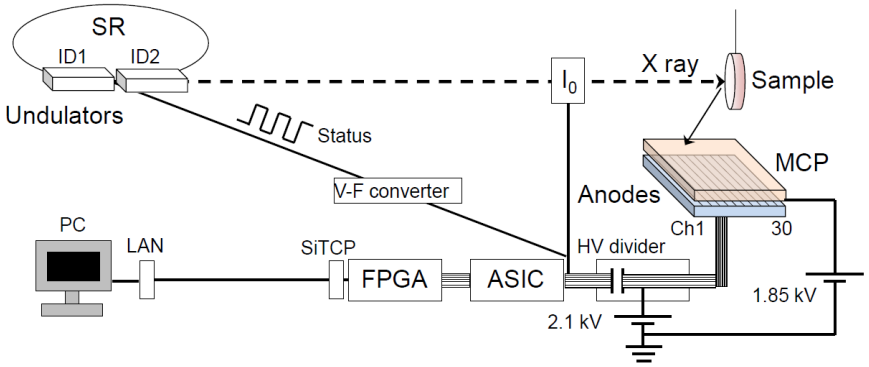

Figure 2. Schematic diagram for the data acquisition system.

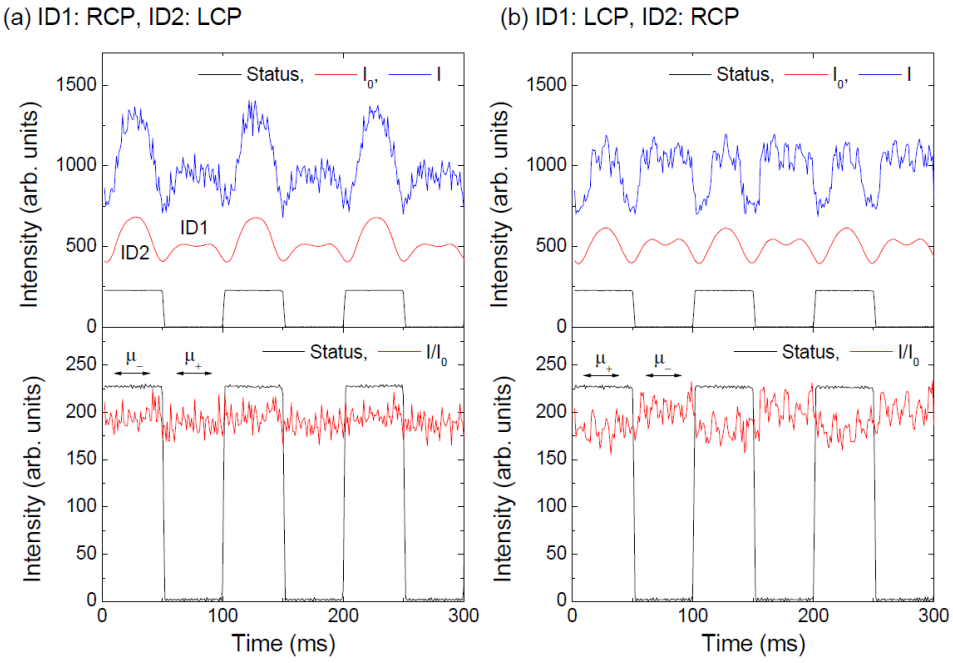

Figure 3. Time dependence of electron pulse count (I) for Ch 18, together with that of incident X-ray intensity (I_0) and I/I_0, taken at the Co L_3 peak-top energy (779 eV) with 10 Hz polarization switching. The X-ray polarizations of ID1 and ID2 were set to (a) RCP and LCP, respectively, and (b) *vice versa*. The status signal represents which undulator (ID1 or ID2) is active at each moment.

The obtained XMCD spectra are shown in Fig. 4. Some shoulder features are found in the absorption spectra, which are characteristic of Co oxide. Moreover, the shoulder features are more prominent and the XMCD difference signal is weaker at Ch 29 compared with those at Ch 18. Since the probing depth is smaller for Ch 29 than Ch 18, owing to more grazing electron emission angle, this indicates

that the surface of the Co film is preferentially oxidized. Feasibility of the depth-resolved XMCD technique with the multi-anode MCP system and polarization switching has been thus demonstrated.

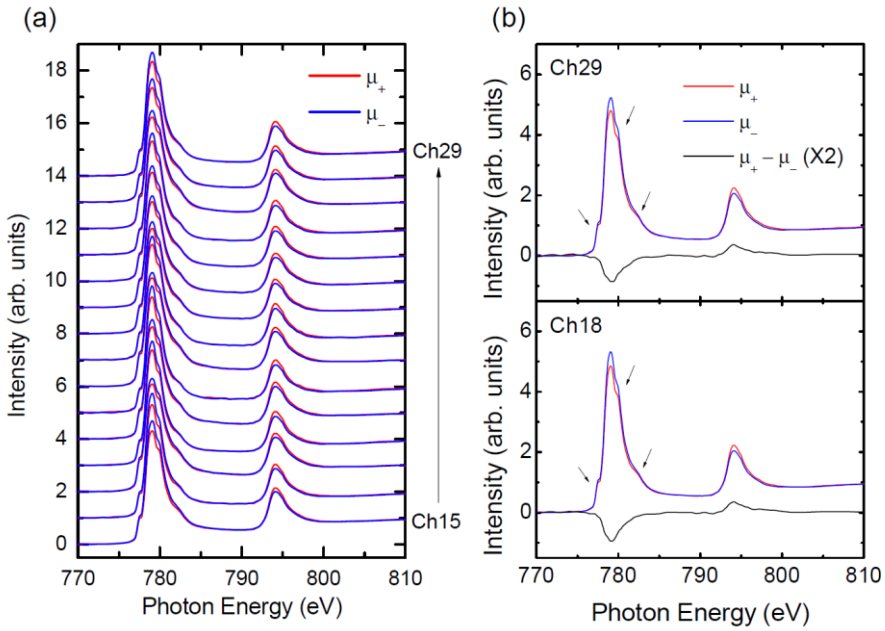

Figure 4. (a) Co L-edge X-ray absorption spectra for RCP and LCP, μ_+ and μ_-, respectively, for Ch 15-29, and (b) XMCD spectra for Ch 18 and 29. Arrows indicates spectral features for Co oxide.

4. Summary

We have developed the depth-resolved XMCD technique by combining the multi-anode MCP system with polarization switching between RCP and LCP. Feasibility of the technique has been demonstrated by measuring a naturally-oxidized Co thin film, which shows rather weak XMCD signal and depth-dependent chemical and magnetic structures.

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