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Development of an X-Ray-Detected Ferromagnetic Resonance Spectrometer with an Out-of-Vacuum Photodetector

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Detection and manipulation of spin dynamics are essential for spintronics applications, where spin currents serve as information carriers and can switch magnetization as digitized data. X-ray-detected ferromagnetic resonance (XFMR) spectroscopy is a powerful experimental technique that enables element-specific analysis of spin precession dynamics in the GHz regime [1]. XFMR is particularly useful for analyzing spin dynamics in multilayered and multielement structures that are commonly used in spintronic materials.

We have developed an XFMR spectrometer at BL-19B of the Photon Factory [2]. The master oscillator signal is delayed, and its higher harmonics are generated, filtered, and amplified through a microwave (MW) circuit. An MW signal in the GHz range is fed into a coplanar waveguide on which the sample is mounted. Spin precession in the sample, i.e., ferromagnetic resonance under static and MW magnetic field, is detected via the X-ray magnetic circular dichroism (XMCD) effect.

Figure 1(a) shows a schematic of the detection system. We employed X-ray-excited optical luminescence (XEOL) from the sample substrate to obtain the X-ray absorption signal. XEOL is generated in a substrate material such as MgO by X-ray irradiation through the sample film. The emitted XEOL is collimated and focused by plano-convex lenses inside a vacuum chamber and detected by a photodetector located outside the vacuum chamber. This design enables easy replacement of the photodetector. Users can also install devices such as spectrometers or two-dimensional detectors (e.g., visible-light cameras) depending on their experimental requirements.

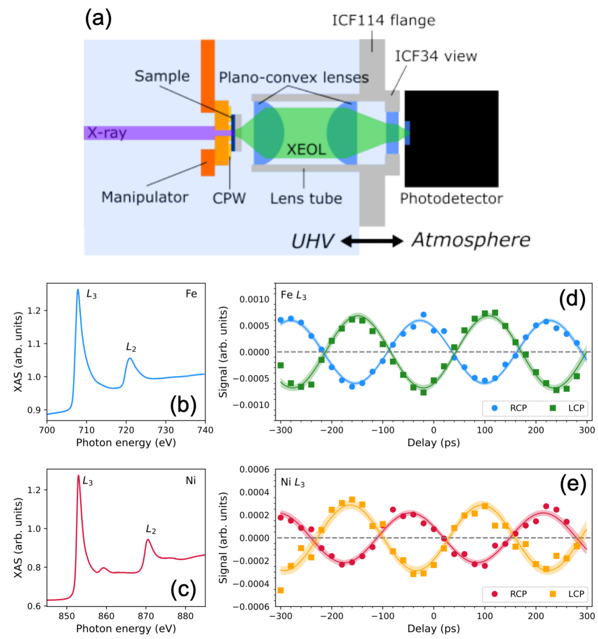

Fig. 1: (a) Schematic of the XEOL detection system. (b) Fe and (c) Ni $L_{2,3}$ XAS spectra obtained by XEOL detection. XFMR delay scans at 3.5 GHz measured at the (d) Fe and (e) Ni L_3 edges, respectively. The figures are licensed under CC BY 4.0 and adapted from Ref. [2] with modifications by the authors.

To demonstrate the performance of the XFMR spectrometer, we measured XAS and XFMR delay scans of a permalloy ($Ni_{80}Fe_{20}$) film. A 30-nm-thick $Ni_{80}Fe_{20}$ film was deposited on a MgO(001) substrate and capped with a 2-nm-thick Cu layer.

XEOL-detected X-ray absorption spectra at the Fe and Ni $L_{2,3}$ edges are shown in Figs. 1(b) and 1(c), respectively. Because bulk-averaged information can be obtained with XEOL detection, metallic-like spectral line shapes are observed for both Fe and Ni. Representative XFMR results at 3.5 GHz are shown in Figs. 1(d) and 1(e) for Fe and Ni, respectively. Delay scans at the Fe and Ni L_3 edges clearly exhibit sinusoidal signals. The signal amplitudes are inverted for right-circularly polarized (RCP) and left-circularly polarized (LCP) X-rays, indicating the XMCD effect. Thus, we successfully obtained XFMR signals using the present out-of-vacuum photodetector system.

Recently, we have been developing another XFMR spectrometer at the soft- and tender-X-ray beamline BL13U at NanoTerasu [3], based on the knowledge and techniques gained from this project.

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