Construction and Development of Time-Resolved XMCD-PEEM System using Femtosecond Laser Pulse at BL25SU

Although ultrafast dynamics measurements became accessible with the development of ultrafast laser technology, their combination with pulsed synchrotron radiation is becoming an even more powerful technique. Ultrafast magnetization dynamics in micron-sized magnetic materials is now one of the issues relating to the development of faster and higher density data storage devices. In this article, we introduce a time-resolved magnetization imaging system using a stroboscopic pump-probe method [1] installed in **BL25SU**.

Magnetic domain imaging was performed by combining the X-ray magnetic circular dichroism with photoelectron emission microscopy (XMCD-PEEM). The achieved lateral resolution was ~100 nm. The time evolution of magnetic domain structures was obtained by a pump-probe method. The probe light was circularly polarized X-ray pulses, which were isolated bunches in a several bunch mode operation of the SPring-8 storage ring shown in Fig. 1. In this mode, twelve isolated bunches containing 1.6 mA were separated by 342.1 ns (repetition rate of 2.92 MHz) with an additional 342.1-ns-long bunch train. The temporal resolution was estimated to be ~100 ps, because of jitter (~60 ps) and the X-ray pulse width (~40 ps). The pump was the magnetic field pulses switched by the femtosecond laser pulses. The repetition rate of the laser pulse was tuned to 2.92 MHz so as to be synchronized with the isolated bunches. The diagram of the pump-probe system is shown in Fig. 1.

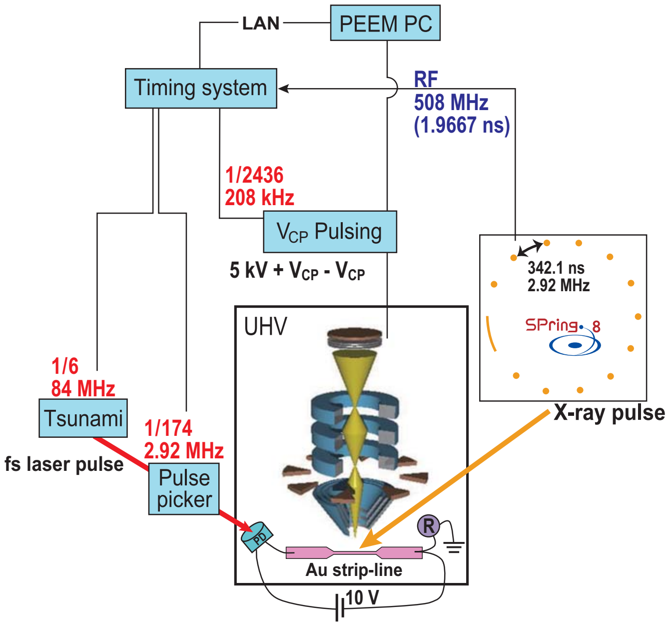

Fig. 1. Diagram of the pump-probe system. The timing system [details in Ref. 2] is triggered by the rf signal and distributes output signals to the custom-build V_{CP} system, the oscillator (Tsunami), and the pulse picker, which reduce the frequency of the laser pulse to the same as that of a single bunch.

Electrons projected by the X-rays from the bunch train were gated off with a custom-built power supply dropping the voltage synchronized with the bunch train, since they did not provide time-resolved signals. Figure 2 showns the measured characteristics of the power supply, where the PEEM image intensity is plotted as a function of the delay time between the bunch train and the gating out period of the channel plate. When the bunch train overlaps with the gating out period, all the electrons excited by radiation from the bunch train are blanked out. This leads to the lowest intensity (III in Fig. 2) because the PEEM intensity is only from the isolated bunches.

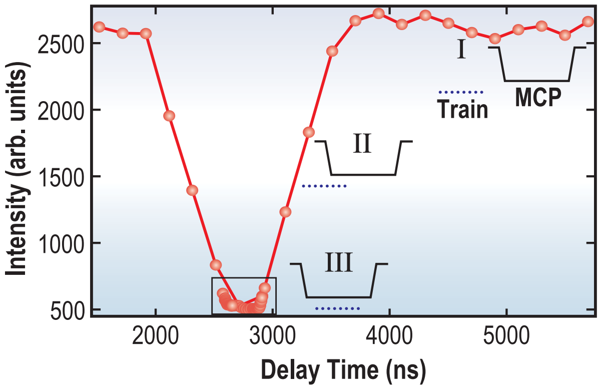

Fig. 2. Evaluation of the pulsing of the channel plate voltage power supply. The y axis is the PEEM image intensity and the x axis is the delay between the bunch train and the period for which the channel plate voltage is turned off.

Magnetization dynamics has been observed for $Fe_{20}Ni_{80}$ (FeNi) disks (6 μm in diameter) fabricated onto a Au stripline (10 μm in width and 100 nm thickness). When the thickness of the magnetic sample is smaller than its radius, with negligible magnetic anisotropy energy, the sample shows closure magnetic patterns to minimize the stray field energy, known as the magnetic vortex structure (Fig. 3(c)). In our experiment, the excitation energy to generate a magnetic event, i.e., a shifting of the core from the middle of the disk, was provided by the external field pulse turned on by the femtosecond laser pulse in the following way. A fast photodiode connected to the stripline with inversely biased to 10 V was switched on by the femtosecond laser pulse and electric current flowed in the stripline. The current generated magnetic field pulses that acted on the spins in the disks, resulting in the shift of the core positions. The cores move in a direction perpendicular to the field direction.

The time zero, at which the current pulse flowed under the magnetic disk exactly when the X-ray pulses hit the disk, was inferred from the shift of the morphological structure. The shape of the field pulse was obtained as well. Since the PEEM detects electrons, the magnetic field created around the sample distorts the images. As a consequence, the images shift along the stripline perpendicular to the field direction. Figure 3(a) shows the absorption contrast of two FeNi disks on the stripline using the incident X-ray photon energy 5 eV below the Fe-L_3 absorption edge to observe the shape of the disks clearly. A series of PEEM absorption images were taken with a 50 ps delay increment of the femtosecond laser pulse. The integrated intensity over one region, indicated by a red rectangular box in Fig. 3(a), from each image is clipped and aligned with the delay (Fig. 3(b)). At around 0.5 ns, one can see the start of the shift, while the width of the field was around 300 ps (full width at half maximum).

Snapshots of the spin motion of a FeNi disk in 200 ps steps are displayed in Figs. 3(c)-3(g) in which the stripline lies from top to bottom. The orange, green, red, and black arrows in Fig. 3(c) indicate the magnetization of the vortex structure, core polarization, incidence direction of X-rays, and external field direction, respectively. The magnetic structure just before the field pulse is shown in Fig. 3(c). The core is at the middle of the disk. Through Figs. 3(c)-3(g), one can see the core moves upward during the field pulse. The core displacement from the disk center is shown in Fig. 3(h) for 70 ns with 500 ps delay increment. After the core reached the edge of the disk as shown in Fig. 3(g), the core undergoes a one-axial oscillatory motion about the disk center (Fig. 3(h)). The frequency of the core motion is around 50 MHz, which reproduces the observation in Ref. [3].

In summary, we have succeeded in observing magnetization dynamics images in the sub-ns time scale. This method can be applied for time-resolved photoemission and magnetization reversal measurements.

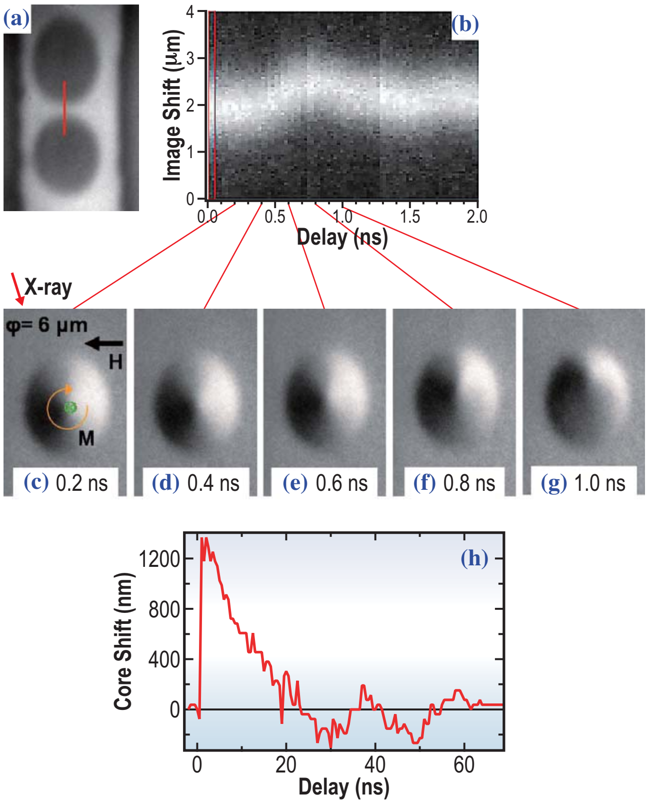

Fig. 3. **(a)** An X-ray absorption contrast image of two FeNi disks (φ = 6 μm) on the Au stripline. **(b)** Shape of the magnetic field pulse. Part of the absorption image [red rectangular box in **(a)**] with a 50 ps delay increment is clipped and lined up from left to right. Images **(c)**-**(g)** show the dynamics of the magnetic structure of a FeNi disk obtained with a 200 ps time increment. **(h)** The displacement of the vortex core from the disk center.

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