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A new sample holder for laser-excited pump-probe magnetic measurements on a Focus photoelectron emission microscope

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A custom-made Omicron-compatible sample holder for time-resolved photoelectron emission microscopy experiments is presented. It comprises a sample plate with four contacts that hosts a chip carrier where the semiconductor substrate is mounted. Covering the sample holder, a 6 mm diameter mask protects electrostatically the sample from the extractor lens voltage while keeping the imaging quality unperturbed. The improvements are a greater sample lifetime and the ability to withstand much higher currents in the stripline that provides the magnetic pulse to the magnetic microstructure. © *2008 American Institute of Physics.* [DOI: 10.1063/1.2884709]

I. INTRODUCTION

Laterally resolved magnetic studies on ultrashort time scales are vital to understand various magnetic phenomena such as precessional switching[1–6] or domain creation and domain wall motion,[7–9] important processes for technological applications but also very interesting from the fundamental point of view.

The requirements that need to be fulfilled for such experiments—high spatial and temporal resolution, together with chemical and magnetic sensitivity—are met by time-resolved synchrotron x-ray photoelectron emission microscopy (PEEM): the x-ray absorption cross section is resonantly enhanced at the atomic absorption edges, and by changing the circular or linear polarization of the incoming light, magnetic dichroic effects are manifested in different intensities for sample areas with different magnetization directions.

When time-dependent effects are being investigated in time domain, the system is usually excited by a magnetic field or a laser pulse. One way to generate such a pulse is by shining a femtosecond laser onto a photoconductive switch placed between the two ends of a stripline (a narrow and ultrathin metallic wire fabricated on top of a semiconducting substrate), to which a voltage difference is constantly applied. By tuning the delay time between the laser and the x-ray pulses, the evolution of the magnetization can be temporally and laterally resolved.[10]

Such an experiment requires special sample holders that can provide the voltage difference to the stripline ends and protect the stripline-sample unit from the high-voltage difference applied to the first lens of the microscope to maximize the extracted electron yield. Here, we present a recently developed sample holder suited for these needs and compatible with the Focus PEEM with integral sample stage (IS-PEEM) (Focus GmbH), capable of incorporating chip carriers that host the sample.

II. APPARATUS DESCRIPTION

PEEM measurements are based on the detection of secondary electrons emitted by samples illuminated with ultraviolet light or x rays, the energy of which is tuned to an absorption edge of any of the elements present in the sample. In the case of the $L_{2,3}$ absorption edges of transition metals, in the soft x-ray energy range, the 2 nm information depth of the photoelectrons detected by the microscope make PEEM a very surface-sensitive technique, with typical probing depths of a few nanometers. Several electric or magnetic lenses project the electrons onto a microchannel plate imaged by a charged-coupled device camera. In order to maximize the detected yield, a high voltage is applied between the sample and the first lens, the so-called extractor lens. In the case of the Focus-PEEM, the sample is kept on ground potential with respect to the high voltage of the extractor.

Figure 1(a) shows the measurement scheme: the pump is realized by means of a femtosecond laser ($\lambda = 800$ nm) shone onto a photoconductive switch, the ends of which are subject to a tunable voltage difference. When the laser is on, a current pulse travels along the stripline producing, in turn, a magnetic pulse. The duration of this magnetic pulse depends on the time scale of the laser pulse, but the determining factor is the electron-hole pair lifetime of the substrate. Magnetic pulses of full width at half maximum (FWHM) ~70 ps and of about 60 Oe are currently achieved, being able to affect the magnetization of a soft magnetic Permalloy (Py) layer in the sample. As probe, we use the PEEM images with x-ray magnetic circular dichroism (XMCD) contrast. X-ray pulses from a synchrotron light source in single-bunch mode have typically a FWHM ~50 ps. By synchronizing the laser

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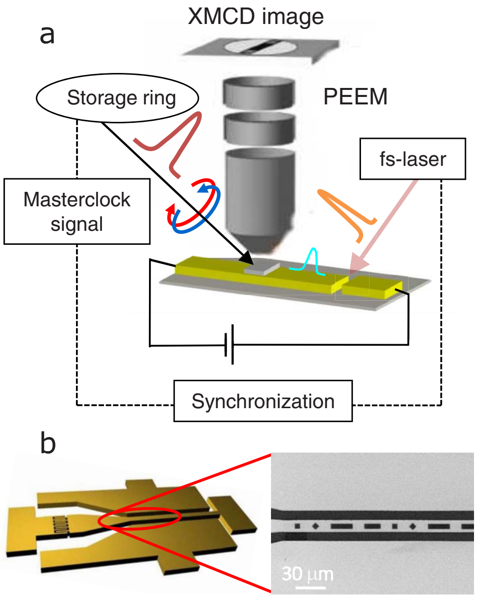

FIG. 1. (Color online) (a) Schematics of the time-resolved XMCD-PEEM measurements. (b) Sketch of the stripline waveguide and a SEM image of the magnetic microstructures grown onto the stripline.

pulse and tuning the delay time to the x-ray bunch, we can scan the evolution of the sample magnetization.

Figure 1(b) shows a sketch of the stripline-waveguide set (left) and an scanning electron microscopy (SEM) image of the magnetic microstructures grown on top. The magnetic pulse is generated by a 10 μm wide stripline, surrounded by a waveguide on ground potential to improve the homogeneity of the field along the stripline. Both are fabricated by electron-beam lithography on a 100 nm thick Au layer deposited on top of the semiconducting substrate. The magnetic microstructures, deposited on top of the stripline to maximize the effect of the magnetic field pulse, emit the detected electrons upon illumination by the x-ray beam.

The technical difficulties of this type of measurements are mainly twofold: (i) to bring the dc voltage to the ends of the stripline and (ii) to keep the sample surface as clean as possible. Previous mounting systems comprised the use of silver glue to contact electrically the two pads of the GaAs wafer to two Cu leads mounted onto the sample plate and isolated from it. Under the high-voltage potential of the extractor lens, the silver glue may accidentally degas in bursts, likely causing the destruction of the stripline.

III. DESIGN

In order to solve the technical challenges, a completely revised mounting scheme has been adopted, avoiding the use of silver glue on the sample surface and keeping the electrical connections away from the extractor lens. It comprises a new Omicron-compatible Ti sample plate, shown in Fig. 2, that hosts a commercially available leadless chip carrier [panel (a), part No. LCC02834, Spectrum Semiconductor Materials, Inc.], wire bonded to the four sections of the sample—two in the stripline and two in the waveguide. The Au pads on the back side of the chip carrier touch four spring contacts (part No. BP3, Interconnect Devices, Inc.) when the chip carrier is pressed down by the sample holder mask. Two of these contacts, numbered as 1 and 2 in panel (b), are equipotential with the sample holder, and are connected to the two sides of the waveguide. The other two spring contacts are isolated from the sample plate and connected to the Cu leads at the bottom side of the sample plate. These leads enter in physical contact with two corresponding spring hooks mounted on the PEEM manipulator when the sample holder is inserted. From there, two of the available wires of the feedthrough plugs are used to power the stripline voltage with a standard power supply. Since the samples are close to the switch, and the stripline voltage is applied continuously, impedance matching between the stripline and the cables is not important, and has not been pursued.

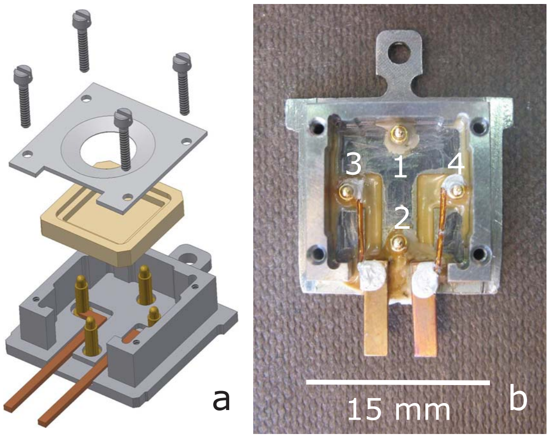

FIG. 2. (Color online) Drawing (a) and photograph (b) of the sample holder comprising the sample plate with spring contacts, chip carrier, and mask.

The mask, besides ensuring the mechanical stability of the chip carrier, has a 6 mm diameter tapered opening to allow the laser and x-ray beam to access the stripline. Such an opening acts as an extra lens of the electron microscope that reduces somewhat the electron yield captured by the microscope. However, its dimension and height with respect to the stripline ($\sim$0.8 mm) are chosen so that it shadows fully the four wire bonding sets and partially the photoconductive switch, preventing them from being eroded by the extractor voltage and lengthening enormously the lifetime of the sample. From the practical point of view, the designed system facilitates the sample exchange, while keeping the capability of quick in-vacuum sample transfer to the PEEM apparatus.

IV. RESULTS AND DISCUSSION

Time-resolved PEEM measurements with the new sample holder have proven the advantages during operation: the lifetime of the switch under normal operation conditions of laser power and extractor voltage were greatly increased, allowing us to measure the same sample for several days. At the same time, the imaging properties of the microscope and the profile of the magnetic field pulses could be maintained.

Figure 3 shows characteristic XMCD-PEEM images of two 20-nm-thick Py microstructures on top of a 10 μm wide Au stripline, obtained with the old (a) and new (b) sample mountings. These images are the result of calculating the

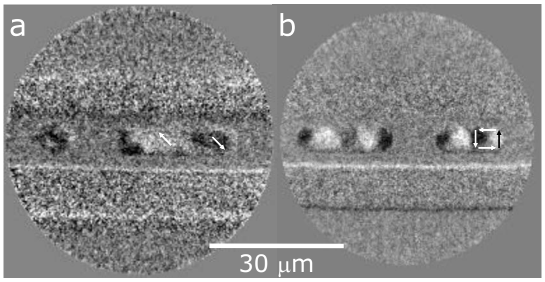

FIG. 3. XMCD-PEEM images of two magnetic structures as measured (a) on the previous sample holder and (b) with the presented mounting system. Two magnetic structures are imaged in each case, displaying brighter and darker areas in regions with opposite magnetization directions.

asymmetry of two images taken with left- and right-circularly polarized x rays. The areas of different intensities that can be observed inside the structures correspond to the different magnetic domains. The white and black domains in panel (b) have the magnetization pointing upward and downward, respectively, whereas the magnetization vector in panel (a) is along an intermediate direction. The magnetization vector inside the gray areas is such that the flux lines are closed, as indicated by arrows in Fig. 3. It is clear that the spatial resolution is not compromised by the mask of the new sample plate, although the exposure time was four times longer for the image in panel (b).

Figure 4 compares the magnetic field pulses obtained with the old and the new sample holders. They are derived from the image distortion in the border region between the stripline and the waveguide, normalized to the average current flowing through the stripline.[10] In both cases, the pulse shape comprises a first main peak with FWHM ~70 ps and a number of oscillations, typical from current reflections in the different parts of the stripline circuit. It is clear that the new design results in a narrower pulse and in an approximately ten times larger maximum magnetic field.

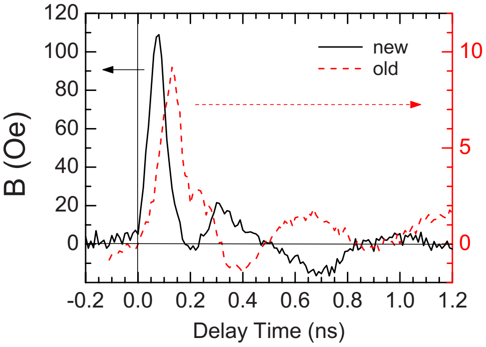

FIG. 4. (Color online) Temporal evolution of the magnetic field pulses produced by the stripline with the new setup (full line) and with the previous one (dashed).

V. SUMMARY

A new sample mounting system suitable for time-resolved measurements using a Focus-PEEM is presented, including a new sample holder. By using wire bonding and chip carriers, it avoids the presence of silver glue on the sample surface. Furthermore, a mask hides the electrical connections from the high extractor lens voltage, greatly increasing the lifetime and sturdiness of the samples and thus allowing us to perform time-consuming measurements at much higher currents through the stripline. Meanwhile, the imaging properties are not compromised.

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